VEHICULAR AIR POLLUTION

Experiences from Seven Latin American Urban Centers

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Contents

Figures

Tables

Boxes

Maps

Foreword

Deteriorating air quality is a major environmental problem in many Latin American urban centers, including megacities like Mexico City, São Paulo, Santiago, and Buenos Aires. Most air pollution in Latin America, which occurs in highly urbanized areas with unfavorable topographical and meteorological conditions, is caused by motor vehicles. During 1970-90 the growth of the region's vehicle fleet was phenomenal: it grew by about 250 percent, reaching 37 million vehicles. With new economic and trade liberalization policies and the formation of various trade blocks in the region, the vehicle fleet is expected to grow even more quickly over the next few decades. If appropriate measures are not taken soon, vehicular air pollution in Latin America and the Caribbean is likely to worsen, posing a great threat to human health and welfare.

The idea for this study emerged during a 1993 World Bank-sponsored Urban Environment Conference in Quito, Ecuador. During the conference the severity of air pollution in Mexico and São Paulo and the pollution control measures taken in both urban centers were presented. Participants at the conference, most of whom were high-level government officials from throughout Latin America, felt that these and other city experiences on vehicular air pollution should be more widely disseminated. This idea was subsequently accepted by the World Bank, and the Environment Unit of the Latin American and the Caribbean Region (LATEN) was entrusted to undertake this work.

This study, which took almost three years to complete, is a result of extensive research. It includes contributions from government representatives, consultants, and nongovernmental organizations (NGOs) from various Latin American countries. The report was also aided by Bank experts who are working on the vehicular air pollution problem in Latin America. The report is intended mainly for policymakers in Latin America and the Caribbean who are responsible for controlling and managing air pollution, as well as for technical audiences and citizens groups. The detailed case studies should also interest policymakers in other parts of the world.

The report has five chapters. Chapter 1 provides an overview of vehicular air pollution, focusing on population, urbanization, and motorization trends and economic and trade developments in Latin America and the Caribbean. Chapter 2 discusses sources, properties, emission characteristics, dispersion, and environmental and health effects of vehicular air pollutants. This chapter also quantifies the health effects of air pollution and provides ambient air quality standards adopted in Latin American and Caribbean countries. Chapter 3 presents the vehicle- and fuel-targeted and transport management measures used to control vehicular air pollution, drawing on examples from the United States, European Union countries, and others. Chapter 4 provides case studies for seven Latin American urban centers: Mexico City, Santiago, São Paulo, Belo Horizonte, Buenos Aires, Rio de Janeiro, and Santafé de Bogotá. Each case study analyzes ambient air quality, sources of pollution, institutional responsibilities, and measures implemented to abate vehicular air pollution, and evaluates these measures. Chapter 5

draws conclusions based on the findings of the report and provides lessons learned from implementation of air pollution measures in various urban centers.

I would like to thank Bekir Onursal (Senior Environmental Specialist, LATEN) and Surhid Gautam (Consultant, LA1CO) for preparing this report. Extensive help was provided by various colleagues in the Bank who have been duly identified and acknowledged. My hope is that this report provides insight to vehicular air pollution in Latin America and the Caribbean and can help policymakers design air pollution control strategies.

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Abstract

Latin America and the Caribbean is the most urbanized region in the developing world with a rapidly growing motor vehicle fleet. The number of urban areas with populations exceeding 1 million was 43 in 1994 and is expected to increase to 52 in 2010. Airborne pollutant levels in many urban areas far exceed the national, regional, or local standards and World Health Organization guidelines. The main source of air pollution in these urban areas is motor vehicles, especially those which are old and poorly maintained. Ozone, particulate matter, and carbon monoxide are pollutants of greatest concern. This report analyzes the pollutants emitted by motor vehicles, their effects, and measures targeted to vehicles, fuels, and transport management to control them. Case studies for seven urban areas Mexico City, Santiago, São Paulo, Belo Horizonte, Buenos Aires, Rio de Janeiro, and Santafé de Bogotá are presented to illustrate how these measures have been used in the region and how they can be strengthened.

EXECUTIVE SUMMARY

In recent years policymakers in metropolitan areas throughout the developing world have been working to monitor and mitigate worsening levels of air pollution. For several reasons efforts to stem air pollution have been especially intense in Latin America and the Caribbean. The region's urbanization rate is the highest in the developing world. Population growth has given the region four of the world's ten most populated urban centers—São Paulo, Mexico City, Buenos Aires, and Rio de Janeiro—as well as thirty-nine others with populations exceeding 1 million people. And motorization, with large numbers of old and poorly maintained vehicles as well as growing domestic and imported vehicles, is on the rise. As a result airborne pollutant levels in many of the region's urban centers far exceed national, regional, or local standards and World Health Organization guidelines. The pollutants of greatest concern are ozone, particulate matter, and carbon monoxide. In Mexico City, São Paulo, and Santiago these and other air pollutants threaten human health and quality of life. Other urban centers of the region—such as Belo Horizonte, Buenos Aires, Rio de Janeiro, and Santafé de Bogotá—are expected to face similar problems. What actions should the region's policymakers take to prevent and control these problems?

Because most of the region's urban air pollution is contributed by motor vehicles, this report attempts to answer that question by analyzing the pollutants emitted by motor vehicles, their effects, and the measures that can be used to control them. By helping the region's policymakers to formulate and implement strategies to control pollutants, this report hopes to lower pollution levels and raise the quality of life for people in the region. These policy measures typically focus on vehicles, fuels, and transport management. Seven case studies are presented to illustrate how these policies have been used in the region and how they can be strengthened.

Formulating and implementing a comprehensive and effective urban air quality management strategy require a coordinated effort among national, regional, and local institutions representing the various jurisdictions in urban areas. At a minimum, institutions responsible for environment, transport and traffic, fuel quality and supply, industry, and health issues should participate. The participation of the scientific and business communities, labor unions, and nongovernmental organizations is also important. Moreover, a participation plan should be developed to ensure that the public's views are identified and incorporated into the decisionmaking process.

Formulation and implementation of specific pollution control measures generally have been hampered by unclear or overlapping institutional responsibilities; inadequate equipment, technical expertise, and human and financial resources; weak financial management; lack of political will; and limited public support or participation. The institutions responsible for these efforts must strengthen their human and financial resources and their management systems if they are to implement and enforce an effective air quality management strategy. The exact composition of the strategy cannot be the same for all urban centers, but should be based on the specific air pollution problems and other characteristics of each urban center. Any air pollution abatement and control strategy must be

guided by a careful evaluation of emissions and ambient air quality data, air dispersion models, and estimated costs and benefits of different measures. Still, some general guidelines can be recommended for most Latin American and Caribbean urban areas.

Vehicle-targeted measures should address both new and in-use vehicles. Establishing emission standards for new vehicles is an effective measure in vehicle-manufacturing countries where state-of-the-art pollution control technologies have not yet been adopted. These standards must be achievable in terms of technology availability and must weigh the potential benefits against the additional cost to consumers. Imported vehicles should be subject to international standards for new model-year vehicles. Compliance should be monitored both for imported vehicles and newly manufactured domestic vehicles. Given the composition and age of the vehicle fleet in Latin America and the Caribbean, policies should be developed that keep old and poorly maintained vehicles off the road. Emission standards for in-use vehicles should be established and verified through periodic inspection and maintenance programs and roadside inspections. Mexico City's experiences with inspection and maintenance programs are valuable. These measures can be complemented with programs to purchase and scrap the oldest and most polluting vehicles.

Fuel quality standards compatible with international standards should be established, and measures to meet these standards should be designed and implemented. Unleaded gasoline with minimal sulfur content should be used in new model-year vehicles equipped with catalytic converters. The lead content of gasoline used by older vehicles should be reduced and ultimately eliminated to minimize human exposure to airborne lead. In doing so, however, it is also important to evaluate the health and environmental impacts of the reformulated gasoline—especially its effect on emissions from vehicles not equipped with catalytic converters. Oxygenates can be used both as a replacement for lead to enhance the octane number, and as an additive to reduce carbon monoxide emissions in urban areas (especially at high altitudes) with high ambient carbon monoxide concentrations. Where feasible, ether-based oxygenates should be used rather than alcohol-based oxygenates. In addition, the vapor pressure of gasoline should be lowered to reduce hydrocarbon emissions and ambient ozone concentrations, and the aromatic hydrocarbon content (including benzene) should be lowered to reduce human exposure. Diesel fuel standards should include limits for parameters that affect emissions of sulfur, particulate matter, and carcinogens. In locations where compressed natural gas or liquefied petroleum gas are available, conversion of high-use vehicles (such as buses) to these alternative fuels should be considered. Fuel taxes should be used to promote use of cleaner alternative fuels or cleaner grades of the same fuels and to reduce fuel consumption and associated pollutant emissions.

By themselves *transport management measures* are insufficient to eliminate air pollution problems, but are important as a complement to vehicle- and fuel-targeted measures in designing air quality management strategies. Traffic flow should be improved through carefully planned infrastructure investment, traffic management, road pricing, high-occupancy vehicle restrictions, and other measures that reduce travel time and pollutant emissions. Driving bans for responding to emergency episodes of extreme air pollution should be designed to prevent strategies that circumvent the bans, should avoid exemptions that make the bans porous (and so defeat their purpose), and should reward the use of clean vehicles. Growth in the number of vehicles in circulation should be slowed by improving the quality, efficiency, accessibility, and value of public transport, and by improving conditions for nonmotorized transport. In the long term land use planning and control measures should be used to relieve pressures on urban centers and to create multinucleated urban areas.

Although some measures, such as eliminating lead from gasoline, should be used as extensively as possible, no single set of measures can be recommended for the entire region. Each urban area has specific pollution problems and unique environmental, physical, social, and economic factors, and so must develop its own mix of pollution control strategies. Measures that improve transport management may share common principles and dynamics, but should be tailored to each area. Even fuel standards, which every country should have, may vary according to local conditions. Whatever the approach, the tools and knowledge are available to make substantial gains at reasonable cost in most cities, and concerns about the environment, human health, and quality of life provide a compelling case for making vehicular pollution control a top priority.

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Vehicular Air Pollution: An Overview

Air pollution is the presence of pollutants in the atmosphere from anthropogenic or natural substances in quantities likely to harm human, plant, or animal life; to damage human-made materials and structures; to bring about changes in weather or climate; or to interfere with the enjoyment of life or property (Cooper and Alley 1986; Elsom 1987). The amount of pollutants released to the atmosphere by fixed or mobile anthropogenic sources is generally associated with the level of economic activity. Meteorological and topographical conditions affect dispersion and transport of these pollutants, which can result in ambient concentrations that may harm people, structures, and the environment. In general, the effects on people are most intense in large urban centers with significant emission sources, unfavorable dispersion characteristics, and high population densities.

Deterioration of air quality is a major environmental problem in many large urban centers in both industrial and developing countries. Although urban air quality in industrial countries has been controlled to some extent during the past two decades, in many developing countries it is worsening and becoming a major threat to the health and welfare of people and the environment (WHO/UNEP 1992). The Latin American and the Caribbean region is no exception. Air quality in many urban centers of the region exceeds national, regional, or local standards and World Health Organization (WHO) guidelines. The most common urban air pollutants in the region include nitrogen oxides (NO and NO_2, collectively represented as NO_x), carbon monoxide (CO), volatile organic compounds (VOCs), ozone, sulfur dioxide (SO_2), particulate matter (PM), and lead. In large urban centers such as Mexico City, São Paulo, and Santiago, air pollutants threaten human health and quality of life. Because of deteriorating air quality, other urban centers in the region such as Belo Horizonte, Buenos Aires, Rio de Janeiro, and Santafé de Bogotá are expected to face similar problems. Preventing and controlling air pollution in rapidly growing urban centers in the region will likely be major challenge for the future.

Air pollution is worse in locations with unfavorable topographical or meteorological characteristics. In São Paulo, Santiago, Mexico City, and Rio de Janeiro, for example, meteorological factors such as thermal inversions restrict dispersion of pollutants and result in high ambient pollutant concentrations. Unfavorable topography (a problem in Mexico City, Santiago, and some other urban centers) and wind direction have similar effects. Although pollutant emissions in Santiago are about 16 percent of those in São Paulo, the magnitude and severity of air pollution episodes are similar. The canyon effect of tall buildings in downtown areas also has a significant influence on ambient air concentration of pollutants emitted (such as CO and NO_x) from vehicles. The health effects of pollutants depend on many factors, including the number and age group of exposed people and their health status, ambient concentrations and types of pollutants, and dose-response functions.

Increasing urbanization and industrialization result in more energy demand, which generally leads to higher emissions of air pollutants. Emissions from fixed sources such as refineries, power and industrial plants, commercial and residen-

tial buildings, chemical and fuel storage facilities, and gasoline stations are the main sources of air pollution in some cities of the world. But for most Latin American urban centers, motor vehicles are the main contributor to deteriorating ambient air quality. Motor vehicles account for 99 percent of total CO emissions, 54 percent of hydrocarbons, and 70 percent of NO_x in Mexico City; 96 percent of CO, 90 percent of hydrocarbons, 97 percent of NO_x, and 86 percent of SO_2 in São Paulo; and 94 percent of CO, 83 percent of hydrocarbons, and 85 percent of NO_x in Santiago. Vehicular air pollution is also becoming severe in many other Latin American urban centers such as Santafé de Bogotá. Furthermore, emissions from natural sources (such as fugitive dust) contribute to pollutant emissions in some urban centers of Latin America, including Santiago and Mexico City.

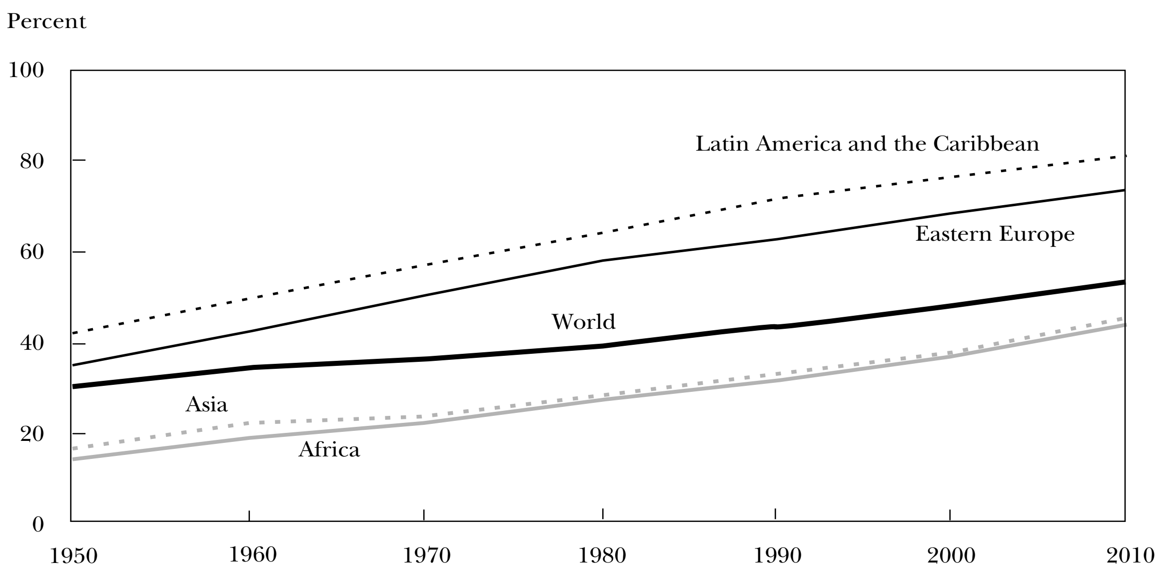
Urbanization in Latin America and the Caribbean

Latin America and the Caribbean has long been the most urbanized region in the developing world and this trend shows no sign of changing (Figure 1.1). In 1950 only 42 percent of the region's population was living in urban centers; by 1990 this percentage had risen to about 72 percent (with an urban population of 315 million; Table 1.1), much greater than in Eastern Europe (63 percent, with an urban population of 61 million), Africa (32 percent, with an urban population of 206 million), and Asia (31 percent, with an urban population of 974 million; UN 1993).

Much of the air pollution in Latin America and the Caribbean occurs in major urban centers. In 1990 four urban centers—São Paulo, Mexico City, Buenos Aires, and Rio de Janeiro—ranked second, fourth, eighth, and tenth among the world's ten largest urban agglomerations (UN 1993). In 1994 forty-three of the region's cities had populations of more than one million people (Table 1.2).

The main cause of the region's high urbanization has been an unequal land tenure system, which does not provide enough land for most families in rural areas to feed themselves. In addition, during the 1960s and the first half of the 1970s improvements in production led to economic growth that strengthened and expanded the wage-earning middle class. The increasing per capita gross domestic product (GDP) was sufficient to generate high expectations among marginalized segments of the population. Although jobs in urban centers did not pay well, they provided higher living standards than could be obtained in rural areas. As a result there were massive population movements

Figure 1.1 Population residing in urban areas, 1950–2010



Source: UN 1993.

Table 1.1 Urbanization in Latin America and the Caribbean, 1970–94

Region/country	Urban population (thousands) 1970	1980	1990	1994	Urban population (percent of total population) 1970	1980	1990	1994	Annual urban population growth (percent) 1970–80	1980–90	1990–94
South America	114,651	163,670	221,121	—	60.0	68.2	75.2	—	3.6	3.1	—
Argentina	18,784	23,401	27,829	30,096	78.4	82.9	86.1	88.0	2.2	1.7	1.6
Bolivia	1,762	2,467	3,656	4,176	40.8	44.2	51.2	58.0	3.4	3.9	3.2
Brazil	53,500	80,334	112,116	122,507	55.8	66.2	75.2	77.0	4.1	3.4	2.7
Chile	7,150	9,054	11,145	12,040	75.2	81.2	84.6	86.0	2.4	2.1	1.8
Colombia	12,218	16,957	22,604	26,136	57.2	63.9	70.0	72.0	3.3	2.9	2.7
Ecuador	2,392	3,815	5,937	6,496	39.5	47.0	56.3	58.0	4.8	4.5	3.6
French Guiana	33	49	73	—	67.4	70.8	74.6	—	4.0	4.1	—
Guyana	209	228	261	—	29.4	30.1	32.8	—	0.9	1.4	—
Paraguay	872	1,312	2,030	2,496	37.1	41.7	47.5	52.0	4.2	4.5	4.4
Peru	7,574	11,168	15,041	16,704	57.4	64.6	69.8	72.0	4.0	3.0	2.6
Suriname	171	158	200	—	45.9	44.8	47.5	—	–0.8	2.4	—
Uruguay	2,306	2,484	2,751	2,880	82.1	85.2	88.9	90.0	0.7	1.0	0.9
Venezuela	7,680	12,510	17,478	19,504	72.4	83.3	90.5	92.0	5.1	3.4	2.9
Central America and Mexico	36,189	53,796	74,486	—	53.8	60.2	65.7	—	4.1	3.3	—
Belize	61	72	96	—	50.9	49.4	50.5	—	1.7	2.9	—
Costa Rica	687	985	1,429	1,617	39.7	43.1	47.1	49.0	3.7	3.8	3.3
El Salvador	1,414	1,880	2,296	2,520	39.4	41.5	44.4	45.0	2.9	2.3	2.7
Guatemala	1,864	2,587	3,628	4,223	35.5	37.4	39.4	41.0	3.3	3.4	4.0
Honduras	759	1,317	2,244	2,726	28.9	36.0	43.7	47.0	5.7	5.5	4.9
Mexico	29,705	44,485	61,317	66,375	59.1	66.3	72.6	75.0	4.1	3.3	2.8
Nicaragua	970	1,497	2,197	2,604	47.2	53.4	59.8	62.0	4.4	3.9	4.2
Panama	729	973	1,279	1,404	47.6	49.7	52.9	54.0	2.9	2.8	2.7
The Caribbean	11,604	15,549	19,870	—	46.7	53.4	59.1	—	3.0	2.5	—
Barbados	89	100	115	—	37.1	40.1	44.7	—	1.2	1.4	—
Cuba	5,129	6,592	7,809	—	60.2	68.1	73.6	—	2.5	1.7	—
Dominican Republic	1,781	2,877	4,329	4,864	40.3	50.5	60.4	64.0	4.9	4.2	3.1
Haiti	893	1,269	1,855	2,170	19.8	23.7	28.6	31.0	3.6	3.9	4.0
Jamaica	776	998	1,266	1,375	41.5	46.8	52.3	55.0	2.5	2.4	2.1
Trinidad & Tobago	612	682	801	858	63.0	63.0	64.8	66.0	1.1	1.6	1.7
Other countries	2,324	3,031	3,695	—	54.6	62.4	68.5	—	2.7	2.0	—
Latin America and the Caribbean	162,444	233,015	315,477	—	57.4	65.0	71.5	—	3.7	3.1	—
World	1,352,143	1,752,063	2,282,367	2,520,585	36.6	39.4	43.1	45.0	2.6	2.7	2.3

— Not available.
Source: UN 1993; World Bank 1996.

from rural areas to cities. During the 1980s, however, urban population increased at a slower pace than during the previous decade. This slowdown in urbanization can be attributed to the following factors:

- Employment opportunities in urban centers decreased partly as a result of the recessionary effects of the debt crisis. Structural adjustment policies also adversely affected urban employment.

Table 1.2 Urban agglomerations with populations of more than 1 million people in Latin America and the Caribbean, 1994

Country	*Urban agglomeration*	*Population (thousands)*
Argentina	Buenos Aires	12,034
	Córdoba	1,258
	Rosario	1,165
Bolivia	La Paz	1,143
Brazil	Belém	1,109
	Belo Horizonte	4,199
	Brasília	3,201
	Campinas	2,119
	Curitiba	2,422
	Fortaleza	2,378
	Goiania	2,141
	Manaus	1,637
	Porto Alegre	3,569
	Recife	2,614
	Rio de Janeiro	11,467
	Salvador	2,758
	Santos	1,333
	São Paulo	20,113
Chile	Santiago	5,249
Colombia	Barranquilla	1,113
	Cali	1,724
	Medellín	1,710
	Santafé de Bogotá	5,452
Costa Rica	San José	1,186
Cuba	Havana	2,219
Dominican Republic	Santo Domingo	2,510
Ecuador	Guayaquil	1,947
	Quito	1,691
Guatemala	Guatemala City	1,676
Haiti	Port-au-Prince	1,217
Mexico	Guadalajara	3,088
	Guadalupe	1,498
	Mexico City	15,453
	Monterrey	2,738
	Naucalpan	1,693
	Puebla de Zaragoza	1,182
Nicaragua	Managua	1,092
Paraguay	Asunción	1,022
Peru	Lima	7,266
Uruguay	Montevideo	1,318
Venezuela	Caracas	2,924
	Maracaibo	1,551
	Valencia	1,211

Source: UN 1993 and 1996.

- With fewer children born in rural areas, migration to urban centers decreased. In addition, birth rates in urban centers fell at an even faster rate.
- Some firms moved out of crowded, expensive urban centers (such as São Paulo) to nearby small towns, forming polycentric urban areas (*Oxford Analytica*, 6 June 1996).

Based on urbanization data for 1994 (see Table 1.1), the region can be divided into four groups. The first group includes countries with an urbanization level greater than 85 percent—Argentina, Chile, Uruguay, and Venezuela. These South American countries have had the highest urbanization levels in the region since 1970. Although the pace of urbanization in Argentina,

Chile, and Uruguay was lower than the regional average during 1970–80 and 1980–90, in Venezuela it was higher, mainly because of heavier migration from rural areas. Within this country group three urban centers in Argentina (Buenos Aires, Córdoba, and Rosario), three in Venezuela (Caracas, Maracaibo, and Valencia), and one each in Chile (Santiago) and Uruguay (Montevideo) have populations exceeding 1 million. La Plata, Mar del Plata, Mendoza, and San Miguel de Tucumán in Argentina and Barquisimeto, Ciudad Guyana, and Maracay in Venezuela have populations between 500,000 and 1 million.

The second group includes countries with an urbanization level between 70 and 85 percent—Brazil, Colombia, Cuba, French Guiana, Mexico, and Peru. In 1990 these six countries accounted for about 70 percent of the region's population. Among them, French Guiana historically had high levels of urbanization. During 1970–80 and 1980-90 this group's urban population growth rate was similar to the regional average, except for French Guiana (where it was higher) and Cuba (where it was lower because urbanization occurred earlier; Villa 1992). Within the second group, fourteen urban centers in Brazil (Belém, Belo Horizonte, Brasilia, Campinas, Curitiba, Fortaleza, Goiania, Manaus, Porto Alegre, Recife, Rio de Janeiro, Salvador, Santos, São Paulo), six in Mexico (Guadalajara, Guadalupe, Mexico City, Monterrey, Naucalpan, and Puebla de Zaragoza), four in Colombia (Barranquilla, Cali, Medellín, and Santafé de Bogotá), and one each in Cuba (Havana) and Peru (Lima-Callao) have populations exceeding 1 million. Jaboatão, João Pessoa, Maceió, Natal, São Luis, Teresina, and Mossoró in Brazil; Cartagena in Colombia; Chihuahua, Ciudad Juárez, León, Mérida, Mexicali, San Luis Potasí, Tampico, Tijuana, and Torreón in Mexico; and Arequipa and Trujillo in Peru have populations between 500,000 and 1 million.

The third group includes countries with moderate urbanization levels (between 50 and 69 percent). Within this group three countries—Dominican Republic, Nicaragua, and Trinidad and Tobago—had urbanization levels greater than 60 percent in 1994. Among them, Nicaragua had the highest and Trinidad and Tobago the lowest annual rates of urban population growth. Belize, Bolivia, Ecuador, Jamaica, Panama, and Paraguay were below the 60 percent urbanization level. Within the third group two urban centers in Ecuador (Guayaquil and Quito), and one in Bolivia (La Paz), Dominican Republic (Santo Domingo), Nicaragua (Managua), and Paraguay (Asunción) have populations greater than 1 million. Santa Cruz in Bolivia and Santiago de Caballero in Dominican Republic are within the 500,000 to 1 million population range.

The fourth group includes countries with urbanization levels below 50 percent—Barbados, Costa Rica, El Salvador, Guatemala, Guyana, Haiti, Honduras, Suriname. Among them, Haiti and Honduras have much higher urban growth rates mainly because of migration from rural areas. Guatemala City in Guatemala, San José in Costa Rica, and Port-au-Prince in Haiti have populations larger than 1 million. San Pedro Sula and Tegucigalpa in Honduras have populations between 500,000 and 1 million.

Motorization in Latin America and the Caribbean

An overview. The motor vehicle fleet in Latin America and the Caribbean increased from 10.6 million vehicles in 1970 to 25.2 million in 1980 and 37.1 million in 1990 (Table 1.3). In 1994 the fleet reached 42.8 million vehicles and consisted of 31.8 million cars and 11.0 million trucks and buses (AAMA 1996). The region's share of the global fleet in 1994 was only 6.8 percent overall; 6.6 percent for cars, and 7.3 percent for trucks and buses (Figure 1.2). Cars constituted between 70 and 90 percent of the national motor vehicle fleets, a distribution similar to that in the United States (75 percent) and Canada (79 percent). Argentina, Brazil, Mexico, and Venezuela together accounted for 84 percent of the cars and 78 percent of the trucks and buses in the region (AAMA 1996).

Latin America and the Caribbean has higher motorization levels than other developing regions except Eastern Europe.[1] For example, the region's motorization level is about three times that of Asia (excluding Japan) and four times that of Africa. Motorization in the region increased from 38 vehicles per 1,000 people in 1970 to 70 vehicles per 1,000 people in 1980, and 84 vehicles per 1,000 people in 1990 (see Table 1.3). In 1994 motorization in the region

1. Motorization is defined as the number of motor vehicles per thousand people.

Table 1.3 Motor vehicle fleets and motorization in Latin America and the Caribbean, 1970–90

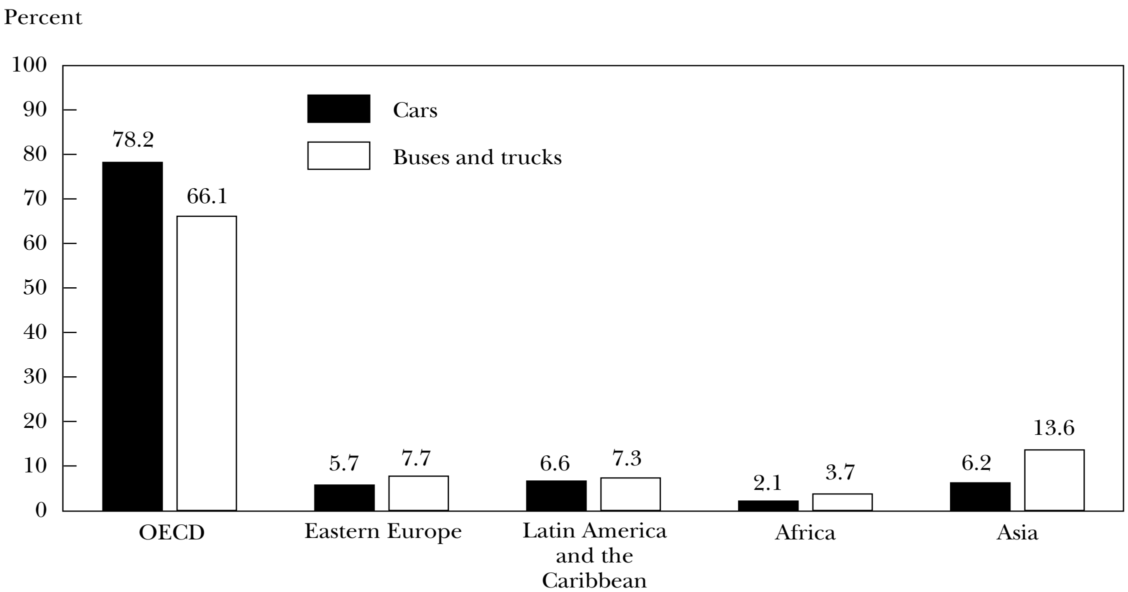
	Vehicles in circulation (thousands)[a]			*Motorization (vehicles in circulation per 1,000 people)*			*Annual growth rate of vehicles in circulation (percent)*	
Region/country	*1970*	*1980*	*1990*	*1970*	*1980*	*1990*	*1970–80*	*1980–90*
South America	8,098	18,738	25,028	42	78	85	8.8	2.9
Argentina	2,357	4,176	5,786	98	148	179	5.9	3.3
Bolivia	5	64	317	1	12	44	2.9	17.4
Brazil	3,540	10,160	13,063	37	84	87	11.1	2.5
Chile	326	588	1,017	34	53	77	6.1	5.6
Colombia	295	753	1,381	14	28	42	9.8	6.3
Ecuador	91	215	240	15	26	23	8.9	1.1
French Guiana	10	—	—	204	—	—	—	—
Paraguay	28	67	110	12	21	26	9.1	5.1
Peru	359	489	625	27	28	27	3.1	2.5
Suriname	24	32	48	65	91	114	2.9	4.1
Uruguay	209	261	258	74	89	83	2.2	–0.1
Venezuela	854	1,933	2,183	81	128	113	8.5	1.2
Central America and Mexico	2,133	5,773	10,958	32	65	97	10.6	6.6
Belize	—	12	5	—	82	26	—	–8.4
Costa Rica	58	175	250	34	77	82	11.7	3.6
El Salvador	64	140	160	18	31	30	8.1	1.3
Guatemala	70	334	230	13	48	25	16.9	–3.7
Honduras	36	71	133	14	19	26	7.0	6.5
Mexico	1,792	4,847	9,882	36	72	117	10.5	7.4
Nicaragua	53	68	74	26	24	20	2.4	0.9
Panama	60	126	224	39	64	93	7.6	5.9
The Caribbean	410	665	1098	20	27	39	5.0	5.1
Barbados	23	29	45	96	116	175	2.3	4.5
Cuba	—	—	—	—	—	—	—	—
Dominica	3	—	4	43	—	56	—	—
Dominican Rep.	60	145	270	14	25	38	9.2	6.4
Haiti	20	37	55	4	7	8	6.4	4
Jamaica	63	133	112	34	63	46	7.8	–1.7
Trinidad & Tobago	90	168	342	93	155	276	6.4	7.4
Other countries	151	153	270	35	32	50	0.1	5.8
Latin America and the Caribbean	10,641	25,176	37,084	38	70	84	9.0	4.0
World	246,368	411,076	582,982	67	92	110	5.3	3.6

— Not available.
a. Excludes two- and three-wheelers.
Source: MVMA 1971, 1982, and 1992 for number of vehicles; UN 1993 for population data.

reached 89 vehicles per 1,000 people (AAMA 1996).

The overwhelming concentration of motor vehicles in urban centers is an important contributing factor to the urban air pollution problem in Latin America (Table 1.4). In 1994, for example, the Santiago Metropolitan Area contained 58 percent of the motor vehicle fleet in Chile, the Buenos Aires Metropolitan Area contained 51 percent of the fleet in Argentina, and the Santafé de Bogotá Metropolitan Area contained 28 percent of the fleet in Colombia. The three largest metropolitan areas in Brazil (São Paulo, Rio de Janeiro, and Belo Horizonte) col-

Figure 1.2 Global distribution of the motor vehicle fleet, 1994



Note: The percentages do not add to 100 because not all countries are included (e.g. Turkey, Greece). Japan is included in the OECD country group rather than in Asia.
Source: AAMA 1996.

lectively had 45 percent of the national motor vehicle fleet (31, 10, and 4 percent, respectively).

Motorization levels in these urban areas are much higher than the respective national levels (see Table 1.4). The 1994 motorization levels in the São Paulo Metropolitan Area was 2.9 times higher than the national average in Brazil. The motorization level in metropolitan areas exceeded the national level by 98 percent in Santafé de Bogotá, 68 percent in Santiago, 56 percent in Belo Horizonte, 54 percent in Rio de Janeiro, 43 percent in Buenos Aires, and 27 percent in Mexico City. This concentration is even greater in the urban core of metropolitan areas.

Along with rising incomes in highly urbanized areas of the region, the vehicle fleet has grown

Table 1.4 Motor vehicle fleets and motorization in selected Latin American urban areas, 1994

	Motor vehicle fleet		*Motorization*	
Urban area	*Total (million)*	*Urban share of national fleet (%)*	*At urban areas (motor vehicle fleet per thousand people)*	*Urban/ National*
Mexico City	3.00	24	177	1.27
Santiago	0.64	58	133	1.68
São Paulo	4.70	31	277	2.89
Rio de Janeiro	1.55	10	148	1.54
Belo Horizonte	0.62	4	150	1.56
Buenos Aires	2.92	51	237	1.43
Santafé de Bogotá	0.46	28	89	1.98

Note: Excludes two- and three-wheelers.
Source: Authors' estimates based on data from Chapters 1 and 4.

at a rapid pace. To respond to increasing demand for motor vehicles, some countries in the region have developed and expanded domestic automotive industries. Between 1990 and 1993 the number of vehicles assembled and manufactured in the region increased by 55 percent (from 1.949 million vehicles in 1990 to 3.014 million vehicles in 1993; Piquini 1995). Trade liberalization policies, international trade agreements, and national trade pacts also have promoted lower prices and increased sales of new motor vehicles. But while the number of new vehicles (with lower emissions) is increasing, most older, poorly maintained, and more polluting vehicles have remained in use and the average age of national motor vehicle fleets is still high. The average age of cars is thirteen years in Costa Rica, twenty years in Venezuela, and twenty-three years in Paraguay. Motor vehicles older than ten years old make up 50 percent of the fleet in Argentina, 60 percent in Ecuador, and 64 percent in El Salvador. In Lima about 75 percent of vehicles are more than ten years old, and in Mexico City the average vehicle age is 8.5 years. These older cars are responsible for an inordinately high share of motor vehicle emissions and resulting deterioration of ambient air quality in urban areas.

Despite the growth of the vehicle fleet, transport infrastructure and services in Latin America and the Caribbean often have not been improved or adequately maintained. As a result many urban centers in the region are plagued by congestion and by a subsequent worsening of air quality from vehicular emissions. This problem has not been adequately addressed for various reasons, including weaknesses in legal and institutional frameworks, administrative bottlenecks, insufficient financial resources, lack of air quality management planning, and inadequate implementation of policies for air pollution control.

Motor vehicle ownership. Motor vehicle ownership is affected by various factors including economics, culture, and geography. Economic factors, especially per capita income, appear to be the driving force behind the growth of motor vehicle ownership in Latin America and the Caribbean as well as elsewhere (Faiz and others 1990; Faiz, Gautam, and Burki 1995; O'Brian and Karmokolias 1994; Stares and Zhi 1997).

Between 1970 and 1980 the motor vehicle fleet in Latin America and the Caribbean increased by 137 percent (at an annual average of 9.0 percent), while the global motor vehicle fleet grew by only 67 percent (at an annual average of 5.3 percent). The increase in motorization was 84 percent in the region and 37 percent in the world (see Table 1.3). During the 1970s growth in per capita incomes was fairly high for most countries in the region (Table 1.5). This growth largely resulted from a postwar economic boom (1950–73) in the United States, Europe, and Japan. But even when economic growth in the OECD countries faltered after the first oil shock (1973–74), most Latin American and Caribbean countries continued to grow at a fast pace. The oil shock had a limited impact because the region was experiencing a substantial trade expansion and commodities boom. Brazil, which had liberalized its economy in the 1960s, avoided the full impact of the oil shock through massive borrowing in the 1970s. Oil-exporting countries like Ecuador, Mexico, and Venezuela benefited from the windfall. The region was also able to maintain a fairly high level of investment and imports from industrial countries (Teitel 1992).

Between 1980 and 1990 the motor vehicle fleet in Latin America and the Caribbean increased by 47 percent (at an annual average of 4.0 percent), while the global motor vehicle fleet grew by 42 percent (at an annual average of 3.6 percent). The region's growth in motorization was the same as the global increase (20 percent), although because of unfavorable economic conditions it was considerably lower than in the 1970s. In the 1980s, for a number of reasons, the rapid economic growth of the previous decades was not sufficient to ensure the long-term sustainability of the region's economy. First, excessive protectionism and government control created a rigid economic structure unable to respond to global changes. Second, the region's inward-looking development strategy greatly discouraged exports. Third, many countries became incapable of providing efficient social services because of the increasing burden of inefficient public sectors and tax systems. Finally, unlike the first oil shock, the shock of 1980 had strong adverse effects on the region. An increase in interest rates, caused by the introduction of floating interest rates and deregulation of the banking system in the United States, exposed many countries in the region to high-cost financing. The oil shock also reduced the volume of international trade and led to a fall in commodity prices. Instead of adjusting to this changing

Table 1.5 Per capita income in Latin America and the Caribbean, 1970–94

	GNP per capita (U.S. dollars)[a]				Annual growth rate of GNP per capita (percent)[b]		
Region/country	*1970*	*1980*	*1990*	*1994*	*1970–80*	*1980–90*	*1990–94*
South America							
Argentina	1,160	2,590	2,370	8,110	0.7	–1.8	6.9
Bolivia	180	570	630	770	1.9	–2.6	1.9
Brazil	420	2,160	2,680	2,970	5.9	0.6	0.3
Chile	720	2,290	1,940	3,520	0.5	1.1	5.9
Colombia	340	1,260	1,260	1,670	4.0	1.1	3.1
Ecuador	290	1,100	980	1,280	5.3	–0.8	1.6
French Guiana	940	200	—	—	–0.4	—	—
Guyana	370	690	330	530	6.4	–5.8	10.5
Paraguay	260	1,410	1,110	1,580	5.9	–1.3	–0.5
Peru	450	1,080	1,160	2,110	0.2	–2.0	3.2
Suriname	530	2,770	3,050	860	6.8	–5.0	0.6
Uruguay	820	2,620	2,560	4,660	3.2	–0.9	3.9
Venezuela	980	3,910	2,560	2,760	2.2	–2.0	0.6
Central America and Mexico							
Belize	—	980	1,990	2,530	—	2.5	1.1
Costa Rica	560	1,390	1,900	2,400	2.6	0.6	—
El Salvador	300	670	1,110	1,360	1.3	–0.6	4.3
Guatemala	360	1,080	900	1,200	2.8	–2.1	–0.2
Honduras	280	560	590	600	0.5	–1.2	0.7
Mexico	670	1,980	2,490	4,180	3.1	–0.9	0.7
Nicaragua	430	760	420	340	–2.9	—	—
Panama	730	1,730	1,830	2,580	1.2	–2.0	5.9
The Caribbean							
Barbados	570	3,270	6,540	6,560	3.2	1.4	–1.1
Cuba	530	—	—	—	—	—	—
Dominica	280	640	2,220	2,800	–3.1	3.0	2.0
Dominican Republic.	350	1,190	830	1,330	3.3	–0.4	2.9
Haiti	110	280	370	230	1.8	–2.3	–9.6
Jamaica	670	1,090	1,500	1,540	–2.8	–0.4	3.5
Trinidad & Tobago	860	5,010	3,610	3,740	3.9	–6.0	–0.7

— Not available.
a. At current prices.
b. At constant prices.
Source: World Bank 1972, 1983, 1992, and 1996.

situation, the region continued to borrow under unfavorable conditions to finance high government deficits that led to spiraling inflation, which affected income distribution. The high inflation also resulted in reduced savings and investments, which hampered economic growth (Edwards, 1995). Despite the decline in per capita income during the 1980s, inflationary conditions led to the emergence of upper-income groups whose vehicle acquisitions helped increase motorization levels in countries such as Argentina, Bolivia, Ecuador, Mexico, Peru, and Venezuela (Tables 1.3 and 1.5).

Since the mid-1980s, however, economic reforms in the region have been impressive. These reforms have included implementation of major stabilization programs, opening up of economies to international competition, and privatization of a large number of state-owned enterprises. The decline in per capita income during 1982–86 was subsequently recovered in many countries. Most countries, especially the

advanced reformers, experienced respectable growth during the early 1990s. After accelerating in the late 1980s, inflation has declined substantially throughout the region. The economic recovery was also assisted by the massive inflow of foreign capital in the beginning of 1991, coupled with expansion of exports and rising productivity in the manufacturing sector (Edwards 1995). Despite this progress, several problems persist a decade after the debt crisis. These problems include severe deterioration of the physical infrastructure, increases in poverty, and double-digit inflation in many countries. In addition, because economic reforms were not accompanied by the modernization of political institutions, political tensions (and in some cases civil unrest) have developed in such countries as Brazil, Guatemala, Haiti, Peru, and Venezuela.

Cross-sectional regression analyses were carried out on per capita income and motorization levels for the same set of twenty-one countries of the region for 1970, 1980, and 1990. The results show a strong correlation between these two variables, confirming that per capita income is a significant factor for motorization (Figure 1.3).[2] The income elasticity coefficients for the three years were 1.59, 1.09, and 1.18, respectively (implying that a 1 percent increase in incomes would lead to 1.59, 1.09, and 1.18 percent increases in vehicle ownership). These elasticity coefficients are similar to those found in other studies (ranging from 1.02 to 1.59) conducted for various years and groups of countries during 1968-90 (Stares and Zhi 1997).

$$\log(\text{number of vehicles in circulation}/1{,}000\text{ people})_{1990} = -1.97 + (1.18 \times \log \text{GNP/capita})$$

$$\log(\text{number of vehicles in circulation}/1{,}000\text{ people})_{1980} = -1.78 + (1.09 \times \log \text{GNP/capita})$$

$$\log(\text{number of vehicles in circulation}/1{,}000\text{ people})_{1970} = -2.85 + (1.59 \times \log \text{GNP/capita})$$

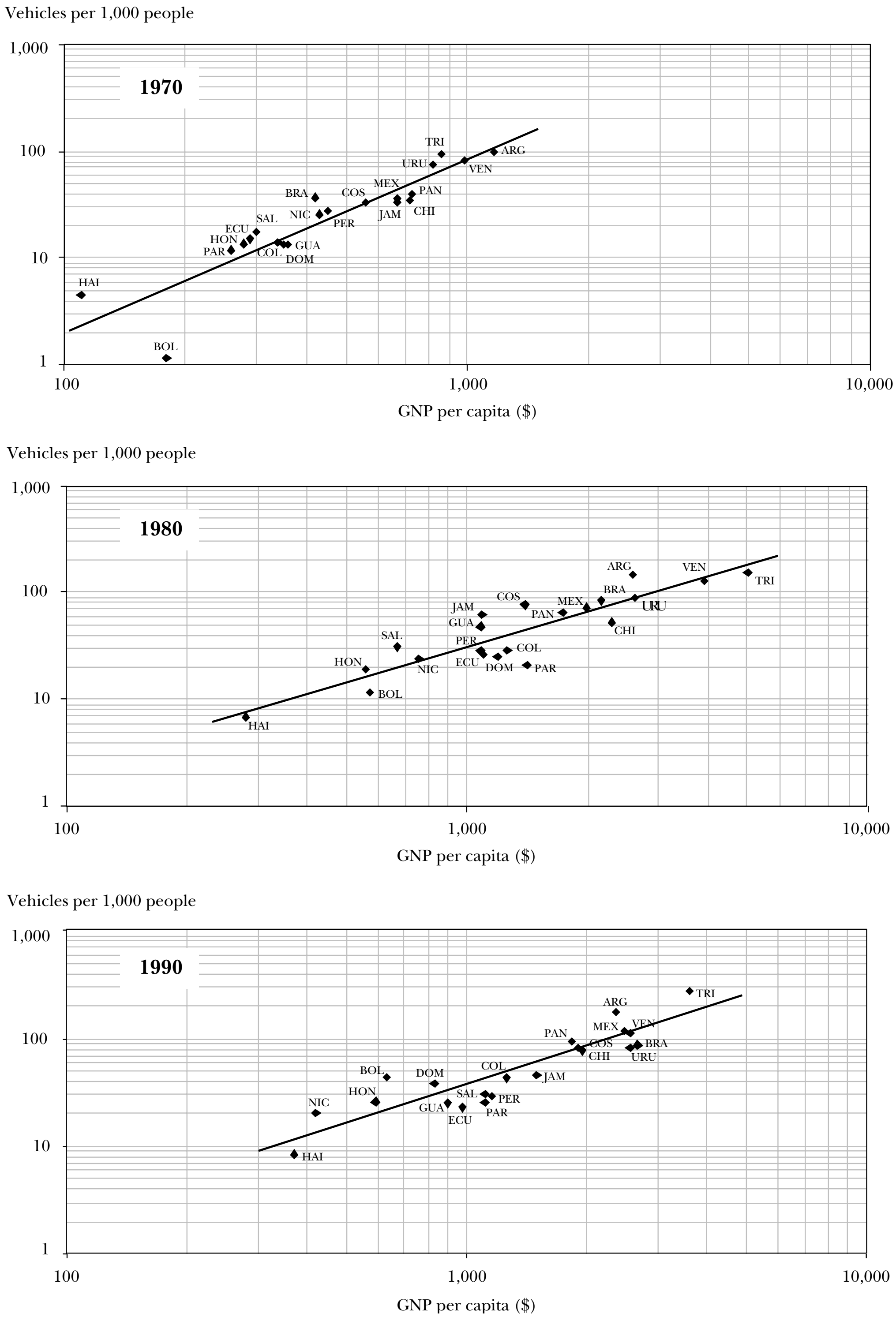
Motor vehicle supply. The great majority of new vehicles sold in Latin America and the Caribbean are produced within the region, though a small percentage are imported from outside, mostly from OECD countries. The main motor vehicle producers in the region are Brazil (1.39 million vehicles in 1993), Mexico (1.08 million vehicles in 1993), and Argentina (0.34 million vehicles in 1993). Smaller numbers of motor vehicles are produced in Chile, Colombia, Peru, Uruguay, and Venezuela. Although most motor vehicle manufacturers in the region serve their domestic markets, Mexico exports 44 percent of its production and Brazil exports 24 percent. However, Brazil sells 88 percent of its exports within the region (70 percent to Argentina alone), while Mexico sell only 9 percent of its exports within Latin America and the Caribbean (90 percent of its exports go to the United States and Canada; AAMA 1995; Piquini 1995).

From its establishment in the late 1950s through its development in the following two decades, the automotive industry in the region was marked by strong government involvement. Local industries emerged and flourished thanks to government import substitution policies, which were politically attractive because they generated local employment opportunities and independence from international markets. Local industries were protected by both tariff and nontariff barriers, which in some cases banned importation of foreign-made vehicles, leaving participation in local production as the only option available to foreign vehicle manufacturers. Governments also provided large tax incentives to local automotive industries. As a result of these protections and incentives, local automotive industries thrived in Argentina, Brazil, Chile, Colombia, Ecuador, Mexico, Uruguay, and Venezuela. In 1980 total production for these eight countries reached a record 2.2 million. Other Latin American and Caribbean countries with smaller markets and lower per capita incomes did not develop their own industries but allowed vehicle imports (Sánchez 1992). The emergence of the debt crisis in 1981 caused the region's economies to spiral downward, however. Vehicle production dropped by 22 percent in just one year (to 1.8 million in 1981) and remained below the 2 million mark until the end of the decade (Piquini 1991).

With economic liberalization, most countries in the region began to move away from the import substitution, state-controlled development model. In Chile this process was initiated in 1975 and followed by privatization and deregulation after the debt crisis of 1982. Mexico in 1988, Argentina in 1989, Venezuela in 1990, and Colombia in 1991 took decisive steps to liberalize their economies. In 1993 vehicle sales in the region increased to 2.4 million (59 percent more

2. The r^2 and t statistics were 0.82 and 9.2 for 1970, 0.81 and 9.1 for 1980, and 0.82 and 9.2 for 1990.

Figure 1.3 Per capita income and motorization in Latin America and the Caribbean, 1970, 1980, and 1990



Source: MVMA 1971, 1982, and 1992 for motorization data, UN 1993 for population data, and World Bank Atlas (various years) for per capita income data.

than the 1990 level and 13 percent more than the 1980 level) and vehicle production increased to 3.0 million (55 percent more than the 1990 level and 38 percent more than the 1980 level). Although Latin American markets are now open to imports, they are not totally free of restrictions. For example, in Mexico import of vehicles is restricted to vehicle manufacturers. In Argentina there are import quotas and taxes. Brazil's market is free of quotas, but a 35 percent tax is charged for all imported vehicles. Import taxes also exist in Colombia and Venezuela (Piquini 1995).

Latin American countries have also entered into trading blocs. In 1993 Mexico signed the North American Free Trade Agreement (NAFTA) with the United States and Canada, allowing expansion and modernization of its automotive industry as well as integration with the U.S. industry. That same year Colombia, Ecuador, and Venezuela—members of the Andean Pact that also includes Bolivia, Chile, and Peru—formed a trading bloc by agreeing on a common automotive policy. Argentina, Brazil, Paraguay, and Uruguay formed the Southern Cone Common Market (Mercosur), which became effective on January 1, 1995. That agreement established free circulation of goods, services, financial resources, and workers; eliminated nontrade barriers; set a single tariff for goods; and implemented similar macroeconomic policies in several areas, including transport. Through agreements signed in 1986 and 1990 and followed by Mercosur, Argentina and Brazil have almost integrated their automotive industries (Piquini 1995). Thus the region's previously closed automotive industry has become subject to intense competition and a demand for higher-quality vehicles.

Mexico is a good example of successful economic restructuring. The Mexican program focused on four interrelated issues: price stabilization, privatization, domestic deregulation, and trade liberalization (Sánchez 1992). Prices were stabilized through social pacts and the public deficit was controlled through tax reform, major cuts in public sector investment, elimination of subsidies (including on gasoline), and an aggressive privatization program. Deregulation lifted requirements on the number of vehicle models produced by each company in Mexico, specific vehicle components produced in Mexico, and operation of the Mexican trucking industry. With the foreign investment law of 1990, foreign companies were permitted to have up to 100 percent ownership under certain conditions. Trade liberalization reduced the licensing requirements for importation and tariffs (Sánchez 1992). NAFTA has further liberalized Mexico's trade policies.

The Argentine government's economic policy of 1989 included price stabilization through dollarization of the economy, tax reform, and privatization. In 1991 a sectoral pact cut the price of vehicles by about 30 percent. As a result vehicle production increased fourfold in three years. Brazil's domestic automotive markets, which had been closed to external competition, opened in 1990, and imported vehicles accounted for 8 percent of sales in 1993. Because of competition from foreign imports, vehicle prices dropped by 25 percent (in dollar terms) between 1992 and 1994 (Piquini 1995). In traditionally closed economies like Colombia and Venezuela, imported vehicles account for about 40 percent of the market (O'Brian and Karmokolias 1994). Since the early 1990s growth in the region's automotive industry has been so spectacular that companies struggling with overcapacity just a few years before are now striving to find extra capacity. In 1994 car manufacturers were planning to invest $3.1 billion in Argentina, Brazil, and Mexico (Piquini 1995).

The Outlook

The urban growth rate in Latin America and the Caribbean is expected to slow as a result of declining overall population growth, less migration from rural areas, and the lower birth rates of the earlier migrants. Still, by 2010 about 80 percent of the region's population is expected to live in urban areas (see Figure 1.1; UN 1993). Moreover, nine urban areas in addition to the forty-three listed in Table 1.2 will have populations greater than 1 million: Mendoza in Argentina; Santa Cruz in Bolivia; São Luis in Brazil; Santiago de Caballero in Dominican Republic; Tegucigalpa in Honduras; Ciudad Juárez and León in Mexico; and Barquisimeto and Maracay in Venezuela.

As a result of economic growth and trade liberalization, vehicle sales in Latin America and the Caribbean are expected to grow considerably to reach 4.5 million a year in 2000 (about three times more than in 1990). This will consist of about 3.3 million passenger cars, 900,000 light-duty commercial vehicles, and 300,000

heavy-duty commercial vehicles (Piquini 1995). Most of these vehicles, especially cars, will enter the urban fleet. Far fewer vehicles will be retired from the urban fleet than added, resulting in a much greater number of vehicles on the road, more congestion, and more fuel consumption. Unless adequate air pollution control measures are adopted soon, urban air quality will worsen considerably causing adverse health effects not only for highly vulnerable population groups (children, the sick, and the old) but for the general population as well.

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2

AIR POLLUTANTS AND THEIR EFFECTS

Air pollutants can be grouped in two categories: *primary*, if emitted directly into the atmosphere, and *secondary*, if formed in the atmosphere as a result of chemical reactions (such as hydrolysis, oxidation, or photochemical reactions) that involve primary pollutants. Primary pollutants emitted by motor vehicles include carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbon compounds (HC), sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulate matter (PM), and lead. Secondary pollutants associated with motor vehicle emissions include nitrogen dioxide (NO_2), photochemical oxidants (for example, ozone), and sulfuric or nitric acids and their salts (that is, sulfate and nitrate aerosols). NO_2 is formed through oxidation in the air of nitric oxide (NO), a gaseous pollutant formed at high combustion temperatures and emitted by motor vehicles. Ozone (O_3) is formed from NO_x and reactive HC in the presence of sunlight. SO_2 and NO_x can react with atmospheric moisture, oxygen, and PM to form sulfuric or nitric acid or their salts.

This chapter provides an overview of the sources, properties, and emission characteristics of vehicular air pollutants. Factors that affect dispersion of these pollutants, such as meteorological and topographical factors, are then reviewed. A discussion of health and environmental effects and some quantification of effects on human health is then presented. Finally, the ambient air quality standards adopted by different Latin American countries are provided and the design options for ambient air quality monitoring systems are discussed.

Pollutant Emissions from Motor Vehicles

Motor vehicle emissions result from fuel combustion or evaporation. The most common types of transport fuels are gasoline (in leaded or unleaded form) for light-duty vehicles (such as cars) and diesel fuel for heavy-duty vehicles (such as buses and trucks). Other commercial fuels used in light-duty vehicles include alcohols (such as ethanol and methanol), gasoline-alcohol mixtures, compressed natural gas (CNG), and liquefied petroleum gas (LPG). For heavy-duty vehicles other commercially available fuels include gasoline, CNG, and LPG.

Emissions from motor vehicles with spark-ignition engines (for example, gasoline-fueled vehicles) are from the exhaust, engine crankcase, and fuel system (carburetor, fuel line, and fuel tank). CO_2 and water vapor (H_2O), the main products of combustion, are emitted in vehicle exhaust. The major pollutants emitted from gasoline-fueled vehicles are CO, HC, NO_x, and lead (only for leaded gasoline fuel). In addition, SO_2 may also be present in exhaust gases. The air conditioning system, tires, brakes, and other vehicle components also produce emissions.

For a given fuel quality, concentrations of many of these pollutants are influenced by such factors as the air-fuel ratio in the cylinder at the time of combustion, ignition timing, combustion chamber geometry, engine parameters (for example, speed, load, and engine temperature), and use of emission control devices. Vehicles with electronic fuel injection engines electronically maintain an air-fuel ratio of about 14.7:1 (that is, 14.7 grams of air per gram of gasoline, which

is the stoichiometric ratio for the air-gasoline mixture) to achieve complete combustion. Higher ratios ("lean" mixtures) produce less HC and CO emissions, while lower ratios ("rich" mixtures) produce more CO and HC emissions from unburned or partially burned fuel. Ignition timing also affects the combustion process. The air-fuel ratio and ignition timing are readily adjustable, both in design specifications and field tune-up adjustments (Bellomo and Liff 1984). Light-duty gasoline-fueled vehicles not equipped with pollution control devices have the highest exhaust emissions during acceleration, followed by deceleration, cruising, and idling cycles (Table 2.1). Thus frequent cycle changes, as required by stop-and-go traffic patterns in congested urban areas, increase pollutant emissions. At higher cruising speeds HC and CO emissions decrease, while NO_x and CO_2 emissions increase. Three-way catalytic converters installed on gasoline-fueled vehicles can reduce CO and HC emissions by about 90 percent and NO_x emissions by 70 percent from uncontrolled levels (see Chapter 3).

Evaporative emissions are HC vapors lost directly to the atmosphere, mainly from the fuel tank and carburetor. Fuel tank losses consist primarily of the more volatile fractions of fuel displaced from the vapor space above the liquid fuel in the fuel tank and mainly occur as a result of a temperature change in the fuel tank; they may also be caused by diurnal temperature changes. Losses from the carburetor, called *hot soak emissions*, occur when a hot engine is stopped. Evaporative emissions from the carburetor have been greatly alleviated with the advent of electronic fuel injection engines that maintain fuel under pressure and prevent its escape from the system. Hot soak and diurnal emissions are controlled by on-board activated carbon canisters. Evaporative emissions also occur during refueling through displacement and spillage and account for a large proportion of HC emissions.

Crankcase blow-by (also called running loss emissions) are unburned or partially burned fuel components that, under pressure, escape from the combustion chamber, pass the pistons, and enter the crankcase. In older model-year vehicles these emissions were vented to the atmosphere. In newer model-years they are controlled by recycling to the engine through the intake system (Faiz, Weaver, and Walsh 1996).

The pollutants from diesel-fueled vehicles are PM (including smoke), NO_x, SO_2, CO, and HC. Most of these pollutants are emitted from the exhaust. Because diesel engines operate at high air-fuel ratios (about 30:1), they tend to have low HC and CO emissions. They have considerably higher PM emissions than gasoline-fueled vehicles, however. For heavy-duty vehicles, CO, HC, and NO_x, emissions in the exhaust also vary with driving modes, engine speed, and load. Table 2.2 shows the effects of different driving

Table 2.1 Exhaust emissions from uncontrolled light-duty gasoline-fueled vehicles at different driving modes

(parts per million)

Mode	*CO*	*HC*	*NO_x*	*CO_2*
Idling	16	1.3	0.1	68
Accelerating				
0–15 mph	2,997	536	62	10,928
0–30 mph	3,773	757	212	19,118
Cruising				
15 mph	67	5.1	0.8	374
30 mph	30	3.0	2.0	323
45 mph	28	2.9	4.2	355
60 mph	29	2.9	6.4	402
Decelerating				
15–0 mph	1,902	344	21	5,241
30–0 mph	1,390	353	41	6,111

mph = Mile per hour.
Source: Bellomo and Liff 1984.

Table 2.2 Exhaust emissions from uncontrolled heavy-duty vehicles at different driving modes

(parts per million)

	Gasoline-fueled vehicle			Diesel-fueled vehicle		
Mode	*CO*	*HC*	*NO_X*	*CO*	*HC*	*NO_X*
Idling	69,000	5,300	30	Trace	400	60
Accelerating	29,000	1,600	1,020	1,000	200	350
Cruising	27,000	1,000	650	Trace	100	240
Decelerating	39,000	10,000	20	Trace	300	30

Source: Faiz and others 1994.

modes on pollutant emissions from uncontrolled heavy-duty vehicles. Two-way catalytic converters used in diesel-fueled vehicles can reduce CO emissions by 80 percent and a large portion of HC present in PM emissions (see Chapter 3).

Ambient air temperature also affects the emission rates of pollutants from vehicles. Higher temperatures promote evaporative emissions that contain the more volatile fraction of HC in gasoline but result in lower emissions of HC and NO_x from the vehicle exhaust. CO emissions tend to be higher at lower temperatures. PM and SO_2 emissions are not affected by ambient air temperature.

In addition, at higher altitudes, where air density is lower, the fuel-air ratio of the mixture admitted to the engine of vehicles equipped with carburetors or continuous fuel injection systems becomes larger. A higher ratio lowers engine power output and increases CO and HC emissions from gasoline-fueled vehicles. Engine adjustments for higher altitudes are required to reduce these emissions. For vehicles equipped with electronic fuel injection systems, which automatically compensate for altitude changes, such adjustments are not necessary (Faiz, Weaver & Walsh 1996).

Air Pollutants

Carbon monoxide. Carbon monoxide (CO), a colorless and odorless gas that is slightly denser than air, is emitted by natural and anthropogenic sources. Anthropogenic sources form CO from incomplete combustion of carbonaceous fuels in motor vehicles, heating and industrial facilities, thermal power plants, and incinerators. Residence time and turbulence in the combustion chamber, flame temperature, and excess oxygen affect CO formation. Conversion of CO to CO_2 in the atmosphere is slow and takes two to five months (Masterson, Slowinski, and Stanitski 1985).

Motor vehicles (especially cars) are the main contributors to anthropogenic CO emissions. Worldwide anthropogenic CO emissions for 1995 are estimated at 350 million tons, 59 percent of which were contributed by the transport sector, 39 percent by the residential and commercial sectors, and 2 percent by the industrial and power sectors. Developing countries contribute 50 percent of global CO emissions. In developing countries the transport sector accounts for 53 percent of CO emissions and the residential and commercial sectors, 46 percent. In Latin American urban centers motor vehicles are responsible for 60 to more than 90 percent of CO emissions (OECD/IEA 1991).

Nitrogen oxides. Nitrogen oxides include nitric oxide (NO), nitrogen dioxide (NO_2), nitrous oxide (N_2O), dinitrogen trioxide (N_2O_3), and nitrogen pentoxide (N_2O_5). Nitrogen oxides are produced by natural phenomena such as lightning, volcanic eruptions, and bacterial action in the soil and by anthropogenic sources such as combustion of fuels in internal combustion engines, thermal power plants, industrial and heating facilities, and incinerators. NO and NO_2, collectively represented as NO_x, are the main nitrogen oxides emitted by vehicles. About 90 percent of these emissions are in the form of NO. NO is produced in the vehicle engine by combustion of nitrogen at high temperatures. NO_2, formed by oxidation of NO, has a reddish-brown color and pungent odor. In the atmosphere it may be involved in a series of reactions (in the presence of ultraviolet radiation) that produce photochemical smog, reducing visibil-

ity. It may also react with moisture in air to form nitric acid (HNO_3) aerosols. In the lower atmosphere (troposphere) NO_2 forms ozone by reacting with HC. In the upper atmosphere it reacts with chlorine monoxide to form chlorine nitrate, which releases ozone-destroying chlorine atoms upon reaction with hydrogen chloride.

Motor vehicles are the main contributors to anthropogenic NO_x emissions. Worldwide anthropogenic NO_x emissions for 1995 are estimated at 93 million tons, 43 percent of which were contributed by the transport sector, 32 percent by the power sector, 12 percent by the industrial sector, 8 percent by the residential and commercial sectors, and 5 percent by other sources. Developing countries contribute 26 percent of global NO_x emissions. In developing countries the transport sector accounts for 49 percent of NO_x emissions, and the power sector, 25 percent; the industrial sector, 11 percent; the residential and commercial sectors, 10 percent; and other sources, 5 percent (OECD/IEA 1991).

Hydrocarbon compounds. Hydrocarbon compounds (HC) are defined chemically as compounds consisting of carbon and hydrogen. In air quality studies, however, the term hydrocarbons is often extended to include a variety of other volatile organic compounds (VOCs) such as alcohols and aldehydes. Most HC are not directly harmful to health at concentrations found in ambient air. Through chemical reactions in the troposphere, however, they play an important role in forming NO_2 and ozone, which are health and environmental hazards. Among the various HC, methane (CH_4) does not participate in these reactions. Because the remaining HC, *nonmethane hydrocarbons (NMHC)*, are reactive in forming secondary air pollutants, they are the focus of air quality studies (Horowitz 1982).

HC are emitted from natural and anthropogenic sources. Natural sources include anaerobic decomposition of plants in swamps and marshes, seepage from natural gas and oil fields, and emissions from trees. The first two sources mainly produce methane, and the third source produces photochemically reactive HC (Horowitz 1982). Anthropogenic emission sources include motor vehicles, gasoline and solvent storage tanks and transfer stations, petroleum refineries, and chemical and petrochemical plants. HC emissions from motor vehicles occur from unburned fuel or from partial combustion of fuels. About 55 percent of HC emissions from gasoline-fueled vehicles with no emission controls originate in the exhaust system, 13 to 25 percent come from the crankcase blow-by, and 20 to 32 percent evaporate in the fuel lines, fuel tank, and carburetor. Methane constitutes 5 to 15 percent of HC emissions from vehicles not equipped with catalytic converters and up to 40 percent of exhaust HC from catalyst-equipped vehicles. This is because the catalysts are less effective in oxidizing methane than other hydrocarbons. In the presence of ultraviolet radiation, NMHC and NO_x react with oxygen to form ozone in the troposphere. The reaction time varies from less than an hour to several days depending on the reactivity of the NMHC.

Motor vehicles emit toxic HC, including benzene, 1,3-butadiene, aldehydes, and polycyclic aromatic hydrocarbons (PAH). Benzene is an aromatic HC present in gasoline. About 85 to 90 percent of benzene emissions come from exhaust and the remainder comes directly from gasoline evaporation and through distribution losses (Faiz, Weaver, and Walsh 1996). The benzene in exhaust originates both from partial combustion of other aromatic HC compounds in gasoline such as toluene and xylene; and from the benzene already in gasoline. Benzene constitutes 63 to 85 percent of the toxic emissions in exhaust from gasoline-fueled cars equipped with fuel-injected engines and new technology, and 36 to 65 percent from older model-year cars equipped with carbureted engines and catalytic converters (Table 2.3; AQIRP 1991). Aldehydes and 1,3-butadiene are not present in gasoline, diesel fuel, ethanol, or methanol but are present in their exhaust emissions as partial combustion products. Aldehydes are also formed in the atmosphere from other mobile source pollutants and have a high photochemical reactivity in ozone formation. The major types of aldehydes formed include formaldehyde and acetaldehyde. Combustion of ethanol favors acetaldehyde emissions and combustion of methanol favors formaldehyde emissions. Controlled gasoline-fueled cars have higher emissions of formaldehyde than acetaldehyde (see Table 2.3). Uncontrolled gasoline-fueled vehicles emit 0.6 to 2.3 grams of aldehydes per liter and uncontrolled diesel-fueled vehicles emit 1 to 2 grams of aldehydes per liter (Wijetilleke and Karunaratne 1995). PAH are emitted at a higher rate in the exhaust of diesel-fueled vehicles than gasoline-fueled vehicles.

Table 2.3 Exhaust emissions of toxic air pollutants from gasoline-fueled cars

	Benzene	*1, 3 Butadiene*	*Formaldehyde*	*Acetaldehyde*
1989 model-year cars[a]				
Toxic emissions[b] (mg/km)	4.4–10.8	0.3–0.9	0.7–2.1	0.4–0.8
Percent of toxic emissions	60–85	6–10	7–24	2–8
1983–85 model-year U.S. cars[a]				
Toxic emissions[b] (mg/km)	7.7–14.4	0.6–2.6	4.4–11.9	1.5–2.7
Percent of toxic emissions	36–66	2–11	22–49	7–13

a. The 1989 model-year U.S. cars are equipped with fuel-injected engines and new technology. The 1983–85 model-year U.S. cars are old catalyst-equipped cars with carbureted engines.
b. Total toxic emissions range from 6.3 to 13.1 mg/km for 1989 model-year cars and from 16.9 to 25.0 mg/km for 1983–85 model-year cars.
Source: AQIRP 1991.

Ozone. Ozone is a colorless gas that occurs in two separate layers of the atmosphere. Ozone in the outer (stratospheric) layer of the atmosphere is generated by photolysis of oxygen or naturally occurring HC, and protects the earth from ultraviolet rays. In the lower (tropospheric) layer, *ground-level ozone* is formed by the reaction of VOCs and NO_x with ambient oxygen in the presence of sunlight and high temperatures. Ground-level ozone is a major constituent of smog in urban areas and motor vehicles are the main anthropogenic emission source of its precursors. Areas downwind of urban centers may also be affected by ground-level ozone as winds carry VOCs and NO_x from their original sources. The reactions that form ground-level ozone also produce small quantities of other organic and inorganic compounds such as peroxyacetylnitrate (PAN) and nitric acid (Horowitz 1982). Ground-level ozone concentrations depend on the absolute and relative concentrations of its precursors and the intensity of solar radiation, which exhibits diurnal and seasonal variations. Thermal inversions increase ground-level ozone concentrations (World Bank 1996).

Sulfur dioxide. Sulfur dioxide (SO_2) is a stable, nonflammable, nonexplosive, colorless gas that can be detected by taste at concentrations as low as 1,000 $\mu g/m^3$ or by smell at concentrations above 10,000 $\mu g/m^3$. It is extremely soluble in water. SO_2 is produced by the combustion of sulfur-bearing fossil fuels for thermal power generation, heating, cooking, and transportation. Petroleum refining and ore smelting are additional sources. In the atmosphere SO_2 may be converted to sulfur trioxide (SO_3) by reacting with oxygen. SO_2 and SO_3 react with the moisture in air to form sulfurous (H_2SO_3) and sulfuric (H_2SO_4) acids, which may be transported by winds many hundreds of kilometers before falling to earth as acid rain. Sulfates may also be produced through reaction of these sulfur compounds with metals present in PM.

Annual global emissions of SO_2 are estimated at 294 million tons. Of this, 160 million tons are from anthropogenic sources. About 90 percent of these emissions originate from the northern hemisphere; the United States and the republics of the former Soviet Union are the two biggest sources (UNEP 1991). The transport sector's contribution to global SO_2 emissions is estimated at 2 to 6 percent.

Particulate matter. Particulate matter (PM) consists of fine solids and liquid droplets, other than pure water, that are dispersed in air. PM originates from natural as well as anthropogenic sources. Natural sources include wind-blown soil dust, volcanic ash, forest fires, sea salt, and pollens. Anthropogenic sources include thermal power plants, industries, commercial and residential facilities, and motor vehicles using fossil fuels.

Total suspended particulates (TSP) are particles with an aerodynamic diameter of less than 70µm.[1] PM larger than 10µm in diameter results from physical actions such as wind erosion or grinding operations and tend to settle near their

1. 1µm = 1 micrometer = 1 micron = 10^{-6} meter.

emission source. PM with an aerodynamic diameter of 10µm or less, known as *suspended inhalable particulate matter* or *PM-10*, remains in the atmosphere for longer periods because of its low settling velocity. PM-10 can penetrate deeply into the respiratory tract and cause respiratory illnesses in humans. PM with an aerodynamic diameter of 2.5-10 µm or less is defined as *fine particles (PM-2.5)*, while larger PM is called *coarse particles.*

Coarse particles are generally emitted from wind-blown dust, vehicles traveling on unpaved roads, materials handling, and crushing and grinding operations. Nearly all PM emitted by motor vehicles consists of fine particles and a large fraction of these particles has an aerodynamic diameter less than 1 µm. PM-2.5 results from combustion of fossil fuels in power generation and manufacturing facilities, residential fireplaces and wood stoves, and agricultural burning. PM-2.5 can also be formed in the atmosphere as aerosols from chemical reactions that involve such gases as SO_2, NO_x, and VOC. Sulfates, which are commonly generated by conversion from primary sulfur emissions, make up the largest fraction of PM-2.5 by mass. (Pope and others 1995). PM-2.5 can also form as a result of solidification of volatile metal salts as crystals following cooling of hot exhaust gases from vehicles in ambient air (Winchester 1989). PM-2.5 can remain suspended in the air and travel long distances.

Gasoline-fueled vehicles have lower PM emission rates than diesel-fueled vehicles. PM emissions from gasoline-fueled vehicles result from unburned lubricating oil, and ash-forming fuel and oil additives (Faiz, Weaver, and Walsh 1996). For vehicles fueled by leaded gasoline, lead compounds account for a major portion of PM emissions. PM emitted by diesel-fueled vehicles consists of soot formed during combustion, heavy HC condensed or adsorbed on the soot, and sulfates. These emissions contain polycyclic aromatic hydrocarbons (PAH). In older diesel-fueled vehicles the contribution of soot to PM emissions is between 40 and 80 percent. With the advance of emission control measures in engines, however, the contribution of soot has been reduced considerably. Heavy HC, referred to as the soluble organic fraction of PM, originate from lubricating oil, unburned fuel, and compounds formed during combustion (Walsh 1995).

Black smoke, associated with the soot portion of PM emitted by diesel-fueled vehicles, is caused by oxygen deficiency during the fuel combustion or expansion phase. Blue, gray, and white smoke are caused by the condensed HC in the exhaust of diesel-fueled vehicles. Blue or gray smoke results from vaporized lubricating oil, and white smoke occurs during engine start-up in cold weather. Diesel fuel additives such as barium, calcium, or magnesium reduce smoke emissions, but increase PM sulfate emissions. These additives may also increase PAH emissions. Copper-based additives can reduce PM emissions, but may catalyze the reaction between HC and trace amounts of chlorides in diesel fuel to form dioxins, which are emitted in the exhaust (Faiz, Weaver, and Walsh 1996). The use of barium and copper in diesel fuel additives is of concern because of their toxic properties.

Lead. Motor vehicles fueled with leaded gasoline are the main source of lead in ambient air. Tetraethyl lead is added to gasoline to increase the fuel's octane number, which improves the antiknock characteristics of the fuel in spark-ignition engines. About 70 to 75 percent of this lead is transformed into inorganic lead in vehicles' engines upon combustion and emitted to the atmosphere through the exhaust pipe along with 1 percent of the organic lead that passes through the engine unchanged. The rest of the lead remains trapped within the exhaust system. Organic lead emissions usually occur as vapor, while inorganic lead is emitted as PM, often less than 1 µm in size.

Inorganic lead in ambient air also originates from emissions from coal combustion and various lead-based industries such as lead smelters and lead battery plants. Although lead in gasoline accounts for less than 10 percent of all refined lead production, about 80 to 90 percent of lead in global ambient air originates from combustion of leaded gasoline (GEMS 1988).

Carbon dioxide. Carbon dioxide (CO_2) is a greenhouse gas.[2] Between 1970 and 1992 CO_2 concentrations in the atmosphere increased from 325 ppm to 356 ppm (WRI 1994). The increase in CO_2 concentrations, which is associated with

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2. Greenhouse gases are gases that absorb some of the heat radiated from the earth's surface, which would otherwise escape into the space. This process raises the temperature of the atmosphere. Besides CO_2, greenhouse gases include water vapor, methane, nitrous oxide, ozone, and other trace gases.

global warming, results mainly from increased combustion of fossil fuels (including motor vehicle fuels) and land use (including deforestation).

Between 1970 and 1992 energy-related global CO_2 emissions increased from about 15 billion tons to 22 billion tons. During this period CO_2 emissions grew by 28 percent in OECD countries and 82 percent in non-OECD countries. The largest CO_2 emitters were the United States, the former Soviet Union, and China (EIA 1994a).

In 1992 Latin America and the Caribbean emitted about 1.1 billion tons of CO_2, less than any other non-OECD region except Africa. CO_2 emissions resulted mainly from combustion of oil and also from natural gas and coal. Brazil and Mexico together contributed 52 percent of the region's CO_2 emissions. Other major CO_2 emitters were Venezuela, Argentina, and Colombia, with a total contribution of about 26 percent. The transport sector's share in CO_2 emissions from these five countries was 36 percent (EIA 1994b).

Chlorofluorocarbons. Chlorofluorocarbons (CFCs) are used mainly in aerosols, solvents, foam blowing, refrigerators, and air conditioners. The source of CFC emissions from motor vehicles is the freon gases used in air conditioners. The contribution of motor vehicles to global CFC emissions is estimated at about 28 percent (Faiz, Weaver, and Walsh 1996).

Unlike other pollutants, CFCs are unaffected by natural cleansing mechanisms such as rain. CFCs emitted into the atmosphere rise to the stratospheric layer within ten years and are estimated to remain there for about 400 years. CFC molecules struck by ultraviolet radiation release chlorine atoms, which destroy ozone by forming chlorine monoxide. Furthermore, when a free oxygen atom reacts with a chloride molecule, an oxygen molecule is formed and a chlorine atom is released to destroy more ozone. Ozone destruction in the stratosphere implies more exposure to ultraviolet radiation with a wavelength range of 295 nm to 300 nm (UV-B), which is biologically the most damaging (USEPA 1995).[3]

Global CFC emissions increased exponentially during the 1960s and early 1970s but declined after the ban on CFC use in the United States in 1984 and the signing of the Montreal Protocol in 1987. The Montreal Protocol calls for restrictions on the production and consumption of CFCs and halons according to the following timetable: a return to 1986 levels by 1989, 80 percent of 1986 levels by 1994, and 50 percent of 1986 levels by 1999. Developing countries follow a less restrictive schedule. The protocol was strengthened by the London Agreement of 1990, which included a faster timetable and complete phaseout of certain ozone-depleting chemicals. The 1992 Copenhagen amendments, which are not yet in effect, further shortened the phaseout schedule. In 1991 global CFC emissions were estimated to be 400,000 metric tons, of which only 3.5 percent (or 14,000 metric tons) came from Latin American countries (WRI 1994).

Quantifying Pollutant Emissions

Air pollution in urban areas originates from mobile, stationary, and natural sources. The contribution of each source type is site-specific. The systematic collection and compilation of detailed information about pollutant emissions in a given area is referred to as an "emissions inventory." An inventory should contain as much information as necessary on the type of sources, composition of emissions, and rates of emissions for various pollutants. The inventory must be kept current to study the impacts of changes in pollution sources (such as an increase in the vehicle fleet) and the effectiveness of air pollution control strategies on ambient air quality (Rossano and Rolander 1976). Only a few urban centers (Mexico City, São Paulo) in Latin America and the Caribbean maintain up-to-date emission inventories. In some urban centers (Belo Horizonte, Rio de Janeiro, Santiago, Santafé de Bogotá) emission inventories were developed as part of specific environmental projects but have not been updated to be used as a continuing planning tool for air quality management. In other urban centers (Buenos Aires) no systematic effort has been made to develop emission inventories.

Developing an accurate emissions inventory for motor vehicles is a complex task. Emissions modeling of a motor vehicle fleet consists of quantifying emission-producing activities through a travel demand model or other means of estimation; providing data on vehicle, fuel,

3. 1 nm = 1 nanometer = 10^{-9} meter.

operating, and environmental characteristics to the computer model; running the emission rate model to predict activity-specific emission factors for a given vehicle, fuel, operating, and environmental characteristics (that is, emission rates from mobile sources); multiplying each activity estimate by its activity-specific emission factor; and summing the estimated emissions for all activities. Typical vehicle, fuel, operating, and environmental characteristics that affect motor vehicle emission rates are shown in Table 2.4.

Ambient concentrations of pollutants can be predicted through estimation of emissions from pollution sources and dispersion modeling. A commonly used source for estimating emission rates is the USEPA's emission factor database (Compilation of Air Pollutant Emission Factors, commonly referred as AP-42). Because many factors affect pollutant emission rates from vehicles, the USEPA has developed a computer model that estimates pollutant emissions under selected conditions. A recent version of this model, called MOBILE5a, estimates emission factors for exhaust, evaporative, hot-soak, and diurnal emissions for each vehicle type and model-year and the total emissions for the vehicle fleet. The air pollutants modeled in MOBILE5a are CO, HC, and NO_x. Input data include such parameters as the type and model-year of motor vehicles, vehicle-kilometers traveled per year, speed characteristics, fuel type and vapor pressure, inspection and maintenance program features, tampering effects, and summer and winter diurnal temperatures. The vehicle types considered in the model are light-duty gasoline vehicles, light-duty gasoline trucks (two types), heavy-duty gasoline vehicles, light-duty diesel vehicles, light-duty diesel trucks, heavy-duty diesel vehicles, and motorcycles. Emission factors derived from MOBILE5a under specific conditions for U.S. gasoline-fueled passenger cars and trucks, and U.S. diesel-fueled passenger cars, trucks, and buses are shown in Annex A to this chapter. These results illustrate the effects control technologies can have on pollutant emissions under these conditions. Because MOBILE5a cannot estimate PM and SO_2 emissions, in 1995 the USEPA introduced another model, PART5, for these pollutants. PART5 uses input parameters similar to those for MOBILE5a.

MOBILE5a can be used to estimate emission factors and total emissions from vehicles in a developing country only after certain modifications to the model have been made. The MOBILE5a modifications made in a recent air pollution study in Monterrey, Mexico are shown in Table 2.5. One of these modifications involved matching exhaust and evaporative emission control technologies between U.S. and Mexican vehicles (Table 2.6). The results indicate that a typical model-year vehicle in Monterrey (for example, a typical 1985 model-year light-duty gasoline-fueled vehicle) has the same rate of pollutant emissions as an older typical model-year vehicle in the United States (for example, a typical 1972 model-year light-duty gasoline-fueled vehicle). Another major difference that was taken into account was the types of vehicle fleets in Mexico and the United States. The Mexican registration data revealed a larger fraction of older cars in Monterrey than in the United States (Radian Corporation 1995).

Table 2.4 Typical factors affecting motor vehicle emission rates

Vehicle parameters	*Fuel parameters*	*Vehicle operating conditions*	*Environmental parameters*
Vehicle class	Fuel type	Average vehicle speed	Altitude
Model-year	Oxygen content	Load (such as air conditioner, heavy loads)	Humidity
Fuel delivery system	Fuel volatility	Cold or hot start mode	Ambient temperature
Emissions control system	Sulfur content		Diurnal temperature changes
Onboard computer control system	Benzene content		
Control system tampering	Olefin and aromatic HC content		
Inspection and maintenance history	Lead and metals content		

Source: Adapted from Guensler 1994.

Table 2.5 List of modifications to adopt MOBILE5a to Monterrey, Mexico

Parameter	*Modification*
Basic exhaust emission rates of HC, CO, and NO_X; HC evaporative emissions	Matched appropriate exhaust and evaporative emissions control technology between the United States and Mexico (exhaust from inspection data, evaporation from assumptions made for the Mexico City vehicles)
Registration distribution	Based on registration and inspection data
Vehicle kilometer traveled by vehicle type	Based on Mexican records and inspection data
Tampering offsets and tampering rates	MOBILE5a correction based on Mexican vehicle technology
Inspection and maintenance program credits	MOBILE5a correction based on Mexican vehicle technology
Temperature and Reid Vapor Pressure (RVP) corrections for exhaust emissions	MOBILE5a correction factors based on equivalent Mexican vehicle technology
Fraction of carburetor/fuel injection vehicles	MOBILE5a correction factors based on equivalent Mexican vehicle technology
Speed, air conditioning, extra load, towing	MOBILE5a correction factors based on equivalent Mexican vehicle technology
Operating mode corrections	MOBILE5a correction factors based on equivalent Mexican vehicle technology
Fleet kilometer accumulation distribution	MOBILE5a values as a function of vehicle age (data from Mexican authorities)
Crankcase emissions	MOBILE5a relationships for equivalent Mexican technology
Evaporative emissions (vehicles with RVP, temperature, fuel tank level, vehicle driving conditions)	MOBILE5a relationships for equivalent Mexican vehicle technology
Running loss relationships with RVP and temperature	MOBILE5a relationships for equivalent Mexican vehicle technology
Miles per day and trips per day as a function of vehicle kilometers	MOBILE5a relationships for equivalent Mexican vehicle technology
Anti-tampering program benefits	MOBILE5a values for equivalent Mexican vehicle technology
Idle emissions	MOBILE5a relationships for equivalent Mexican vehicle technology

Source: Radian Corporation 1995.

Dispersion of Air Pollutants

Ambient concentrations of pollutants result not only from the magnitude of pollutant emissions but also from the way in which primary pollutants are transported and dispersed and react with each other in the atmosphere to form secondary pollutants. These mechanisms are affected by a number of meteorological factors:

- Wind moves air pollutants from one location to another. The trajectory followed by airborne pollutants and the extent of their dilution depend on wind direction and speed.
- Higher temperatures increase the reactivity of primary pollutants in the atmosphere in forming secondary pollutants. In addition, higher temperatures promote evaporative emissions from vehicles.
- Solar radiation enhances the formation of secondary pollutants such as ozone. The intensity of solar radiation is affected by the amount of cloud cover. Urban centers in warm, sunny locations with high traffic densities (such as Mexico City and São Paulo) tend to be especially prone to the formation of ozone from emissions of HC and NO_x.
- Ceiling height, or mixing height or depth, is the height above the earth's surface at which relatively vigorous vertical mixing occurs. It is used to represent the dispersion capacity of the atmosphere. The mix-

Table 2.6 Equivalent model-years for Monterrey, Mexico and U.S. vehicles

Mexican vehicle model-year	*U.S. vehicle model-year*		
	Type 1[a]	*Type 2*[b]	*Type 3*[c]
1971	1968	1968	1971
1972	1968	1968	1971
1973	1971	1971	1971
1974	1971	1971	1971
1975	1971	1971	1971
1976	1971	1971	1971
1977	1971	1971	1971
1978	1971	1971	1971
1979	1971	1971	1971
1980	1971	1971	1971
1981	1972	1972	1972
1982	1972	1972	1972
1983	1972	1972	1972
1984	1972	1972	1972
1985	1972	1972	1972
1986	1972	1972	1972
1987	1972	1972	1972
1988	1975	1974	1974
1989	1975	1974	1974
1990	1980	1974	1974
1991	1980	1974	1974
1992	1981	1974	1974
1993	1988	1977	1977
1994	1988	1981	1981
1995	1989	1981	1981

a. Light-duty gasoline vehicles.
b. Light-duty gasoline trucks, heavy-duty gasoline vehicles, light-duty diesel vehicles, light-duty diesel trucks, and heavy-duty diesel vehicles.
c. Motorcycles.
Source: Radian Corporation 1995.

ing height varies by the time of the day and month of the year. For example, in Santiago, Chile, the mixing height is as low as 300 meters during the winter and as high as 1,000 meters during the summer. The mixing height is affected by thermal inversion. Under normal conditions, when the air temperature decreases with altitude, hot pollutant gases rise to high altitudes. Under isothermal conditions, however, when there is no change of temperature with altitude, an inversion layer forms above the ground, trapping primary pollutants and enhancing formation of secondary pollutants in the atmosphere. These conditions are of greatest concern when wind speeds are low. Thermal inversions are observed in many Latin American urban centers, including Mexico City, Santiago, São Paulo, and Rio de Janeiro.

- Precipitation affects ambient pollutant concentrations because it washes out pollutants, particularly PM, from the air. In the presence of acidic pollutants, humidity contributes to corrosion of limestone buildings, sculptures, and metallic structures.
- Local topography also influences the transportation and dispersion of air pollutants. Urban centers with relatively level topography, such as Buenos Aires, have better wind dispersion. The presence of an ocean coastline can lead to onshore and offshore diurnal wind patterns that help disperse pollutants. Hills and mountains that surround urban centers often act as downwind barriers. For example, in the Mexico City Metropolitan Area the surrounding mountains tend to limit air circulation, trapping pollutants within a valley. Daytime winds in the Valley of Mexico carry pollutants from

Box 2.1 Commonly used air dispersion models for vehicular emissions

Among the air dispersion models discussed below, only the Urban Airshed Model (UAM) is able to simulate an entire urban area (the others are microscale models) and incorporate reactive pollutants. The UAM is recommended for urban areas with an ozone problem.

CALINE 3 (California Line Source Model-Version 3). This USEPA-approved Gaussian model is used to predict dispersion of nonreactive pollutants near highways and main streets. It is not suitable for urban areas with complex terrain, urban street canyon conditions (building heights over three stories), wind speeds less than 1 m/sec, or distances over 10 km. It also contains an algorithm for deposition and settling velocity so that PM concentrations can be predicted.

CALINE4. This model updates CALINE3 but has not been approved by the USEPA. It accounts for queuing, delays, excess emission rates due to modes, and cruising.

HIWAY2. This USEPA-developed Gaussian model lacks the sophistication of CALINE3 or CALINE4 but is easier to use. It provides ambient pollutant concentrations based on uniform emission rates (that is, it does not take into account interrupted flows at intersections). It is not suitable for complex terrain, street canyon conditions, or calm atmospheric conditions.

TEXIN2. This Gaussian model incorporates features of MOBILE and CALINE3. It accounts for queuing, delays, excess emission rates due to modes, and cruising. It is not suitable for simulating conditions in which the wind speed is less than 1 m/sec and receptors are at heights above 10 meters.

UAM (Urban Airshed Model). This USEPA-approved model is an urban-scale, three-dimensional, grid-type numerical simulation model that can be used for mobile and fixed emission sources. The model incorporates a photochemical kinetics mechanism for urban atmospheres. It is designed for computing short-term (one or two days) ozone concentrations resulting from emissions of NO_x and volatile organic compounds. Simulation of CO is optional.

Source: USEPA 1993.

the heavily industrial areas of the north and northwest to the populated areas, causing severe air pollution. Polluted air trapped by the high mountains to the south recirculates and exacerbates the air pollution. This area tends to experience the highest frequency of ozone standard violations, with levels in excess of the Mexican standard more than 88 percent of the days in a year.

- Within an urban center, buildings and other structures can have a great effect on the dispersion of air pollutants. The "street canyon" effect occurs when tall buildings prevent wind dispersion of low-level emissions (Bellomo and Liff 1984).

Using actual or estimated pollutant emission data, air dispersion models predict ambient air concentrations based on atmospheric and topographic conditions. Typical air dispersion models used in the United States for vehicular emissions are described in Box 2.1. Among the various pollutants emitted by vehicles, chemically reactive pollutants (such as NO_x) are particularly difficult to simulate because they form secondary pollutants. Typical inputs to such dispersion models include information on emission sources (for example, frequency distribution of emissions from major sources in the area under study), meteorological parameters (wind speed and direction, vertical atmospheric temperature profile, radiation intensity), and a kinetic mechanism to describe the rates of atmospheric chemical reactions as a function of pollutants present. Validation and fine tuning of models with actual monitoring data are necessary.

Health Effects of Air Pollutants

Air pollutants emitted by motor vehicles have a number of adverse effects on human health. Inhalation is the main route of exposure to air pollutants originating from motor vehicle emissions. Other exposure routes—drinking water contamination, food contamination, and absorp-

tion through the skin—are also possible. Exposure by inhalation directly affects respiratory, nervous, and cardiovascular systems of humans, resulting in impaired pulmonary functions, sickness, and even death.

Carbon monoxide. CO absorbed through the lungs reduces the blood's capacity to transport available oxygen to the tissues. CO bonds with hemoglobin (Hb) to form carboxyhemoglobin (COHb), which lowers the oxygen level in blood. Because more blood is needed to supply the same amount of oxygen, the heart must work harder.

The relationship between ambient CO concentrations in air and COHb levels in blood depends mainly on the duration of exposure and the pulse rate of the exposed person (that is, intensity of physical effort). Body size, lung condition, and barometric pressure also affect CO uptake. The COHb level is normally about 1.2 to 1.5 percent, but it can reach 4 to 7 percent among one-pack-a-day cigarette smokers. At about 5 percent the COHb level begins to induce adverse health effects. Some studies have shown that impaired judgment starts at even lower COHb levels of 3.2 to 4.2 percent (Romieu 1992).

CO uptake impairs perception and thinking, slows reflexes, and may cause drowsiness, angina, unconsciousness, or death (Romieu 1992). Exposure of pregnant women to CO has been linked to low birth weights and retarded postnatal development. The synergistic effect of CO with other pollutants promotes illness in people with respiratory problems. Increased concentrations of CO are also associated with reduced worker productivity and general discomfort.

An exposure to concentrations of 45 mg/m^3 of CO for more than two hours adversely affects a person's ability to make judgments. Two to four hours of exposure at 200 mg/m^3 raises the COHb level in the blood to 10 to 30 percent and increases the possibility of headaches. Exposure to 1,000 mg/m^3 of CO raises the COHb level in blood to more than 30 percent and causes a rapid increase in pulse rate leading to coma and convulsions. One to two hours of exposure at 1,830 mg/m^3 results in 40 percent COHb in blood, which may cause death (MARC 1991).

Nitrogen dioxide. NO_2 is an irritating gas that is absorbed into the mucous membrane of the respiratory tract. The most adverse health effect linked to NO_2 occurs at the junction of the conducting airway and the gas exchange region of the lungs. The upper airways are less affected because NO_2 is not very soluble in aqueous surfaces. Exposure to NO_2 is linked with increased susceptibility to respiratory infection, increased airway resistance in asthmatics, and decreased pulmonary function. Short-term exposure to NO_2 has been associated with a wide range of lower respiratory illnesses in children (cough, runny nose, and sore throat are among the most common), as well as increased sensitivity to urban dust and pollen. Health effects of occupational exposure to NO_2 range from inflammation of the mucous membrane of the tracheobronchial tree to bronchitis, bronchopneumonia, and acute pulmonary edema. Nitric and nitrous acids or their salts are present in the blood and urine after exposure to NO_2 (Romieu 1992).

Lung function is affected by 30-minute exposure to a NO_2 concentration of 560 $\mu g/m^3$ with exercise, 940 $\mu g/m^3$ in asthmatic people, and above 1,300 $\mu g/m^3$ for a 10- to 15-minute exposure in healthy people. Eleven epidemiological studies of long-term exposure found that a 30 $\mu g/m^3$ increase in indoor NO_2 concentrations from gas stoves causes respiratory illnesses to increase by 20 percent among children under 12 years of age (Romieu 1992). The relationship between outdoor NO_2 exposure and acute health effects, however, has not been demonstrated consistently from epidemiological studies because of other intervening factors such as exposure to other pollutants, smoking habits, and indoor exposure to NO_2. In one study exposure to a daily mean NO_2 concentration of 244 $\mu g/m^3$ was associated with sore throats among adults (Schwartz and Zeger 1990).

Benzene. About 50 percent of inhaled benzene is absorbed. Part of the absorbed benzene is exhaled by respiration and eliminated through the urinary tract. Benzene maintained in the human body is concentrated in the fat tissue and bone marrow.

Benzene has toxic and carcinogenic effects. The toxic effects are associated with the central nervous system as well as the hematological and immunological systems. Toxic effects on the nervous system have been observed following exposure to concentrations higher than 3,200 mg/m^3 (1,000 ppm). Occupational studies of high-level exposure to benzene have found that it can

damage the respiratory tract, lung tissue, and bone marrow and can cause death. Carcinogenic effects include leukemia. The risk of lifetime exposure to 1 μg/m^3 of benzene is estimated to range from 0.08 to 10 excess leukemia deaths per million (Romieu 1992).

Polycyclic aromatic hydrocarbons. PAH, absorbed in the lungs and intestines and metabolized in the human body, are mutagenic and carcinogenic. Epidemiological studies have identified 50 percent greater risk of bladder cancer among truck drivers and delivery men exposed to diesel engine exhaust. It is also estimated that 9 of 100,000 people exposed to 1 μg/m^3 of benzo[a]pyrene, a PAH, over a lifetime, would develop cancer. There no known threshold level for carcinogenic effects of benzo[a]pyrene (Romieu 1992).

Aldehydes. Aldehydes are absorbed in the respiratory and gastrointestinal tracts and metabolized. Once metabolized they are excreted from the human body. Adverse health effects of formaldehyde include eye and nose irritation (at a concentration of 0.06 mg/m^3), irritation of mucous membranes and alteration in respiration (at a concentration of 0.12 mg/m^3), coughing, nausea, and shortness of breath. The threshold for tissue damage is about 1 mg/m^3. Occupational exposure to formaldehyde is associated with risk of cancer (Romieu 1992).

Ozone. One of the most widespread traffic-induced air pollutants is ozone formed in the troposphere, a principal ingredient of urban smog. Adverse health effects of ozone have been observed for exposure periods as short as five minutes. These effects become much more pronounced during longer exposure periods (for example, over six hours) at moderate exercise levels. Changes in pulmonary function have been reported for one- to three-hour exposures during exercise (Romieu 1992). Ozone can cause severe damage to lung tissues and impair defenses against bacteria and viruses.

Short-term adverse health effects have been observed from hourly exposures to ozone concentrations as low as 200 μg/m^3. These effects include eye, nose, and throat irritation, coughing, throat dryness, thoracic pain, increased mucous production, chest tightness, lassitude, malaise, and nausea. A decrease in pulmonary functions in children and young adults has been reported at hourly average ozone concentrations in the range of 160 μg/m^3 to 300 μg/m^3. In a study conducted among schoolchildren in Mexico City, acute and subacute effects of ozone on lung functions were reported. Because the decrease in lung functions was smaller than that observed in another study, it was suggested that children chronically exposed to ozone could tend to develop a tolerance to it (Romieu 1992).

A study on the long-term health effects of ozone exposure in southern California found that it may reduce pulmonary function (Detels and others 1987). The synergistic effects of ozone and other pollutants (sulfates and NO_2), and absence of a threshold value for ozone have also been reported (Romieu 1992).

Based on results of different studies in the Los Angeles area (Krupnick, Harrington, and Ostro 1990; Schwartz and Zeger 1990; Whittemore and Korn 1980), Ostro (1994) estimated the effects of ozone on respiratory symptoms (for example, chest discomfort, coughing, wheezing, sore throat, cold, and flu), eye irritation incidents, and asthma attacks. For a 1 μg/m^3 increase in the annual average of 1-hour daily maximum ozone, Ostro predicted 28 to 97 respiratory symptom days per person per year, 23 to 30 eye irritations per adult per year, and 39 to 190 asthma attacks per asthmatic person per year.

Sulfur dioxide. SO_2, an irritating gas that is absorbed in the nose and aqueous surfaces of the upper respiratory tract, is associated with reduced lung function and increased risk of mortality and morbidity. Adverse health effects of SO_2 include coughing, phlegm, chest discomfort, and bronchitis. Some of the SO_2 emissions from mobile or fixed sources are transformed in the atmosphere into sulfate aerosols (discussed below), which are also associated with mortality and morbidity.

SO_2 exacerbates the effects of PM, and vice versa. The World Health Organization (WHO) has determined that the effects of 24-hour human exposure to SO_2 include mortality at ambient concentrations above 500 μg/m^3 and increased acute respiratory morbidity at ambient concentrations above 250 μg/m^3. Annual exposure to SO_2 causes increased respiratory symptoms or illness at ambient concentrations above 100 μg/m^3 (WHO 1987). In recent studies, however, the adverse effects of SO_2 have been

observed at lower concentrations (Romieu 1992).

Correlations between exposure to SO_2 and mortality have been established through studies performed in different parts of the world, including England, France, Greece, and Poland. In the London study a correlation between ambient SO_2 concentrations and mortality from chronic bronchitis was found at an SO_2 level of 172 μg/m^3 (and at a smoke level of 80 μg/m^3) among men above 65 years of age and women between 45 and 65 years of age (Chinn and others 1981). In another study associations between ambient SO_2 concentrations and respiratory deaths in Marseilles and Lyon and between ambient SO_2 concentrations and cardiovascular deaths in Marseilles were observed among individuals over 65 years of age. In these studies the outcomes were observed at daily averages for ambient concentrations of SO_2 and TSP of 78 μg/m^3 and 106 μg/m^3, respectively, and monthly SO_2 averages above 182 μg/m^3 (Derriennic and others 1989). In the Athens study ambient SO_2 concentrations and mortality were correlated at mean daily SO_2 and black smoke levels of 85 μg/m^3 and 63 μg/m^3, respectively (Hatzakis and others 1986). In the Cracow study a relationship was found between ambient SO_2 and PM concentrations and mortality for men (Krzyzanowski and Wojtyniak 1982). Based on the literature, Ostro (1994) estimated that a 10 μg/m^3 drop in ambient SO_2 concentrations would be associated with 0.20 to 1.21 percent drop—equivalent to fifteen to eighty-seven deaths per 1 million people.

A statistically significant correlation between ambient SO_2 concentrations and acute health effects (coughing) was demonstrated for children in Watertown, Massachusetts (Schwartz and others 1991). In another study performed on nursing school students in Los Angeles, a significant association was observed between ambient SO_2 concentrations and chest discomfort (Schwartz, Hasselblad, and Pitcher 1988). Based on these data, Ostro (1994) estimated that a 10 μg/m^3 change in ambient concentrations of SO_2 would cause ten to twenty-six cough incidents among 100,000 children, and five to fifteen chest discomfort incidents among 100 adults.

Particulate matter. Through nasal breathing, PM greater than 10 μm in diameter is deposited in the extrathoracic part of the respiratory tract, while the 2.5 μm to 10 μm fraction is deposited near the fine airways. PM-2.5 is a larger health concern because it can evade the human body's respiratory defense system and reach the lung tissue, where it can remain imbedded for years, or in the case of soluble particles, be absorbed into the bloodsteam (ALA 1997). Particle deposition increases with mouth breathing. PM in ambient air has been associated with increased mortality, morbidity, and reduced lung function. Adverse health effects have been observed in both children and adults. These effects are associated with coughing and respiratory diseases such as pneumonia, asthma, and bronchitis.

PM and SO_2 often occur together in ambient air and may have synergistic effects with other pollutants emitted by motor vehicles. Studies that compare cities have found that SO_2 and PM together account for 4 percent of the variation in death rates from cardiovascular diseases. Although many other factors (such as differences in smoking habits and type of occupation) may also be important, studies conducted in different parts of the world indicate a relatively consistent association between long-term exposures in residential communities polluted by PM and SO_2 and increased mortality rates (Romieu 1992).

Increased mortality and respiratory diseases are associated with PM-2.5 and sulfate air pollution at levels commonly found in the U.S. cities (4 μg/m^3 to 20 μg/m^3 for sulfate and 10 μg/m^3 to 25 μg/m^3 for PM-2.5). Two recent studies conducted in the United States indicate that long-term exposure to an extra 10 μg/m^3 of PM-2.5 is associated with 5 to 10 percent increase in overall mortality and a higher increase in cardiorespiratory mortality (Dockery and Pope 1993; Pope and others 1995). Based on data calculated over a six-year period in the United States, Ostro (1989) found an association between a 1 μg/m^3 increase in the annual mean of PM-2.5 concentrations and a 3.2 percent increase in acute respiratory diseases in adults aged 18 to 65 years. Sulfate aerosols, especially those that are acidic, are considered one of the likely causative agents in the association between PM-2.5 and health effects in the eastern United States. The main health effects of sulfate aerosols include chronic bronchitis and asthma.

An air pollution incident in London during the winter of 1958–59, in which smoke and SO_2 levels exceeded 500 μg/m^3, affected the health of exposed people with preexisting heart and lung diseases, the elderly, and children under five years of age. Further evaluation of data for

this incident and for subsequent years found a strong correlation between ambient PM concentrations and daily mortality in London, with no threshold level of ambient pollutant concentrations for adverse health effects (Ostro 1994). Based on Ostro's analysis, the increase in mortality for a 10 μg/m^3 increase in PM-10 concentration was 0.29 to 0.33 percent from the London study (Schwartz and Marcus 1990), 0.44 to 0.94 percent from a Steubenville study (Schwartz and Dockery 1992b), 0.49 to 1.47 percent from an Ontario study (Plagiannakos and Parker 1988), 0.73 to 1.51 percent from a Santa Clara County study (Fairley 1990), 0.96 to 1.44 percent from a Philadelphia study (Schwartz and Dockery 1992a), and 0.96 to 2.06 percent from a study of "100 U.S. metropolitan areas" (Özkaynak and Thurston 1987). For a 10 μg/m^3 increase in PM-10 concentrations, the corresponding range for the number of deaths would be between forty-five and ninety-one people per million.

Based on 24-hour exposure, smoke at 250 μg/m^3 is associated with increased acute respiratory morbidity among adults, and TSP at 180 μg/m^3 level and PM-10 at 110 μg/m^3 with decrements in lung functions among children. Increased respiratory symptoms or illness would be expected at an annual mean exposure to 100 μg/m^3 of smoke, and decrements in lung function would be expected at an annual mean exposure to 180 μg/m^3 of TSP (WHO 1987). However, more recent studies suggest that health may be affected even at lower concentrations (Romieu 1992).

Dockery, Speizer, and Stram (1989) investigated the effects of PM on lower respiratory illness in children of six cities in the U.S. cities. The study found that chronic cough, bronchitis, and chest illness were positively associated with TSP, PM-15, PM-2.5, and sulfate aerosol. Frequency of earache was associated with ambient PM concentrations; and children with histories of wheeze and asthma had a much higher prevalence of respiratory symptoms, and the symptom rates were stronger among children with hyperactive airways. Using data from this study, Ostro (1994) estimated that a 10 μg/m^3 change in the ambient concentration of PM-10 would cause eight to twenty-four chronic bronchitis incidents among 1,000 children age 17 and under.

Ambient concentrations of PM and exacerbation of asthma attacks were found to be related among children and adults (Whittemore and Korn 1980; Pope and others 1991; Ostro and others 1991). Respiratory symptoms (including chest discomfort, coughing, wheezing, sore throat, cold, and flu) were associated with ambient concentrations of PM-10, using haze as a surrogate measure for fine particles (Krupnick, Harrington, and Ostro 1990). Ostro (1994) estimated that a 10 μg/m^3 change in the ambient concentrations of PM-10 would cause two to twenty-seven asthma attacks among ten asthmatic people, and one to three respiratory symptom days per person per year.

Several epidemiological studies have been carried out to determine the health effects of PM in Latin America. For example, in 1980 a study was conducted in two public elementary schools in Mexico City, one in the industrial area of Xalostoc (with high ambient PM and SO_2 concentrations) and the other in the less industrialized suburban area of San Lorenzo. Children from Xalostoc were found to have a lower pulmonary function than those from San Lorenzo, although no difference was observed in terms of acute or chronic respiratory symptoms and illness. During 1983–84 the prevalence of respiratory symptoms was investigated in three communities southwest of Mexico City. In two of these communities, which were affected by PM emissions from a cement plant, the incidence of chronic cough was found to be significantly related to the length of residency. Among subjects living away from a major emission source, acute respiratory symptoms, possibly related to ozone exposure, were more frequent. During November 1985 to June 1986, another study was conducted involving 6- to 13-year-old school children from three different areas of Mexico City: Xalostoc from the northern area, Morazan from the central area, and Pedregal from the southern area. The study found that respiratory illnesses were higher in the northern and southern areas (with high PM concentrations) than in the central area (Romieu, Weitzenfeld, and Einkelman 1992).

For different areas within the Rio de Janeiro metropolitan region, a statistically significant association was observed between the average annual PM concentrations in ambient air and infant mortality from pneumonia (Penna and Duchiade 1991). Another Brazilian study on the health effects of ambient PM-10 concentrations was conducted between 1984 and 1987 in Vila Parisi (near Cubatão), where industry is the main source of air pollution. The study found that a

decrease in the annual arithmetic average of ambient PM-10 concentrations from 186 μg/m^3 to 151 μg/m^3 (a result of industrial pollution control measures) lowered the share of respiratory problem-related emergency room visits from 31 to 23 percent, and of bronchitis- and asthma-related emergency room visits from 15 to 11 percent. Another study conducted in Cubatão explored the effects of air pollution on the pulmonary functions of 6-year-old schoolchildren. Tests performed on 480 children in 1983 and 630 children in 1985 found an improvement in pulmonary functions that was attributed to the reduction in ambient PM concentrations (Romieu, Weitzenfeld, and Finkelman 1992).

The effects of air pollution in Santiago and Los Andes (a city in Chile considered nonpolluted) on 300 schoolchildren, aged 9 to 13 were studied during November 1987 to March 1988. Respiratory symptoms (coughing, hoarseness, wheezing, nocturnal respiratory malaise) were found to be significantly higher in Santiago. The results of this study suggested an association between these symptoms and PM-10 levels (Romieu 1992).

In another study, daily ambient PM-10 concentrations in Santiago were correlated with total mortality as well as with mortality by population subgroups (all men, all women, and all people over sixty-four) and due to respiratory and cardiovascular disease (Ostro and others 1995). This study found that mortality among the elderly and men due to respiratory and cardiovascular diseases is more responsive to changes in ambient PM-10 concentrations than is total mortality. The results indicate that the estimated impact of PM-10 on mortality in Santiago is consistent with that found in other studies in the United States.

Long-term exposure to PM also was recently found to be related to decrements in lung function or chronic respiratory disease. Lower lung function was associated with exposure to higher ambient PM (as well as higher SO_2, NO_2, and HC) concentrations based on tests performed on nonsmokers from two different communities in southern California (Detels, Tashkin, and Sayre 1991). In another study conducted on nonsmokers in California, statistically significant relationships between ambient concentrations of TSP and ozone were found with several respiratory disease outcomes, including chronic bronchitis (Abbey and others 1993). Based on these results, Ostro (1994) estimated that a 10 μg/m^3 change in the ambient concentration of PM-10 would cause three to nine chronic bronchitis incidents among 10,000 people older than 25.

Exposure to diesel engine exhaust fumes was found to decrease pulmonary function, but the effects were reversible after a few days without exposure. In other studies associations between PM and pulmonary cancer in animals were observed (Romieu 1992). Based on a review of previous research, the International Agency for Research on Cancer (IARC) concluded that diesel PM emissions had possible carcinogenic effects on humans. Confirmatory studies suggest that soot in diesel PM emissions was primarily responsible for lung cancer in rats and, at high PM concentrations, the mutagenic compounds adsorbed onto soot would play a lesser if any role in tumor development. This finding indicates the importance of controlling not only the organic compounds present on soot particle surfaces but also the soot particles themselves (Walsh 1995).

Lead. Most lead in ambient air is in the form of fine particles with an aerodynamic diameter of less than 10 microns (PM-10). Ambient air also contains organic lead compounds as gases. Motor vehicles are the major source of lead in ambient air in many Latin American urban centers, where leaded gasoline is still used. Adults retain 20 to 60 percent of airborne particles, and children have a lung deposition rate that can be 2.7 times higher than that of adults on a unit body mass basis. The proportion of lead absorbed from the gastrointestinal tract is about 10 to 15 percent for adults and up to 50 percent for children. Lead absorption increases in diets with low levels of calcium, vitamin D, iron, and zinc. Lead absorbed in the human body is distributed among bones, teeth, blood, and soft tissues. Most of it is concentrated in bones (70 percent for children and 95 percent for adults). Unabsorbed lead is excreted in the feces, and 50 to 60 percent of the absorbed lead is discharged through the urinary tract. Organic lead is mainly absorbed by the lungs through the respiratory tract and also through the skin (Romieu 1992). Based on a review of epidemiological studies, an increase of 1 μg/m^3 in lead concentrations in ambient air was associated with an increase in blood lead levels of 0.3 μg/dl to 0.5 μg/dl (Brunekreef 1986).

Adverse effects of lead exposure have been observed in small children, women of reproduc-

tive age, and male adults. Newborns and young children are most vulnerable. Exposures to levels of lead commonly encountered in urban environments constitute a significant hazard for children, especially those less than 6 years old. Children with high levels of lead accumulated in their baby teeth experience lower intelligence quotients (IQs), short-term memory loss, reading and spelling underachievement, impairment of visual motor function, poor perception integration, disruptive classroom behavior, and impaired reaction time (USEPA 1990). Based on a recent review of epidemiological studies, an increase in children's blood lead level of 10 μg/dl was associated with a fall of 2.5 IQ points (CDC 1991). Adult women of reproductive age are also a high risk group because lead levels of pregnant women are closely correlated with those of newborns. People who are exposed to lead on the job, such as traffic police inhaling airborne lead particles, also suffer adverse health effects. Among adults lead levels in blood are linked to an increased incidence of high blood pressure. No threshold level for the adverse health effects of lead has been identified.

Several studies in Mexico City have demonstrated correlations between exposure to lead in the environment and lead levels in the human body. One study conducted on women of reproductive age and on children less than 5 years old in two districts of Mexico City, one industrial and the other residential, showed that the blood lead level increased with age, the percentage of children with blood lead levels exceeding 10 μg/dl was higher in the industrial zone, and a significant correlation existed between lead concentration in ambient air and in dust from the streets and from the home environment (for example, windows, furniture, and dirt on children's hands; Romieu and others 1995). In a previous study, exposure to traffic-related pollution was found to be the main determinant of high levels of lead in blood in a sample of ninety children in Mexico City. Children who lived on or close to high-traffic streets had higher lead levels in blood than children who resided in low-traffic areas. The major source of lead was identified as the tetraethyl lead added to gasoline (Romieu, Weitzenfeld, and Finkelman 1992). In addition, children from public schools were found to have higher blood lead levels than children from private schools, indicating socioeconomic differences in lead exposure. From bone lead content measurements of Mexican women of reproductive age, the amount of time living in Mexico City was found to be a strong determinant of bone lead levels. In another study conducted between 1990 and 1992, the average blood lead level in schoolchildren decreased from 15.4 μg/dl to 10.2 μg/dl most likely in response to lower atmospheric lead concentrations resulting from the introduction of unleaded gasoline to the Mexican market. In 1995 the Pan American Health Organization (PAHO) and the Mexican authorities estimated that about 800,000 women in the reproductive age group in Mexico City had blood lead levels above 15 μg/dl, and that each year about 25,000 women would be delivering babies with blood lead above this level. Blood levels of different urban population groups in selected Latin American and Caribbean countries are presented in Table 2.7.

Based on data in the literature, Ostro (1994) established relationships between lead levels in air and effects on human health. Based on this analysis Ostro estimated that a 1 $\mu g/m^3$ increase in ambient lead levels would cause a 0.975 IQ point decrement per child, twenty to sixty-five premature deaths and eighteen to fifty nonfatal heart attacks among 100,000 40- to 59-year-old males, and forty-five to ninety-eight hypertension cases among 1,000 20- to 70-year-old males.

Chlorofluorocarbons. Exposure to increased UV-B radiation is suspected to increase the risk of skin cancer and eye illnesses (especially cataracts) and to adversely affect the immune system. During September and October 1991 a large human population in the southern tip of South America was exposed to UV-B as a result of the Antarctic ozone hole. The affected location with the greatest population density was Punta Arenas in southern Chile (population of 110,000). A review of medical records by an international team of experts concluded a greater frequency of dermatologic visits for warts. Eye and skin examinations on fishermen, shepherds, and hospital workers did not, however, reveal any association with increased UV-B exposure (USEPA 1995).

Quantifying the Health Effects of Air Pollutants

Quantifying the health effects of air pollutants enables researchers and policymakers to esti-

Table 2.7 Blood lead levels of different urban population groups in selected Latin American and Caribbean countries

Country	*Population*	*Age*	*Sample size*	*Range (μg/dl)*	*Average (μg/dl)*	*>10 μg/dl (percent)*
Brazil	Adults	15–49	149	2.8–27.2	11.8 ± 5.2	75
	Children	4–5	199	0.6–35.7	9.6 ± 4.6	30
Chile	Babies	1	200	0.5–18.0	4.3 ± 1.8	5
Ecuador	Children	7	64	17.0–54.0	28.8	100
	Babies	0.1	27	6.0–20.0	14.4	60
	Women	Pregnant	83	—	18.4	60
Mexico	Children	< 5	200	1.0–31.0	9.0 ± 5.8	28
	Adults	15–55	200	1.0–39.0	9.7 ± 6.2	37
	Adults	15–45	3,309	5.0–62.2	10.6	42
Trinidad and Tobago	Women	—	94	1.2–14.4	4.8 ± 2.0	2
	Babies	0.1	94	0.0–8.7	3.4 ± 1.6	0
Uruguay	Children	2–14	48	1.0–31.0	9.5	30

— Not available.
Source: Lacasaña and others 1996.

mate the potential health benefits of pollution control measures. These benefits are compared with the costs of pollution control measures to evaluate their feasibility or to determine the relative merits of alternative measures. Health benefits from reduced levels of air pollution can be quantified using a four-step approach:

- The change in health effect resulting from the change in air pollution is estimated. The relationship between air pollution and health effects, called the dose-response function, can be developed or obtained from published epidemiological studies.
- The population exposed and susceptible to air pollution (POP_i) is determined.
- The change in the air pollution level (dA) from the current to a target level is specified. The target level may be based on the national or local air quality standards, WHO guidelines, USEPA standards, a percentage change (for example, a 10 percent reduction) in the ambient pollutant level, or a percentage reduction in the total emission of a pollutant.
- The unit economic value of the effect (V_i) is developed for the reduced risk of health effects. This could be based on willingness to pay, medical treatment costs, or lost of productive days and years (Ostro 1994).

The benefit of reduced air pollution (dT) can be expressed mathematically as:

$$dT = (b)(POP_i)\ (dA)(V_i)$$

where b is the slope of the dose-response function. The dose-response function can be expressed in absolute terms or in terms of percentages:

Change in the number of affected persons per exposed population per year = (b) (change in ambient pollutant concentration)

Percentage change in the number of affected persons in a year = (b') (change in ambient pollutant concentration).

Epidemiological studies have shown that a 1 μg/m^3 change in ambient PM-10 concentrations results in a change of 0.062 to 0.130 percent in total mortality per year, with a central value of 0.096 percent (that is, $b' = 0.096$; Ostro 1994). Thus a 10 μg/m^3 reduction in ambient PM-10 concentrations would be expected to lower total mortality by 0.96 percent a year.

The coefficient b can be derived from coefficient b'. For mortality, the following relationship relates b' to b:

$$b = (b')\ (1/100)\ (\text{crude mortality rate}).$$

Using the above example and assuming a crude mortality rate of 0.007, the central value of coefficient b for mortality would be $(0.096)(1/100)(0.007) = 6.72 \times 10^{-6}$ for a 1 μg/m^3 change in the ambient concentration of PM-10. This means that if the ambient PM-10 concen-

tration is reduced by 1 μg/m^3, about seven fewer people per 1 million would be expected to die prematurely.

The coefficient *b* or *b'* can be derived from epidemiological studies, which can be performed either through time-series or cross-sectional analyses. Time-series analyses examine the correlation between fluctuations in pollution and health within a single population, and cross-sectional analyses make comparisons between different populations with different population exposures. Time-series analyses address short-term (acute) health effects; cross-sectional analyses pertain mostly to long-term health consequences. Most epidemiological research has been dominated by time-series analysis because it avoids the problem of interpopulation confounding (for example, due to variations in smoking prevalence) that afflicts cross-sectional correlations, and it can be performed using historical data sets for a single population, which are readily available in industrial countries.

In conducting time-series analyses, it is important to remove term fluctuations in the outcome variables related to meteorological factors, temporal trends, and seasonal variations. For example, ozone concentrations are positively correlated with high temperatures, number of sunshine hours, and aeroallergens; and high concentrations of NO_2, other gaseous pollutants, and PM occur together in still weather. For this reason time-series analyses need to identify seasonal weather characteristics and infectious disease epidemics, and account for increases in pollutant concentrations under certain meteorological conditions (LSHTM and St. GHMS 1995). It is also worth noting that respiratory infections are more common in winter, when levels of pollutants such as SO_2 and PM are generally at their peak. Research findings suggest that at least part of the health effects attributed to fluctuations in ambient PM concentrations may actually be due to spikes in respiratory viral infections (Lamm, Hall, and Engel 1994). In time-series analyses clusters of days with high rates of death or hospital admission also need to be accounted for by the serial correlation of variables such as temperature. For example, low temperatures are associated with higher cardiovascular mortality and, since one cold day tends to follow another, days with high cardiovascular mortality tend to cluster as well. Although autoregressive models are useful, in most instances it is difficult to separate the health effects of meteorological conditions from the effects of air pollutant emissions. And because of the high correlation among pollutants, it is often not possible to distinguish the effects of individual pollutants (such as SO_2, sulfates, and sulfuric acid aerosols) from those of PM. Furthermore, time-series analyses need to take into consideration normal weekly fluctuations in medical services (LSHTM and St. GHMS 1995).

The literature finds a strong association between many air pollutants and negative health effects, mainly respiratory system problems. Based on a review of this information, Ostro (1994) summarized the dose-response coefficient *b* associated with the health impacts of PM-10, SO_2, ozone, lead, and NO_2 (Table 2.8). Ostro's investigation did not include CO because little quantitative dose-response information was available for this pollutant due to its rapid dissipation in the environment. Further research is needed to establish the magnitude of the associations, possible interactions between pollutants and other variables, possible threshold (no effect) levels, and the biological mechanisms of action (LSHTM and St. GHMS 1995).

Information on dose-response functions for cities in developing countries—with the exception of Santiago, Beijing, and São Paulo—is not readily available in the literature. The dose-response relationship between PM-10 concentrations and mortality in Santiago was found to be fairly consistent with other analyses (Ostro and others 1995). These studies also found a stronger correlation between PM-10 and mortality among the elderly, people with heart and lung diseases, and men (Table 2.9). Despite similarity in these results, extreme caution is advised in extrapolating the reported dose-response relationships to other situations.

One reason these studies might not be applicable to other circumstances is that the dose-response function may not be valid beyond the range developed in the original study. Most epidemiological studies have assumed a linear dose-response function and suggested that there is no conclusive evidence of threshold values for pollutant concentrations below which no adverse health effects occur. This implies that, even below the ambient air quality standards, air pollutants might still have adverse health effects.

Another concern is associated with the impact of populations' baseline conditions on the dose-response functions. Differences between the baseline conditions of two populations (that is,

Table 2.8 Ranges and central estimates for dose-response coefficients

(change in risk of health effect per exposed person for one unit change in ambient pollutant concentration in a year)

Pollutants and associated health effects	*Ranges of estimates*	*Central estimates*
PM-10		
Premature mortality	4.47×10^{-6} – 9.10×10^{-6}	6.72×10^{-6}
Hospital admissions for respiratory illnesses	6.57×10^{-6} – 15.60×10^{-6}	12.00×10^{-6}
Emergency room visits	12.83×10^{-5} – 34.25×10^{-5}	23.54×10^{-5}
Restricted activity days	4.04×10^{-2} – 9.03×10^{-2}	5.75×10^{-2}
Lower respiratory illnesses in children (per child)	8.00×10^{-4} – 23.80×10^{-4}	16.90×10^{-4}
Asthma attacks (per asthmatic)	1.63×10^{-2} – 27.30×10^{-2}	3.26×10^{-2}
Respiratory symptoms	9.10×10^{-2} – 27.40×10^{-2}	18.30×10^{-2}
Chronic bronchitis (above age 25)	3.06×10^{-5} – 9.18×10^{-5}	6.12×10^{-5}
SO_2		
Respiratory symptoms (per child)	1.00×10^{-5} – 2.62×10^{-5}	1.81×10^{-5}
Chest discomforts (per adults)	5.00×10^{-3} – 15.00×10^{-3}	10.00×10^{-3}
Ozone (1-hour max.)		
Hospital admissions for respiratory illnesses	3.80×10^{-3} – 12.10×10^{-3}	7.70×10^{-3}
Minor restrictions in activity	17.00 – 51.00	34.00
Days with respiratory malaise symptoms	28.11 – 96.60	54.75
Eye irritations	23.40 – 29.90	26.60
Asthma exacerbations (per asthmatic)	38.69 – 189.80	68.44
Lead		
IQ decrement (per child)		0.975
Hypertension (per male aged 20–70)	4.48×10^{-2} – 9.78×10^{-2}	7.26×10^{-2}
Premature mortality (per male aged 40–59)	2.00×10^{-4} – 6.50×10^{-4}	3.50×10^{-4}
Nonfatal heart attacks (per male aged 40–59)	1.80×10^{-4} – 5.00×10^{-4}	3.40×10^{-4}
NO_2		
Respiratory symptoms	6.02 – 14.42	10.22

Note: The unit is $\mu g/m^3$ for PM-10, SO_2, and lead and ppm for ozone and NO_2.
Source: Ostro 1994.

between those considered in the original study and those in the population to which results are extrapolated) may result in different dose-response functions. Most of the dose-response functions have been established through epidemiological studies conducted in industrial countries—particularly in the United States and to a lesser extent in Britain, Germany, and Canada—where the baseline conditions are somewhat different from those of Latin American and Caribbean countries. The following baseline conditions are especially important:

- Differences in lifestyles that affect exposure to outdoor air pollutants. Populations that spend more time outdoors and are more exposed to air pollutants are at a greater health risk than others. For example, for a given ambient concentration of an air pollutant, populations in Latin America and the Caribbean are at a greater health risk than populations in the United States because they spend more time outdoors. Thus extrapolation of a dose-response function developed for a North American population to a Latin American or Caribbean population would likely underestimate health effects.
- Differences in exposure to pollutants from other sources. For example, exposure to cooking fires and space heating in developing countries is a risk factor for a wide range of health outcomes, especially for chronic lung diseases in adults (particularly women) and acute respiratory diseases in children (Chen and others 1990; Smith

Table 2.9 Alternative mortality subgroups from different studies
(percentage change in the number of affected persons in a year for 10 μg/m³ change of PM-10)

Health effect	*Santiago*[a]	*São Paulo*[b]	*Beijing*[c]	*Utah Valley*[d]	*Birmingham Alabama*[e]	*Philadelphia Pennsylvania*[f]
Total mortality	0.7		0.7[g]	1.6	1.1	1.3
Total mortality (over 65 years)	1.0	1.3				1.8
Respiratory disease	1.3			4.3		
Cardiovascular disease	0.8			2.0	1.7	1.8
Chronic obstructive pulmonary disease			1.8			3.4
Chronic lung disease					1.6	
Pneumonia						2.0
All other				0.5	0.6	
Male	1.0					
Female	0.5					

Note: Blank spaces indicate that no data are available.
a. Ostro and others 1995.
b. Saldiva and others 1994.
c. Xu and others 1994.
d. Pope, Schwartz, and Ransom 1992.
e. Schwartz 1993.
f. Schwartz and Dockery 1992a.
g. The coefficient is associated with the summer months.

1993). Dockery and others (1993) found a higher mortality risk from air pollution among people with an occupational exposure to respiratory hazards. Human exposure to lead occurs not only through ambient air, but also through food, water, and, in children, soil and dust.

- Differences in smoking habits. Dockery and others (1993) found a higher mortality risk from air pollution in smokers than in nonsmokers.
- Differences in geographic and climatic conditions—such as altitude, extreme temperature, and humidity—that may exacerbate the adverse health effects of air pollution.
- Differences in nutritional status and deficiencies in vitamins C and E, which weaken the body's defenses against air pollutants.
- Differences in access to medical care that influence the relationship between pollution levels and hospital admissions or emergency room visits. Lack of appropriate medical surveillance and treatment can increase the susceptibility of people at risk (such as the elderly and people with previous respiratory diseases).
- Differences in age distributions. Populations with a higher proportion of very young and old are more affected by air pollution. For example, in Chile the population above 65 years of age is 6 percent of the total population; in the United States this share is 12.9 percent.
- Differences in the cause of death. Extrapolating the effect of air pollution on total death rates from one study in the United States to a population in a developing country would yield incorrect results if the distribution of causes of death differs greatly between the two populations. For example, half the deaths in the United States are caused by cardiovascular disease or respiratory illness, whereas less than 20 percent of deaths in Delhi, India are attributable to these causes. Even if the people in Delhi reacted to a given change in ambient pollutant concentration the same way as in the United States, the effect of the change on total mortality would be lower (Cropper and Simon 1996).
- Differences in public awareness of air pollution. Exposure to outdoor air pollutants can be reduced through preventive measures. For example, billboards in some Latin American cities (such as Mexico City and São Paulo) and television, radio, and

newspapers are used to inform the public about ambient air quality.

- Differences in PM composition or in the mixture of air pollutants with potential synergetic effects.

Once the health response to a given change in ambient pollution is estimated, valuation techniques are used to quantify the benefits of reduced air pollution on human life and health for a selected population. The human capital and willingness to pay approaches are the two most commonly used techniques for valuing premature death. The human capital approach is based on the discounted flow of income from the person during the years he fails to live. This approach is, however, less useful for valuing persons with no income (children, retired people, housewives). The willingness to pay approach measures people's willingness to pay for reductions in their risk of dying. This may be estimated through the wage differentials between riskier and safer jobs (the underlying assumption is that risk-averting people move from higher-paying, risky jobs to lower-paying, safer jobs). Another way of estimating willingness to pay involves asking people how much they would pay to reduce their risk of dying. Because it is hypothetical, however, this approach might lead to higher estimates. Of the two techniques, willingness to pay may be more difficult to apply in developing countries because of its extensive data requirements.

Because valuation of premature mortality involves putting a monetary value on human life, it may raise moral and ethical issues. This should not be a concern, however, because the focus of valuation is not a specific person, but a statistical entity in a selected population. In addition, these estimates are intended to evaluate an air pollution management project or rank air pollution management alternatives within a given urban center or country, not across countries. It should also be noted that the human capital and willingness to pay approaches may not be appropriate for cultures where perceptions of life, health, and death more strongly reflect nonmaterial values.

Morbidity effects due to air pollution can be valued by gauging people's willingness to pay to avert the disease or the cost of illness approach, which involves estimating of medical expenses for disease prevention and treatment and lost wages. Of the two approaches, cost of illness is probably easier to apply in developing countries. This approach does not take into consideration personal discomfort and suffering, however, and provides a lower estimate of health values than the willingness to pay approach (Cropper and Oates 1992).

Environmental Effects of Air Pollutants

The environmental effects of pollutant emissions from motor vehicles include global climate changes from greenhouse gases, acidification of soil and surface waters, adverse effects on some plant (including crop) and animal species, and damage to buildings and structures.

Nitrogen oxides. Strong evidence suggests that NO_x can harm the environment through nitrate formation and acidification of surface waters. The nitrate concentration of ice in Greenland has doubled since the pre-1900 era (Herron 1982). The nitrate concentration of precipitation in Europe increased steadily between 1955 and 1979 (Faiz and others 1990). In 305 lakes in Norway the nitrate concentration doubled between 1974 and 1986 and was apparently associated with a decrease in fish populations (Derwent 1988). A threefold increase in the nitrate aerosol concentration was detected in ambient air at Chilton, U.K. (Watkins 1991). Although not quantified, NO_x is also believed to affect corrosion of materials such as buildings and other humanmade structures. N_2O, as a greenhouse gas, contributes to global climate warming by absorbing infrared radiation.

Ozone. Ozone damages plants and vegetation. The degree of damage is affected by ozone concentration and extent of exposure. Greater damage is also observed with higher light intensity and humidity. Tobacco, a very sensitive plant, can be injured by exposure to an hourly ozone concentration of 80 mg/m^3 or higher. Other sensitive plants, including beans, spinach, and clover may be injured by exposure to 200 mg/m^3 of ozone for several hours. Ozone is believed to be the major contributor to forest damage in the United States (for example, the pines of San Bernardino Forest in southern California), Germany, and Central Europe (Watkins 1991).

Sulfur dioxide. Environmental effects of SO_2 result either directly or indirectly from acid depo-

sition. SO_2 at concentrations as low as 800 μg/m^3 harms crops such as wheat, oat, barley, and cotton. SO_2, along with ozone and NO_x, has damaged forests in Europe (for example, in the Czech Republic). It also has caused the acidification of soils and lakes in Europe (in Finland) and North America and has damaged marble structures and monuments (in Athens) by forming calcium sulfate (gypsum).

Particulate matter. Environmental effects of PM include soiling and degradation of visibility. Large-size PM falls out of the atmosphere based on its settling characteristics and atmospheric conditions (especially wind). PM that settles out of the air adversely affects people's welfare by accumulating virtually anywhere—on buildings, windows, cars, laundry, even inside houses—leaving dirty deposits, requiring frequent cleaning, and damaging some materials.

PM which remains suspended in the air is of smaller size and includes PM emitted by motor vehicles as well as PM formed in the atmosphere such as sulfate or nitrate aerosols. PM in the atmosphere absorbs and disperses light, and hence reduces visibility. The presence of nitrates in PM-2.5 also darkens the color of the sky. The visibility reduction resulting from urban pollution is readily noticeable in Latin American urban centers such as Mexico City and Santiago. Because PM-2.5 can travel long distances, reduction of visibility is also a regional problem. For example, 20 percent of visibility reduction in Rocky Mountain National Park (United States) is attributed to pollution generated in Los Angeles, about 600 kilometers away.

Chlorofluorocarbons. Though injurious UV-B effects have been documented on individual species within marine ecosystems, the nature and extent of ecosystem responses to UV stress are not well understood. The effects of UV-B radiation on marine ecosystems and crops (such as rice production) are now being investigated (USEPA 1995). In addition, CFCs and halons contribute to global climate warming.

Carbon dioxide. CO_2 forms an insulating blanket around the Earth that prevents the escape of heat. This greenhouse effect causes an increase in the earth's temperature. About 50 percent of global warming is caused by CO_2; the rest is caused by methane, ground-level ozone, CFCs, and nitrous oxide. By the end of the twenty-first century this warming is expected to raise the Earth's temperature rise by about 3°C, and could induce changes in rainfall patterns, shifts in climatic zones, and a rise in sea levels.

Ambient Air Quality Standards and Monitoring

Ambient air quality standards. Air quality standards are set to protect society and the environment from the harmful effects of air pollutants. They are designed to achieve a given desirable level of air quality, and frequently serve as a reference base for other standards such as emission standards or fuel quality standards (UN 1987). As such, they do not take into account the costs or benefits associated with these pollutants.

Ambient air quality standards are of two types: primary and secondary. Primary ambient air quality standards are established to protect the most vulnerable groups of population, namely the young, the old, and people in poor health. Short-term standards and guidelines are established to control acute effects that result when high levels of pollution persist for short periods. Typical short-term standards are for 1-hour, 8-hour, and 24-hour averages of pollutant concentrations. Long-term standards and guidelines are designed to protect human health from regular exposure to high levels of pollution over a long period of time (typically one year; WHO/UNEP 1992). Secondary air quality standards are established for nonhealth impacts such as those involving soil, crops, vegetation, human-made materials, animals, wildlife, atmospheric visibility, property damage, transportation hazards, and effects on the economy and personal comfort (Cohn and McVoy 1982).

The United States was the first country to establish ambient air quality standards. The 1970 U.S. Clean Air Act Amendments of the 1967 U.S. Air Quality Act established national primary and secondary ambient air quality standards. The act also gave states the option of establishing their own ambient quality standards, provided they were equal to or more stringent than the national standards. In 1978 lead was added to the list of restricted pollutants, and in 1979 the ozone standard was made more stringent. In 1983 the USEPA revoked the national ambient air quality standards for HC because this pollutant was deemed safe at or near ambient levels and no consistent quantitative relationship was found

nationwide between ambient ozone concentrations and hydrocarbon air quality levels. The USEPA indicated, however, that HC should continue to be controlled because of their contribution to ozone formation and the resultant health and welfare effects of ozone. In 1987 the ambient standard for TSP was abandoned and one for PM-10 was established. With the revision of the National Ambient Air Quality Standards in 1989 secondary standards were abandoned for all pollutants except SO_2. Ambient air quality standards for PM-10 are under review. The USEPA has proposed new standards for PM-2.5 (12.5 μg/m^3 to 20 μg/m^3 on an annual average basis). These standards are estimated to save about 20,000 lives (especially among the elderly and those with existing heart and lung diseases) and result in fewer hospital admissions (by over 9,000 a year) and reduced risk of respiratory diseases (over 60,000 fewer incidences a year of chronic bronchitis, over 250,000 fewer incidences of asthma attacks, and over 250,000 cases of respiratory symptoms). The new standards are also expected to improve haze and reduce soiling and material damage effects. A final decision on the new standards will be taken by July 1997.

Many other countries also have established their own ambient air quality standards, including most Latin American countries. Primary air quality standards have been established in every South American country except Guyana, Paraguay, Peru, Suriname, and Uruguay. No Central American or Caribbean country has such standards, however. Ambient standards are being prepared in Guatemala, Paraguay, Peru, and Uruguay. Primary air quality standards have been established mostly through national legislation and in some cases through regional (provincial) or local legislation. These standards are sometimes complemented by additional legislation on pollutant standards that trigger certain actions by society. For example, attention, alert, emergency, and critical levels of air pollutants (such as CO, NO_2, ozone, SO_2, TSP, and PM-10) have been established in São Paulo. Brazil and Chile are the only Latin American and Caribbean countries that have established secondary ambient air quality standards.

Ambient air quality standards for various Latin American countries are presented in Annex B to this chapter for CO, NO_2, ozone, SO_2, TSP, PM-10, and lead. Related information on U.S. standards and WHO guidelines are also included for comparison. Ambient air quality standards (*STDRF*) are expressed in milligrams per cubic meter (mg/m^3) for CO and micrograms per cubic meter (μg/m^3) for all other pollutants at reference conditions of 25°C temperature and 760 mm Hg pressure. For an urban center with a t °C temperature and p mm Hg pressure, the air quality standard (*STD*) can be obtained through the following relationship:

$$STD = (STDRF)(p)(298)/[(760)(273 + t)].$$

Ambient air quality standards under the reference conditions can be also expressed in terms of parts of pollutant per million parts of air (ppm) using the following relationship:

$$STDRF \text{ (expressed in ppm)} = (STDRF \text{ expressed in } \mu g/m^3)(24{,}500)(10^{-6})/(MW)$$

where MW is the molecular weight of the pollutant.

Ambient air quality monitoring. Ambient air quality monitoring involves measuring pollutants to determine ambient air concentrations. During the 1960s, following identification of the adverse human health effects of certain air pollutants (CO, NO_2, ozone, SO_2, TSP, lead), many industrial countries adopted national ambient air quality standards and initiated ambient air quality monitoring. Most of these monitoring efforts focused on SO_2 and TSP measurements. During the 1970s, with the emergence of motor vehicles as the main source of air pollution in urban areas, air quality monitoring incorporated other traffic-related pollutants such as CO, NO_2, and lead. During this period and mostly in the 1980s urban air quality monitoring was initiated in some developing countries, especially in Latin America and Asia. In recent years greater emphasis has also been placed on the monitoring of photochemical oxidants (especially ozone) and volatile organic chemicals (VOCs) and their precursors as well as PM-10 (instead of TSP, which has a limited value for health effect assessments; WHO/UNEP 1992).

Ambient air quality monitoring in urban areas may have a number of objectives. One is to generate information on the spatial and temporal distribution of air pollution in urban areas. Monitoring data are then compared against air quality standards to identify potential risks to human health or the environment. Data indicating high pollutant concentrations in certain parts of an urban area (such as a business dis-

trict) or during certain periods of the day (peak morning hours) or year (certain months) enable policymakers to take the necessary measures aimed at reducing pollution at these locations or during these periods. Monitoring data also help policymakers evaluate the effectiveness of the control measures they implement. In addition, ambient air quality monitoring can be performed to inform the public on short notice about air quality, especially when pollutant concentrations reach or are about to reach high levels. Such warnings allow the public to take the necessary preventive measures against health-related risks. Ambient air quality monitoring, if conducted over many years, can also be used to generate pollutant trends as an input to medium- or long-term policy decisions for air quality management.

Ambient air quality monitoring involves sampling of pollutants, analysis of the samples, data collection, and data transmission and control. It can be performed using any of a number of systems. *Manually operated sampling* refers to sampling with an instrument for which the start and end of the sampling period are actuated manually. Analyses of samples may be conducted manually or automatically. *Semiautomatic sampling* involves a sampling instrument equipped with automatic sampling capabilities, but which requires manual removal of samples. Analyses of samples may be conducted manually or automatically. Such systems have been used in Latin America for many years. For example, a six-station semiautomatic monitoring system has been operated in Santiago since 1981. However, these stations have lost their importance since a fully automated monitoring network was installed. In São Paulo and Mexico City semiautomatic sampling is conducted to complement the more advanced systems described below. In São Paulo seven of eighteen stations are used to monitor SO_2; the remaining eleven are used for PM-10. In Mexico City the semiautomatic system consists of nineteen stations monitoring TSP and PM-10.

Automatic monitoring involves sampling and analysis performed by an instrument that produces printed data sheets, magnetic tape recordings, and charts without human intervention except for regular maintenance. Some urban areas in Latin America use automatic monitoring systems. For example, Santiago's six automatic monitoring stations measure ambient levels of CO, SO_2, NO_2, ozone, HC, and PM-10. In São Paulo automatic monitoring is conducted by two mobile stations in areas not covered by stationary stations. The monitoring data in these stations are recorded on magnetic tapes and subsequently sent to a central computer system.

Fully automated monitoring with data transmission includes all the above automatic features of monitoring as well as transmission of the electronic output of the instrument, possibly by a telephone line, to a computer at a central control room where data are stored and processed (Rossano and Thielke 1976). In Latin America and the Caribbean such systems are used in São Paulo, Mexico City, and Santiago. The monitoring network in São Paulo includes twenty-five stationary stations that generate monitoring data for PM-10, SO_2, NO_2, CO, and HC. The data are immediately sent by telephone to a central station for computer processing. The air quality information is disseminated to the public using billboards on major roads and through press and communication agencies. The monitoring network in Mexico City is similar to that in São Paulo. This network includes thirty-two stations that monitor ozone, SO_2, NO_2, CO, and PM-10. In Santiago the monitoring network consists of five fully automated stations measuring ambient concentrations of CO, SO_2, NO_2, ozone, HC, and PM-10.

The design of an urban air quality monitoring program should reflect its objectives and include decisions on sampling, measurement, data collection, and data transmission issues. The design should also consider the combined effects of pollutant emission source configurations and the meteorological and topographical features of each urban area. For this reason pollution monitoring should be accompanied by atmospheric monitoring that includes such parameters as wind speed, wind direction, temperature, and humidity. Air monitoring of an entire urban area requires selection of the station locations to cover the varying levels of air pollution across the urban area. However, fixed monitoring stations only provide air quality information for their location and are expensive to install in every part of a city. Because resources are limited, installations should be prioritized based on the significance of air pollution in terms of human health risks and ease of measurement. In some cases fixed monitoring stations may be complemented by mobile stations to spatially extend the monitoring effort.

Every sampling station should be located to ensure that the information it collects is repre-

sentative of its surrounding area. The issues related to pollutant measurement should include types and concentrations of pollutants, required averaging times for sampling, presence of other pollutants that may cause interference with the monitor, and availability and qualifications of available personnel and laboratories. In addition, in selecting the monitoring system, factors such as functional characteristics (measuring ranges, accuracy, repeatability), operational characteristics (complexity in operation and response to external conditions such as temperature and humidity), requirements for technical expertise and maintenance, availability of spare parts, and physical dimensions should be considered.

In terms of data collection, continuous monitoring instruments that present data in bar charts have the advantage of providing a permanent and visual record of information, but they require considerable staff to maintain. Fully automated systems can communicate the measured data from each monitoring station to the central control room. An electronic map in the control room allows the display of monitoring stations where ambient pollutant concentrations exceed a specified level. Such systems help provide short-term warnings to the public about high concentrations of pollutants at specific locations. Air quality data can be disseminated to the public through electronic billboards located in publicly visible areas or to radio and television stations. In Latin America such systems are available in São Paulo and Mexico City. In these cities real-time air quality data are presented using indices and associated qualifiers. For example, in São Paulo the designation for the air quality categories consists of "bad" (index over 200) in the "attention" level, "very bad" (index over 300) in the "alert" level, and "critical" (index over 400) in the "emergency" level. In addition, air quality data are generally disseminated to the press.

The most comprehensive efforts to monitor ambient air quality have occurred in São Paulo, Mexico City, and Santiago. Ambient air quality monitoring in many other cities has been hampered by inadequate financial resource commitments and lack of technical resources and spare parts. For example, until 1982 the monitoring effort conducted by the Municipality of Buenos Aires included twelve stations for gaseous pollutants and twenty-one stations for TSP measurements. This effort was significantly curtailed, however, following budget cuts and a reduction in staff. The municipality's current effort includes monitoring of three pollutants (NO, NO_2, and SO_2) at one stationary station and two pollutants (TSP and lead) by three mobile stations. In Belo Horizonte the air quality monitoring stations established in 1984 experienced operational difficulties and were shut down in 1988 because of a lack of funding. A second monitoring effort initiated in 1991 was suspended in 1992 for the same reason. In Rio de Janeiro an automatic monitoring station provided by the WHO in 1975 could not be fully used because of technical difficulties and a lack of spare parts. The operation of another automatic monitoring station installed in 1986 under the Brazilian-Japanese Technical Cooperation Project also was hampered by a lack of spare parts.

ANNEX A
ESTIMATED EMISSION FACTORS FOR U.S. VEHICLES

Table A.1 Estimated emission factors for U.S. gasoline-fueled passenger cars with different emission control technologies
(grams per kilometer)

Type of control	*CO*[a]	*Methane*[a]	*NMHC*[a]	*NO_x*[a]	*N_2O*	*CO_2*	*Fuel consumption (liters per 100 kilometers)*
Advanced three-way catalyst control							8.4
Exhaust	6.20	0.04	0.38	0.52	0.019	200	
Evaporative			0.09				
Running loss			0.16				
Resting			0.04				
Total emissions	6.20	0.04	0.67	0.52	0.019	200	
Early three-way catalyst control							10.6
Exhaust	6.86	0.05	0.43	0.66	0.046	254	
Evaporative			0.14				
Running loss			0.16				
Resting			0.06				
Total emissions	6.86	0.05	0.79	0.66	0.046	254	
Oxidation catalyst control							16.7
Exhaust	22.37	0.10	1.87	1.84	0.027	399	
Evaporative			0.39				
Running loss			0.17				
Resting			0.06				
Total emissions	22.37	0.10	2.49	1.84	0.027	399	
Non-catalyst control							16.7
Exhaust	27.7	0.15	2.16	2.04	0.005	399	
Evaporative			0.70				
Running loss			0.17				
Resting			0.06				
Total emissions	27.7	0.15	3.09	2.04	0.005	399	
Uncontrolled							16.7
Exhaust	42.67	0.19	3.38	2.7	0.005	399	
Evaporative			1.24				
Running loss			0.94				
Resting			0.06				
Total emissions	42.67	0.19	5.62	2.7	0.005	399	

a. Estimated using the USEPA's MOBILE5a model for the following conditions: temperature of 24°C, vehicle speed of 31 kilometers an hour, gasoline RVP of 9 psi, and no inspection and maintenance program in place.
Source: Faiz, Weaver, and Walsh 1996.

Table A.2 Estimated emission factors for U.S. gasoline-fueled medium-duty trucks with different emission control technologies

(grams per kilometer)

Type of control	*CO*[a]	*Methane*[a]	*NMHC*[a]	NO_x[a]	N_2O	CO_2	*Fuel consumption (liters per 100 kilometers)*
Three-way catalyst control							34.5
Exhaust	10.2	0.12	0.83	2.49	0.006	832	
Evaporative			0.38				
Running loss			0.17				
Resting			0.04				
Total emissions	10.2	0.12	1.42	2.49	0.006	832	
Refueling			0.24				
Non-catalyst control							35.7
Exhaust	47.61	0.21	2.55	3.46	0.006	843	
Evaporative			2.16				
Running loss			0.94				
Resting			0.08				
Total emissions	47.61	0.21	5.73	3.46	0.006	843	
Refueling			0.25				
Uncontrolled							50.0
Exhaust	169.13	0.44	13.56	5.71	0.009	1,165	
Evaporative			3.93				
Running loss			0.94				
Resting			0.08				
Total emissions	169.13	0.44	18.51	5.71	0.009	1,165	
Refueling			0.32				

a. Estimated using the USEPA's MOBILE5a model for the following conditions: temperature of 24°C, vehicle speed of 31 kilometers an hour, gasoline RVP of 9 psi, and no inspection and maintenance program in place.

Source: Faiz, Weaver, and Walsh 1996.

Table A.3 Emission and fuel consumption factors for U.S. diesel-fueled passenger cars and light-duty trucks with different emission control technologies

(grams per kilometer)

Vehicle type	*CO*	*HC*	*NO_x*	*CO_2*	*Fuel consumption (liters per 100 kilometers)*
Passenger cars					
Advanced control	0.83	0.27	0.63	258	9.4
Moderate control	0.83	0.27	0.90	403	14.7
Uncontrolled	0.99	0.47	0.99	537	19.6
Light-duty trucks					
Advanced control	0.94	0.39	0.73	358	13.0
Moderate control	0.94	0.39	1.01	537	19.6
Uncontrolled	1.52	0.77	1.37	559	23.3

Source: MOBILE5a estimates adapted from Faiz, Weaver, and Walsh 1996.

Table A.4 Emission and fuel consumption factors for U.S. heavy-duty diesel-fueled trucks and buses with different emission control technologies

(grams per kilometer)

Vehicle type	*CO*	*HC*	*NO_x*	*PM*	*CO_2*	*Fuel consumption (liters per 100 kilometers)*
U.S. heavy-duty diesel trucks						
Advanced control	6.33	1.32	5.09		982	35.7
Moderate control	7.24	1.72	11.56		991	35.7
Uncontrolled	7.31	2.52	15.55		1,249	45.5
U.S. 1984 measurements						
Single-axle tractors	3.75	1.94	9.37	1.07	1,056	
Double-axle tractors	7.19	1.74	17.0	1.47	1,464	
Buses	27.40	1.71	12.40	2.46	1,233	
New York City vehicles						
Medium-heavy trucks		2.84	23.28	2.46		53.8
Transit buses		5.22	34.89	2.66		80.7

Source: MOBILE5a estimates adapted from Faiz, Weaver, and Walsh 1996.

ANNEX B
Ambient Air Quality Standards and World Health Organization Guidelines

Table B.1 Air quality standards and WHO guideline for carbon monoxide
(milligrams per cubic meter)

	Time-weighted average			
Country	*1 hour*	*8 hours*	*24 hours*	*Other averaging times*
Argentina	57.3	11.5		
Alert level	114.5	17.2		
Alarm level	137.4	34.4		
Emergency level	171.8	57.3		
City of Buenos Aires			3.0	15.0 (20 minutes)
Province of Buenos Aires	45.8	17.2	9.2	
Bolivia	30.0	10.0		
Brazil				
Primary standards	40.0	10.3		
Secondary standards	40.0	10.3		
São Paulo				
Attention level		17.2		
Alert level		34.4		
Emergency level		45.8		
Critical level		57.3		
Chile	40.0	10.3		
Santiago[a]				
Good level		10.3		
Regular level		21.8		
Bad level		34.4		
Critical level		45.8		
Dangerous level		57.3		
Colombia	50.0	15.0		
Santafé de Bogotá	38.4[b]	11.5[b]		
Ecuador	40.0	10.0		
Mexico		12.6		
Mexico City[a]				
Satisfactory level		12.6		
Unsatisfactory level		25.2		
Bad level		35.5		
Very bad level		57.3		
Peru	40.0[c]	20.0[c]		
Venezuela		10.0[d]		
		40.0[e]		
United States	40.0	10.0		
WHO	30.0	10.0		60 (30 minutes)[f]
				100 (15 minutes)[f]

Note: 1 ppm = 1.145 milligrams per cubic meter (mg/m^3). A blank space indicates that no standard was established.
a. Time-weighted averages indicate maximum values for each category.
b. This standard reflects 13°C temperature and 560 mm Hg pressure for Santafé de Bogotá.
c. Proposed standards.
d. 50 percentile (of the 8-hour mean, 50 percent must be below the indicated value).
e. 99.5 percentile (of the 8-hour mean, 99.5 percent must be below the indicated value).
f. The 15-minute and 30-minute values are established to maintain the carboxyhemoglobin level in blood less than 2.5 to 3.0 percent in non-smoking populations.
Source: WHO/UNEP 1992; personal communications with technical experts from different countries.

Table B.2 Air quality standards and WHO guideline for nitrogen dioxide
(micrograms per cubic meter)

Country	Time-weighted average 1 hour	8 hours	24 hours	Other averaging times
Argentina[a]	846			
Alert level	1,128	282		
Alarm level	2,256	564		
Emergency level		752		
City of Buenos Aires		100		400 (20 minutes)
Province of Buenos Aires	376	188	94	
Bolivia	400	150		
Brazil				
Primary standards	320		190	
Secondary standards	320		100	
São Paulo				
Attention level	1,130			
Alert level	2,260			
Emergency level	3,000			
Critical level	3,750			
Chile			100	
Santiago[b]				
Good level	470			
Regular level	1,290			
Bad level	2,110			
Critical level	2,930			
Dangerous level	3,750			
Colombia			100	
Santafé de Bogotá			77[c]	
Ecuador			100	
Mexico	395			
Mexico City[b]				
Satisfactory level	395			
Unsatisfactory level	1,241			
Bad level	2,068			
Very bad level	3,760			
Peru		200[d]		
Venezuela		100[e]		
		300[f]		
United States			100	
WHO[g]	400	150[h]		

Note: 1 ppm = 1,880 micrograms per cubic meter (μg/m³). A blank space indicates that no standard was established.
a. All standards in Argentina are for NO_x (expressed as NO_2).
b. Time-weighted averages indicate maximum values for each category.
c. This standard reflects 13°C temperature and 560 mm Hg pressure for Santafé de Bogotá.
d. Proposed standards.
e. 50 percentile (of the 24-hour mean, 50 percent must be below the indicated value).
f. 95 percentile (of the 24-hour mean, 95 percent must be below the indicated value).
g. WHO guidelines to protect vegetation (in the presence of SO_2 and ozone not exceeding 30 μg/m³ and 60 μg/m³, respectively) are 30 μg/m³ for the annual mean and 95 μg/m³ for the 4-hour mean.
h. The 24-hour WHO guideline is established to protect against chronic exposure, and the 1-hour WHO guideline is designed to provide a margin of protection for lung function in asthmatic people from short-term exposures.
Source: WHO/UNEP 1992; personal communications with technical experts from different countries.

Table B.3 Air quality standards and WHO guideline for ozone
(micrograms per cubic meter)

Country	*Time-weighted average (1 hour)*	*Other averaging times*
Argentina	200	
Alert level	300	
Alarm level	400	
Emergency level	800	
City of Buenos Aires		30 (24 hours) 100 (20 minutes)
Bolivia	236	
Brazil		
Primary standard	160	
Secondary standard	160	
São Paulo		
Attention level	400	
Alert level	800	
Emergency level	1,000	
Critical level	1,200	
Chile	160	
Santiago[a]		
Good level	160	
Regular level	470	
Bad level	780	
Critical level	1,090	
Dangerous level	1,400	
Colombia	170	
Santafé de Bogotá	131[b]	
Ecuador	200	
Mexico	220	
Mexico City[a]		
Satisfactory level	220	
Unsatisfactory level	460	
Bad level	700	
Very bad level	1,200	
Peru		400[c] (30 minutes) 200[c] (8 hours)
Venezuela	240[d]	
United States	235	
WHO	150–200	100–120 (8 hours)[e]

Note: 1 ppm = 2,000 micrograms per cubic meter (µg/m³). A blank space indicates that no standard was established.
a. Time-weighted averages indicate maximum values for each category.
b. This standard reflects 13°C temperature and 560 mm Hg pressure for Santafé de Bogotá.
c. Proposed standards.
d. 99.98 percentile (of the 1-hour mean, 99.98 percent must be below the indicated value).
e. The 8-hour WHO guideline is intended to lessen the potential for adverse acute and chronic effects and to provide an additional margin of protection.
Source: WHO/UNEP 1992; personal communications with technical experts from different countries.

Table B.4 Air quality standards and WHO guideline for sulfur dioxide
(micrograms per cubic meter)

Country	Time-weighted average 1 hour	8 hours	24 hours	1 year	Other averaging times
Argentina					70 (30 days)
Alert level	2,600	780			
Alarm level	13,000				
Emergency level	26,000				
City of Buenos Aires					500 (20 minutes) 70 (30 days)
Province of Buenos Aires	780			78	
Bolivia			365	80	
Brazil					
Primary standards			365	80	
Secondary standards			100	40	
São Paulo					
Attention level			800		
Alert level			1,600		
Emergency level			2,100		
Critical level			2,620		
Chile			365	80	
Santiago(secondary standards)					
North zone	700		260	60	
South zone	1,000		365	80	
Santiago[a]					
Good level			365		
Regular level			929		
Bad level			1,493		
Critical level			2,056		
Dangerous level			2,620		
Colombia			400	100	1,500 (3 hours)
Santafé de Bogotá			307[b]	77[b]	1,152[b] (3 hours)
Ecuador			400	80	1,500 (3 hours)
Mexico			338	78	
Mexico City[a]					
Satisfactory level			338		
Unsatisfactory level			910		
Bad level			1,456		
Very bad level			2,600		
Peru			858[c]	172[c]	
Venezuela			80[d] 200[e] 250[f] 365[g]		
United States			365	80	1,300 (3 hours)
WHO[h]	350[i]		100–150	40–60	500 (10 minutes)[i]

Note: 1 ppm = 2,600 micrograms per cubic meter (μg/m^3). A blank space indicates that no standard was established.
a. Time-weighted averages indicate maximum values for each category.
b. This standard reflects 13°C temperature and 560 mm Hg pressure for Santafé de Bogotá.
c. Proposed standards.
d. 50 percentile (of the 24-hour mean, 50 percent must be below the indicated value).
e. 95 percentile (of the 24-hour mean, 95 percent must be below the indicated value).
f. 98 percentile (of the 24-hour mean, 98 percent must be below the indicated value).
g. 99.5 percentile (of the 24-hour mean, 99.5 percent must be below the indicated value).
h. WHO guidelines for combined exposure to SO_2 and TSP are 50 μg/m^3 for annual mean and 125 μg/m^3 for 24-hour mean.To protect vegetation, WHO guidelines for SO_2 are 330 μg/m^3 for the annual mean and 100 μg/m^3 for the 24 hour mean.
i. The 10-minute WHO guideline incorporates a protection factor of 2, and the 1-hour WHO guideline is a derived equivalent figure.
Source: WHO/UNEP 1992; personal communications with technical experts from different countries.

Table B.5 Air quality standards and WHO guideline for TSP
(micrograms per cubic meter)

Country	*Time-weighted average* 24 hours	*Time-weighted average* 1 year	*Other averaging times*
Argentina			150 (1 month)
City of Buenos Aires			500 (20 minutes) 150 (30 days)
Province of Buenos Aires	150		
Bolivia	260	75[a]	
Brazil			
Primary standards	240	80[a]	
Secondary standards	150	60[a]	
São Paulo			
Attention level	375		
Alert level	625		
Emergency level	875		
Critical level	1,000		
Chile	260	75[a]	
Colombia	400	100[a]	
Santafé de Bogotá	307[b]	77[a,b]	
Ecuador	250	80[a]	
Mexico	260	75	
Mexico City[c]			
Satisfactory level	260		
Unsatisfactory level	445		
Bad level	630		
Very bad level	1,000		
Peru	350[d]	150[d]	
Venezuela	75[e] 150[f] 200[g] 260[h]		
WHO[i]	150–230	60–90	

Note: A blank space indicates that no standard was established.
a. Geometric mean.
b. This standard reflects 13°C temperature and 560 mm Hg pressure for Santafé de Bogotá.
c. Time-weighted averages indicate maximum values for each category.
d. Proposed standards.
e. 50 percentile (of the 24-hour mean, 50 percent must be below the indicated value).
f. 95 percentile (of the 24-hour mean, 95 percent must be below the indicated value).
g. 98 percentile (of the 24-hour mean, 98 percent must be below the indicated value).
h. 99.5 percentile (of the 24-hour mean, 99.5 percent must be below the indicated value).
i. WHO guideline for combined exposure to SO_2 and TSP is 125 $\mu g/m^3$ for 24-hour mean.
Source: WHO/UNEP 1992; personal communications with technical experts from different countries.

Table B.6 Air quality standards for PM-10

(micrograms per cubic meter)

Country	Time-weighted average: 24 hours	Time-weighted average: 1 year
Bolivia	150	50[a]
Brazil		
Primary standards	150	50
Secondary standards	150	50
São Paulo		
Attention level	250	
Alert level	420	
Emergency level	500	
Critical level	600	
Chile	150	
Santiago[b]		
Good level	150	
Regular level	195	
Bad level	240	
Critical level	285	
Dangerous level	330	
Mexico	150	50
Mexico City[b]		
Satisfactory level	150	
Unsatisfactory level	350	
Bad level	420	
Very bad level	600	
United States	150	50

Note: A blank space indicates that no standard was established.
a. Geometric mean.
b. Time-weighted averages indicate maximum values for each category.
Source: WHO/UNEP 1992; personal communications with technical experts from different countries

Table B.7 Air quality standards and WHO guideline for lead

(micrograms per cubic meter)

Country	1 hour	24 hours	3 months	Other averaging times
Argentina				
City of Buenos Aires		1		10 (20 minutes)
Province of Buenos Aires	16	15		10 (30 days)
Bolivia			1.5	
Ecuador			1.5	
Mexico			1.5	
Peru				15[a] (30 days) 5[a] (1 year)
Venezuela		1.5[b] 2[c]		
United States			1.5	
WHO				0.5–1.0 (1 year)[d]

Note: 1 ppm = 2,600 micrograms per cubic meter (μg/m³). A blank space indicates that no standard was established.
a. Proposed standards.
b. 50 percentile (of the 24-hour mean, 50 percent must be below the indicated value).
c. 95 percentile (of the 24-hour mean, 95 percent must be below the indicated value).
d. WHO guideline incorporates a protection factor of two and is based on the assumption that 98 percent of the population will have a lead concentration in blood less than 29 mg/dl.
Source: WHO/UNEP 1992; personal communications with technical experts from different countries.

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3

Abatement Measures for Vehicular Air Pollution

Designing a strategy to abate vehicular air pollution in an urban area requires a good understanding of the nature and magnitude of the air pollution problem and the applicability of various abatement measures. Policy measures can be classified as command-and-control or market-based incentives. The choice of a measure depends on its costs and benefits, as well as on the monitoring and enforcement capabilities of the responsible institutions. More often than not these measures, if well used, complement rather than substitute for one another.

Command-and-control measures for curtailing vehicular air pollution mainly rely on regulatory options. Such measures include emission standards that set a legal ceiling on the quantity or concentration of pollutants discharged from vehicles, standards that specify fuel quality for motor vehicles, requirements to use a certain technology (such as smaller nozzles for fueling unleaded gasoline), testing and certification rules for new vehicles, inspection requirements for in-use vehicles, and traffic restrictions.

Market-based incentives rely on market forces to bring about improvements in ambient air quality. Since pollution can be viewed as a negative externality whose costs are not fully borne by polluters, market-based incentives based on the "polluter pays" principle impose a price on polluting activities, thereby internalizing the cost of the externality. Some polluters may prefer to pay the "price" imposed by the regulator rather than lower their level of pollution, while others may find it cheaper to modify their current activities in ways that reduce or eliminate pollution. The higher the government sets the price of pollution, the greater is the reduction in pollution, assuming adequate institutional support, monitoring, and enforcement (Hamrin 1990). Market-based incentives that have been used to control vehicular air pollution include vehicle taxes, fuel taxes, and congestion charges.

Common measures for reducing air pollution from motor vehicles are shown in Table 3.1. These measures, which target vehicles, fuels, and transport management, are classified as command-and-control measures, market-based incentives, and additional measures. These measures are sometimes accompanied by actions that promote public awareness and education (Box 3.1).

Table 3.1 Typical measures for the abatement of air pollution from motor vehicles

Type of measure	*Command-and-control measures*	*Market-based incentives*	*Additional measures*
Vehicle-targeted	Emission standards and related measures for new vehicles • Emission standards • Certification • Assembly line testing • Recall • Warranty Emission standards and inspection programs for in-use vehicles • Emission standards • Inspection and maintenance programs • Roadside inspection programs Emission restrictions on imported vehicles	Vehicle emission fees Differential vehicle registration fees and taxes Vehicle retrofit programs Vehicle replacement or scrappage incentives	
Fuel-targeted	Gasoline standards • lead • volatility • benzene and other aromatic hydrocarbons • reformulated gasoline • oxygenated gasoline Diesel fuel standards • sulfur • cetane number • aromatic hydrocarbons and density Alternative fuels • compressed natural gas • liquefied petroleum gas • methanol • ethanol	Fuel taxes Tradable permits and credits	
Transport management	Driving bans On-street parking and trading restrictions Traffic priority measures for buses Ride sharing Staggered work hours Speed limits and other traffic management measures Land use planning and controls	Road pricing Area licensing	Provision of public transport services Promotion of non-motorized transport Provision of off-street parking

Source: Based on Carbajo 1994.

Box 3.1 Public awareness and education

Preparing and implementing an effective urban air pollution control strategy requires education at all levels of society, including policymakers, implementing agencies, manufacturing and service industries, and the public. Education of policymakers is fundamental in developing an integrated urban air pollution control strategy that includes cost-effective measures to control vehicular emissions. Education programs expose policymakers to such topics as the type and effectiveness of different air pollution control measures, analytical tools for evaluating these measures, and lessons learned from different countries. For example, an October 1996 seminar in Buenos Aires organized by USEPA was designed for policymakers from the environmental, health, and transport agencies responsible for formulating strategies to reduce vehicular emissions. The seminar focused on identifying main air pollutants and their health effects, interpreting emissions inventory and ambient air quality data, evaluating pollution control measures, developing options for reducing and eliminating lead from gasoline, and preparing an urban transport policy.

Introducing a motor vehicle emissions control technology in a developing country generates a growing need for trained and experienced vehicle mechanics and technicians. A cadre of inspectors and technicians is also required to effectively manage and operate inspection and maintenance programs. At every level of vehicle emission control, efforts should be made to provide appropriate and thorough training of officials, inspectors, technicians, and operators. Training may include such measures as specialized courses, technical meetings, individual instruction, and in-service training. For example, in São Paulo mechanical training courses for servicing vehicles failing the inspections have been provided to technical school instructors. International organizations could also play a catalytic role in organizing training programs. An executive training program on motor vehicles and the environment, recently established by the International Road Federation, provides a useful training opportunity for senior officials in developing countries.

If measures to reduce urban air pollution are to be effective, they must be supported by the public. Public participation through roundtables, seminars, and meetings enhances formulation of a sound package of measures and eases resistance to environmental protection by special interest groups. Public education and awareness campaigns explaining the general nature of air pollution, its adverse health effects, and the ways in which the public can help reduce pollution from motor vehicles increase the degree of success in reaching the desired objectives during implementation of these measures. Several Latin American countries have taken various steps to educate the public on the adverse effects of vehicular air pollution. In Chile, for example, an information campaign was organized to help people understand the drawbacks of using leaded gasoline in cars fitted with catalytic converters. In Honduras, with the help of the Swiss government, numerous public meetings were held and pamphlets were distributed to inform people about the harmful health effects of lead in gasoline. In Trinidad and Tobago local NGOs have written extensively in local newspapers on the health effects of lead. In Uruguay several seminars and workshops have been organized to foster public awareness of vehicular air pollution. These included a roundtable discussion on lead in gasoline, a conference on vehicular air pollution, a roundtable on atmospheric contamination, and a presentation by a local NGO on vehicular air pollution. In Venezuela several NGOs have prepared papers for public dissemination on the health risk of lead and written articles in local newspapers. Continuous public awareness campaigns about the negative effects of leaded gasoline have been organized in Barbados and Costa Rica.

Vehicle-Targeted Measures

Emission Standards and Related Measures for New Vehicles

Emission standards are established to limit discharge of air pollutants from new motor vehicles. These standards are usually accompanied with certification, assembly line testing, recall, and warranty requirements.

Emission standards. Emission standards for new vehicles are generally specified by vehicle class and engine type (based on fuel). Vehicle classes include light-duty vehicles (passenger cars, light-duty trucks, light-duty commercial vehicles), medium-duty vehicles, and heavy-duty vehicles. Engine types include spark-ignition and diesel. Spark-ignition engines use such fuels as gasoline and low-emission fuels (such as CNG and LPG), and diesel engines use diesel fuel. In addition, some emission standards restrict emissions from vehicles operating in a specific geographical area (such as urban buses). Standards for new gasoline-fueled vehicles (or vehicles equipped with spark-ignition engines) generally limit CO, HC, and NO_x emissions in the exhaust and evaporative emissions. In Brazil, where alcohol-based fuels are used in spark-ignition engines, aldehyde emissions are also limited. Standards for new diesel-fueled vehicles generally limit CO, HC, NO_x, PM, and smoke emissions.

All industrial countries have established emission standards for new motor vehicles; the United States was the first country to do so. An overview of U.S. emission standards for new passenger cars, light-duty trucks, and heavy-duty duty vehicles is presented in Annex A to this chapter. New vehicle emission standards in certain Latin American countries have been set using the U.S. standards and, to a lesser extent, the European Union's standards. The emission standards established in Argentina, Brazil, Chile, Colombia, and Mexico are presented and discussed in Chapter 4.

The establishment of emission standards for new motor vehicles has been a major impetus for research and development of engine designs and pollution control technologies. Major advances in this area have come from engine modifications, catalytic converters, on-board canisters, and on-board diagnostics for gasoline-fueled vehicles (Box 3.2); and engine modifications, trap oxidizers, and catalytic converters for diesel-fueled vehicles (Box 3.3).

Emission standards for new vehicles must be backed by stable government policies because of their implications for the automotive industry, petroleum refiners, and consumers. To meet the standards, vehicle manufacturers must invest in research and development that involves modifying vehicle technology, investing in the parts and labor associated with the production of the modified design, and testing for and certifying compliance. Because this effort is extensive, vehicle manufacturers must have sufficient lead time for product research and development—at least three to four years in industrial countries (Nill 1995). For shorter periods of lead time, a phased-in compliance program, such as that used in Brazil, can be used to allow vehicle manufacturers to decide on the combination of vehicle types and models to introduce into the market. In addition, vehicle manufacturers prefer to respond to fewer changes of moderate emis-

Box 3.2 Pollution control technologies for vehicles with four-stroke spark-ignition engines

Formation of pollutants in four-stroke gasoline engines depends on two major factors: the air-fuel ratio and ignition timing. The air-fuel ratio of 14.7:1 is called *stoichiometric* because the mixture has exactly enough air to completely burn the fuel. At air-fuel ratios below stoichiometric high levels of CO and HC are emitted as a result of incomplete combustion of the fuel. CO and HC emissions decrease, but NO_x emissions rise as the air-fuel ratio increases below the stoichiometric value. At ratios slightly higher than stoichiometric (between 14.7 and about 17.6) the CO and HC emissions remain low and NO_x emissions remain high. At higher ratios, the CO and HC emissions rise moderately and NO_x emissions decrease sharply. Ignition timing affects the formation of HC and NO_x. In addition, the air-fuel ratio and ignition timing affect fuel consumption. Pollution control technologies for vehicles with four-stroke spark-ignition engines include:

Engine modifications. The most commonly used engine modifications techniques include:

- Increasing air-fuel ratios above 17:1 (lean burn engines). Satisfactory performance of these engines can be maintained by enriching the mixture during idling, acceleration, and high speed (ECMT 1990).
- Replacing the conventional carburetor and distributive ignition technology with electronic fuel injection and ignition systems to ensure precise control of engine combustion and emission of air pollutants.
- Using exhaust gas recirculation technology to recycle a portion of the exhaust gas from the engine to the incoming air-fuel mixture to reduce peak temperatures in the combustion chamber and lower NO_x emissions from vehicle exhaust. This technology can also be used in conjunction with catalytic converters.

Electronic fuel injection and ignition systems reduce HC and CO emissions but are less effective for NO_x emissions. When fuel ignition timing and exhaust gas recirculation are also electronically controlled, however, NO_x exhaust emissions can be reduced with no change and, in some cases, with an improvement in fuel economy (Faiz 1990). Vehicles equipped with electronic fuel injection systems also do not require engine adjustments at different altitudes, whereas older vehicles equipped with carburetors or automatic injection systems require such adjustments to compensate for the amount of oxygen in the air (Faiz, Weaver, and Walsh 1996).

Catalytic converters. Catalytic converters remove pollutants from the engine exhaust. Two types of catalytic converters are common in motor vehicles: those with oxidation (two-way) catalysts and others with oxidation-reduction (three-way) catalysts. Two-way catalytic converters oxidize CO and HC to CO_2 and water in the presence of platinum or a palladium catalyst. The effectiveness of the catalytic reaction depends on the exhaust gas temperature, air-fuel ratio, and types of HC present in the exhaust gas. Two-way catalytic converters are not fully efficient at temperatures below 250°C for oxidizing CO and below 250°C to 340°C for oxidizing HC. The air-fuel ratio in the engine is maintained above stoichiometric to ensure presence of oxygen in the exhaust for the

sion reductions than multiple changes of small emission reductions to achieve a long-run target. This approach allows manufacturers to best utilize their resources and maintain their competitive position in the market. Furthermore, vehicle manufacturers dislike technology-based standards, which may affect their competitive position in the market.[1] Instead vehicle manufacturers prefer to have the government set emissions standards, but to choose for themselves how to comply. Nevertheless, such standards are still promulgated. For example, a 1996 ordinance by the Municipality of the Metropolitan District of Quito bans circulation of 1997 and newer model-year vehicles not equipped with an evaporative control system, and of 1998 and newer model- year vehicles not equipped with a catalytic converter.

In developing countries the availability and practicality of a pollution control technology must be considered prior to establishing emission standards for new vehicles. Because most of the automotive industry in Latin American countries is linked to international automotive companies from industrial countries, complying

1. Technology-based standards require vehicle manufacturers to use a specified pollution control technology (such as catalytic converters).

oxidation of CO and HC. Highly reactive HC like formaldehyde and olefins are oxidized more effectively than less reactive ones, whereas short-chain paraffins like methane, ethane, and propane are difficult to oxidize. Two-way catalytic converters typically remove about 80 percent of both unburned HC and CO.

Three-way catalytic converters use a combination of platinum, palladium, and rhodium catalyst. These converters oxidize CO and HC to CO_2 and water, and reduce nitric oxide to nitrogen. Oxidation and reduction reactions are optimum at a narrow, stoichiometric range of the air-fuel ratio. In gasoline-fueled cars this range is maintained through the use of exhaust sensors (also known as oxygen sensors) that provide feedback to the electronic injection system. Three-way catalytic converters remove about 90 percent of unburned HC and CO, and about 70 percent of NO_x in the exhaust stream from the engine. Reduction of NO_2 to nitrogen is less efficient at temperatures above 400°C.

Vehicles equipped with catalytic converters must be fueled with unleaded gasoline to avoid deposition and poisoning of the catalysts by lead emissions. In addition, emissions of sulfur and phosphorous from the fuel reduce catalytic activity. Catalysts can also be damaged by excessive temperature caused by combustion of combustible materials in the engine exhaust. To prevent such damage, an electronic fuel injection system with an oxygen sensor in the exhaust (as a feedback) is used. Such a system is called a "closed-loop catalytic converter."

Catalytic converters have been used in the United States since 1975. They have also been used in Japan since the 1970s and in Europe since the 1980s. Compliance with current emission standards for light-duty gasoline-fueled vehicles in these countries requires the use of three-way catalytic converters.

On-board canisters. On-board activated carbon canisters are used to adsorb hot soak and diurnal emissions (which are HC evaporated from gasoline) at removal efficiencies greater than 90 percent. The canisters are purged with the intake air, which directs the removed HC to the engine for combustion. Use of on-board canisters has been compulsory in the United States and Japan since 1970s, and more recently in member countries of the European Union, as well as Switzerland (ECMT 1990).

On-board diagnostics. These systems identify and diagnose emission-related malfunctions in vehicles equipped with electronic engine control systems while the vehicle is actually being driven, and warn the driver with an indicator light (Faiz, Weaver, and Walsh 1996). On-board diagnostics not only alert the vehicle operator to take necessary corrective actions, but help service technicians analyze and repair malfunctions, and facilitate detection of problems during periodic inspection and maintenance (Walsh 1995). California has required on-board diagnostics for some time, and in 1990 the U.S. Clean Air Act was amended to phase in such systems for all new light-duty vehicles in the United States by 1998 (Faiz, Weaver, and Walsh 1996).

with a new standard usually requires adapting an existing control technology rather than researching a new technology. However, this effort still involves redesigning vehicles to incorporate the necessary pollution control technologies. It may also require auxiliary manufacturers to develop and supply some of the needed components. In addition, emission standards for imported vehicles must be compatible with those for domestically manufactured vehicles to avoid adverse impacts on the local manufacturing industry.

Making emission standards more stringent also may affect petroleum refiners. For example, tightening emission limits for lead and sulfur requires reformulation of fuels, which may involve refinery modifications. In such cases refiners need to be given enough lead time to make the necessary process modifications and produce higher-quality fuels.

In setting up emission standards, the ability of potential consumers or society in general (such as through tax incentives) to afford the higher costs of environmentally friendly vehicles must be considered. In addition, consumers must bear the increased maintenance cost of vehicles and the cost of additional fuel for any reduction in fuel economy associated with emissions control technology. Typical performance

Box 3.3 Pollution control technologies for diesel-fueled vehicles

Uncontrolled diesel-fueled vehicles emit the same types of pollutants as uncontrolled gasoline-fueled vehicles. But since diesel-fueled engines operate at higher air-fuel ratios than spark-ignition engines, uncontrolled diesel-fueled vehicles emit less CO and HC. However, uncontrolled diesel-fueled vehicles emit more PM and smoke, which contain unburned HC and other organics. The most commonly used pollution control technologies for diesel-fueled vehicles include:

Engine modifications. Engine modifications include:

- Optimizing combustion using high-pressure fuel injection with electronic control and an altered combustion chamber design. These techniques can reduce HC and smoke emissions.
- Turbocharging and charge cooling. Turbocharging involves compressing the intake air to the combustion chamber, allowing more fuel to be burnt and increasing the power output. Turbocharging lowers PM emissions but increases NO_x emissions. Charge cooling lowers the temperature of the hot air from the turbocharger exhaust, reducing NO_x emissions.
- Injection timing at the top or somewhat before the top of the compression stroke (also called top-dead-center) achieves optimum fuel economy. Injection timing before top-dead-center increases the maximum temperature and pressure in the cylinder and results in greater NO_x emissions and lower PM and HC emissions. Retarding fuel injection to lower peak temperatures and pressures during combustion reduces NO_x emissions but increases fuel consumption as well as smoke and HC emissions, especially under high-load conditions. High fuel injection pressures, with electronic controls, improve fuel atomization and fuel-air mixing and offset the effects of retarded injection timing by increasing the injection rate (Faiz, Weaver, and Walsh 1996).
- Using exhaust gas recirculation to replace some of the intake air, reducing the available oxygen and combustion temperature. This technique can lower NO_x emissions, but causes engine wear due to higher PM emissions.
- Minimizing the amount of lubricating oil that leaks from various sources (such as piston rings, valve guides, or the turbocharger) into the engine to reduce HC emissions (ECMT 1990).

Trap oxidizers. Trap oxidizers remove PM from diesel engine exhaust gases. They include a filtration system to collect PM from exhaust gases and an oxidation system to prevent clogging of the filter through regeneration by oxidation. Trap oxidizers can remove about 90 percent of PM from the exhaust stream of diesel engines. Trap and catalyst technologies can also be used jointly (Walsh 1995).

Catalytic converters. Two-way catalytic converters are used in diesel-fueled vehicles, mostly in cars and, more recently, in heavy-duty vehicles. Besides removing up to 80 percent of CO and volatile organic compounds, they can oxidize a large portion of HC present in the soluble organic portion of PM emissions (soluble organic compounds make up 30 to 70 percent of PM) and decrease odor in exhaust emissions by oxidizing such compounds as aldehydes. The sulfur content in diesel fuel must be low (less than 0.05 percent) to reduce formation of sulfuric acid and sulfates which contribute to PM emissions (Faiz , Weaver, and Walsh 1996).

Two-way catalytic converters are commonly used in industrial countries. Almost all light-duty diesel-fueled vehicles manufactured in Austria, France, and Germany (about 500,000 cars a year) are equipped with two-way catalytic converters. By 1997 all new light-duty diesel-fueled vehicles in Europe will come with two-way catalytic converters to meet the new European standards. In the United States diesel-fueled trucks equipped with two-way catalytic converters were marketed in 1994 to meet the 0.1 g/bhp-h PM standard. The same technology is used for diesel-fueled buses to meet the 0.07 g/bhp-h PM standard (Walsh 1995).

Table 3.2 Estimates for performance and costs of exhaust emission control technologies for light-duty gasoline-fueled vehicles

		Emission standard[a] *(grams per kilometer)*			*Change in fuel economy*	*Estimated cost per vehicle*
Control level	*Control technology*	*CO*	*HC*	NO_x	*(%)*	*($)*
Non-catalyst controls	Ignition timing, air-fuel ratio control, air injection, EGR	1.5	1.5	1.9	–5	130
Two-way catalyst	Oxidation catalyst, ignition timing, EGR	7.0	0.5	1.3	–5	380
Three-way catalyst	Three-way catalyst, closed-loop carburetor	2.1	0.25	0.63	–5[b]	630
Lean-burn engine	Oxidation catalyst, EFI, fast-burn combustion chamber	1.0	0.25	0.63	15	630
U.S. Tier 1	Three-way catalyst, EFI, EGR	1.3	0.16	0.25	5	800

Note: EGR is exhaust gas recirculation; EFI is electronic fuel injection; U.S. Tier 1 is discussed in Annex A to this chapter.

a. At 80,000 kilometers.

b. Change in fuel economy is +5 percent (instead of –5 percent) if EFI is used instead of a carburetor.

Source: Faiz, Weaver, and Walsh 1996 (based on USEPA 1990).

and costs of pollution control technologies are shown in Table 3.2 for light-duty gasoline-fueled vehicles and in Table 3.3 for heavy-duty diesel-fueled vehicles.

Certification, assembly line testing, recall, and warranty. Emission standards for new vehicles are ineffective without a comprehensive program that ensures compliance. For this reason, new vehicle emission standards are generally accompanied by requirements for certification, assembly line testing, recall, and warranty. Manufacturers should be required to:

- Certify that each of their new vehicles complies with emission standards during a specified amount of use or time. For example, in Argentina and Brazil manufacturers of light-duty vehicles are required to certify in writing that their product will comply with emission standards for five years or 80,000 kilometers (whichever comes first). The requirement for heavy-duty vehicles is for five years or 160,000 kilometers. An alternative requirement is that the vehicle's emissions are 10 percent below the levels specified in vehicle emission standards.

  Certification, which involves emission testing of prototype vehicles prior to production, allows manufacturers to identify and correct problems prior to initiation of mass production of vehicles. Testing is usually done by manufacturers and also by government authorities through spot checks. Test conditions should reflect as closely as possible actual fuel types and vehicle operating conditions. Consideration should be given to matching the test fuels with the actual fuels used by vehicles and to measuring CO and HC emissions at colder temperatures and higher altitudes, evaporative emissions at higher temperatures, and cold start and high load operations (Walsh 1995). Among Latin American and Caribbean countries, Brazil conducts certification testing by regulatory authorities. New vehicle models manufactured in Argentina are taken to Brazil for certification.
- Perform assembly line testing during production to ensure compliance with applicable emission standards. Assembly line testing allows government authorities to identify noncompliant vehicles and take necessary measures (such as revoking of certification).
- Recall vehicles in case of noncompliance with emission standards. Recall programs allow manufacturers to design and produce vehicles with a margin of safety to avoid the costs and negative publicity associated with recalls.
- Provide a warranty to consumers for defective design or workmanship of vehicles' emissions control equipment. Warranty programs allow manufacturers to design and produce vehicles with controlled quality, and consumers to have a recourse for noncompliant vehicles resulting from

Table 3.3 Estimates for performance and costs of exhaust emission control technologies for heavy-duty diesel-fueled vehicles

Control level	*Controls required*	*Emission standard*[a] *(g/bhp-h)*		*Fuel economy*[b] *(%)*	*Estimated cost per engine ($)*
		NO_x	*PM*		
Uncontrolled	None (PM level depends on smoke controls and maintenance level)	9.0–16.0	0.75–3.70	0	0
Minimal control	Injection timing, smoke limiter	8.0	0.5–0.75	−3 to 0	0–200
Moderate control	Injection timing, combustion optimization	6.0	0.5	−5 to 0	0–1,500
1991 U.S. standard	Variable injection timing, high pressure fuel injection, combustion optimization, charge-air cooling	5.0	0.25	−5 to 5	1,000–3,000
Lowest diesel standards under consideration	Electronic fuel injection, charge-air cooling, combustion optimization, exhaust gas recirculation, catalytic converter or PM trap	2.0–4.0[c]	0.05–0.10	−10 to 0	2,000–6,000
Alternative-fuel forcing	Gasoline/three-way catalyst, natural gas/lean-burn, natural gas/three-way catalyst, methanol-diesel	2.0	0.04	−30 to 0	0–5,000

a. At full useful life.
b. Potential fuel economy improvements result from addition of turbocharging and intercooling to naturally aspirated engines.
c. Not yet demonstrated in production vehicles.
Source: Adapted from Faiz, Weaver, and Walsh 1996.

manufacturers' fault. Harmonization of test procedures among the trading Latin American countries is important. The implementation of international trade agreements would contribute to the regional harmonization of emission standards and certification programs, avoiding unnecessary investment in time and money for product development and emission testing. Such agreements have already affected the automotive manufacturing industry in Latin America.[2]

Exhaust emission test procedures for light-duty vehicles include the United States test procedure (FTP-75), the European test procedure, and the Japanese test procedure. All three procedures measure exhaust emissions while the vehicle is driven through a specified driving cycle on a chassis dynamometer. Each procedure is based on a different driving cycle. In Latin American countries FTP-75 is the most commonly used procedure. This procedure simulates different urban driving conditions up to a speed of 91 kilometers an hour with an average speed of 31.4 kilometers an hour. However, it fails to cover all speeds and acceleration conditions, or air conditioner operation. These factors may cause substantially higher emissions (Faiz, Weaver, and Walsh 1996).

Test procedures for exhaust emissions from heavy-duty vehicles have been established in the United States, Europe, and Japan. All three procedures measure exhaust emissions of the engine removed from the vehicle using a chassis dynamometer. Latin American countries use ei-

2. For example, Brazil's exports are mainly targeted to other Mercosur countries (Argentina, Paraguay, and Uruguay). In 1993 Brazil exported 331,522 vehicles, of which 75 percent went to the other Mercosur countries and only 13 percent went to other countries in the region. Similarly, because of the North American Free Trade Agreement (NAFTA), in 1993, 91 percent of Mexico's vehicle exports (471,483) went to the United States and Canada. Only 9 percent went to countries in Latin America and the Caribbean (AAMA 1995).

ther the U.S. or European procedure. The U.S. procedure, which replaced an earlier 13-mode steady-state test, uses changes in transient speed and load conditions to simulate in-city driving, whereas the European procedure uses steady-state conditions aggregated according to a weighting scheme. To standardize emissions from heavy-duty vehicles, which have a wide range in sizes and applications, the test results are reported in mass of pollutant emissions per unit of work output (grams per kilowatt-hour or grams per break horsepower-hour) rather than mass of pollutant emissions per distance traveled (grams/kilometer). The USEPA uses a conversion factor of about 0.54 grams per break horsepower-hour to each gram per kilometer (Faiz, Weaver, and Walsh 1996).

Evaporative emissions from gasoline-fueled vehicles are measured either by collection in activated carbon traps or by putting the vehicle in an airtight housing (SHED) and measuring the HC concentration. The SHED method is favored in the United States, Europe, and Latin America (CONCAWE 1994).

Emission Standards and Inspection Programs for In-Use Vehicles

Emission standards are established to control discharge of air pollutants from in-use vehicles through proper vehicle maintenance. Compliance with these standards are verified through inspection and maintenance programs and roadside inspections.

Emission standards. Emission standards for in-use vehicles are generally set based on the vehicle model-year for selected vehicle classes and engine types. Older model-years are usually allowed more lenient emission limits. CO and HC are usually the pollutants limited for in-use vehicles with spark-ignition engines. New emission standards for in-use vehicles in polluted areas of the United States also limit NO_x emissions. Emission standards for in-use diesel-fueled vehicles usually focus on smoke emissions.

In general, industrial countries have established emission standards for in-use motor vehicles. The U.S. federal and the Arizona and Florida state emission standards are presented in Annex A to this chapter. Some Latin American and Caribbean countries have also established such standards. Chapter 4 presents in-use vehicle emission standards in Argentina, Brazil, Chile, Colombia, and Mexico. In addition, the environmental standards promulgated in Bolivia in 1995 limit HC and CO emissions from motor vehicles with spark-ignition engines and smoke emissions from gasoline- and diesel-fueled motor vehicles. These standards are set by vehicle class and model-year. In Costa Rica CO and HC emissions are limited from in-use gasoline-fueled vehicles and smoke emissions are limited from in-use diesel-fueled vehicles. In Venezuela the current regulations restrict only smoke emissions from diesel-fueled vehicles. Nicaragua is preparing in-use vehicle emission standards.

Regulations that include emission standards for in-use vehicles also specify procedures for compliance testing. The most common inspection test involves measuring CO and HC emissions when the vehicle is idling. In the United States and some European countries (for example, Finland, Germany, Sweden) this test has been supplemented with a second measurement when the engine is running at 2,500 rpm with no load. This test, although appropriate for older model vehicles equipped with mechanical carburetors or fuel injection systems, does not give satisfactory results for vehicles using electronic air-fuel ratio control systems because it passes many vehicles that would otherwise fail a comprehensive test. To reduce false failures, some inspection and maintenance programs using the idle/2,500 rpm test procedure require preconditioning of the vehicle at 2,500 rpm with no load before the idle test. This preconditioning helps ensure that the control system is in normal closed-loop operation and the catalytic converter is adequately warmed. Tests conducted in Finland have shown that 95 percent of the vehicles equipped with catalytic converters reach stabilized readings in three minutes. In Austria preconditioning of the vehicle prior to emission testing is mandatory. Because of the problems with the idle/2,500 rpm testing procedure, other tests have been developed (such as ASM5015, ASM2525, ASM2, IM240). IM240, the most advanced of these tests, was recently introduced in the United States. The IM240 test measures pollutants in vehicle exhaust over a four-minute period based on the U.S. federal certification test procedures and is conducted by operating the vehicle in a transient cycle simulating actual stop-and-go driving conditions. This new test is claimed to be about three times more accurate in identifying noncompliant vehicles than the idle/

2,500 rpm test. The main drawback of this procedure is its high capital cost requirement. According to the USEPA, the test equipment costs $150,000 for the IM240 test and $5,000 to $12,000 for the idle/2,500 rpm test. In addition, use of the test equipment is more complex for the IM240 test than for the idle/2,500 rpm test (Faiz, Weaver, and Walsh 1996).

A successful measurement of diesel smoke requires that measurements be taken when engines are under high-load conditions because the low smoke levels emitted under idle or light-load conditions do not easily allow distinction of clean vehicles from smoky vehicles. These standards generally require measurements be made following the Bosch or Hartridge methods, or using an opacimeter. The Bosch method measures soot and other dark materials in the smoke by passing a sample volume of smoke through filter paper and determining the level of darkness on the paper using a photoelectric device. However, this method responds poorly to smoke that is not black. A Hartridge meter draws a continuous sample of the vehicle exhaust emissions into a chamber and measures the attenuation of a beam of light shining through the chamber. A Hartridge meter requires frequent cleaning from exposure to heavy oil smoke. An opacimeter measures the attenuation of a beam of light shining through the smoke plume. This method is more accurate than the Bosch method because it measures both the effects of light absorption (by soot) and light scattering (by oil or fuel droplets) of the entire exhaust emissions.

Emission standards for in-use vehicles should be based on the potential emission reductions that can be achieved through proper maintenance of these vehicles (given the age distribution of the fleet and extent of use of pollution control technologies). Many of the vehicle fleets in Latin America and the Caribbean are old and poorly maintained. For example, the average age of cars is 13 years in Costa Rica (1993), 23 years in Paraguay (1994), and 12 years in Venezuela (Alconsult International Ltd. 1996). Vehicles older than 10 years constitute 50 percent of the motor vehicle fleet in Argentina, 60 percent in Ecuador, and 64 percent in El Salvador (both in 1996). In Lima about 75 percent of vehicles are more than 10 years old, and in Santafé de Bogotá about half of the public transport fleet is more than 20 years old (both in 1996).

The extent of pollution control technology use is also an important consideration in establishing in-use vehicle emission standards. For example, in Costa Rica all new light-duty vehicles entering circulation must be equipped with catalytic converters, but only 8 percent of in-use light-duty vehicles have them. In Colombia, catalytic converter-equipped light-duty vehicles make up less than 5 percent of the fleet and less than 10 percent of new vehicles entering circulation. In Brazil 46 percent of light-duty vehicles are equipped with catalytic converters, and all new vehicles must be equipped with this technology. In Uruguay 43 percent of new vehicles are equipped with catalytic converters (Alconsult International Ltd. 1996).

Technology-based requirements can also be established for in-use vehicles. For example, vertical exhausts installed on in-use diesel-fueled buses can reduce the concentration of exhaust pollutants at breathing level by 65 to 87 percent through dispersion (Faiz, Weaver, and Walsh 1996). This measure has been required in the urban areas of many countries to lessen exposure from diesel bus emissions. For example, vertical exhausts have been required for buses in Santiago since 1987. A similar requirement is being considered for buses in Santafé de Bogotá.

Inspection and maintenance programs. Inspection and maintenance programs involve periodic measurement of emissions from in-use vehicles by regulatory authorities (or their designates) against established emission standards. Such programs:

- Provide regulatory authorities with an effective tool for enforcing established standards for in-use vehicles.
- Put pressure on vehicle owners to bring their vehicles into compliance (through maintenance) prior to inspection.
- Force gross polluters—vehicles unable to meet the standards through maintenance or repair—out of circulation. For example, an exhaust test of 60,000 vehicles in the United Kingdom found that 12 percent of cars were responsible for 55 percent of pollutant emissions (Reynier 1995). A recent survey of five European cities found that about 10 percent of the vehicle fleet is responsible for about 60 percent of CO and 45 percent of HC emissions, and that about 90 percent of HC and NO_x emissions originate from vehicles that are not equipped with catalytic converters (van der Straaten

1995). The situation is similar for urban centers in Latin America and the Caribbean. For example, in 1991 in Mexico City the most polluting 25 percent of the fleet accounted for 47 percent of CO and 62 percent of HC emissions from mobile sources (Beaton, Bishop, and Stedman 1992).

- Identify in-use vehicles that require recalls by vehicle manufacturers.
- Identify in-use vehicle component defects and failures covered by vehicle manufacturers' warranty programs.
- Provide feedback to regulatory authorities on the need for investigations and further tests by vehicle manufacturers on vehicles with consistently high emissions.
- Discourage vehicle owners from tampering with emission control systems or misfueling their vehicles because failing an inspection acts as a strong deterrent. Experience in the United States has shown that faulty or tampered vehicles can emit up to twenty times more pollutants than properly maintained vehicles.

Inspection and maintenance programs are usually of two types: centralized programs, which require all inspections be done in stations specialized in emissions testing and with no vehicle repair capability, and decentralized programs, which require both emissions testing and vehicle repairs be done in private garages. In centralized programs vehicles must be inspected at one of a small number of high-volume inspection stations. If a vehicle fails an inspection at a centralized station, then the driver has to take it elsewhere to be repaired and return it to the station to have it reinspected. The centralized inspection stations are government-controlled and run by either government employees or independent contractors. Governments typically franchise a single contractor to build and operate the inspection station in a given area and allow the contractor to charge a set fee that allows for profit and recovery of operating costs and capital during the franchise period. Governments also may issue multiple franchises in an area to reduce its dependence on any one contractor (for example, in Mexico City franchises were awarded to five contractors). Franchises are usually awarded using a competitive bidding process.

The large number of private garages in decentralized inspection and maintenance programs allows vehicle owners to drive shorter distances for inspection. However, inspection results may lack the accuracy of automated centralized stations. In addition, inspections usually are not performed very promptly because the main function of these garages is to repair vehicles. Furthermore, the regulatory authority must employ a larger surveillance team in order to control the quality of service provided by the large number of private garages.

The design of the inspection and maintenance program affects the share of the in-use vehicle fleet inspected at centralized stations relative to private garages. For example, in New Jersey, where vehicle owners have a choice between free centralized inspections and paid inspections in private garages, 80 percent of drivers have chosen centralized inspection. But in Mexico City, just 20 percent of the vehicle fleet was inspected at centralized public stations in the early 1990s because of the associated inconvenience: the vehicle owners had to first go to an agency of the Treasury to pay for the inspection and then take the receipt to a centralized inspection station. In addition, there were often lines at the centralized stations. People who used the centralized stations perceived this service to be more honest because of the potential for fraud by private garages. Integrating fee payment and inspection at the same facility would reduce any inconvenience associated with central inspection centers (McGregor and Weaver 1994).

Centralized inspections are much cheaper for vehicle owners because of their favorable economy of scale. The nine centralized, contractor-run programs in the United States cost, on average, less than $8 an inspection. The centralized programs in Arizona, Connecticut, and Wisconsin use dynamometers and loaded test procedures and charge fees ranging from $7.50–10. In California's decentralized idle/2,500 rpm program inspection fees average about $40. In most cases IM240 testing in centralized facilities costs less than $20 a vehicle in the United States (McGregor and Weaver 1994). For comparative purposes Table 3.4 presents some cost estimates for centralized and decentralized programs in the state of Arizona. Based on these estimates, as well as on its greater effectiveness, Arizona decided to retain a centralized system.

A centralized program is likely to have higher start-up costs than a decentralized program because of the costs associated with constructing centralized inspection stations. In Maryland, for

Table 3.4 Estimated costs of centralized and decentralized inspection and maintenance programs in Arizona

Variable	*Centralized manual lane*	*Centralized automated lane*	*Decentralized automated inspection station*
Tests per hour	6–12	20–30	2–5
Tests per man-hour	1.5–4.0	6–15	1–3
Labor cost per test	\$2.00–\$5.33[a]	\$0.53–\$1.33[a]	\$4.00–\$12.00[b]
Equipment cost per test	\$0.50–\$1.00	\$0.50–\$1.00	\$3.00–\$5.00
Facilities cost per test	\$2.00–\$3.00	\$1.50–\$2.00	\$5.00–\$10.00
Data collection cost per test	\$0.50–\$1.00	\$0.10–\$0.25	\$0.50–\$1.00
Administration cost per test	\$0.35–\$0.50	\$0.20–\$0.30	\$1.00–\$2.00
Total cost[c]	\$6.00–\$10.18	\$3.08–\$4.63	\$15.00–\$28.50

a. At \$8.00 an hour.
b. At \$12.00 an hour.
c. Does not include overhead or profit.
Source: Rothe 1990.

example, a private contractor was selected through competitive bidding to construct ten new inspection stations, with an average of five lanes each. These stations are expected to inspect 1.6 million vehicles a year. A large portion of the fee charged by each station is retained to recover its investment and operating costs; the rest is returned to the state to cover the administrative costs of the program (Faiz, Weaver, and Walsh 1996).

A centralized program does not always have high investment costs. In New Jersey, for example, the state incorporated its emissions testing program into an existing centralized safety inspection program, thus avoiding the cost of new construction (Faiz, Weaver, and Walsh 1996). Decentralized programs are less expensive to set up than centralized programs but are more expensive to operate. Operating costs include licensing for numerous stations, certification of repair facilities, and supervision of stations.

The frequency of vehicle emissions testing varies by location. In the United States vehicles are inspected annually in forty-five of the fifty states. In Japan new vehicles require inspection after the first three years and every two years thereafter. In the European Union the inspection schedule depends on the vehicle type: for heavy-duty diesel vehicles an annual inspection is required regardless of the vehicle's age; for spark-ignition vehicles an annual inspection is required for vehicles older than three years; and for light-duty diesel vehicles an annual inspection is performed after the vehicle is four years old and every two years thereafter. In Singapore a different inspection schedule is used for different type of vehicles (Table 3.5).

Table 3.5 Motor vehicle inspection schedule in Singapore, by vehicle age

Type of vehicle	*Less than three years*	*Three to ten years*	*More than ten years*
Motorcycles and scooters	Exempt	Annually	Annually
Cars and station wagons	Exempt	Every two years	Annually
Private hire cars	Annually	Annually	Not required
Public service vehicles			
Taxis	Every six months	Every six months	Not required
Public transport buses	Every six months	Every six months	Every six months
Trucks and goods vehicles	Annually	Annually	Annually
All other heavy vehicles	Annually	Annually	Annually

Source: Faiz, Weaver, and Walsh 1996.

In the Mexico City Metropolitan Area (MCMA) a voluntary inspection and maintenance program was introduced in 1988. In 1989 inspection of in-use vehicles was made compulsory with one test per year; in 1990 the number of inspections was increased to two per year. This program encompassed all gasoline-fueled and diesel-fueled vehicles. Inspections were carried out at about 1,650 authorized private and 26 high-volume government-operated centralized inspection stations. However, it became increasingly clear that the private garages were not performing inspections properly, and since January 1996 all inspections in the MCMA have taken place at one of the centralized facilities. Although this change has caused serious congestion problems at the stations, those problems are expected to be overcome through an expanded system that will be put in place in 1997.

In the Buenos Aires Metropolitan Area three different jurisdictions are involved in vehicle inspections. Periodic inspections of exhaust emissions from commercial vehicles operating within the Federal Capital are conducted by a private firm under a ten-year concession agreement with the Municipality of Buenos Aires. Periodic inspections of private cars registered in the Federal Capital have not started yet. However, the Municipality of Buenos Aires has begun the bidding process for concessioning of periodic inspection services to private firms. The Province of Buenos Aires recently started periodic inspections of private and commercial vehicles under concession agreements between provincial authorities and private firms. The inspection schedule is set at once a year for private cars and trucks, and twice a year for taxis, private chauffeured cars, and buses. Commercial vehicles operating between the Federal Capital and a province or between two provinces are inspected at private stations certified by national authorities. Inspection frequency is set at six months for buses and twelve months for trucks. Inspections include safety and mechanical checks as well as measurement of smoke emissions for diesel-fueled vehicles and CO and HC emissions for spark-ignition vehicles.

Several years ago periodic inspection and maintenance was made mandatory for all vehicles in Santiago. There are two inspection stations for buses, three for taxis and trucks, and twenty for private cars. All inspection stations are owned and operated by private concessionaires. The inspection schedule is once a year for private cars and trucks, and twice a year for taxis and buses.

In São Paulo the Program to Control Air Pollution from Motor Vehicles (PROCONVE) authorizes state and local governments to inspect in-use vehicles for pollutant emissions. The São Paulo inspection and maintenance program is expected to start in 1997 (see Chapter 4).

In Costa Rica the Transportation Law specifies the inspection schedule of motor vehicles. The schedule is annual for all light-duty vehicles except cars less than five years old, every two years for cars less than five years old, and every six months for public transport vehicles (taxis, buses, and microbuses) and heavy-duty trucks. Inspections are conducted at government-approved private garages (Weaver 1996).

The on-board emission diagnostics installed in newer model vehicles in the United States are expected to become common in other countries as well, including those in Latin America and the Caribbean. These systems will likely simplify periodic inspection tests, perhaps requiring no more than a check of the system's indicator light, and will help service technicians to identify and repair malfunctions (Faiz, Weaver, Walsh 1996).

Roadside inspection programs. In urban centers where periodic inspection and maintenance programs are not implemented (such as Belo Horizonte, Rio de Janeiro, Santafé de Bogotá, and São Paulo) roadside inspections help identify grossly polluting vehicles. These inspections—performed on the roadside and weight stations or safety inspection stations—have focused mostly on visible smoke emissions from diesel-fueled vehicles, especially buses and trucks. Roadside inspections involve stopping vehicles that appear to emit excessive amounts of smoke and testing the exhaust emissions using a smoke opacimeter. Vehicles found to be in violation of smoke emission standards are fined or prohibited from circulation until the problem is resolved.

Roadside inspections have also been used to supplement inspection and maintenance programs in Latin American urban centers such as Mexico City and Santiago. Because the time and place of these inspections cannot be predicted they are difficult to defeat through tampering of vehicle components that affect exhaust emissions.

Roadside inspections for invisible CO and HC emissions involve stopping vehicles at random, which inconveniences drivers of vehicles that are

in compliance with the standards. However, a new technology that measures concentrations of CO and HC by infrared remote sensing coupled with a video camera shows promise in identifying gross polluters without stopping vehicles. This technology, however, is limited to measuring only instantaneous emissions (which may not be representative of the vehicle's overall emissions) in one lane of a road. The potential application of remote sensing for emissions compliance appears to be bringing gross polluters to inspection stations.

Emission Restrictions on Imported Vehicles

Many countries impose restrictions on imported vehicles as a measure to limit emissions of air pollutants. In general, these restrictions are associated with the model-year or age of the vehicle, use of a certain emission control technology, or compliance with in-country new vehicle emission standards. For example, in Costa Rica all motor vehicles imported to the country after January 1995 must be equipped with emissions control devices and meet the emission standards for new vehicles. In Bolivia all motor vehicles that enter into circulation should meet the emission standards established in 1995. In Ecuador, although no emission standards have been set for new vehicles, import of used vehicles is prohibited effective August 1996. In El Salvador all vehicles imported after January 1998 must be equipped with an emission control system. In Nicaragua emission standards are being prepared for imported vehicles according to the legal framework established in 1996.

Imported vehicles should be checked to ensure compliance with local requirements. Some countries in Latin America and the Caribbean (such as Argentina) require certification testing of vehicles in their country of origin. A visual inspection of the emission control label (located under the hood in U.S.-manufactured vehicles) confirms that the vehicle complies with emission standards in the country of origin (McGregor and Weaver 1994). This information and a visual check of all emission control equipment listed in the label would be sufficient for inspecting a new vehicle at the point of entry to the importing country. Although review of the emission label is useful, it may not provide accurate information about the actual performance of in-use vehicles, especially those which are excessively worn, poorly maintained, or used with tampered emission control equipment. To ensure that the imported in-use vehicle is in acceptable condition, a recent certification of emission testing in the country of origin may be required. As a supplement or alternative to this requirement, all imported in-use vehicles may be subject to emission testing in the importing country

Vehicle Emission Fees

A vehicle emission fee is a charge levied by the government on the amount of pollutants emitted by the vehicle. A uniform fee can be set by vehicle type (such as heavy-duty vehicles) based on average emissions determined from driving cycle emission tests. Another option may be to set a fee for each vehicle based on its emission factors and the distance traveled since the last inspection. This scheme encourages vehicle owners to adjust the engine before inspection to reduce emissions, but also creates an incentive to cheat by tampering with the odometer. A variation of this scheme, which involves levying fees on new vehicle models based on their expected lifetime emissions, may induce demand for cleaner vehicles, but does not provide any incentive for vehicle owners to properly maintain their vehicles or drive less. Emission fees are not currently imposed on vehicles anywhere in the world, although the European Union is considering the introduction of emission fees for heavy-duty trucks (Carbajo 1994).

Differential Vehicle Registration Fees and Taxes

The vehicle registration fee or taxing scheme can be designed so that it influences consumers to buy fuel-efficient and low-polluting vehicles (such as vehicles equipped with catalytic converters) rather than energy-inefficient and highly polluting vehicles. This goal can be achieved by using differential vehicle registration or taxation (Carbajo 1994).

The vehicle registration fee scheme can be part of a vehicle replacement program aimed at taking old polluting vehicles out of circulation. For example, in Singapore car owners who re-

place their cars within ten years with new cars are entitled to exemption from registration fees. This is a significant benefit because car registration fees are very high in Singapore. They include a 45 percent import duty on the open market value of the car, a registration fee of $640, and an additional registration fee of 150 percent on the open market value of the car. In addition, during its use each car owner has to pay an annual road tax based on the vehicles' engine capacity (Carbajo 1994).

Annual vehicle taxes can favor less-polluting vehicles through differential taxation based on the use of pollution control technologies or vehicle age. For example, in Germany vehicles that are not equipped with emission control technologies to comply with European Union regulations are subject to a higher tax (based on 100 cubic centimeters of engine displacement) than vehicles that comply. Similarly, vehicles equipped with catalytic converters are given a tax credit that is positively correlated with engine displacement volume.

The design of the vehicle taxing scheme can also incorporate the vehicle age to favor less-polluting and newer vehicles. But higher taxes for older vehicles would likely be regressive and politically difficult to implement. In some countries, however, the vehicle tax declines with the age of the vehicle. This is the case for Mexico, where vehicles ten years or older are exempt from the annual vehicle tax. This scheme has adverse environmental consequences because it encourages the presence of old, highly polluting cars in the fleet.

Vehicle Retrofit Programs

Retrofit programs are implemented to bring in-use vehicles manufactured without emission controls in compliance with emission standards. Retrofitting may take different forms including engine work, installing pollution control components, or changing fuel systems to burn cleaner fuels. These programs, which are generally associated with incentives, target grossly polluting high-use vehicles, especially diesel-fueled urban buses.

Between 1991 and 1995 about 4,100 urban buses in Mexico City were retrofitted with new engines to reduce pollutant emissions. With establishment of the Permanent Program for Correcting Excessive Black Smoke in early 1992, buses exceeding the 40-Hartridge-unit standard were taken from service for revision. Fuel injection pumps were also recalibrated and injectors were replaced to reduce other air emissions from these buses. In 1996 about 1,000 heavy-duty diesel-fueled vehicles installed catalytic converters to be exempt from the two-day driving ban in Mexico City. In addition, under a government-sponsored program about 27,000 buses and trucks and 1,300 commercial microbuses have their fuel systems converted to LPG.

The urban bus retrofit program in Romania involves installing a deep-bed particle filter in the exhaust system of diesel-fueled buses. This technology requires the addition of an iron-based catalyst to the fuel to lower the combustion temperature of soot. Deep-bed filtration can reduce black smoke emissions from heavy-duty diesel-fueled vehicles by about 85 percent, but with a fuel penalty of 2 to 6 percent. The installed system costs about $1,500 in Romania (Bloom 1997).

Another technology, which has been tested in England, shows some promise for retrofitting diesel-fueled urban buses. A secondary filter, which supplements the conventional cartridge-filter, can capture the light fraction of lubricating oil. The captured oil is vaporized by a heating element and recycled to the fuel inlet. This technology is claimed to reduce the PM emissions by about 50 percent and cost about $500 (*The Economist*, 23 November 1996).

A ceramic coating technology has been applied to in-use diesel-fueled buses in the United States and is being tested on diesel engines in Mexico City. When ceramic coating is applied to combustion area components of a diesel engine, the coated engine emits 50 to 90 percent less black smoke and generates a fuel savings of up to 9 percent. When combined with engine retarding, this technology can remove up to 40 percent of NO_x. Use of this technology with an oxidation catalyst can remove up to 70 percent PM, up to 50 percent of CO, and up to 40 percent NO_x (Viola 1996).

In Argentina about 400,000 vehicles have their fuel systems converted to CNG, about 270,000 of which circulate in Buenos Aires. CNG-fueled vehicles in Buenos Aires include a large percentage of taxis and light-duty trucks, and some private cars. The Argentine government's differential taxation policy for these fuels was the incentive for these conversions.

Vehicle Replacement or Scrappage Incentives

Vehicle replacement or scrappage programs are designed to eliminate the most polluting vehicles (gross polluters) that are responsible for a disproportionate share of vehicular air pollutant emissions in a given area. These programs provide financial incentives to scrap or replace such vehicles. A classic example of such a program is from Hungary, where the City of Budapest initiated the "green-two-stroke" program, which provided public transport passes to car owners in exchange for voluntary elimination of high-polluting cars. This program also allowed car owners to sell their Trabants and Wartburgs (former East German two-stroke engine models) to the city for a higher price than the prevailing market rate and to use the money as part of the downpayment on new cars equipped with emission controls. In February 1994 more than 14,000 car owners applied to exchange their cars for public transport passes at the rate of a four-year pass for each Trabant and a six-year pass for each Wartburg.

In 1990, as part of the South Coast Recycled Auto Project (SCRAP), the Union Oil Company of California (UNOCAL) initiated a program to scrap 7,000 pre-1971 cars for $700 each (U.S. Congress/OTA 1992). Between 1990 and 1995, 9,200 heavily polluting vehicles were removed from circulation in southern California. The fourth phase of this program (SCRAP IV) is under way. This phase targets pre-1975 vehicles, which can emit 50 to 100 times more pollutants per kilometer traveled than new vehicles and which account for disproportionately high amounts of pollutant emissions among mobile sources in the Los Angeles Basin. According to the estimates made by UNOCAL, taking these old cars out of circulation will eliminate 45,000 kilograms of HC, 14,000 kilograms of NO_x, and 273,000 kilograms of CO emissions each year over the next three years (*Oil and Gas Journal,* 1995).

In February 1994 a car replacement program was introduced in France. This program entitled owners of cars older than ten years to replace them with a new car for $936. Within a year 450,000 old cars had been replaced by new cars that complied with the latest emission standards. This program generated a noticeable reduction in motor vehicle pollutant emissions—within a year CO emissions had fallen by 6 percent (Reynier 1995). In 1996 the Municipality of Quito (Ecuador) eliminated about 1,000 diesel-fueled buses older than twenty years from circulation for about $2,560 per bus.

Fuel-Targeted Measures

Fuel standards to control air pollutant emissions from vehicles typically target lead, volatility, and benzene and other aromatic hydrocarbons in gasoline and sulfur, cetane number, aromatic hydrocarbons, and density in diesel fuel. Production and use of reformulated and oxygenated gasoline also have been required in some countries. In addition, alternative fuels have been used in place of conventional fuels (gasoline and diesel fuel) in some countries as an urban air pollution control measure or as part of a national energy policy. The most common alternative fuels include compressed natural gas (CNG), liquefied petroleum gas (LPG), methanol, ethanol, and mixtures of gasoline and ethanol (gasohol).

Gasoline Standards

Standards for gasoline have been set in many industrial and some developing countries to reduce or eliminate the adverse health and environmental effects associated with its handling and use. These standards affect fuel refiners and distributors, vehicle manufacturers, and consumers. The most common gasoline standards affecting motor vehicle emissions include parameters for lead, volatility, benzene, and other aromatic hydrocarbons. In addition, standards are established for reformulated and oxygenated gasoline.

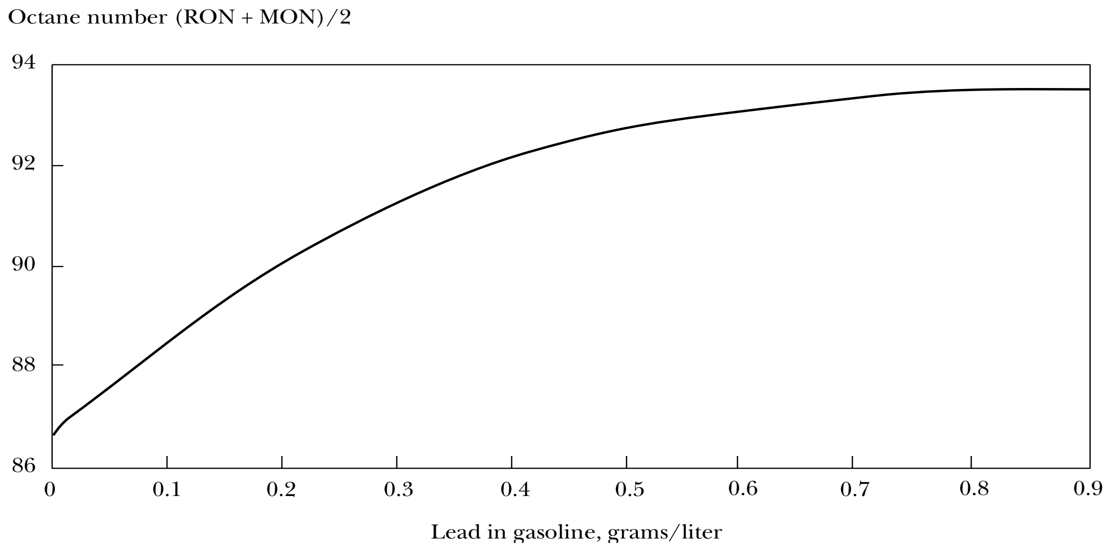
Lead. Poorly timed combustion of the gasoline-air mixture causes a knocking effect in spark-ignition vehicles. This effect, which lowers an engine's efficiency and useful life, is reduced by using a gasoline with a high octane number.[3] One way to increase the octane number is to add lead compounds—such as tetra-ethyl lead (TEL) or tetra-metyl lead (TML)—to gasoline. The octane improvement of gasoline decreases with each increment of lead added, however (Figure 3.1). With the exception of two small plants in Russia and in Germany, Octel Ltd. is the only company in the world that produces gasoline lead additives (Thomas 1995a).

Besides boosting octane, TEL lubricates the exhaust valve seats of vehicles. This lubrication prevents wear (called "valve seat recession") under severe driving conditions (prolonged high speed, towing, and hilly terrain) of older model vehicles manufactured with soft valve seats. This concern was the reason lead was not completely eliminated from gasoline in the United States (where the limit for lead was 0.0267 g/liter for several years) and Europe (where the limit for lead is 0.15 g/liter).

Lead antiknock compounds in gasoline, the main source of ambient lead concentrations in most urban environments, have adverse health impacts (see Chapter 2). Reducing or phasing out lead in gasoline is the most effective way to lower ambient lead concentrations. Lead in gasoline was first restricted in 1967 in some urban centers (Moscow, Leningrad, Kiev, Baku,

3. The octane number ranges between 0 for n-heptane and 100 for iso-octane. The higher a gasoline's octane is, the better is its antiknock performace. Gasolines have two octane ratings: research octane number (RON), which measures antiknock performance at low engine speeds; and motor octane number (MON), which measures antiknock performance at high engine speeds. For any gasoline, RON is higher than MON, usually by 8 to 12 numbers (World Bank 1996a).

Figure 3.1 Relationship between lead addition and octane number



Note: RON is the research octane number and MON is the motor octane number.
Source: Thomas 1995a.

Odessa) and tourist areas of the Soviet Union, although it continued to be used freely in other parts of the country (Thomas 1995a). Lead reduction programs were initiated in Japan and the United States in the 1970s as a result of a better understanding of the risk of lead exposure and the introduction of catalytic conversion technology for motor vehicles.[4] In 1975 Japan completely eliminated lead from regular grade gasoline, although premium grade leaded gasoline continued to be sold until 1987 (Thomas 1995b).

The lead elimination program proceeded somewhat slower in the United States. The first action was taken with the 1970 Clean Air Act, which established ambient air quality standards for lead. This act was followed by a 1973 mandate that ensured a sufficient supply of unleaded gasoline for 1975 model-year catalytic converter-equipped cars. Accordingly, effective July 1, 1974, gasoline stations selling more than 757,000 liters (200,000 gallons) of gasoline a year were required to also sell unleaded gasoline (OECD/IEA 1993). To meet the demand for unleaded gasoline, U.S. refiners invested in refinery modifications to make up the deficit in octane number previously provided by lead additives. Production of leaded gasoline in the United States decreased steadily in favor of unleaded gasoline. For example, in 1981 gasoline deliveries between the two grades were equally split, but in 1992, 98 percent of deliveries were unleaded gasoline. In 1988 the lead content of gasoline was limited to 0.0267 g/liter (0.1 g/gallon). Leaded gasoline was banned effective December 31, 1995.

One of the concerns about selling leaded and unleaded gasoline at the same time is misfueling, which is the handling or use of leaded gasoline as unleaded gasoline. Because of price differentials between the two types of gasoline, some consumers in the United States have attempted to remove catalytic converters and fuel tank inlet restrictors to misfuel their cars. In addition, the USEPA has identified several major cases where leaded gasoline was deliberately sold as unleaded (Hillson 1995). The USEPA used several measures to curtail misfueling: manufacturers of unleaded gasoline-fueled cars were instructed to install inlet restrictors on fuel tanks and put labels on cars; gasoline retailers were instructed to use smaller nozzles at unleaded pumps and were prohibited from fueling unleaded-fueled cars with leaded gasoline (with fines imposed if they were caught doing so); and

4. Leaded gasoline cannot be used in vehicles equipped with catalytic converters.

enforcement authorities (such as the USEPA and state officials) conducted misfueling inspections of gasoline retailers and contamination inspections of distributors, terminals, and wholesale purchasers.[5]

In Europe a 1978 European Union (EU) directive (78/611/EEC) limited the lead content of leaded gasoline to between 0.15 g/liter and 0.40 g/liter. In 1983 Germany became the first country in Europe to produce and distribute unleaded gasoline and to manufacture cars equipped with three-way catalytic converters. The sale of regular leaded gasoline was banned in Germany but premium leaded gasoline continued to be marketed, though at a higher price than unleaded gasoline (Töpfer 1995). A 1985 European Union directive (85/210/EEC) allowed marketing of unleaded gasoline with a maximum lead content of 0.013 g/liter and a premium unleaded gasoline effective October 1989. The directive also encouraged member countries to promote the use of unleaded grades through economic incentives. By 1992 the lead content of leaded gasoline in the European Union countries was not more than 0.15 g/liter (except in Portugal, where it was 0.40 g/liter), and 46 percent of the gasoline marketed in the European Union contained lead (CONCAWE 1994). In addition, Austria (in 1993), Denmark (1994), Finland (1995), the Slovak Republic (1994), and Sweden (1994) have completely banned lead in gasoline. Outside Latin America and the Caribbean, other countries that have completely eliminated lead in gasoline include Canada (1990), the Republic of Korea (1994), and Thailand (1995).

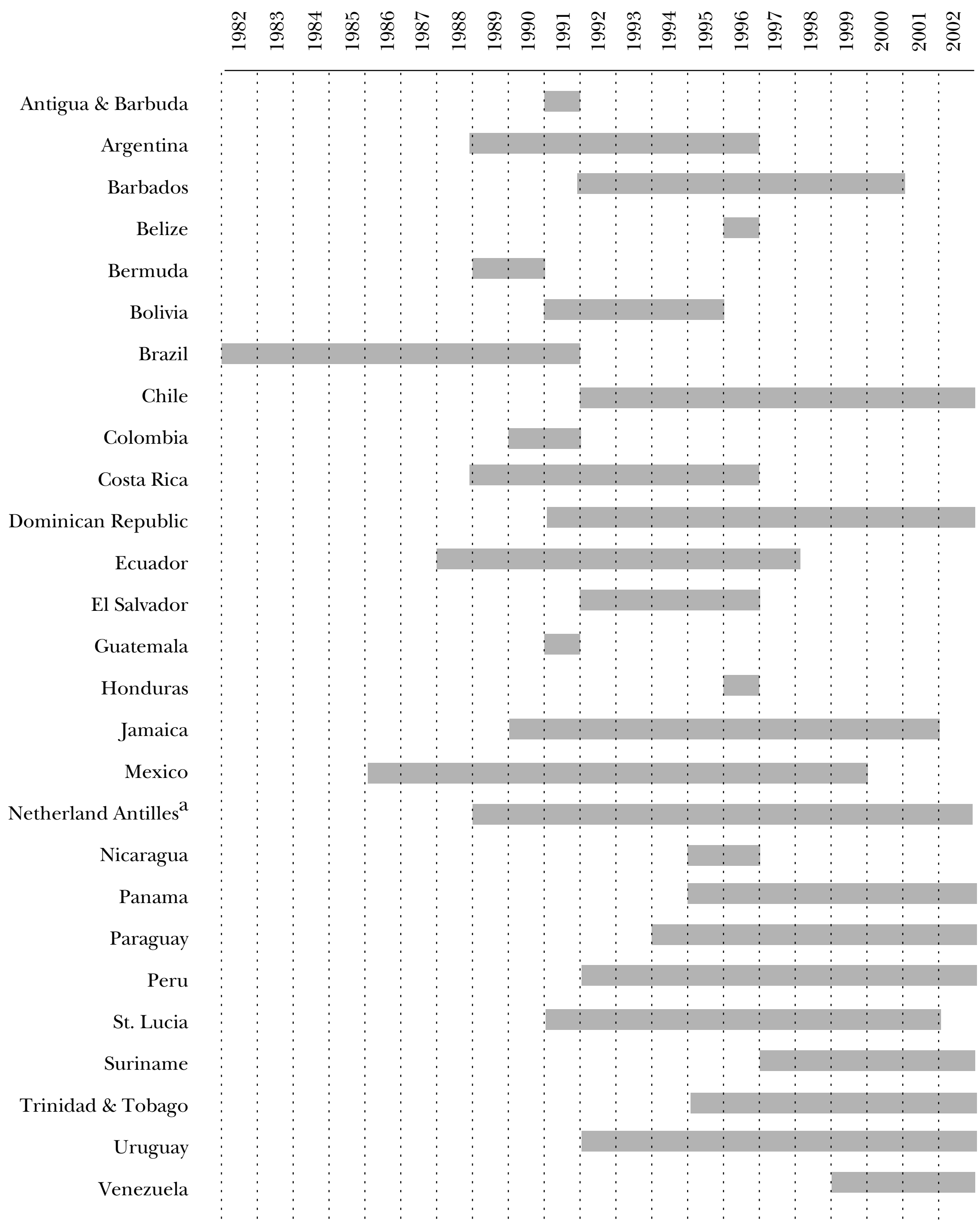
Following the 1994 Summit of the Americas meeting in Miami, where thirty-four government leaders committed to the concept of pollution prevention partnership, technical experts across the Western Hemisphere identified lead as a priority issue and resolved to develop and implement national action plans to phase out lead in gasoline. Many countries in Latin America and the Caribbean have taken major steps toward reducing or eliminating lead in gasoline (Figure 3.2). The amount of lead added to gasoline in the region dropped from 27,400 tons in 1990 to 10,300 tons in 1996, with Venezuela and Peru being the main contributors to lead pollution (about 3,000 tons and 1,000 tons in 1996). Lead in gasoline has been completely eliminated in Antigua and Barbuda (in 1991), Argentina (1996), Belize (1996), Bermuda (1990), Bolivia (1995), Brazil (1991), Colombia (1991), Costa Rica (1996), El Salvador (1996), Guatemala (1991), Honduras (1996), and Nicaragua (1996). In Venezuela unleaded gasoline is produced for the export market and the domestic market is served with leaded gasoline. In some countries of the region (Barbados, Chile, Dominican Republic, Ecuador, Mexico, Panama, Paraguay, Peru, St. Lucia, Trinidad and Tobago, and Uruguay) both unleaded and leaded gasoline are marketed. Barbados, Ecuador, and Mexico are planning to be lead free by 2000, Jamaica and St. Lucia by 2001, Panama by 2002, Trinidad and Tobago by 2005, Venezuela by 2007, and Peru by 2009. The percentage of unleaded gasoline consumed in the region is projected to increase from the current 68 percent to 83 percent by 2000, and the amount of lead added to gasoline is projected to fall to 6,250 tons by 2000 (Alconsult International Ltd. 1996). At a World Bank-organized seminar in Santiago in September 1996, representatives of the region's countries recommended that priorities be established in national plans for eliminating lead in gasoline and that greater resources be dedicated toward this end. Reducing the concentration of lead in leaded gasoline to the lowest possible level was viewed as the first step. Other measures included monitoring ambient air quality and the health impacts of lead reduction, controlling vehicular emissions, investing in refinery upgrading, setting norms and regulations, and conducting public awareness campaigns and training programs.

In Latin American and Caribbean countries that are currently using leaded gasoline, the lead content is generally lower than the limit specified in fuel quality standards. The available data also indicate that leaded gasoline is the predominant type of gasoline consumed in these countries (Table 3.6).

There are a number of ways to reduce or eliminate lead in gasoline. Countries that have refineries can boost the octane number of the gasoline blend through refinery investments. Properties of crude oils, complexities of refinery designs, and operating conditions of refinery units are important factors affecting these modifications. One option involves transforming low-octane straight-chain paraffins into high-octane aromatic or branch-chain paraffins. This

5. Contamination inspections helped ensure that the unleaded fuel supply was not contaminated by lead.

Figure 3.2 Timelines for eliminating leaded gasoline in Latin America and the Caribbean
(from beginning of availability of unleaded gasoline to end of availability of leaded gasoline)



Note: Beginning year and ending year of periods do not necessarily include the whole year. All periods after 1996 are projected until 2002.
a. Data is only for Aruba.
Source: Adapted from Alconsult 1996; Ecopetrol 1996; *Registro Oficial* 793 dated Oct. 2, 1995, Ecuador.

Table 3.6 Standards, quality, and consumption of leaded gasoline in Latin America and the Caribbean, 1996

Country	*Regulated lead content (gram/liter)*	*Marketed lead content (gram/liter)*	*Leaded gasoline consumption (percentage of total gasoline)*
Barbados	—	0.79	60
Chile	0.60	0.31	72
Dominican Republic	0.40	0.40	69
Ecuador	0.84	0.50	76
Jamaica	—	0.77	70
Mexico	0.06–0.08	0.11	44
Netherlands Antilles[a]	—	0.23	50
Panama	0.76	0.45–0.63	7
Paraguay	0.15	0.20	99
Peru	0.74	0.41–0.62	75
Trinidad and Tobago	0.40	0.15–0.45	99
Uruguay	—	0.58	96
Venezuela	0.85	0.30–0.40	100

— Not available.
a. Data is only for Aruba.
Source: Alconsult International Ltd. 1996; Pesce 1996.

may involve modifying, expanding, or adding a catalytic reforming unit.[6] Increasing the severity[7] of the catalytic reforming unit, however, increases the yield of aromatic hydrocarbons, which results in high benzene emissions with adverse health effects. By investing in alkylation[8] or isomerization[9] units the octane number can also be increased. Another option to refiners involves investing in an oxygenate plant that can produce or blend an oxygenate with gasoline. The Chilean government's policy for short-term refinery upgrading includes remodeling existing catalytic cracking units (replacing the catalysts and operating at conditions that would yield a product with the maximum achievable octane number), constructing new low-pressure catalytic reforming units, and converting existing high-pressure catalytic reforming units to isomerization units. The government's long-term policy includes adding a continuous regeneration unit to the catalytic reforming units and producing methyl tertiary-butyl ether (MTBE) and di-isopropyl ether (DIPE). Refinery upgrading in Argentina has involved investments for catalytic reformer modifications and for new reforming, isomerization, alkylation, and MTBE units. Similar modifications have taken place in Mexican (see Chapter 4) and Venezuelan refineries.[10] Refinery upgrade investments are under way in Ecuador and Nicaragua and are planned in Argentina, Costa Rica, Jamaica, Mexico, Trinidad and Tobago, Uruguay, and Venezuela.

Refinery upgrading, especially when a new unit is required, is capital intensive. Estimates

6. Catalytic reforming involves catalytic reaction of low-octane naphtha (35–55 RON) with hydrogen under pressure (4.4–34 atmospheres) and at high temperatures (450–510°C) to produce a high-octane naphtha (90–102 RON).

7. Severity can be increased by reducing pressure or increasing temperature.

8. Alkylation involves reaction of olefins having three to five carbon atoms in their structures (that is, C_3 to C_5) with isobutane in the presence of a liquid catalyst (such as sulfuric or hydrofluoric acid). The C_3 to C_5 olefins (propylene, n-butene, isobutene) are produced mainly from the fluid catalytic cracking (FCC) unit. The alkylation reaction products (alkylates) are high octane blendstocks (92–97 RON). Alkylation is suitable only for refineries equipped with FCC units.

9. Isomerization involves producing an isomer from light naphtha (that is, the C_5 and C_6 fraction from the atmospheric distillation unit). This process increases the RON from 70–78 to 85–90.

10. The refinery upgrade investments in Venezuela have been made to produce unleaded gasoline for the export market.

for refinery investments to increase gasoline's octane number are provided in Chapter 4 in the Mexico City and Santiago sections. It costs $0.02 to $0.03 a liter to remove lead from gasoline with initial levels of 0.6 g/liter or more, and $0.01 to $0.02 a liter for initial levels of about 0.15 g/liter (World Bank 1996a). The refining cost of removing lead from gasoline is lower for complex (deep conversion) refineries than for less sophisticated (for example, hydroskimming) refineries, which require more expensive processes (USEPA 1995).[11]

Some Latin American and Caribbean countries meet the local market demand for unleaded gasoline by importing. The imported gasoline or naphtha is either blended with locally produced low-octane unleaded gasoline or naphtha (as in Costa Rica, Dominican Republic, El Salvador, and Nicaragua) or sold in the local market (as in Barbados, Honduras, Paraguay, St. Kitts, and St. Lucia). In some countries (Chile, Guatemala, Uruguay) locally produced low-octane gasoline or naphtha is blended with an imported oxygenate (MTBE or ethanol) to produce a high-octane gasoline. In Costa Rica high-octane gasoline is produced also by blending imported high-octane gasoline with imported MTBE. The series of events that led to the elimination of lead from gasoline in Costa Rica are presented in Box 3.4.

Although reducing or eliminating lead in gasoline definitely has positive health impacts, consideration should also be given to the health impacts of the gasoline produced (after refinery modifications) to meet lower lead requirements. The reforming process increases the content of benzene and other aromatic compounds in the gasoline blend. Benzene is carcinogenic. In addition, this and other aromatic compounds are toxic. Olefins and alkylbenzenes (such as m-xylene and trimethylbenzene), when evaporated, have high reactivity for ozone formation. Lighter hydrocarbons have higher volatility than the other hydrocarbons in the gasoline blend. Oxygenates, upon combustion, produce higher emissions of aldehydes (such as acetaldehyde) than gasoline but result in lower CO and HC emissions. Ethanol (an alcohol-based oxygenate) is more volatile than ether-based oxygenates.

The minimum engine octane requirement of older model gasoline-fueled vehicles (equipped with carburetors or continuous fuel injection systems) is influenced by altitude. The octane number requirement decreases by about 10 units for an altitude change from sea level to 1,000 meters (Faiz, Weaver, and Walsh 1996). By supplying lower octane gasoline in urban centers at higher altitudes savings can be achieved in refinery investments or in foreign exchange needed for importing oxygenates, high-octane naphtha, or high-octane gasoline. If leaded gasoline is still used in the country, the minimum octane requirement may be met by reduced lead addition to gasoline. In Latin America such a strategy may be beneficial for countries (such as Bolivia, Chile, Colombia, Ecuador, and Mexico) with urban centers at high altitudes (such as La Paz, Santiago, Santafé de Bogotá, Quito, Mexico City, Monterrey, Puebla de Zaragoza, and León).

The implications for motor vehicle components of shifting from leaded to unleaded gasoline also should be considered. Because lead serves as a lubricant between exhaust valves and their seats, unleaded gasoline may cause valve seat recession under severe driving conditions in vehicles without hardened seat valves. But this problem is not likely to occur under normal driving conditions and in newer vehicles with hardened valve seats. Moreover, a lead concentration of 0.05 g/liter of gasoline is sufficient to prevent seat valve recession in vehicles without hardened seat valves. And the presence of lead in gasoline increases the risk of other vehicle maintenance problems that may be more severe than valve seat recession (Thomas 1995a).[12]

A country's lead elimination strategy should include a realistic time schedule that takes into account, among other factors, the availability and capabilities of domestic petroleum refineries. In most Latin American and Caribbean countries production of unleaded gasoline to meet octane number requirements is not likely to be imme-

11. Hydroskimming refineries include atmospheric and vacuum distillation, hydrodesulfurization, catalytic reforming, and blending and possibly isomerization operations. Deep conversion refineries include the same operations as hydroskimming refineries and other operations such as fluid catalytic cracking, coking, hydrocraking, isomerization, alkylation, polymerization, and oxygenate (such as MTBE or TAME) production.

12. Lead scavengers such as ethylene chloride or ethylene dibromide form corrosive halogenated compounds that degrade exhaust valves, spark plugs, mufflers, and exhaust pipes.

Box 3.4 How was lead eliminated from gasoline in Costa Rica?

A series of events led to the elimination of lead from gasoline in Costa Rica:

- Promulgation of Decree 19,088-S-MEIC-MIRENEM, which established a seven-year period to eliminate lead from gasoline (1989).
- Introduction of 95-octane super gasoline, which is imported (1990).
- Undertaking of technical studies to evaluate alternative options for producing unleaded gasoline with 88 octane (1991–92).
- Promulgation of the Transit Law, which establishes requirements for motor vehicle registration and emission standards (1993).
- Opinion survey of regular gasoline consumers to gather their views about the introduction of unleaded gasoline to the market and to devise a public awareness campaign strategy (1994).
- Introduction of an environmentally friendly super gasoline (1994). This gasoline is produced by blending imported high-octane unleaded gasoline with 10 percent by volume MTBE content (also imported).
- A massive campaign on the benefits of environmentally friendly super gasoline through television announcements and distribution of pamphlets (1994)
- Establishment of an inter-institutional commission for all entities involved in the elimination of lead from gasoline, including vehicle importers, the agency in charge of regulating prices, the Costa Rican refinery (RECOPE), fuel consumers, and ministries of the environment, energy, public works, and transportation (1994).
- Evaluation of the impacts of lead elimination from regular gasoline (1995).
- Use of unleaded gasoline in RECOPE's entire fleet to prove to consumers that unleaded gasoline has no adverse impacts on engines (1995).
- Reduction of the price difference between regular and unleaded gasoline to 5 percent (1995).
- Promulgation of Decree 24,637-MIRENEM-S, which prohibited the use of leaded gasoline in public institution vehicles (1995).
- Introduction of a new unleaded gasoline called "bio-plus" (April 1996). This was done without any public announcement to allow time to clean the storage and distribution network of any residual lead. Bio-plus is prepared by blending naphtha produced by RECOPE and imported high-octane naphtha.
- Announcement of the introduction of bio-plus to the market and associated media campaigns through television and press (May 1996).

Source: Ministry of the Environment and Energy of the Republic of Costa Rica 1996.

diately possible because of the lack of adequate refinery capacity and infeasibility of suitable process reconfiguration. Furthermore, investments for certain refinery reconfigurations may take two to five years to materialize. In the interim it might be possible to modify certain operating parameters of the refinery process units. In addition, gasoline can be blended with oxygenated additives or imported unleaded gasoline. Any deficit in the octane number could then be remedied by blending with lead additives.

A lead elimination strategy with a realistic schedule also should include policies other than establishing fuel standards for unleaded gasoline. Such options may include other command-and-control measures that are necessary to monitor and enforce production, distribution, and final sale of the unleaded gasoline to the consumer (such as labeling, testing, reporting requirements, and prohibition of misfueling) as well as penalties for violation. While compliance with fuel specifications has to be ensured and enforced, prohibition of misfueling is not likely to be effective if gasoline pricing creates incentives for misfueling. To avoid misfueling, the two gasoline grade should be taxed differentially so that, at a minimum, unleaded gasoline is not sold at a higher retail price than leaded gasoline.

Finally, any lead elimination strategy should be considered separately from the vehicle-targeted policy option that requires catalytic converters on gasoline-fueled vehicles. Although the catalytic converter-equipped vehicles cannot run with leaded gasoline (lead poisons the catalyst),

the opposite is not true. That is, vehicles designed to run on leaded gasoline can also use unleaded gasoline.

Volatility. Because of its toxicity and ozone and smog formation effects the vapor pressure of gasoline is limited. Gasoline with a low vapor pressure—as measured by Reid vapor pressure, or RVP—has lower evaporative and fugitive emissions than gasoline with a higher vapor pressure. In tests performed on European vehicles not equipped with pollution control devices, evaporative emissions were found to nearly double when the RVP of gasoline increased from 9 psi to 11.9 psi (McArragher and others 1988). In tests performed on vehicles with evaporative controls in the United States, diurnal emissions increased by more than five times (as a result of the saturation of the charcoal canister) and hot-soak emissions by 25 to 100 percent for the same increase in RVP (USEPA 1987). In tests performed as part of the U.S. Air Quality Improvement Research Program, a 1 psi reduction in RVP from 9 psi to 8 psi decreased total evaporative emissions by 34 percent, CO emissions by 9 percent, and exhaust HC emissions by 4 percent, without affecting NO_x emissions (Faiz, Weaver, and Walsh 1996). Refueling emissions also increase when fuels have higher RVP. Refueling emissions from gasoline were about 30 percent higher when the fuel's RVP increased from 9.3 psi to 11.5 psi (Braddock 1988).

In the United States vapor pressure limits for gasoline were first implemented in 1989. These limits, which established maximum RVP values for gasoline during the summer months (May through September), varied between 9.5 psi and 10.5 psi for different states. In 1992 a more stringent set of limits was imposed. Accordingly, the RVP of gasoline was restricted to 9.0 psi for the cooler northern states during May through September and to 7.8 psi for the warmer southern states during June through September. In 1995 RVP limits in the ozone nonattainment areas (which are served by reformulated gasoline) of the northern and southern states were reduced to 8.1 psi and 7.2 psi, respectively. In 1996 the maximum RVP value for reformulated gasoline used in the Los Angeles metropolitan area was set at 7.0 psi.

The European Union has established eight volatility classes for gasoline from which each member country must specify one for each defined period of the year and for a defined region to attain national requirements. The range for the maximum values of RVP for these classes is between 10.1 psi and 14.5 psi (CONCAWE 1994).

Some Latin American and Caribbean countries have limited the vapor pressure of leaded and unleaded gasoline. In most instances the quality of marketed gasoline meets these requirements (Table 3.7).

The USEPA estimates that a U.S. refiner's long-term cost of meeting the 9.0 psi RVP limit for gasoline is $0.0038 a liter (based on a price of $20 a barrel of crude oil). Deducting the benefits resulting from the savings in fuel losses through evaporation and improved fuel economy, the net cost to the consumer is estimated to be $0.0012 a liter (Faiz, Weaver, and Walsh 1996).

Ambient temperatures must be taken into consideration when establishing RVP limits for fuels. Because a fuel's volatility increases with temperature, lower RVP limits may be required in tropical countries with little variation in seasonal and diurnal temperatures. In countries where differences between summer and winter temperatures are more pronounced, separate volatility limits may be established for each season. In colder countries less stringent RVP limits should be used to avoid problems associated with fuel volatilization, which affect engine startup and driveability.

Benzene and other aromatic hydrocarbons. Aromatic hydrocarbons are hydrocarbons that contain one or more benzene rings in their structures. Although aromatic hydrocarbons help raise the octane number of gasoline, their content in gasoline is often restricted because of their toxic properties. They also contribute to higher CO and HC in exhaust emissions from motor vehicles (AQIRP 1990).

Some countries regulate benzene and aromatic hydrocarbon content of gasoline. For example, benzene is limited to 1.0 percent by volume in the United States; 3.0 percent in Italy and New Zealand; 3.5 percent in Thailand; and 5.0 percent in Australia, all EU countries except Italy, and the Republic of Korea. The aromatic hydrocarbon content is limited to 25 percent by volume in the United States, 33 percent in Italy, 50 percent in Thailand, and 55 percent in the Republic of Korea. In Latin America and the Caribbean benzene in gasoline is limited in a few countries, and aromatic hydrocarbons only in Mexico (Table 3.8).

Table 3.7 Standards and quality for Reid vapor pressure of gasoline in Latin America and the Caribbean, 1996

(pounds per square inch)

	Gasoline standard		*Marketed gasoline quality*	
Country	*Leaded*	*Unleaded*	*Leaded*	*Unleaded*
Argentina	—	—	—	8.5–12.0
Bolivia	9.0	—	—	8.0–8.5
Brazil	—	10.0[a]	—	9.8–10.9[a]
Chile	10.0–12.5[b]	10.0–12.5[b]	7.6–13.5	7.0–13.5
Colombia	—	8.5	—	7.5–8.5
Costa Rica	10.0	10.0[c]	—	less than 10
Dominican Republic	9.5	—	9.5	9.5
Ecuador	—	—	9.2	6.5–8.4
El Salvador	10.0	10.0	8.0–9.0	—
Honduras	10.0	—	—	—
Jamaica	—	—	10.0	10.0
Mexico	6.5–8.5[d]	6.5–8.5[e]	7.5	7.9–10.1
Nicaragua	10.0	—	—	—
Panama	10.0	—	—	—
Paraguay	7.5–10.0	—	8.0	8.0
Peru	10.0	—	6.3–9.0	6.9–8.7
Trinidad and Tobago	9.5	—	8.1	8.1
Venezuela	9.5	—	7.7	—

— Not available.
a. The fuel is a mixture of 22 percent by volume ethanol with 78 percent gasoline.
b. The lower limit is for summer months; the higher limit is for winter months.
c. Proposed limit.
d. Applicable to metropolitan areas.
e. For the Mexico City metropolitan area. In 1998 the current limit (6.5–9.5 psi) for the Monterrey and Guadalajara metropolitan areas will be reduced to 6.5–8.5 psi.
Source: Alconsult International Ltd. 1996; Berumen 1996; Ruiz 1996.

Table 3.8 Standards and quality for benzene and aromatic hydrocarbons content of gasoline in Latin America and the Caribbean

(percent by volume)

	Gasoline standard (max.)		*Marketed gasoline quality*	
Country	*Benzene*	*Aromatic hydrocarbons*	*Benzene*	*Aromatic hydrocarbons*
Argentina	4.0	—	0.8–2.5	16.8–44.4
Chile	5.0	—	1.4–1.8	19.2–49.0
Colombia				
Unleaded regular	0.8	—	0.64–0.80	22.1–24.4
Unleaded extra	0.9	—	0.91–0.93	23.2–28.3
Mexico	2.0[a]	30[b]	0.45–2.1	25.0–33.3
Trinidad and Tobago	5.0	—	5.0	—

— Not available.
a. For the Mexico City, Monterrey, and Guadalajara metropolitan areas. For the rest of the country, the standard for benzene is 4.9 percent by volume.
b. For the Mexico City, Monterrey, and Guadalajara metropolitan areas.
Source: Alconsult International Ltd. 1996; Berumen 1996; Ecopetrol 1996; Ruiz 1996.

A U.S. oil-automotive industry research group evaluated the effects of the aromatic hydrocarbons content of gasoline on toxic emissions (benzene, 1,3-butadiene, formaldehyde, and acetaldehyde) from catalytic converter-equipped cars. Reducing the aromatic hydrocarbons content of gasoline from 45 to 20 percent lowered toxic emissions by 34 to 36 percent in 1989 model-year cars and 7 to 17 percent in 1983–85 model-year cars. Benzene accounted for 60 to 85 percent of toxic emissions from the newer cars and 36 to 66 percent of toxic emissions from the older cars (AQIRP 1991b). The same reduction in the aromatic hydrocarbons content lowered CO by 14 and HC emissions by 6 percent in the exhaust (AQIRP 1990).

Reformulated gasoline. Reformulated gasoline is gasoline with lower emission characteristics than conventional gasoline. A reformulated gasoline may include any of the following properties listed below (Wijetilleke and Karunaratne 1992). Most research in reformulating gasoline, however, has focused on reducing volatility, reducing sulfur, and adding oxygenates (Faiz, Weaver, and Walsh 1996).

- An octane number consistent with the compression ratios of vehicles
- No or a minimum amount of heavy metals (such as lead or manganese) for lower toxic exposure
- A small fraction of volatile components for reduced evaporative or fugitive emissions of unburned gasoline
- Small amounts of benzene and other aromatic hydrocarbons for reduced evaporative and exhaust emissions and lower exhaust emissions of CO and unburned HC
- A small fraction of olefins for lower photochemical reactivity in evaporative emissions and for lower gum formation and plugging of fuel injectors
- An increased fraction of alkylates for clean combustion
- A small amount of sulfur for higher catalyst efficiency and lower sulfur emissions in the exhaust.
- Presence of oxygen for lower exhaust emissions of CO and HC
- Additives for cleaning deposits, reducing misfire, and improving fuel delivery to help reduce emissions.

Exhaust emission tests, performed with reformulated gasoline (with 11 percent MTBE content) and industry-average gasoline on catalytic converter-equipped older and newer cars, indicate that reformulated gasoline emits 12 to 27 percent less NMHC, 21 to 28 percent less CO, and 7 to 16 percent less NO_x than the industry-average gasoline. However, adding 11 percent MTBE as an oxygenate increased aldehyde emissions by 13 percent (Faiz, Weaver, and Walsh 1996). Aldehydes, through photochemical reactions, may contribute to the formation of peroxiacetyl nitrates, which are health hazards (Wijetilleke and Karunaratne 1992).

In the United States reformulated gasoline is prepared to reduce emissions of ozone (which form volatile organic compounds, or VOCs) during the high ozone season and emissions of toxic air pollutants during the entire year. The 1990 Clean Air Act amendments required that effective January 1, 1995, reformulated gasoline be used in those parts of the United States with the worst ozone problems (where the population exceeds 250,000 people).[13] Gasoline consumption in these areas—which cover six entire states and portions of twelve other states that include twelve major urban areas—accounts for 30 percent of all gasoline sold in the United States. The USEPA's final rule on reformulated gasoline, announced in December 1993, mandates that all reformulated gasoline contain a minimum 2.0 percent of oxygen by weight and a maximum of 1.0 percent of benzene by volume. The presence of heavy metals (such as lead or manganese) is not allowed. The amount of detergents is not specified, although their presence is required to prevent accumulation of deposits in engines or vehicle fuel supply systems. The average for T_{90}, sulfur, and olefins content must not exceed the 1990 average (Table 3.9).

Implementation of this program consists of two phases. The first phase, which covers the period between January 1, 1995 and January 1, 2000, targets a 15 to 17 percent reduction in VOC and toxic emissions from motor vehicles based on the average 1990 U.S. baseline (see Table 3.9). The second phase starts in January 2000 and targets a 25 to 29 percent reduction in VOC emissions, 20 to 22 percent reduction in toxic emissions, and 5 to 7 percent in NO_x emissions, again based on the average 1990 U.S. baseline.

13. These areas are those where the U.S. ambient air quality standard is exceeded for ozone (also called non-attainment areas for ozone).

Table 3.9 Baseline parameters for gasoline in the United States
(1990 average)

Additive	*Standard*
Benzene	1.6 percent by volume
Aromatic hydrocarbons	28.6 percent by volume
Olefins	10.8 percent by volume
Sulfur	338 ppm
T_{90}[a]	167°C
Reid vapor pressure	8.7 psi

a. T_{90} is the temperature at which 90 percent of fuel is evaporated. T_{90} has been related to engine deposits and engine oil dilution.
Source: CONCAWE 1994.

Refiners must certify their reformulated gasoline through the use of a "simple model" (applicable only for 1995–97) or a "complex model", both of which were specified by the USEPA.

The U.S. reformulated gasoline program includes an "antidumping" rule that also restricts the properties of non reformulated gasoline produced in the United States. Accordingly, during 1995-97 olefins, sulfur, and T_{90} are not allowed to exceed their values for 1990 by more than 25 percent. Subsequently, emissions of NO_x, benzene, and toxics are limited by their respective values for 1990, and VOC emissions are to be controlled by regional RVP limits (CONCAWE 1994).

Examples of other countries which produce reformulated gasoline include Finland and Thailand. Finland's reformulated gasoline program was implemented in two stages. An interim reformulated gasoline (called "city gasoline") and a more severely reformulated gasoline, with reduced levels of benzene and sulfur, introduced in January 1993 and March 1994, respectively (Table 3.10). Both initiatives were supported by tax incentives.

In Thailand regular leaded gasoline was the only gasoline grade available for light-duty motor vehicles until 1993, when two additional grades of reformulated gasoline (called "premium leaded" and "premium unleaded") were introduced. Each grade includes two types, Type 1 for rural areas and Type 2 for urban areas (Table 3.11). The requirements for Type 1 gasoline are the same as for Type 2 gasoline, except that Type 1 does not have any requirement for the minimum MTBE content.

In Latin America and the Caribbean reformulated gasoline has been produced in Mexico since 1992, when standards were established to control the content of benzene, aromatic hydrocarbons, and olefins in gasoline and the 1986 RVP specification was tightened. The specifications for benzene, aromatic hydrocarbons, and olefins were tightened again in 1994. Argentina's 1996 fuel quality standards also require reformulated gasoline (see the Mexico City and Buenos Aires sections of Chapter 4).

The production of reformulated gasoline requires refinery modifications that are dictated by the configuration of the refinery and properties of the crude oil processed at the refinery. These modifications may involve such unit operations as reforming, alkylation, isomerization, and oxygenates production or blending. Each modification has a different effect on the composition and properties of gasoline and, therefore, on the concentration of pollutants in the exhaust emissions from motor vehicles. The incremental cost of producing reformulated gasoline depends on the extent of refinery modifications; the cost to U.S. refiners ranges from $0.008 to $0.013 a liter to meet the first phase of the federal program, about $0.03 a liter to meet the second phase of the federal pro-

Table 3.10 Properties of severely reformulated and city gasoline in Finland

Additives	*City gasoline*	*Severely reformulated gasoline*
Oxygen (percent by weight)	2.0–2.7	2.0–2.7
Benzene (maximum percent by volume)	3.0	1.0
Sulfur (maximum ppm by weight)	400	100
RVP (summer/winter) (maximum psi)	10.1/13.0	10.1/13.0

Source: CONCAWE 1994.

Table 3.11 Compositional constraints for regular and Type 2 gasoline grades in Thailand

	Type 2 gasoline (reformulated)		
Additive	*Regular gasoline*	*Premium leaded*	*Premium unleaded*
Lead (maximum gram/liter)	0.15[a]	0.15[a]	0.013
Sulfur (maximum percent by weight)	0.15	0.15	0.10
Benzene (maximum percent by volume)	3.5	3.5	3.5
Aromatic hydrocarbons (maximum percent by volume)	—	50[b]	50[b]
MTBE (percent by volume)			
Minimum	—	5.5	5.5
Maximum	10.0	10.0	10.0

— No limit is established.
a. This limit was reduced to 0.013 gram/liter effective January 1995.
b. This limit will be reduced to 35 percent by volume effective January 2000.
Source: CONCAWE 1994.

gram, and about $0.05 a liter to meet the second phase of the California program[14] (USEPA 1994; Faiz, Weaver, and Walsh 1996). To comply with Mexican gasoline quality requirements Pemex invested $344 million in fourteen projects at different refineries (see the Mexico City section in Chapter 4). In addition, Pemex has undertaken ten new projects requiring a total investment of about $1 billion between 1996 and 1998 (Table 3.12). To meet the Argentine fuel quality requirements YPF has invested $170 million in refinery modifications that included alkylation, isomerization, and oxygenation (MTBE and TAME) units (Tanco 1996). Esso is planning to increase its reformer capacity, and Eg3 is planning to add a high severity reformer and MTBE and isomerization units (Alconsult International Ltd. 1996).

Before launching a reformulated gasoline program, an evaluation should be made of reformulated gasoline production capabilities that considers crude properties, existing refinery configurations, and oxygenate supply options. In addition, a careful analysis should be made of the impacts on vehicle emissions and ambient air quality. This analysis should ensure that the reformulated gasoline does not create other emissions or ambient concentrations of pollutants which pose serious health threats. Given these considerations, the benefits of reformulated gasoline are more modest for catalytic converter-equipped vehicles than for older uncontrolled vehicles because catalytic converters already remove a large fraction of pollutants from combustion gases (a large fraction of CO and HC by two-way catalytic converters and CO, HC, and NO_x by three-way catalytic converters). Thus a reformulated gasoline program is more suitable for urban centers or countries where most in-use vehicles lack catalytic converter technology.

Design and implementation of a gasoline reformulation program must consider a set of command-and-control measures and, possibly, some market-based incentives. In the United States the measures and incentives included in this program include prohibition of the sale of conventional gasoline by refiners, distributors, or retailers for use in ozone nonattainment areas; establishment of certification procedures for reformulated gasoline; specification of sampling, testing, and record-keeping requirements to prevent violation of regulations; establishment of a credit system (see section on market-based incentives, below); and penalties for violations. In establishing the requirements for reformulated gasoline in the United States the energy requirements, health and environmental impacts, and costs of achieving emission reductions were taken into consideration.

Oxygenated gasoline. Oxygenates are added to gasoline to increase its oxygen content and, therefore, enhance cleaner combustion in motor vehicles. Combustion of oxygenated gasoline produces lower CO and HC exhaust emissions than straight gasoline. NO_x emissions, however, may increase. Oxygenates also have higher

14. The second phase of the California gasoline program is expected to result in about 30 percent reduction in HC and toxic air emissions compared with the fuels sold in 1990.

Table 3.12 Mexico's refinery investment program, 1996–98

Refinery/project	*Capacity (barrels a day)*	*Investment (million $)*	*Estimated completion date*
Salina Cruz			
Alkylation	14,100	57	1996
Isomerization	13,400	30	1996
Tula			
Hydrodesulfurization of intermediate distillates	25,000	72	1996
Alkylation	7,500	32	1996
Isomerization	15,000	26	1996
H-Oil	50,000	623	1997
Salamanca			
Hydrodesulfurization of intermediate distillates	25,000	73	1996
Alkylation	3,400	26	1996
Isomerization	12,000	25	1996
Madero			
Isomerization	12,000	47	1998

Source: Berumen 1996.

blending octane numbers than most other gasoline components except for aromatic hydrocarbons. Oxygenates, however, can potentially reduce fuel economy because of their lower volumetric energy content than conventional gasoline.

Oxygenates are either alcohol-based or ether-based. Alcohol-based oxygenates include methanol[15] and ethanol;[16] ether-based oxygenates include methyl tertiary butyl ether (MTBE), ethyl tertiary butyl ether (ETBE), and tertiary amyl methyl ether (TAME). The most commonly used oxygenates are MTBE and ethanol. Of the two groups, ether-based oxygenates are preferred for processing and environmental reasons (for example, alcohol-based oxygenates have higher evaporative emissions than ether-based oxygenates because of their higher blending RVP).[17]

Oxygenated fuel tests performed on 1989 model-year gasoline-fueled U.S. vehicles with 10 percent (by volume) ethanol blends, 15 percent (by volume) MTBE blends, and 17 percent (by volume) ETBE blends[18] had similar effects on pollutant exhaust emissions: a reduction of 5 percent in HC, 4 percent in NMHC, and 9 percent in CO emissions. A 5 percent increase in NO_x emissions was also noted with oxygenate blending (AQIRP 1991a). In Mexico City the addition of 5 percent MTBE to leaded gasoline reduced CO emissions by 15 percent and HC emissions by 12 percent from non-catalyst gasoline-fueled vehicles. This addition did not increase NO_x emissions (CMPCCA 1995).

Gasoline quality standards in some countries establish limits for oxygen or oxygenate content (Table 3.13). In Latin America and the Caribbean these limits have been set in Argentina, Brazil, and Mexico, and are proposed in Costa Rica. However, despite the absence of such regulations, increasing amounts of oxygenates have been used in the 1990s because countries in the region are rapidly eliminating or reducing lead in gasoline. The predominant types of oxygenates used are ethanol in Brazil, MTBE and TAME

15. Methanol is obtained in a refinery from the synthesis gas produced by steam reforming.

16. Ethanol is produced from fermentation of renewable resources such as sugar cane or corn.

17. Ether-based oxygenates are produced from reactions between alcohols and olefins: MTBE from a reaction between methanol and isobutylene; ETBE from a reaction between ethanol and isobutylene; and TAME from a reaction between methanol and isoamylene. Because isobutylene is more readily available than isoamylene in a refinery, production of MTBE or ETBE is preferred over TAME.

18. The oxygen content in the gasoline-oxygenate blends was 3.7 percent (by weight) for ethanol, 2.7 percent for MTBE, and 2.7 percent for ETBE.

Table 3.13 Oxygenate requirements for motor vehicle fuels

Country/oxygenate type	Standard
Latin American countries	
Argentina	
MTBE (maximum percent by volume)	15.0
Ethanol (maximum percent by volume)	5.0
Isopropyl alcohol (maximum percent by volume)	5.0
Tertiary butyl alcohol (maximum percent by volume)	7.0
Isobutyl alcohol (maximum percent by volume)	7.0
Oxygen (maximum percent by weight)	2.7
Brazil	
Ethanol (minimum percent by volume)	22.0
Costa Rica	
Oxygen (minimum percent by weight)	2.0[a]
Mexico	
Oxygen (minimum percent by weight)	1.0[b]
(maximum percent by weight)	2.0[b]
Others	
Republic of Korea	
Oxygen (minimum percent by weight)	0.5
South Africa	
Oxygen for 95 RON (maximum percent by weight)	2.8[c]
Oxygen for 91 RON (maximum percent by weight)	3.7[d]
Thailand	
MTBE (minimum percent by volume)	5.5[e]
MTBE (maximum percent by volume)	10.0
United States[f]	
Oxygen (maximum percent by weight)	2.7

a. Proposed standard.
b. Applies to metropolitan areas (Mexico City, Guadalajara, Monterrey). No standards have been established for the rest of the country.
c. Corresponds to 7.5 percent alcohol by volume (85 percent ethanol and 15 percent propanol).
d. Corresponds to 9.5 percent alcohol by volume (85 percent ethanol and 15 percent propanol).
e. For reformulated gasoline required in urban areas.
f. "Gasohol" consisting of gasoline with 10 percent alcohol by volume is permitted. This fuel contains 3.5 percent oxygen by weight.
Source: CONCAWE 1994; DDF 1996; Ministry of the Environment and Energy of the Republic of Costa Rica 1996; Resolution 54/96 of the Argentine Ministry of Economy.

in Mexico, and MTBE in some other countries of the region. MTBE production units have been built in Argentina, Mexico, and Venezuela. Many countries of the region—including Chile, Costa Rica, Guatemala, Jamaica, Peru, and Uruguay—increase the octane number of gasoline by importing MTBE.

In the United States the oxygenated gasoline program was established by the 1990 Clean Air Act amendments to reduce vehicular emissions in areas with the worst CO problems (that is, areas where the national ambient air quality standard for CO is exceeded). The act requires the use of gasoline with a minimum oxygen content of 2.7 percent for a minimum of four months in areas where ambient CO concentrations are 9.5 ppm or higher based on two-year CO data. The act also requires labeling of oxygenated gasoline, established a credit system (discussed under the section on market-based incentives, below), and introduced enforcement measures and penalties if the requirements are not met. If the ambient air quality for CO cannot be reached in a nonattainment area, then the 2.7 percent oxygen requirement is raised to 3.1 percent.

U.S. refiners and marketers prefer ether-blended gasoline over alcohol-blended gasoline because of its lower vapor pressure and octane-

boosting ability. In addition, ether-based gasoline is not prone to phase separation or to water extraction. Ether-based oxygenated gasoline costs between $0.01 and $0.03 a liter more than straight gasoline (Faiz, Weaver, and Walsh 1996).

Use of oxygenated gasoline may be beneficial for traffic-congested Latin American and Caribbean urban centers with high ambient CO concentrations (such as Buenos Aires) and for urban centers that are located at high altitudes and have significant fraction of the motor vehicle fleet equipped with carburetors or continuous fuel injection systems (such as Quito and La Paz). Development of an oxygenated gasoline program requires a careful evaluation of the impacts on vehicle emissions and ambient air quality. This analysis needs to include NO_x and reactive HC emissions, especially in urban centers where ozone is a health problem.

Diesel Fuel Standards

Standards for diesel fuel have been established in many industrial and some developing countries. The main diesel fuel parameters affecting pollutant emissions are sulfur content, cetane number, aromatic hydrocarbons, and density.

Sulfur. The presence of sulfur compounds in diesel fuel results in SO_2 and PM emissions from the exhaust of diesel-fueled vehicles. Metal sulfates and sulfuric acid in the form of PM constitute 1 to 3 percent sulfur emissions from heavy-duty diesel-fueled vehicles and 3 to 5 percent of sulfur emissions from light-duty diesel-fueled vehicles. They also account for about 10 percent of PM emissions from these vehicles (Faiz, Weaver, and Walsh 1996). These emissions have adverse health and environmental impacts (see Chapter 2).

In catalyst-equipped diesel-fueled vehicles, the oxidation catalyst converts SO_2 from the engine into SO_3. But the presence of SO_2 in the engine exhaust reduces the catalyst's efficiency at oxidizing CO and HC.

The quality of diesel fuel produced in developing countries is generally lower than in industrial countries. Because of the higher demand for diesel fuel in developing countries refiners have expanded the distillate cut from the atmospheric distillation unit to include the heavier fraction. As a result, diesel fuel in developing countries generally has a higher sulfur and more asphaltic and carbonaceous content (Wijetilleke and Karunaratne 1992).

In Canada and the United States the sulfur content of diesel fuel is limited to 0.05 percent by weight. In 1993 the European Union established a sulfur limit for diesel fuel of 0.2 percent by weight effective October 1, 1994 and 0.05 percent by weight effective October 1, 1996. In Japan the sulfur content of diesel fuel was limited 0.2 percent in 1992 and 0.05 percent in May 1997. Thailand also has adopted a phased reduction of sulfur in diesel fuel used in urban areas, from 0.25 percent in January 1996 to 0.05 percent by January 2000. In the Republic of Korea the sulfur content of diesel fuel will be reduced to 0.05 percent by 1998 (CONCAWE 1994).

Some Latin American countries regulate the sulfur content of diesel fuel. In Argentina the sulfur content of diesel fuel is limited to 0.25 percent by weight. In Brazil it was limited to 0.5 percent by weight for urban areas and 1.0 percent for rural areas, but in October 1996 the 0.5 percent limit was reduced to 0.3 percent and the 1.0 percent limit was reduced to 0.5 percent. In Chile the limit is 0.3 percent for the Metropolitan Region (which includes Santiago) and 0.5 percent for the rest of the country. In May 1998 these limits will be reduced to 0.2 and 0.3 percent, respectively. In Colombia the current limit is 0.4 percent. This will be reduced to 0.1 percent in 1998 and 0.05 percent in 2002. In Mexico the limit for the low-sulfur diesel fuel (called Diesel Sin) used in urban areas is the same as in the United States (0.05 percent). In 1995 the sulfur content of Diesel Sin was between 0.03 and 0.05 percent (DDF 1996). The limit for high-sulfur diesel fuel used for intercity transport was 0.5 percent. However, the high-sulfur diesel fuel was eliminated from the market in February 1997.

Along with sulfur content standards, tax incentives are used to lower the sulfur content of diesel fuel sold in some European countries. For example, in 1992 Denmark introduced a tax incentive for lower sulfur grade diesel fuel (with a maximum of 0.05 percent) and in 1993 for "no sulfur" grade diesel fuel (with a maximum of 0.005 percent). In Sweden low sulfur and low aromatic grades of diesel fuel receive tax breaks. Since 1993 the use of sulfur-free diesel fuel in Finland has been encouraged by a tax incentive (CONCAWE 1994).

The sulfur content of diesel fuel can be re-

duced by hydrodesulfurization.[19] Low-pressure hydrodesulfurization units are capable of removing 65 to 75 percent of the sulfur, lowering aromatic levels by 5 to 10 percent, and increasing the cetane number by 1 to 2 points. However, newer high-pressure hydrodesulfurization units can remove more than 95 percent of sulfur and lower aromatic levels by 20 to 30 percent (Faiz, Weaver, and Walsh 1996). In Europe the cost of reducing sulfur in diesel fuel from 1.0 percent to 0.05 percent ranges from $0.009 to $0.014 a liter (CONCAWE 1989).

Cetane number. The cetane number is a measure of the spontaneous ignition quality of diesel fuel at the same temperature and pressure as in the combustion chamber of the engine.[20] The cetane number of diesel varies from 43 to 57 (with an average of 50) in Europe, but is lower in the United States (40 to 44). The cetane index, occasionally used instead of cetane numbers, is an approximation of the cetane number based on an empirical relationship with gravity and volatility parameters.

The higher the cetane number, the shorter the delay between injection and ignition and the better the ignition quality. A higher cetane number is desirable because it improves combustion, reduces HC, CO, and PM emissions especially during vehicle warm-up, improves cold starting, reduces white smoke after starting, and lowers noise levels (OECD/IEA 1993). At lower cetane numbers, especially at cetane numbers below 45, black smoke and HC and CO emissions increase. It is estimated that a two-point reduction in the cetane number from a European median of 50 could increase NO_x emissions by 2 percent and PM emissions by up to 6 percent. The emission benefits, however, may not be significant beyond the current European levels. Diesel fuels with high cetane numbers, which tend to be paraffinic, could also cause driving problems in cold weather conditions (Faiz, Weaver, and Walsh 1996).

The cetane number of diesel fuel is affected by crude fuel properties and refinery operations. Diesel fuels with straight-chain hydrocarbons have higher cetane numbers than those with branched hydrocarbons and those with a higher aromatic content. The cetane number is controlled by maintaining a proper boiling range of the cut from the atmospheric distillation unit. Inclusion of the lighter naphtha fraction into this cut reduces the cetane number. Some refineries, such as those in the United States, catalytically crack heavy oil to produce gasoline and blend the cracked stream containing high percentages of aromatic hydrocarbons into the diesel cut. However, this practice increases the aromatic HC content and reduces the cetane number. To boost the cetane number, these refineries may need to switch to hydrocracking or segregate the highly aromatic distillate streams for use in other products such as fuel oil. The addition of certain barium or calcium derivatives in diesel fuel suppresses smoke emissions but increases PM-sulfate emissions. Copper-based diesel fuel additives may increase dioxin emissions.

The cetane number of diesel fuel is regulated in some Latin American countries. For example, the required minimum cetane number is 40 in Brazil, 45 in Chile and Colombia, 48 (for low-sulfur diesel fuel) and 45 (for high-sulfur diesel fuel) in Mexico, and 50 in Argentina. These limits compare with minimum cetane number requirements of 40 in the United States, 47 in Finland (for reformulated diesel), and 47 and 50 for the two grades of urban diesel fuel in Sweden (CONCAWE 1994). In 1995 the typical observed value for the cetane number of diesel fuel was 49 in Chile and 55.4 (for low-sulfur diesel fuel) in Mexico (Ruiz 1995; DDF 1996).

Aromatic hydrocarbons and density. The aromatic HC content of diesel fuels depends on crude properties and refinery operations. Blending of the diesel cut from the catalytic conversion and atmospheric distillation units increases the aromatic HC content of diesel fuels.

The aromatic HC content, cetane number, and density of diesel fuels are closely related. Diesel fuels with a higher aromatic HC content tend to be denser and have lower cetane numbers. A high aromatic HC content is associated with difficulty in cold engine starting, and in-

19. Hydrodesulfurization involves catalytic reaction of sulfur-containing oil molecules (the diesel fraction from the atmospheric distillation unit and light oils from catalytic cracking and coking units) with hydrogen. This process removes sulfur as hydrogen sulfide.

20. The cetane number of a fuel is determined by comparing its ignition property with that of a fuel mixture consisting of n-cetane (a straight-chain paraffinic hydrocarbon whose assigned cetane number is 100) and heptamethyl nonane (a branched paraffinic hydrocarbon whose cetane number is 15).

Table 3.14 Standards for aromatic HC, PAH, and density of diesel fuel in Finland, Sweden, and the United States

Country	*Aromatic HC (maximum % by volume)*	*PAH (maximum % by volume)*	*Density (kg/m^3)*
Finland—Reformulated diesel fuel	20		
Sweden—Urban diesel 1	5	0.02	800–820
Urban diesel 2	20	0.1	800–820
United States (California)	10	1.4	824–860

Note: A blank space indicates that no standard was established. Aromatic HC is aromatic hydrocarbons; PAH is polycyclic aromatic hydrocarbons.
Source: CONCAWE 1994.

creased HC, NO_x, and noise emissions. Exhaust emissions from combustion of highly aromatic diesel fuels contain carbonaceous PM that include soot, soluble organic fraction, and PAH. These emissions can be reduced with diesel fuel additives. Higher density diesel fuels result in black smoke and PM emissions (Faiz, Weaver, Walsh 1996).

In Europe the aromatic HC content of diesel fuel has been regulated in Finland and Sweden (Table 3.14). Sweden has established aromatic HC and PAH limits for two diesel fuel grades, which are supported by tax incentives. The regulation also specifies the density requirement for these fuels. Diesel fuel specifications in California limit aromatic HC and PAH content, fuel density, and other parameters such as sulfur (see Table 3.14). A diesel fuel with different parameters is allowable as long as its emissions are not greater than those of this reference fuel (CONCAWE 1994).

The aromatic HC content of diesel fuel is limited to 20 percent by volume in Colombia. In Mexico the limit is 30 percent by volume for low-sulfur diesel fuel. In 1995 the low-sulfur Mexican diesel fuel contained 26.6 percent aromatic HC (DDF 1996). Density of diesel fuel is limited between 820 kg/m^3 and 880 kg/m^3 in Brazil and between 830 kg/m^3 and 870 kg/m^3 in Chile.

Alternative Fuels

Since the 1970s rising oil prices and greater concerns about the health and environmental effects of air pollution have prompted the development of alternative fuels for the transport sector. These fuels include compressed natural gas (CNG, composed mainly of methane), liquefied petroleum gas (LPG, composed of propane and butane), methanol (made from natural gas, coal, or biomass), ethanol (made from grain or sugarcane), vegetable oils, electricity, hydrogen, synthetic liquid fuels (derived from hydrogenation of coal), and various fuel blends such as gasohol. A number of alternative fuels have been used commercially in an effort to curtail air pollution in urban centers (Tables 3.15 and 3.16). Among these, CNG and LPG reduce pollutant emissions and provide some economic benefits for certain applications and in specific locations. Alcohol fuels (ethanol and methanol), because of their lower ratio of carbon to hydrogen (4:1 for ethanol, 3:1 for methanol, and 6:1 for diesel fuel and gasoline), result in lower CO_2 emissions than gasoline and diesel fuel but are more expensive. Hydrogen and methanol burn efficiently and are intrinsically low-polluting fuels but are uneconomic at the present time. There are no greenhouse effects associated with the use of hydrogen because its combustion does not produce CO_2. However, hydrogen is difficult to store in motor vehicles and its production from fossil fuels would probably generate high pollutant emissions (ECMT 1990). In addition, on a unit energy basis hydrogen is about twice as expensive as gasoline at the wholesale level and more than thirty times as expensive at the retail level. Use of electricity as a fuel substitute for road-based vehicles can also reduce pollutant emissions considerably, although this reduction is often very costly. In addition, electric cars have considerably shorter driving ranges than cars fueled by conventional fuels.

The potential environmental benefits of alternative fuels must be considered with caution. In

Table 3.15 Properties of some conventional and alternative fuels

Property	*Gasoline*	*Diesel*	*Methane*	*Propane*[a]	*Methanol*	*Ethanol*
Energy content (LHV) (MJ/kg)	44.0	42.5	50.0	46.4	20.0	26.9
Liquid density (kg/liter)	0.72–0.78	0.84–0.88	0.4225	0.51	0.792	0.785
Liquid energy density (MJ/liter)	33.0	36.55	21.13	23.66	15.84	21.12
Gas energy density (MJ/liter)						
At atmospheric pressure	n.a.	n.a.	0.036	0.093	n.a.	n.a.
At 2,900 psi pressure	n.a.	n.a.	7.47	n.a.	n.a.	n.a.
Boiling point (°C)	37–205	140–360	–161.6	–42.15	65	79
Research octane number	92–98	25	120	112	106	107
Motor octane number	80–90	n.a.	120	97	92	89
Cetane number	0–5	45–55	0	2	5	5

n.a. Not applicable.
Note: LHV is lower heating value.
a. Most of the LPG sold in the U.S. is propane.
Source: Weaver 1995.

many instances the same or even better emission reductions can be achieved with conventional fuels in vehicles equipped with advanced emissions control systems.

Compressed natural gas. After coal, natural gas is the world's most abundant fossil fuel with proven reserves estimated to be twice those of petroleum. In Latin America and the Caribbean, the largest proven natural gas reserves and production are located in Mexico and Venezuela. Other countries with high natural gas production are Argentina, Trinidad and Tobago, Brazil, Colombia, and Bolivia.

Natural gas contains predominantly methane (95 to 99 percent) with the balance made up by other gases (such as ethane and propane). It is used mainly in the industrial and domestic sectors, as well as in the transport sector. Large quantities of natural gas are transmitted and distributed by land through gas pipelines. For bulk shipment by sea or train, it is liquefied and maintained at cryogenic temperatures (that is, as LNG). It is also transported in a compressed form in cylinders for short distances. Natural gas is stored as a liquid or compressed gas. However, for use as a transport fuel it is stored in vehicles in heavy cylinders as a gas pressurized to about 3,000 psi and at ambient temperatures (that is, as CNG).

Almost all the CNG-fueled light-duty vehicles in the world have been retrofits from gasoline-fueled vehicles. Such retrofits allow the vehicle to be fueled with either CNG or gasoline. Vehicle conversion for CNG fueling includes installation of at least one high-pressure storage cylinder, a gas fueling outlet, piping from the cylinder to the engine, a CNG supply gauge and a switch on the dashboard indicating the fuel entering the engine, a pressure regulator to reduce the tank's gas pressure to atmospheric pressure, and an emergency fuel shut-off system. In

Table 3.16 Prices of some conventional and alternative fuels in the United States
(fourth quarter 1992 dollars)

	Gasoline	*Methanol*	*Ethanol*	*LPG*	*CNG*
Wholesale ($/liter)	0.13–0.18	0.08–0.11	0.34–0.38	0.07–0.12	0.07–0.13
Wholesale ($/therm)	0.41–0.54	0.56–0.74	1.70–1.91	0.29–0.53	0.26–0.52
Retail ($/liter)	0.26–0.35	0.21–0.24	—	0.25–0.29	0.11–0.24
Retail ($/therm)	0.78–1.06	1.41–1.62	—	1.12–1.29	0.41–0.93

— Not available.
Note: 1 therm = 0.009478 MJ.
Source: Faiz, Weaver, and Walsh 1996.

Table 3.17 Exhaust emissions from CNG- and diesel-fueled buses
(grams per kilowatt hour)

Bus type	*CO*	*HC*	*NO_x*	*PM*
CNG-fueled city bus	0.4	2.1	4.3	< 0.05
CNG-fueled regional bus	2.5	3.1	2.9	< 0.05
Diesel-fueled bus	4.0	1.2	14.0	0.55
1996 European Union Standard	4.0	1.1	7.0	0.15

Note: The tests were performed in the Netherlands on two buses equipped with DAF GKL1160 engines. These engines were converted to lean-burn naturally-aspirated engines with an oxidation catalyst for CNG testing.
Source: *Prensa Vehicular* 70. October 15, 1994.

addition, modifications to the carburetor or the fuel injection system are needed.

In the United States tests performed on dual-fuel light-duty vehicles with model-years ranging from 1983 to 1987 (with sophisticated controls) show that as much as a 97 percent reduction in CO emissions can be achieved with CNG over gasoline if the vehicle is properly calibrated with leaner air-fuel ratios. These tests also confirmed the results of previous tests conducted on pre-1981 model-year dual-fuel light-duty vehicles. In addition, tests on the newer vehicles indicate that CO emissions can be as low as 0.17 gram/km, NO_x emissions can be significantly higher (as much as 195 percent) if design tradeoffs are not implemented, and NMHC emissions can be higher or lower (Alson, Adler, and Baines 1989). Exhaust emissions from combustion of CNG do not contain benzene, 1,3 butadiene, formaldehyde, or lead. There are no evaporative or running loss emissions with CNG because the fuel system is sealed.

Very few light-duty vehicles are of original equipment manufacture (OEM; that is, designed to use CNG). In the United States OEM CNG-fueled vehicles are mostly operated by gas companies. Optimization of the engine design for these vehicles (to reduce pollutant emissions) includes raising compression ratios to take advantage of their higher octane rating, advanced timing, and leaner operation. Tests performed in the United States on pick-up trucks designed to burn CNG indicated emission reductions of up to 99 percent for CO and about 30 percent for NMHC relative to comparable gasoline-fueled vehicles. However, the CNG-fueled vehicles yielded higher NO_x emissions (Alson, Adler, and Baines 1989).

CNG has also been used as a transport fuel in retrofitted diesel-fueled buses or buses originally designed to burn CNG. Compared with diesel-fueled buses, CNG-fueled buses have lower NO_x, CO, and PM emissions but higher HC emissions, which mostly consist of methane (Table 3.17). Combustion of CNG does not emit SO_2.

A major concern with light-duty dual-fuel vehicles is the size and weight of the CNG storage cylinder. Depending on its material construction, a full CNG cylinder weighs more than twice as much as and up to five times as much as a full gasoline tank to provide the same amount of energy. Space and weight considerations in light-duty dual-fuel vehicles restrict the maximum number of CNG cylinders in the trunk to two or three. This limits the travel range of vehicles before refueling. A typical fueling by "fast fill" systems takes five to ten minutes. In addition, CNG is less readily available than gasoline at retail fuel stations in urban centers and may not be available at all outside urban areas. For these reasons gasoline- or diesel-fueled cars generally are not converted to CNG by private vehicle owners. However, in countries where CNG is cheaper than gasoline and the trunk space is not very important, owners of light-duty commercial vehicles prefer the CNG conversion. This is the case for taxi drivers in Buenos Aires, where vehicle conversion costs are recovered in about two years through fuel savings. A further concern about the additional weight of CNG is associated with the reduction in acceleration rates, need for longer braking distances, and decreases in the fuel efficiency of vehicles.

Many of the concerns that exist with light-duty CNG-fueled vehicles are not relevant for CNG-fueled buses. Since CNG-fueled urban buses have space for CNG cylinders in the chassis area, they are not affected by the travel range restriction. However, CNG cylinders and their associated tubing add additional weight on buses. In addi-

tion, CNG-fueled buses can be refueled through "slow fill" systems overnight at a central station.

CNG's potential as a transport fuel is strongly affected by its price in the local market. Although natural gas is much cheaper to produce than gasoline, it is much more expensive to distribute. In addition, it requires costly compression to about 3,000 psi. A CNG refueling station that serves 100 cars a day can cost as much as $300,000, $150,000 of which is for compression equipment and fuel pumps. Gas compression and refueling costs add between $0.016 and $0.024 to the price of natural gas energy equivalent of a liter of gasoline (CCEEB 1990). Costs incurred by vehicle owners for CNG retrofitting range from $1,000 to $1,500 for light-duty vehicles, $2,000 to $3,000 for light-duty trucks and vans, and $5,000 to $7,000 for buses. A new bus designed to use CNG costs 15 to 20 percent more than a similar diesel-fueled bus.

CNG has been used in many countries. About 300,000 vehicles in Italy, 200,000 vehicles in Russia, 55,000 vehicles in the United States, 45,000 vehicles in New Zealand, and 40,000 vehicles in Canada run on CNG. In the United States many utility companies operate vehicles powered exclusively by CNG.

Among Latin American and Caribbean countries, Argentina uses CNG most extensively as a motor vehicle fuel. In addition, CNG-fueled vehicles circulate in Brazil, Colombia, Mexico, Peru, Trinidad and Tobago, and Venezuela. Since the initiation of Argentina's 1985 tax exemption program for natural gas, about 400,000 vehicles have been retrofitted to burn CNG. About 270,000 of these vehicles are circulating in the Buenos Aires Metropolitan Area. Over 80 percent of about 46,000 taxis, many light-duty trucks and chauffeured short-term cars, and some private cars and buses circulating in Buenos Aires are fueled with CNG. Elsewhere in the region, General Motors recently introduced CNG-ethanol dual-fuel capability in two of its new vehicle models in Brazil. In São Paulo about 3,000 taxis run on the CNG-ethanol dual-fuel system, and 80 urban buses are fueled with CNG. In Rio de Janeiro about 2,000 taxis have been retrofitted to use CNG since 1990, and 200 buses are CNG-fueled. CNG has not been used as a transportation fuel in Santiago because it is not locally available. However, use of CNG in buses will be considered when natural gas is made available from Argentina through a pipeline. Mexico City's CNG program was initiated in 1992 as a pilot program. It included the supply of an additional 2.5 million cubic meters a day of natural gas (enough to fuel 45,000 vehicles) by the national petroleum company Pemex, construction of a new service station for CNG fueling and rehabilitation of an existing station, and conversion of some private and commercial vehicles, police cars, and microbuses. In addition, a LNG plant was constructed to supply fuel for buses and trucks (CMPCCA 1995). About 6,000 light-duty vehicles in Venezuela and 3,000 in Trinidad and Tobago use CNG.

CNG's market potential as a motor vehicle fuel could be increased if vehicle manufacturers commit to CNG-fueled vehicle development programs that lead to technological advances in engine, storage cylinder, and vehicle designs.

Liquefied petroleum gas. Liquefied petroleum gas (LPG) is a by-product of natural gas treatment at cryogenic temperatures, whereby liquefied components are purified and then maintained as a pressurized liquid for ease of handling. LPG is also a by-product of crude oil refining. It consists mainly of propane and butane, with some minor quantities of propylene and other hydrocarbons. Propane and butane can be used separately or in mixtures. Since propane has a superior knock resistance (with an octane number of 112, which is superior to gasoline but lower than natural gas), it is preferred over butane for use as a transportation fuel.

LPG is produced in countries with natural gas and petroleum exploitation or refining capabilities. LPG is distributed overland by pipelines, railroad cars, and trucks. Where LPG is transported by sea in tankers and barges, it is received in bulk storage and distribution terminals. Uses of LPG include residential and commercial heating, chemical manufacturing, agricultural product drying, industrial processing, and transport.

About 3.9 million vehicles operate on LPG worldwide. LPG is very popular in Asian countries, including Japan, Thailand, and the Republic of Korea. In Japan alone some 1.5 million cars are fueled with LPG. In addition, many three-wheelers in Asian countries have been converted to LPG. The use of LPG is also growing quickly in Europe (for example, in the Netherlands and Austria). The United States and Canada are estimated to have 330,000 and 140,000 LPG-fueled vehicles, respectively. About 90 percent of these fleets are commercially operated.

In Latin America and the Caribbean LPG is used extensively as a motor vehicle fuel in Venezuela (68,200 barrels per day or bbd) and Suriname (36,011 bbd). Other countries of the region using LPG include Bolivia (7,448 bbd), Costa Rica (1,250 bbd), Dominican Republic (6,850 bbd), Mexico (3,000 bbd), and Paraguay (957 bbd). In addition, LPG is used to some extent in Colombia, El Salvador (2 bbd), Peru, and St. Kitts-Nevis (12 bbd; Alconsult International Ltd. 1996; Berumen 1996).[21] To date about 28,300 passenger and freight vehicles and vans in Mexico City have been converted to LPG. Of these, more than 95 percent belong to commercial companies. Pemex supports this program through production of LPG. Ten LPG fueling stations have been constructed to fuel about 8,000 vehicles on a daily basis. In addition, most commercial companies that have converted their fleets to LPG have their own storage and fueling facilities (Sánchez 1996). In Santafé de Bogotá a fuel switching program for buses and taxis has been initiated by the Santafé de Bogotá District Environmental Agency in coordination with the national oil company Ecopetrol.

Throughout the world, most LPG-fueled vehicles are conversions from gasoline-fueled cars, although there are some OEM LPG-fueled vehicles. For example, Nissan and Toyota in Japan and Hyundai in the Republic of Korea manufacture LPG-fueled taxis, and Ford in the United States manufactures LPG-fueled medium-duty trucks. Most gasoline-to-LPG conversions dedicate the engines to LPG use because of differences in optimal settings for either fuel. However, dual-fuel LPG vehicles are also available. An LPG-fueled car or truck essentially has the same engine as a gasoline-fueled vehicle with the exception of the carburetor or fuel injection system. This is because LPG, which enters the engine as a gas, requires metering through throttling instead of the complex liquid-to-gas atomization system used for gasoline. Storage of LPG at moderately high pressure (up to 200 psi) requires the use of cylinders, which take about 45 percent more space than a gasoline tank holding an equivalent amount of fuel. Although LPG tanks are heavier, the fuel is lighter than gasoline, so the total weight of the tank and fuel is about 20 kilograms more for a mid-size LPG-fueled car than for a gasoline-fueled car. Refueling LPG vehicles requires additional fittings to attach the dispensing nozzle to the vehicle. To avoid overpressuring, an overfill prevention device is also required to ensure that the LPG cylinder is not filled more than 80 percent (CCEEB 1990).

LPG-fueled vehicles have lower CO, CO_2, and PM emissions than gasoline-fueled vehicles and do not emit lead or SO_2. CO emissions are 25 to 80 percent lower. Evaporative emissions from LPG-fueled vehicles are negligible because of the tight seals for the LPG fuel system. NO_x emissions from LPG-fueled vehicles not equipped with catalytic converters are higher than those from similar gasoline-fueled vehicles because of the higher flame temperature. However, LPG-fueled vehicles with catalytic converters produce NO_x emissions similar to gasoline-fueled vehicles and less than diesel-fueled vehicles. HC emissions from the exhaust of LPG-fueled vehicles, although exceeding those from gasoline-fueled vehicles in certain cases, are less reactive in forming ozone (CCEEB 1990).

LPG can deliver up to 85 percent of gasoline's kilometers per liter. The engine power and acceleration performance of LPG-fueled vehicles are similar to gasoline-fueled vehicles. LPG, because of its ability to vaporize at low temperatures, has an advantage over other liquid fuels for cold weather starting. This characteristic prevents much of the engine wear and crankcase oil dilution by fuel leaks during starting and warm-up periods (CCEEB 1990).

Especially in LPG-producing countries, LPG is a cheaper fuel than gasoline or diesel fuel. The wholesale price of propane closely follows those of gasoline and diesel fuel. In the United States the wholesale price of a liter of propane is about half that of a liter of gasoline.[22] However, this relative price advantage may not be maintained at the retail level because of the higher transportation and storage costs and greater retail margin (due to lack of economies of scale) for LPG.

LPG is an attractive automotive fuel because it is cheaper than gasoline or diesel fuel in many locations. In addition, the cost of converting a gasoline- or diesel-fueled vehicles to LPG is low. The cost of converting light-duty gasoline-fueled vehicles to LPG ranges from $2,000 to $3,000,

21. All consumption figures are for 1995.

22. In mid-1996 the Gulf Coast wholesale price of LPG varied between $0.073 and $0.092 a liter.

depending on the size of the fuel cylinders. For high-use vehicles (taxis, light-duty commercial trucks, urban buses) this cost usually can be recovered within a few years. A new LPG-fueled medium-duty truck costs about $1,000 more than a similar gasoline-fueled truck.

Canada is an example of a country where successful conversion to LPG (propane) has occurred (Box 3.5). In the United States LPG is used mainly in commercial fleets, including light- and medium-sized commercial trucks (for example, for carrier services and newspaper distribution), taxis, police cars, and buses (school buses, urban buses, and special service buses). In Houston, Texas, conversion of the urban bus fleet was initiated in 1990. Emission tests performed on these buses indicated full compliance with California's stringent standards for NMHC, CO, NO_x, and PM (J.E. Senior Consultants Inc. 1993).

Methanol. Methanol, or methyl alcohol, is a chemical that can be produced from natural gas, liquid hydrocarbons, coal, or biomass. The most economical way to produce methanol is from natural gas. Methanol is a feedstock for the production of chemicals such as formaldehyde, solvents, and acetic acid. In the past fifteen years, it has also been increasingly used to produce MTBE, an octane-boosting gasoline additive. The use of methanol as a dedicated transport fuel has been limited.

As a transport fuel, methanol contains 48 percent of gasoline's and 43 percent of diesel fuel's energy content per liter (see Table 3.15). However, this lower energy density is somewhat compensated by methanol's higher octane number, which allows higher engine compression ratios and improved fuel efficiency. As a result about 1.8 liters of methanol are required to travel the same distance as 1.0 liter of gasoline. Thus methanol-fueled vehicles require more frequent refueling for a given fuel storage tank capacity or greater fuel storage capacity (and cost) for the same refueling frequency.

Because methanol has a higher auto-ignition temperature than diesel fuel, it does not ignite in a diesel engine under normal operating conditions. For this reason the use of methanol in a diesel engine requires installation of either a spark plug to convert the engine into a spark-ignition engine or a heating element (called a "glow plug") to raise the temperature in the combustion chamber above the auto-ignition temperature of methanol.

Combustion of methanol does not produce SO_2 or lead emissions. As compared to gasoline, combustion of methanol in motor vehicles produces lower emissions of benzene and polycyclic aromatic hydrocarbons. Methanol-fueled vehicles, however, emit unburned methanol and considerably higher levels of formaldehyde than gasoline-fueled vehicles. Despite the high reactivity of formaldehyde, the ozone forming po-

Box 3.5 Liquefied petroleum gas in Canada

The Canadian government began promoting the use of propane in the transport sector in 1980 by providing a $280 grant to vehicle owners to convert to propane or purchase a new propane-fueled vehicle. This program was bolstered by provincial governments through such incentives as the removal of sales taxes on propane, propane-fueled vehicles, and propane conversion kits. By 1985 about 130,000 vehicles, most of which were commercial (urban truck fleets and taxis), had been converted to propane and were served by about 4,000 propane fueling stations. The payback periods were about three years with the incentives and four years without. Because of the plentiful supply of propane, the federal government's financial incentives were removed in March 1985 and efforts were directed toward working with provincial governments and the propane industry to foster continued growth in the demand for propane as a transport fuel. The government's new measures included a research and development partnership between the federal government of Ontario and Chrysler Canada to provide propane technology on vehicles manufactured in Canada; demonstration project to promote the use of propane in urban buses in Ottawa; a grant to the industry association for market development; public information campaigns; and use of propane within the Canadian federal fleet. The use of propane in the transport sector is expected to continue to grow as retail fuel pricing differentials do not diminish.

Source: Sathaye, Atkinson, and Meyers 1989; Sauvé 1989.

tential of total HC emissions is less for methanol than gasoline. Tests performed on catalytic converter-equipped methanol-fueled light-duty vehicles indicate that NO_x emissions are at least twice as high as their gasoline counterparts. As compared to diesel fuel, methanol-fueled heavy-duty engines emit substantially less PM and, for some engine designs, less NO_x. Methanol-fueled buses, however, require evaporative emissions controls that are not needed with diesel-fueled buses as well as oxidation catalysts for controlling CO, methanol, and formaldehyde emissions. (CCEEB 1990).

Because of its low volatility and high heat of vaporization, methanol is associated with difficult engine starting at ambient temperatures below 10°C. This also causes high emissions of CO, methanol, and formaldehyde. In addition, methanol-fueled vehicles have higher maintenance costs than gasoline-fueled vehicles because methanol and the formic acid it forms are corrosive chemicals and can dissolve materials such as solder, aluminum, and rubber. Experience with certain engine designs suggests that the engine life for these designs is likely to be considerably shorter than for gasoline-fueled engines. Although the excessive engine wear problem has been substantially solved by fuel and lubricant additives, methanol-fueled cars still require frequent oil and filter changes.

Another disadvantage of methanol is associated with its safety characteristics. Methanol burns with a nearly invisible flame during daylight, making detection and control of fires difficult. In addition, at ambient temperatures methanol vapors in the fuel tank are in the explosive range. Furthermore, methanol is a toxic chemical. Its adverse health effects include skin irritation, visual disturbances (including blindness), loss of muscular coordination, dizziness, nausea, abdominal cramps, delirium, coma, convulsions, respiratory failure, cardiac arrest, and death.

To improve the cold start, flame luminosity, and vapor explosivity problems of pure methanol, a blend consisting of 85 percent methanol and 15 percent gasoline (M85) was developed and tested on vehicles. Use of the M85 fuel requires simple modifications on gasoline-fueled cars, including changes to the carburetor (or fuel injection system) and the materials in the fuel delivery system, and an increase in the compression ratio. M85-fueled cars have CO emissions similar to gasoline-fueled cars but 30 to 44 percent less ozone-forming HC emissions (CCEEB 1990).

Methanol has been used in professional racing cars because it allows fast acceleration and speed in high-performance engines. There are only about 800 dedicated methanol-fueled vehicles worldwide. About 600 passenger cars—manufactured by Ford and Volkswagen—have been operated under the California Energy Commission's (CEC) methanol vehicle program. This program has shown the potential application for methanol-fueled vehicle technology under warm weather conditions, while indicating areas for improvement. In 1986 the commission initiated a new phase aimed at developing flexible-fuel vehicles that can operate on gasoline, methanol, ethanol, or mixtures of these fuels.

In Brazil methanol was used as a component of the transport fuel blend MEG during 1990–93 to overcome the ethanol shortage caused by a drop in sugar cane production. During this time about 7 billion liters of MEG were consumed in the State of São Paulo, mostly in the São Paulo metropolitan area. This fuel—a mixture of 33 percent methanol, 60 percent ethanol, and 7 percent gasoline—has properties and fuel consumption characteristics similar to ethanol. The emissions from both fuels are the same, except that acetaldehyde emissions from MEG are about 50 percent lower and formaldehyde emissions are about 5 percent higher. Use of MEG in ethanol-fueled light-duty vehicles does not require any special engine modification or calibration.

The use of methanol in diesel-fueled heavy-duty vehicles also has been studied. Since 1983 the Golden Gate Transit Company has been operating two methanol-fueled buses in San Francisco. One of these buses was modified with a spark plug and the other with a glow plug. The technical problems encountered with these buses have included fuel pump breakdowns and frequent spark plug or glow plug failures. Particulate emissions from these buses are lower than from comparable diesel-fueled buses, but CO and formaldehyde emissions are higher. Various transit authorities in the Los Angeles area also have demonstrated the application of methanol on heavy-duty diesel vehicles (urban buses, school buses). In addition, several diesel engine manufacturers (Caterpillar, Cummins, Ford, Detroit Diesel, and Navistar) are conducting research on the use of methanol in diesel engines.

A major drawback of methanol as a transport fuel is its relatively high and volatile price relative to conventional transport fuels. The price of methanol in the world market increased from \$0.06 a liter in the early 1980s and about \$0.17 a liter in the late 1980s to about \$0.47 a liter in 1994. Methanol would have to cost \$0.10 a liter to compete with the spot price of gasoline of \$0.18 to \$0.20 a liter on an equivalent energy efficiency basis (Faiz, Weaver, and Walsh 1996). There is little prospect for methanol to become price-competitive with conventional transport fuels unless world oil prices increase substantially.

Ethanol. Ethanol, or ethyl alcohol, is a chemical that can be produced by fermentation of sugar extracted from biomass such as sugarcane or corn, or by catalytic hydration of ethylene. It is marketed as a final product, industrial feedstock, or transport fuel. As a transport fuel ethanol has been used as a dedicated fuel in hydrous form or in combination with gasoline (the resulting fuel is called "gasohol") or gasoline and methanol (the resulting fuel is called MEG; see above) in anhydrous form. Ethanol marketed as a transport fuel is derived from biomass in most countries and its price as a transportation fuel is tied to food prices. In Brazil the ethanol industry (the world's largest) is based almost entirely on sugar cane, whereas more than 80 percent of the U.S. ethanol plant capacity (the world's second largest) uses corn as the input material.

As a transport fuel, ethanol's properties lie between methanol and gasoline. The energy density of ethanol is about two-thirds that of gasoline but greater than that of methanol. Ethanol has about the same octane number as methanol (see Table 3.15). Because it is water soluble, it must be kept free of water if it is blended with gasoline for use as a transport fuel. Its corrosion characteristics are milder than those of methanol's but more severe than gasoline's.

Ethanol or gasohol can be used in spark-ignition engines with the same type of engine modifications required for methanol-fueled vehicles. The exhaust emissions control technology used in Brazil for ethanol- or gasohol-fueled light-duty vehicles has improved over the years. The current technology includes multipoint fuel injection, mapped electronic ignition, and closed-loop three-way catalytic converters with feedback control of the air-fuel ratio (Branco and Szwarc 1993). Control of aldehydes to meet stringent emission requirements is expected to be achieved through use of a palladium catalyst relocated near the engine. For evaporative emissions, a charcoal canister placed near the front wheel was first used. This control was subsequently improved through the installation of thermal insulation between the carburetor and the engine.

Ethanol does not emit SO_2 and has negligible PM emissions. SO_2, PM, CO, and NO_x emissions from uncontrolled ethanol-fueled vehicles are less than those from gasoline or gasohol-fueled vehicles of the same model-year. Because of ethanol's lower CO emissions, 10 percent ethanol blends (or MTBE gasoline blends) in gasoline are required in certain U.S. cities. Uncontrolled ethanol-fueled vehicles emit more aldehydes (especially acetaldehyde) from the exhaust than similar gasoline-fueled vehicles. However, these emissions can be controlled with the use of a catalytic converter. Cold start emissions from ethanol- and gasohol-fueled vehicles are not a problem in countries with a hot climate (such as Brazil) but may be a concern for other locations. Quantitative data on typical emissions from ethanol-, gasohol-, and gasoline-fueled vehicles are shown in Chapter 4 in the section on São Paulo.

In the United States subsidies ensure that ethanol is produced from biomass (mostly by corn fermentation) instead of ethylene hydration. Ethanol production in the United States costs about \$0.33 a liter (\$1.24 a gallon), including the subsidy (Rendleman and Hohmann 1993). Since a liter of ethanol contains two-thirds the energy of a liter of gasoline, the wholesale price of ethanol at the plant gate, on an energy equivalent basis, ranges from \$0.39 to \$0.61 a liter. The State of California's Energy Commission has concluded that ethanol production from conventional feedstocks (such as corn) would not be economical in California. In addition, the U.S. Department of Agriculture has argued that, since much of the benefit of ethanol subsidies goes to large producers and retailers instead of farmers, subsidized ethanol production is an inefficient way of raising farm income. Furthermore, the subsidy program raises beef and pork prices in the United States (CCEEB 1990).

In Latin America and the Caribbean ethanol is used in Brazil (Box 3.6) and Paraguay as a light-duty motor vehicle fuel. In Brazil ethanol is used instead of gasoline either as an anhydrous form in a blend with gasoline (78 percent gasoline with 22 percent ethanol) or in hydrous form

Box 3.6 Proalcohol program in Brazil

The Proalcohol Program in Brazil has been the largest alternative fuels program in the world to date. This program was initiated by the Brazilian government in 1975 in response to a sharp increase in world oil prices that adversely affected Brazil's foreign debt and economic growth and a rapid decrease in world sugar prices that put the recently expanded and modernized Brazilian sugar industry in a difficult financial situation. The Proalcohol Program was implemented in two phases. The first phase, implemented during 1975–79, aimed at increasing the percentage of ethanol in gasohol to 20 percent nationwide. The second phase, carried out during 1979–85, focused on providing 100 percent hydrous ethanol (containing 96 percent ethanol and 4 percent water by volume) to ethanol-dedicated vehicles.

Ethanol produced by private distillers was purchased by government entities (first the National Petroleum Council and then by Petrobrás, the national petroleum company of Brazil) on a sugar-equivalent basis according to fixed prices and quotas. Incentives for producers included credit subsidies for up to 75 percent of investment costs and government assurance of a 6 percent return on investments for supplying ethanol to the government. In 1979 the goals of the program's first phase were reached because the 20 percent ethanol blend did not require major modifications in vehicle or fueling station technologies, and the ethanol supply was provided through use of excess capacity and rapid construction of new distilleries. Auto manufacturers demonstrated the feasibility of using ethanol as a dedicated fuel in spark-ignition engines, but did not commit themselves to mass production.

The second phase of the program promoted the use of hydrous ethanol in light-duty vehicles. It was initiated as a result of increasing world oil prices and Brazilian foreign debt. Specific goals of this phase included increasing production of ethanol-dedicated vehicles to 50 percent of new vehicle sales and supplying and distributing 10.6 billion liters of ethanol by 1985. The second goal required an investment of $5 billion for a 150 percent increase in alcohol production capacity. The necessary funds were provided by both domestic sources (fuel taxes, vehicle licensing fees, and so on) and international financial institutions. Consumer incentives to buy new cars included lower purchase taxes and registration fees, smaller downpayments, longer repayment periods, and lower fuel costs. For example, taxi drivers buying new vehicles were exempt from taxes—the equivalent of about a 50 percent discount. The pump price of ethanol was guaranteed to be no more than 65 percent of gasohol, providing ethanol a 20 percent advantage in cost per kilometer. However, the actual ratio of the ethanol-gasoline price varied over time.

The auto manufacturing industry invested heavily in tooling and research and development on ethanol-fueled vehicles. However, the first generation ethanol-dedicated new vehicles and retrofits caused customer dissatisfaction because of the lack of technical expertise by auto manufacturers in producing alcohol-fueled cars and by unauthorized mechanics in conducting poor vehicle conversions. The auto manufacturing industry regained public confidence by improving engine quality. As world sugar prices rose, the government raised the price of ethanol in the late 1980s from 40 percent of the price of gasoline toward the 65 percent limit. This measure resulted in a drop in ethanol-fueled vehicle sales. The incentives for distillers and consumers were removed and then restored, in some cases more strongly, raising the demand for ethanol-dedicated cars in 1984 and 1985.

Between 1976 and 1985 investment in the Proalcohol Program totaled $3.7 billion for the Brazilian government and $2.7 billion for the private sector, and the foreign exchange savings were $8.9 billion. In 1983 the real cost of ethanol to replace a barrel of gasoline was estimated at $40 to $65 in the southeast regions and $100 in the northeast regions.

Other implications of Proalcohol included the use of additional land for sugar cane plantations, creation of new jobs (about 900,000 direct jobs), increased agricultural productivity for sugar cane (from 46 tons a hectare before the program to 54 tons a hectare in 1987, and up to 94 tons a hectare in the State of São Paulo), increased ethanol conversion productivity from sugar cane (from 57 liters a ton before Proalcohol to 71 liters a ton in 1987), increased environmental emissions from distilleries located in rural areas, and decreased motor vehicle pollution in urban areas for ethanol-to-gasoline (or ethanol-to-gasohol) substitution. In addition, increasing national demand for diesel fuel and penetration of ethanol in the transport fuels market put consider-

(Box continues on the following page.)

Box 3.6 *(continued)*

able pressure on Petrobrás' refinery operations. Greater quantities of surplus gasoline had to be exported to foreign markets, particularly to the United States.

Although the Proalcohol program in Brazil has been a remarkable technical success, it has also become an economic burden. In 1995 subsidies to the program totaled $1.9 billion, or $0.15 a liter. Based on current gasoline price projections, it is expected that the use of ethanol as a gasoline additive will completely dominate the ethanol fuel by the turn of the century. However, with about 4.5 million ethanol-dedicated cars still driving the streets of Brazil, a steady and reliable supply of this fuel will continue to be needed if the engines of these vehicles are not modified.

Source: Faiz, Weaver, and Walsh 1996; Sathaye, Atkinson, and Meyers 1989; Trindade and Carvalho 1989.

(with 4 percent water content). In 1995, 11.3 million motor vehicles in Brazil used ethanol or ethanol blend. In Paraguay about 10 percent of cars are fueled with ethanol. Although air quality improvements can be achieved through the use of ethanol as an alternative fuel, the Brazilian experience indicates that there is a delicate balance among sugar cane farmers, alcohol distillers, petroleum refiners, and auto manufacturers. Given a sharp rise in oil prices, countries that would potentially have an interest in embarking on a similar program would be those with food surpluses and energy deficits.

Fuel Taxes

Fuel taxes are intended to serve as a proxy for vehicle emission taxes in order to reduce vehicle travel and air pollutant emissions. Fuel taxes can be used differentially among various fuels to promote the consumption of cleaner fuels. For example, in Mexico the retail price differential between diesel fuel and CNG (3.4 percent in 1994 and 1.1 percent in 1995 in favor of CNG) was widened (to 11 percent in 1996) by differential taxation to promote greater use of CNG-fueled vehicles (O'Ryan 1996). In the Buenos Aires Metropolitan Area more than 80 percent of gasoline-fueled taxis have had their fuel systems converted to CNG in response to the Argentine government's heavy taxation of gasoline and tax exemption for CNG. In contrast, less than 2 percent of the diesel-fueled buses in the same area have had their fuel system converted to CNG because until recently both diesel fuel and CNG were exempt from fuel taxes and had about the same retail price. However, a recent tax placed on diesel fuel has created a price differential which is expected to provide incentives for converting diesel-fueled vehicles to CNG.

Differential fuel taxes can be used between leaded and unleaded gasoline or between low- and high-sulfur diesel fuel to promote consumption of the cleaner fuel. A tax differential between leaded and unleaded gasoline is commonly used as an economic incentive to curtail air pollution. As a percentage of pretax price, unleaded gasoline is taxed lower than leaded gasoline in all European Union countries except Greece. This has contributed to a substantial increase in the use of unleaded gasoline in these countries. For example, the consumption of unleaded gasoline in the European Union rose from 1 percent of the gasoline market in 1986 to 41 percent in 1991 and to 54 percent in 1992. In Germany, for example, although premium leaded gasoline is still available (sale of regular leaded gasoline is banned), it is considerably more expensive than unleaded gasoline because higher taxes are levied on it (Töpfer 1995). In 1992 unleaded gasoline accounted for 85 percent of the gasoline market in Germany, 76 percent in the Netherlands, and 47 percent in the United Kingdom (CONCAWE 1994).

In Thailand, before elimination of lead in gasoline, unleaded gasoline was taxed at a lower rate than leaded gasoline to nearly equalize the prices of these grades at the pump (the price of unleaded gasoline is only $0.004 a liter less than that of leaded gasoline). As a result the switch from leaded to unleaded gasoline occurred in less than five months (Bartone and others 1994). In Singapore a differential tax caused unleaded gasoline to cost $0.10 a liter less than leaded gasoline.

In Latin American and the Caribbean coun-

tries where both leaded and unleaded gasoline are available, the leaded grade typically has a lower tax and retail price than the unleaded grade. For example, in January 1996, Peru's tax on low-octane gasoline was $0.225 a liter for the leaded grade and $0.293 for the unleaded grade, with respective retail prices of $0.383 and $0.468 a liter (Alconsult International Ltd. 1996). In Costa Rica unleaded gasoline had the same retail price as leaded gasoline when it was first marketed in 1989, but the price ratio of unleaded to leaded gasoline (which is determined by a regulatory agency) was increased as high as 1.15 in 1992 ($0.400 a liter versus $0.348 a liter).[23] This ratio was then reduced to 1.09 in early 1996 ($0.825 a liter compared with $0.755 a liter) just before lead was eliminated from gasoline. In Uruguay the retail price of unleaded gasoline is about 5 percent higher than leaded gasoline of the same octane number.

For some Latin American and Caribbean countries, however, differences in retail leaded and unleaded gasoline prices are small or nonexistent. In Ecuador the respective taxes are $0.063 and $0.069 a liter and the retail prices are $0.330 and $0.349 a liter (Alconsult International Ltd. 1996). In Mexico the 1991 price gap of $0.09 a liter between unleaded and leaded gasoline grades has been reduced to $0.02 a liter as a result of higher taxes on leaded gasoline (see Chapter 4). In Chile, retail prices of the 93-octane leaded and unleaded gasoline grades have been the same since September. In Barbados leaded and unleaded gasoline grades also sell at the same price. In El Salvador unleaded gasoline sold for $0.003 to $0.021 (0.6 to 5.2 percent) more a liter than leaded gasoline in 1994–95.[24] However, in 1996, before lead was eliminated from gasoline in July, unleaded gasoline sold for up to $0.011 a liter less than leaded gasoline.

Differential taxation policy has been used in several European and Latin American countries to promote use of diesel fuels with lower sulfur content. For example, in Denmark the lower-sulfur diesel fuel (containing 0.05 percent sulfur by weight) was given a $0.015 a liter tax incentive compared to regular diesel fuel (containing 0.20 percent sulfur by weight). The tax incentive for the low-sulfur diesel fuel used by public buses was even greater ($0.045 a liter). In Sweden, the low-sulfur diesel fuel marketed in urban areas (containing 0.02 percent sulfur by weight) was taxed $0.025 a liter less than the high-sulfur diesel fuel (containing 0.1 to 0.2 percent sulfur by weight) used for intercity transport. The tax incentive between the ultralight diesel fuel (containing 0.001 percent sulfur by weight) used by urban buses and the high-sulfur fuel was $0.058 a liter (CONCAWE 1994). In Brazil the two grades of diesel fuel (0.5 percent sulfur by weight for intercity transport and 0.3 percent sulfur by weight for urban transport) are taxed differentially to yield the same retail price. The same policy was followed in Mexico for the two diesel fuel grades (0.5 sulfur by weight for intercity transport and 0.05 percent sulfur by weight for urban transport) until the high-sulfur grade was totally eliminated from the market in February 1997.

Lower taxes and retail prices for motor vehicle fuels also encourage more fuel consumption, which results in increased air emissions. Among Latin American and Caribbean countries, Venezuela has the lowest tax and retail price for low-octane leaded gasoline (a tax of $0.016 a liter and a retail price of $0.106 a liter in January 1996). In comparison, the fuel tax and retail price for low-octane leaded gasoline in Paraguay were $0.283 and $0.497 a liter, and in Uruguay $0.431 and $0.790 a liter (Alconsult International Ltd. 1996).

High taxes on fuels alter the market demand for energy-efficient vehicles, which in turn affect the design and production mix of newer models and, possibly, the market share of vehicle manufacturers. Evidence from industrial countries suggests that higher gasoline taxes and prices are associated with higher fuel efficiency. This is the case for Italy, which has high gasoline taxes (74.3 percent in 1993) and a fuel-efficient vehicle fleet.

Some lessons can be learned from the lead elimination program in the United States. During implementation of this program no fiscal

23. At the request of the national refinery (RECOPE), the regulatory agency determines fuel prices in Costa Rica by analyzing the cost structure of all petroleum derivatives in the country. In addition to this analysis done at least once a year, the regulatory agency adjusts fuel prices based on variations in international fuel prices and the exchange rate.

24. Since January 1994 the Energy, Mines, and Hydrocarbons Department of the Ministry of Economy has determined, on a weekly basis, the maximum prices that fuel importers and local refiners can bill to distributors. Distributor and retailer margins are not controlled by the government.

incentives were established to encourage the use of unleaded gasoline. This lead to the contamination and misfueling of gasoline even though the USEPA established some command-and-control measures to prevent such events (Hillson 1995). In Mexico the large price difference between unleaded and leaded gasoline grades in 1991 also encouraged the use of leaded gasoline, even in cars equipped with catalytic converters (such misfueling renders the catalyst ineffective).

Tax incentives have also been adopted to encourage the use of cleaner fuels through vehicle or facility conversions. For example, since July 1994 the state of Connecticut (United States) has been providing a corporate tax break to any commercial fleet owner that converts its vehicle fleet from gasoline to cleaner fuels, such as CNG or electricity. For every dollar spent on converting vehicles to cleaner fuels or building fuel stations with CNG, fleet owners have been allowed to deduct 50 cents from their corporate profit tax. Moreover, after the conversion the new fuel is exempt from the state fuel tax ($0.08 a liter).

Tradable Permits and Credits

In the early 1980s a tradable permit system for lead was initiated in the United States. This system established rights for refiners to use certain amounts of lead additives and allowed them to trade unused lead rights to other refiners. The 1985 rule, which reduced the lead standard in gasoline from 0.291 gram a liter (1.1 grams a gallon) to 0.027 gram a liter (0.1 gram a gallon), also allowed refiners to bank lead rights. These rights could be used or sold to others through the end of 1987. During this period trading of lead rights became very common in the United States. Lead rights, which were worth about $0.05 a gram of lead, provided significant incentives for unscrupulous companies to sell false lead rights at discount prices (Hillson 1995).

However, the tradable permit system for lead was monitored by the USEPA through reporting and auditing mechanisms. A system was established for refiners to make a quarterly report of the amount of lead actually used, the amount of leaded gasoline produced, and the amount of lead the refiner was allowed to use. The USEPA received as many as 900 quarterly reports from refiners and reviewed them for errors and self-reported violations. In addition, the USEPA reviewed reports sent by lead additive manufacturers.

USEPA officials expanded their monitoring of lead trading through on-site audits of refiners. These audits involved close scrutiny of refinery records of gasoline production and lead use, banking, and trading. The audits revealed that some refiners had greatly overstated their production volume to falsely indicate compliance with the lead standard. The USEPA issued civil penalties for violations, including a number of multimillion-dollar enforcement cases. As a result of the audits, refiners began taking greater care in preparing their reports (Hillson 1995). The U.S. experience with the tradable permit system indicates that establishment of strong oversight coupled with financial penalties for violations are necessary for the success of such a system.

The marketable (tradable) credit system has also been used for reformulated and oxygenated fuel programs in the United States. Under such a system the credit is given to refiners, blenders, or importers who certify that the quality of their gasoline is superior than that established in the 1990 amendments to the Clean Air Act for reformulated or oxygenated gasoline. The parameters used to determine fuel quality are oxygen, aromatic hydrocarbons, and benzene under the reformulated fuel program and oxygen under the oxygenated fuels program. The credit may then be used by the same person or transferred to another person for use within the same nonattainment area during the allotted period specified in the regulations. No transfer of credit is allowed between nonattainment areas. The marketable credit system establishes requirements for the issuance, application, and transfer of credits.

TRANSPORT MANAGEMENT MEASURES

Many large cities, including those in Latin America, suffer from traffic congestion caused by rapidly rising ownership of private cars. In addition, the increasing number of public transport vehicles, which use urban roads to cope with the transportation needs of quickly growing low- and middle-income urban populations, contributes to traffic congestion.

Traffic congestion burdens productivity because of the cost of time lost during travel. In addition, the slow movement of motor vehicles on congested roads results in higher fuel consumption and increased rates of pollutant emissions. Typical relationships between vehicle speeds and emission rates of major air pollutants from gasoline-fueled cars, gasoline-fueled heavy-duty vehicles, and diesel-fueled heavy-duty vehicles are shown in Figure 3.3. As the figure shows, HC and CO emissions from all vehicle types and NO_x emissions from heavy-duty vehicles fall when traffic speeds reach 50 to 60 kilometers an hour—a speed that is feasible wherever road safety and the physical layout of the urban area permit. Safety and layout concerns, in turn, can be achieved through transport management measures.

Transport management options are mostly directed toward promoting the use of public transport in lieu of private cars. The use of public transport vehicles can reduce emissions per passenger traveled. For example, in Mexico City the use of a bus in lieu of a catalytic converter-equipped private car is estimated to result in a reduction of 40 percent in NO_x emissions, 95 percent in HC emissions, and 98 percent in CO emissions per passenger-kilometer traveled (Table 3.18). If the private car is assumed to be uncontrolled, then the emission reductions would be even greater: about 70 percent for NO_x and over 99 percent for HC and CO. In addition, a shift to the public transport mode suppresses extensive demand for road use and improves the traffic flow, which further reduces pollutant emissions.

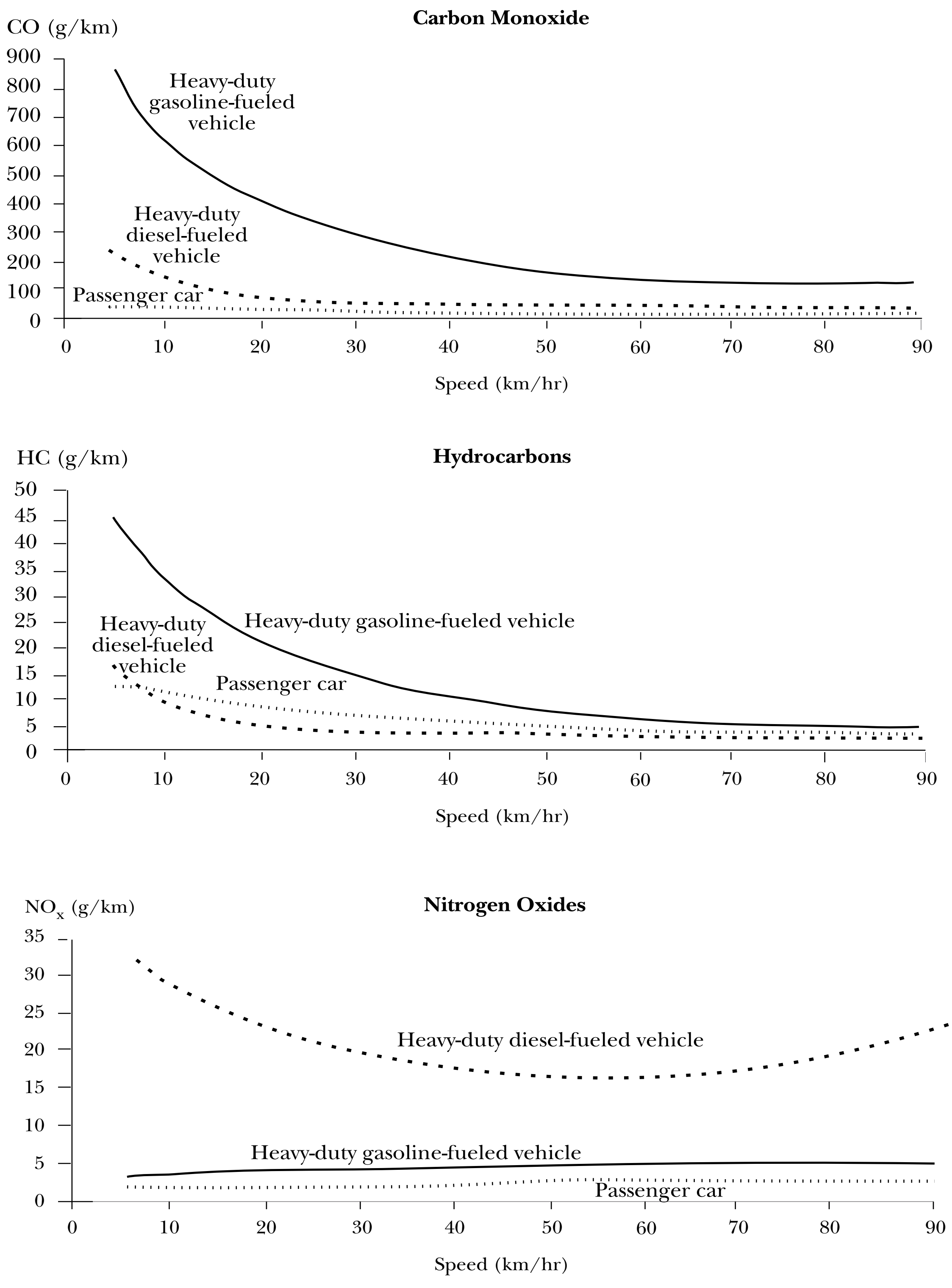
The package of transport management options chosen must be tailored to each urban center because many factors—such as physical infrastructure, characteristics of the urban transport system, layout of the urban area, and transport demand—need to be taken into consideration. In all cases the selected options must be able to meet specific needs, beneficial and fair to the community as a whole, flexible enough to respond to changing situations, simple and inexpensive to enforce, and easy for users to understand and comply with (ECMT 1990).

Driving Bans

Measures have been taken to curtail air pollution in urban centers by banning vehicle circulation based on vehicle type, day of the week, time of the day, or location. Vehicle bans have been used in different forms in a number of urban centers. One of the best-known types of vehicle ban is the "odds and evens" scheme. Under this scheme vehicles with license plates ending in an odd number are allowed to drive on odd dates and vehicles with license plate ending in an even number are allowed to drive on even dates.

Since 1989 Mexico City has used another form of driving ban in which cars are restricted from

Figure 3.3 Pollutant emission rates from vehicles as a function of vehicle speed



Note: Emission rates are for vehicles not equipped with pollution control devices.
Source: Faiz, Weaver, and Walsh 1996.

Table 3.18 Pollutant emissions by different transport modes in Mexico City
(grams per passenger-kilometer traveled)

Transport mode	*CO*	*HC*	*NO_x*
Private car (catalytic converter-equipped)	45.2	4.4	1.0
Taxi	96.9	9.5	2.2
Microbus	9.7	1.2	0.2
Urban bus	0.7	0.2	0.6

Note: For comparison, trucks are estimated to emit 20.77 grams of NO_x per passenger-kilometer traveled, 7.71 grams of HC per passenger-kilometer traveled, and 18.76 grams of CO per passenger-kilometer traveled.
Source: CMPCCA 1995.

driving one day of a weekday depending on their license plate number. This ban has not proved effective because many families in Mexico City have purchased a second car with a different license plate number for use on the banned weekday. In addition, most of these second cars, which were brought in from other parts of Mexico, adversely affected ambient air quality because they were older models with no or limited pollution control equipment. As a result of the apparent failure of this driving ban, a two-day ban has been in place since December 1995. Under this program 40 percent of the vehicles (except buses) in the MCMA are prohibited from circulation when the air pollution level exceeds a certain level (IMECA 250). This emergency measure has only been applied once, and it received quite a negative response from the public.

A similar program was implemented in Buenos Aires for a short period, but was suspended because it was found to be ineffective. In addition, in Buenos Aires and Santiago taxis with no passengers are prohibited from entering certain downtown areas. As a result of this program and of parking ban measures, the traffic flow in a forty-block section of Santiago was reduced by 30 percent. Vehicle bans are also used in some European cities such as Bologna, Cologne, and Rouen (ECMT 1990). The government of Athens, after implementing a program that allowed cars to enter the downtown area only on alternate days, initiated a three-month experimental total ban for cars, taxis, and motorcycles in April 1995 (*The Times,* 11 April 1995).

The movement of heavy trucks, although necessary for some businesses in city centers, generates air and noise pollution. Trucks can also be dangerous to other road users, including pedestrians and bicyclists. In addition, they damage roads because of their heavy axle loadings. Truck passage on narrow roads and on weak or low bridges is also restricted based on weight, width, or length limitations. Some urban areas have implemented bans on truck circulation in an effort to maintain smooth traffic flows during the daytime or during rush hours. In certain cities (for example, Windsor in the United Kingdom) truck circulation is totally banned.

Closure to traffic of traffic-congested commercial areas or environmentally sensitive residential areas of urban centers reduces vehicular air pollution in those sections. For commercial areas this measure is even more effective if pedestrians in the banned area benefit from improved public transport services. Traffic bans have been implemented in some Latin American cities, including Buenos Aires, Córdoba, Lima, Mendoza, and San José.

In San José (Costa Rica) the municipality closed the Central Avenue to traffic. To achieve this the municipality, which was in poor financial condition, convinced local businesses to finance 50 percent of the required works. The municipality also prohibited street vendors on the Central Avenue and enforced this rule strictly. This pedestrian area provides a nice environment for the people of San José. In Cartagena, however, following the traffic ban in certain sections of the colonial part of the city, streets became greatly crowded by informal traders. Following complaints by local businesses and residents, the ban was lifted within three years of implementation. In some German cities streets in certain downtown areas have been closed to traffic since the late 1970s. This measure has brought remarkable success in increasing the number of pedestrians and decreasing motor vehicle traffic. For example, within one year pedestrian flow had increased by 40 percent in Banberg and 25 percent in Aachen (Hass-Klau 1993).

On-Street Parking and Trading Restrictions

In many urban areas road capacities are reduced mostly by on-street parking and stopping of vehicles to load and unload passengers and goods. Especially during peak hours, these movements slow down the traffic flow and raise pollutant emissions from motor vehicles. Traffic flows in heavily congested streets can be improved by imposing on-street parking restrictions, which can be implemented at all times, during the daytime, or only at peak hours. These restrictions require installation of signs and a firm enforcement effort through fining, wheel clamping, and towing. Although on-street parking restrictions are simple and inexpensive to implement, they can generate public opposition. For this reason, in devising a strategy for parking restrictions, priority should be given to business and shopping traffic instead of commuters who can use public transport.

To improve traffic flow in the central area of San José, a World Bank-financed project implemented parking restrictions and banned parking along priority bus routes. The project also installed parking meters to encourage quick turnover, designed formal loading and unloading spaces, and strengthened enforcement. These measures proved effective—the travel speeds of buses increased and the flow of the remaining traffic improved (World Bank 1986).

Street trading in crowded streets can adversely affect traffic flows because it attracts pedestrians. This problem can be avoided by introducing controls on street trading. In Lima, Peru street trading was tackled by setting up a special force to enforce street trading regulations and divert street trading to more suitable locations. In addition, the creation of pedestrian streets attracted both pedestrians and street traders. As a result the traffic flow in the central area improved (World Bank 1986).

Traffic Priority Measures for Buses

Traffic priority measures for buses in urban centers increase the attractiveness of bus services by reducing transit time and increasing the reliability of service. These measures also have environmental benefits: they curtail fuel consumption and pollutant emissions from road transport because they allow faster speeds for buses and eliminate cars from traffic by shifting users to bus transport. Types and effectiveness of various bus traffic priority measures are shown in Table 3.19. Among these, the most effective measures include exclusive bus routes and lanes, contra-flow lanes for buses, and bus flow lanes during rush hours.

Bus routes and exclusive bus lanes that are physically separated from general traffic by means of barriers—also called "busways"—have been effectively used in some Latin American urban centers. For example, in Santafé de Bogotá two lanes in each direction of a major avenue have been physically separated from general traffic for use as a busway. Busways are also used in such Latin American cities as Curitiba, Porto Alegre, and Lima.

Another priority measure involves dedicating certain lanes of an existing route to buses. Bus lanes are very common in European and North American cities, and are also used in some Latin American cities (such as Buenos Aires and Santiago). In some cities bus lanes are used solely

Table 3.19 Effects of bus priorities on bus exhaust emissions
(percent)

Type of measure	*Portion of daily bus travel affected*	*Reduction in bus journey times*	*Reduction in bus exhaust emissions*
Peak period with flow bus lanes	5	15	20
Contra-flow lanes (all-day)	2	30	35
Motorway privileges	1	50	60
Signal preemption	20	10	12
Bus routes	2	50	60
Priority turns and other measures	5	5	7

Source: ECMT 1990.

during rush hours (Washington, D.C.). Effective operation of bus lanes requires enforcement to ensure that the lanes are not occupied by cars. Bus lanes cut bus and car travel times by up to 30 percent in Bangkok. In Manila the travel time of buses was halved because bus lanes increased their average speed from 9 to 18 kilometers an hour.

The contra-flow lane measure involves establishing an exclusive bus lane counter to the direction of general traffic. This measure is effective because it ensures that bus drivers and general traffic stay in their lane to avoid head-on collisions.

The benefits of bus priority measures outweigh their costs only in highly congested corridors. In addition, busways and bus lanes are not very effective in corridors where traffic is interrupted by the movement of crossing vehicles. To reduce such delays, buses in certain cities are fitted with mechanisms that modify the traffic signals for priority passage (that is, the traffic signal stays or turns green when buses approach).

Bus priority measures cost less than subways as a means of public transport. For example, an exclusive bus lane requires investment of less than $1 million per kilometer, a busway in an existing corridor costs about $2 million per kilometer, and a new busway costs $7 million to $12 million per kilometer. These costs compare with $22 million to $60 million per kilometer for an elevated metro and $50 million to $165 million per kilometer for an underground metro. Metros have several key advantages over bus priority measures, however, they can operate at higher speeds (28 to 37 kilometers an hour for metro compared with 15 to 22 kilometers an hour for busways or bus lanes) and carry more passengers (50,000 to 75,000 passengers an hour per lane for metro compared with 10,000 to 25,000 passengers an hour per lane for bus priority measures; UN 1994).

Ride Sharing

Another option for reducing congestion and curtailing air pollution involves setting a requirement for the minimum number of people traveling in light-duty vehicles (cars and vans). Such a measure necessitates building special infrastructure that includes, at a minimum, special routes or lanes in an urban area. Ride sharing (also called car or van pooling) is especially effective in locations where traffic congestion spreads to the suburbs of a metropolitan area. Successful car/van pooling programs establish traffic priorities for high-occupancy vehicles, parking privileges for ride sharers, assistance in matching commuters, and an employer incentive program (ECMT 1990). For example, in major traffic corridors leading into Washington, D.C. high-occupancy vehicle lanes and routes are maintained in the direction toward the city during the morning rush hours and in the opposite direction during the evening rush hours. The minimum occupancy requirement in vehicles using these routes is set at two or three people depending on the corridor. Special parking lots for ride sharers are also provided at suburban areas near the high-occupancy vehicle route. Assistance in matching commuters is provided through telephone hotlines. Employer incentives—such as company-provided or arranged transportation, or free parking space for high-occupancy vehicles—encourage employees to share rides.

Staggered Work Hours

Traffic congestion in urban areas generally occurs before and after work, school, and shopping hours. One measure to relieve congestion and reduce vehicular air pollution involves staggering of these hours. In addition, staggered work hours reduce the load on public transport systems. Staggered work hours have been used, on a compulsory basis by some governments and private businesses. For example, in the Republic of Korea staggered work hours are used by a major television company. In Singapore there are different peak hours for two-shift schools and businesses. In many European cities shop closings are delayed on the busiest days of the year to smooth out shopping and other peak hours (ECMT 1990).

In cases where the nature of employment does not require all employees to start and finish work together, staggered work hours have been used on a voluntary basis under "flextime" arrangements. However, widely staggered work hours are not acceptable for many businesses because they reduce the interaction among workers or with clients. Another impediment to staggered hours arises in situations that require multipurpose trips such as taking a child to school on the way to work (Gwilliam 1995).

Speed Limits and Other Traffic Management Measures

Speed limits in urban areas are set primarily for road safety, but vehicle speeds also affect fuel consumption and pollutant emissions from vehicle exhausts. Fuel consumption starts to increase at speeds above 60 kilometers an hour. Although HC and CO emissions are not sensitive to speeds above 60 kilometers an hour, NO_x emissions increase slightly for gasoline-fueled vehicles and sharply for diesel-fueled vehicles. In residential areas traffic speeds can be effectively controlled by a combination of speed limits and careful design of road layouts (ECMT 1990).

Other traffic management measures are intended to establish a smooth traffic flow and increase road safety by minimizing conflicting movements between vehicles and between vehicles and pedestrians. Some traffic management measures include installation of signals at intersections, re-routing of traffic, prohibition of conflicting turns, designation of one-way streets, and segregation of motorized and non motorized traffic. These measures are much less costly than building additional infrastructure. Traffic flow can be improved through such modifications to existing infrastructure as widening of roads to provide turning lanes, extra lanes for express bus or high-occupancy vehicles, construction of short road links at critical locations; and building footbridges, flyovers, or tunnels for pedestrians. Traffic flow also can be improved substantially by changing the direction of traffic on certain roads during rush hours. This approach has been widely adopted in the United States and is common in several Latin American and Caribbean countries. A more sophisticated traffic management measure includes traffic control systems that use vehicle detectors and link traffic signals to computers to optimize traffic flow. Although such systems are expensive, they are effective in enhancing traffic flows (World Bank 1986). The traffic management measures chosen for a given urban area should reflect the physical layout of the urban area, the density of street space, and the characteristics of the urban transport system.

Land Use Planning and Controls

Land use planning establishes patterns for land development in urban centers. Because it specifies areas for residential, educational, commercial, industrial, and recreational facilities, planning controls future population densities in these areas that affect the demand for transport services and the associated air pollution. Effective land use planning reduces the amount of travel for work and other activities by bringing schools, offices, shops, and recreational facilities closer to residential areas. Environmentally sound land use policies create mixed-use multinucleated urban areas that promote walking for short trips and mass transit for long trips. Still, even though land use planning can create a desirable urban environment for the future, it cannot solve immediate traffic-related air pollution problems.

In Curitiba success in maintaining acceptable air quality levels can be attributed to a master plan that effectively integrated land use, road, and transport policies. This plan, prepared in 1965, created a structure for urban growth based on linear-guided land development with limited physical expansion of the central area. Land use legislation encouraged urban growth along five main axes served by express buses. Prior to the construction of these roads, the municipal government acquired land along or near these roads and built high-density housing for about 17,000 low-income families. Development permits limited the ratio of total floor area to plot size based on the distance from roads served by public buses. For example, the maximum ratio was set at six for developments along the five major axes and four for developments close to roads served by other urban buses. The city center was relieved from commercial pressures and became friendlier to pedestrians. In addition, the city's open leisure space increased by two orders of magnitude in twenty-three years (from 0.5 square meter per inhabitant in 1970 to 50 square meters per inhabitant in 1993; Rabinovitch 1993).

Many other urban centers in Latin America and the Caribbean, however, suffer from transport and environmental problems caused by growth without proper consideration for urban planning. For example, in Asunción most streets constructed in the growing parts of the metropolitan area during the past twenty years are not connected to the city center. As a result the few avenues that extend the suburbs to the city center are congested with heavy traffic caused by trucks, buses, and cars. This transport problem is expected to be addressed as part of the new urban development plan for Asunción. The plan

also calls for the closure of the city's historic area to motor vehicle traffic.

Preparation and implementation of an urban plan for a metropolitan area requires coordination among various administrative entities representing different jurisdictions within the area. In Latin American and Caribbean urban centers such coordination tends to be rather weak. In addition, the regional trend toward decentralization of administrative and institutional responsibilities will compound this problem unless appropriate actions are taken. For example, one factor contributing to the transport problem in Asunción has been the lack of coordination among the Ministry of Public Works and the twenty-four municipalities in the Asunción metropolitan area. In Venezuela, following promulgation of the 1989 law that transferred central responsibilities to local authorities, each of the five municipalities forming the city of Caracas prepared a different urban policy, urban development plan, and urban transport plan according to its respective priorities. However, the central government is still responsible for certain transport-related activities. For example, the Ministry of Transportation and Communications is responsible for motor vehicle administration and traffic enforcement (such as issuance of fines), and the Ministry of Finance is responsible for establishing parking tariffs.[25] In November 1996 the five municipalities have finally agreed to form a metropolitan transport authority for the Caracas metropolitan area to bring about an integrated solution to the city's transport management problems.

For many urban centers in developing countries, land use controls have not been able to curtail traffic densities and vehicular air pollution. Implementation of urban plans has suffered from disregard for regulations, inadequate enforcement, and public opposition.

Road Pricing

Congestion in urban area roads imposes costs not only on road users but also on pedestrians, businesses, and communities exposed to air and noise pollution from the traffic. Road pricing involves charging a fee to motorists for the use of a road in an effort to encourage the use of public transport, high-occupancy vehicles, or congestion-free alternate routes, or to induce driving at off-peak hours. If motorists are charged a fee for the delay they cause by using a particular road, they will use the road only if the benefits exceed the toll. The main advantage of road pricing is that it encourages vehicle owners to find ways to reduce congestion. This has a direct impact on ambient air quality because less congestion means reduced pollutant emissions from vehicles.

The setting of road prices is a technically, administratively, and politically challenging task. Technically, it is difficult to estimate accurately the social and other costs caused by congestion and associated air pollution. In addition, predicting the effects of road pricing on congestion, traffic patterns, and public transport or high-occupancy vehicle use may be complex.

In considering this policy option, the availability of non congested alternative routes and the efficiency of the existing public transport system must be carefully reviewed. In addition, existing infrastructure must permit isolation of a toll road without impeding traffic flow on other roads and installation of entry points to the toll road. Toll booth systems suffer from being land-intensive because they require large plots of open space for toll plazas and are labor-intensive because they require hiring toll operators. The design of toll roads also requires an enforcement system—such as a police force or electronic devices—that identifies drivers who evade road charges. More important, collection of fees at toll booths may cause additional congestion in urban areas because it is time-intensive. This congestion can be reduced through prepayment methods (such as monthly fees) and appropriate identification of vehicles. Under area licensing schemes vehicles entering an urban center during peak hours display a daily or monthly license that traffic authorities can check without stopping traffic. Electronic road pricing with automatic vehicle identification requires a transponder (known as a "tag," which may be based on optical and infrared systems, induced loop systems, radio frequency and microwave systems, or smart card systems) that stores a unique identification code for each vehicle, an interrogator that reads the transponder and decodes its iden-

25. The Ministry of Transportation and Communications issues licenses to vehicles entering the traffic but does not check their emissions. Because the Ministry of Finance established the same parking rate for the entire city of Caracas, vehicles are not discouraged from entering congested sections of the city.

tification, and a computer system that transmits, analyzes, and stores the data. Electronic road use charging is superior to manual approaches from the perspective of road users, road authorities, and society as a whole (Hau 1992).

Consideration must also be given to the timing and duration of road charges. Short charging periods are likely to cause congestions just before or after the restricted period, while long charging periods may lead to underutilization of road capacity. In Singapore, for example, entry to the central business district was subject to a fee that originally was charged between 7:30 A.M. and 9:30 A.M. for low-occupancy vehicles (fewer than four people per vehicle). Because this measure resulted in major congestion right after this restricted period, the restricted period was extended to 10:15 A.M. The extension proved effective because it eliminated the congestion (World Bank 1986).

In Latin America, road pricing is used in Buenos Aires (see Chapter 4). Examples of road pricing strategies used in other parts of the world are shown in Table 3.20. Singapore has been the pioneer in road pricing. In 1995 its labor-intensive area licensing scheme (with toll booths at twenty-six entry points) was converted to an electronic road pricing system. The bids received for installation ranged from $22.7 million for a simple automatic vehicle identification system to $90.6 million for a sophisticated "smart card" system with numerous options. The authorities adopted the smart card system as the basis for their electronic road pricing system. This system is based on a two-way communications link between an on-board unit (consisting of a smart card, smart card reader, and transponder) and a roadside antenna. Installation (including the electric enforcement system) and five-year maintenance of the system cost $44.2 million and $11.6 million, respectively (Hau 1992). In Hong Kong the electronic road pricing system, tested on 2,500 vehicles, allowed for more accurate road use charges and eliminated toll booth-induced congestion by mounting electronic plates underneath vehicles, recording vehicles at charging points equipped with electronic loops, and billing monthly road charges.

Preliminary experience with road pricing on a Los Angeles highway has proven to be effective. Before road pricing was introduced, an eight-lane highway (four lanes in each direction) was experiencing severe congestion, especially during peak hours. Through a franchise agreement between the state of California and a private contractor, four additional lanes (two in each direction) were constructed in the middle of the original highway. An electronic road pricing system using radio technology was selected to identify vehicles on the newly constructed 16-kilometer highway. This technology uses overhead antennas and a small, windshield-mounted transponder to collect tolls electronically without stopping at toll booths.

The system's sophisticated electronics can handle up to 2,500 vehicles per hour per lane, and can recognize vehicles at speeds well in excess of legal speed limits. The units are more than 99.9 percent accurate. The private contractor can set road prices based on traffic congestion with the provision that it must return to the state half the proceedings above an agreed rate of return. The current pricing system, established for vehicles occupied by only one or two passengers, has prices ranging from $0.25 for low-traffic periods to $2.50 for peak traffic hours.

Table 3.20 Examples of congestion pricing, 1994

Type of congestion pricing	*Location*	*Year introduced*
Flat charge to enter the central or downtown area of a metropolitan area during rush hours	Singapore	1975
	Hong Kong	Tested in 1983–85 and abandoned
Flat charge to enter the central or downtown area of a metropolitan area	Bergen	1986
	Oslo	1990
	Trondheim (Norway)	1991
	Stockholm	1997
Rush hour toll surcharge on an intercity expressway	Paris	1992

Source: Gomez-Ibañez and Small 1994.

No charges are levied from high-occupancy vehicles.[26] Another feature of this system is that road maintenance and operation of the charge system, including enforcement, are the responsibility of the franchised company. Fines for drivers abusing the payment system start at $100 and go up to $500. Since this system was implemented in December 1995, traffic has been flowing very smoothly at high speeds in the toll highway. The older portion of the highway is still congested (Warriner 1996).

Area Licensing

Area licensing is a charge that can be applied for the use of roads in designated sections of an area during specified times of the day or days of the week. The area licensing scheme introduced in Singapore in 1975 is a good example of this charge. This scheme originally targeted passenger cars but was subsequently modified to include all vehicles except ambulances, fire engines, police vehicles, and public buses. It was used as part of a larger package of measures for improving public transport and the environment. Under this scheme vehicle owners were required to buy special licenses to enter certain restricted zones during morning rush hours. Other measures included in the policy package included free passage into the restricted zone for car pools, increased parking charges within the restricted zone, strict enforcement at the twenty-eight entry points into the restricted zone, and progressively more onerous taxes on the import, purchase, and registration of cars (Bernstein 1991).

Since 1991 Singapore has used a "weekend car" scheme. Under this scheme weekend car drivers enjoy a 70 percent reduction in road taxes and a tax rebate of up to $9,600. Weekend cars, identified by their red license plates, are allowed to circulate only between 7 P.M. and 7 A.M. on weekdays, after 3 P.M. on Saturdays, and all day on Sundays and public holidays. These vehicles can also be driven outside these periods for up to five days a year by displaying a special day license. Each additional day license costs $13 (Carbajo 1994).

26. Vehicles with three or more occupants are given a transponder with a special code and asked to use certain lanes.

Provision of Public Transport Services

Public transport systems aim to efficiently move large numbers of people using buses, microbuses, vans, trolleybuses, tramways, metros, or trains. The provision of public transport can affect air quality in urban centers. Since congestion-induced air pollution in urban centers is mostly attributed to the growing number of private cars, promotion of public transport can be considered an air pollution control measure. Although public transport vehicles also emit air pollutants, their contribution to pollution per person transported is much less than that of private cars.

Among public transport modes, rail transport is more attractive than road-based transport because it operates over protected rights of way, carries more passengers per trip, and provides a faster and more reliable service in highly congested areas and over longer distances. In addition, electrified rail transport is more environmentally attractive, especially in cases where the primary fuel source for electricity generation is natural gas. However, rail-based transport requires a higher investment and cannot serve as many locations as road-based transport services. Among the rail-based public transport systems, metros offer the highest capacity at the highest speed, but require very high construction costs and sophisticated technology. Metros are mostly used for short trips within the central area of congested urban centers (for example, Buenos Aires) and by those who live or work near the metro stations.

Buses are the least expensive and most flexible way of meeting a range of demands in urban areas. The attractiveness of buses in congested areas can be increased through bus priority measures and through provision of express buses operating over long distances in areas not served by rail. Express buses can be enhanced by "park and ride" facilities at the suburban end of the route and a pleasant walking environment at the city center. In developing countries smaller buses (such as minibuses) are both cost-effective and popular with users. These vehicles, which cost less per seat than large buses, can operate at higher speeds than large buses on narrow and congested streets and are financially viable in low-density areas, providing frequent service despite low demand.

In Latin America and the Caribbean most urban public transport services are provided by

buses, minibuses, and vans. In some South American cities (Buenos Aires, Montevideo, Rio de Janeiro, Santafé de Bogotá, and Santiago) trolleybuses used to be operated but were subsequently taken out of service. Only Mexico City, Recife, São Paulo, and Valparaiso are now served by trolleybuses. Metro has been used in Buenos Aires since 1913, in Mexico City since 1969, in São Paulo since 1974, in Santiago since 1975, in Rio de Janeiro since 1979, and in Caracas since 1982. In other cities (Belo Horizonte, Porto Alegre) electrified urban railways—known as "surface metros"—are dedicated to passenger transport. Light rail transit is used in a few cities including Campinas, Buenos Aires, and Mexico City. In Buenos Aires and Mexico City these systems are connected to the metro. In addition, some South American cities (Buenos Aires, Rio de Janeiro, São Paulo) are served by a suburban rail system (UN 1994).

To ease congestion and reduce the contribution of buses to air pollution, bus capacities can be increased. For example, in Porto Alegre buses are fit with an extension unit during rush hours (UN 1994). In Curitiba large-capacity buses (for 270 persons) have been used to provide express service.

To curtail air pollution in urban areas, use of public transport in lieu of private cars can be promoted through such incentives as improvements in the quality of public transport services, reduction of fares, and simplification of fare structures. These incentives are intended to reduce riders' overall cost of using the public transport system.[27]

For users one of the most important attributes of a public transport system is the extent and quality of its service. Because public transport is less flexible in timing and routing than private transport, its appeal is limited. Public transport's appeal can be increased by providing a dense network of frequent and reliable service with convenient interchanges. Service elasticities have not been determined for Latin American urban centers. In European cities, however, service elasticities of 0.4 are common (ECMT 1990).[28]

Lower fares also would encourage public transport ridership. Fare elasticities have not been determined for Latin American urban centers, but in European cities fare elasticities of –0.3 are common (ECMT 1990).[29] During non-rush hours fare elasticities are higher because of the availability of other transport modes and less congestion.

Simplification of the fare structure through flat or zonal fares along with the use of prepaid passes or integrated fares between different transport modes can increase the perceived value of public transport and hence its ridership. Such a scheme, introduced first in Stockholm in the early 1970s, has been used in many large European cities. In London, mostly as a result of restructuring and integration of fares between the metro and bus system in 1983, ridership for these modes increased by 30 percent within five years while car commuting dropped by 17 percent (ECMT 1990). Some fare integration has been established for the bus-metro and bus-rail systems in São Paulo and for the rail-metro systems in Rio de Janeiro. However, lack of fare integration between different modes of transport—a result of weak transport regulatory institutions and the desire of private bus companies for a large share of the fares—is common in many other urban centers in the region, including Buenos Aires and Santiago.

The private sector can play an important role in promoting public transport. For many decades public transport services in the urban centers of developing countries, including those in Latin America, were provided by large government entities under the pretext of "protection from unfair competition." These public entities suffered from cost-ineffectiveness, competition for revenues, and inflexibility in coping with changing conditions (for example, the ability to hire and lay off staff). Subsidies, financed by taxes levied from all citizens—public transport riders and others—were justified on the grounds of providing the public with satisfactory service at affordable fares. However, these subsidies did not produce the expected results because they did not affect the transport patterns of car drivers who placed a high value on the comfort and convenience of driving their private cars. Furthermore, only about half of these subsidies were

27. The overall cost is the sum of the riders' cost of time for accessing, waiting for, and riding public transport, in addition to the cost of the fare.

28. In these cities a 10 percent improvement in public transport services would increase public transport ridership by 2 percent assuming a 50:50 split between the private and public transport.

29. Assuming a fare elasticity of –0.3 and modal split of 50:50 between private and public transport, a 10 percent fare reduction would increase public transport ridership by 1.5 percent.

actually reflected in lower fares, and in many instances they resulted in larger staffs, wages, and unit costs. Since large government-owned public transport companies provided low-quality services, people willing to pay higher prices for better services were forced to use private cars or taxis. This pattern increased congestion and adversely affected bus services, used mostly by low- and middle-income people.

Ample evidence exists of the efficiency of transport services provided by private companies, which operate with a profit motive and staff accountability. For example, World Bank studies indicate that in Bangkok, Calcutta, and Istanbul the costs of private bus companies are 50 to 60 percent of those of publicly owned and operated bus companies. These studies also found no evidence that private bus companies are less safe or poorer service providers than public companies, or are only willing to operate on the most profitable routes (World Bank 1986).

In Latin America and the Caribbean private bus companies operate in many urban centers, including Buenos Aires, Guatemala City, Kingston, Porto Alegre, San José, Santafé de Bogotá, Santiago, and São Paulo. After Santiago's public bus company was dissolved, private transport companies started providing a variety of public transport services with thirty-five seat buses, fifteen seat minibuses, and shared-ride taxis. Between 1978 and 1984 the number of public transport vehicles increased by 50 percent for buses, nearly 100 percent for minibuses, and 300 percent for shared-ride and regular taxis (Meyer and Gomez-Ibañez 1991).

In Asunción about 70 to 80 percent of daily trips are made by public transport. The public transport system, which is totally private, consists of 2,400 buses operating on 165 routes under set tariffs. The main transport management problem appears to be the lack of planning of routes, which is caused by the lack of coordination among various transport authorities (the Ministry of Public Works and the twenty-four municipalities in the Asunción metropolitan area).

Public transport in Lima used to be provided by 4,000 old and poorly maintained buses under a controlled tariff system. Following an abrupt policy change, implemented through legislative decree, import of buses was liberalized and bus routes and tariffs were set free. As a result the number of registered buses, most of which were small (12 to 24 passenger capacity), increased drastically, to 43,000. Because these microbuses increased traffic congestion, eleven routes were auctioned. The selection criteria favored bigger and newer buses as well as larger transport companies. Through this process, bus service to users was considerably improved.

In Montevideo the public transport system included tramways until the 1950s. These were replaced by trolleybuses until the late 1970s, and then by buses. Until 1975 the municipality provided about 40 percent of public transport services, which were passed over to the cooperatives formed by public employees. The municipality still regulated bus routes, tariffs, and schedules, however. In 1990, because most buses were old and the transport system was not responding to the public's needs, new measures were implemented. These included restructuring previous bus routes, creating new bus routes, and directing the express bus system (*diferenciales*) to suburbs away from the city center, adjusting tariffs based on cost studies, renovating the bus fleet, constructing bus terminals, and installing signals at bus stops. Currently, mass transport services are provided by 1,460 buses owned by five private companies (three cooperatives and two incorporated companies). These buses account for 63 percent of the daily trips in Montevideo. Only 20 percent of trips are made by private cars, 12 percent by taxis, and 4 percent by other modes. Bus subsidies are equivalent to 8 percent of bus company billings to cover rides by students and retired people.

Curitiba is Latin America's best example of an urban center with an efficient public transport system. During the 1960s Curitiba was slowly moving toward a car-dominated city with increasing congestion, while its bus system was inadequate to curb the use of private cars. Following the 1965 master plan, express bus services were established in the 1970s on restricted lanes along each of the city's five axes. Express buses were complemented by interdistrict and feeder buses operating on other routes. Each type of bus was color-coded. The public transport system was fully integrated through large bus terminals at the end of each of the five express busways for people to transfer to interdistrict, feeder, or intermunicipal buses. Smaller bus terminals were built every two kilometers along each express route. These terminals were equipped with newspaper stands, public telephones, post offices, and small commercial facilities. A single fare was established for all buses running within Curitiba. A prepayment scheme eliminated the need for the bus crew to collect fares and freed up space for more passengers. Special tubular station plat-

forms, raised to the same height as the express bus floor, reduced boarding and deboarding time by 300 percent. A bus-activated electronic traffic light system was established as a bus priority measure. In the downtown area priority was given to pedestrians over private cars. In 1992, 270-passenger express buses (with five lateral doors that facilitated passenger entry from and exit to newly accommodated tubular platforms) were introduced to replace the lower-capacity (110 passengers) buses. The average life of buses has been maintained at three years, nearly one-third the average for other Brazilian cities. The older buses were recycled to serve as classrooms for vocational training (for example, carpentry, hairdressing, word processing). As a result of these measures public transport ridership in Curitiba increased dramatically: since 28 percent of express bus riders are previous private car drivers, the city's fuel consumption has been cut by 25 percent. Curitiba's public transport system now serves 1.3 million passengers a day and attracts two-thirds of the city's population. Although Curitiba has the highest per capita car ownership in Brazil, its air pollution is one of the lowest among Brazilian urban centers (Rabinovitch 1993).

Curitiba's integrated transport network is managed by a mixed-capital company created by the municipal government. This company is responsible for developing bus timetables and frequencies, implementing new bus routes, calculating the necessary number of buses, monitoring the network's performance, training drivers and conductors, responding to bus riders' suggestions and complaints, and managing interstate and municipal bus terminals, public parking systems, and paving programs. Fares, which are some of the cheapest in Brazil, are set by this company and the municipal government based on monitoring of the number of bus passengers. The buses are operated by private companies through a permit system on specific routes. Since 1987 the city has paid the bus companies based on the number of kilometers of transport provided (Rabinovitch 1993).

Promotion of Nonmotorized Transport

Promotion of nonmotorized transport can reduce the use of motor vehicles and associated air pollutant emissions. Walking can be promoted by providing sidewalks, improving the quality of walking environment, making city centers more friendly to pedestrians, and closing certain streets to motor vehicle traffic. Use of bicycles can be enhanced by constructing bikeways, promoting domestic bicycle manufacturing, and reducing import taxes on bicycles. In addition, nonmotorized traffic can be improved through provision of additional security. Lack of security threatens nonmotorized traffic in certain sections of Latin American cities. For example, although bike paths are available in Lima, they are not used extensively for fear of personal attack (World Bank 1996b). Safe walking or cycling is also a concern in certain sections of Rio de Janeiro.

Curitiba has done well at promoting nonmotorized transport. Its road network is designed in a way that allows pedestrians and bikers to share the roads efficiently with cars. By the end of 1992 the city had 150 kilometers of bike paths integrated with the public transport network and with green areas. In the city center pedestrians are given higher priority than private cars (Rabinovitch 1993). In Santafé de Bogotá and Rio de Janeiro certain avenues are closed to traffic for bikers and pedestrians on Sundays and holidays. In Denmark there are 4.2 million bicycles among 5.2 million people, and in Copenhagen about one-third of commuters ride to work on bicycles.

Provision of Off-Street Parking

In areas where on-street parking is restricted or banned, off-street parking can be used to provide parking in congested urban areas, especially where business activities are predominant. Construction of off-street parking facilities should only be permitted at suitable locations through land use regulations, and operation of these facilities—including setting of parking fees—should be left to the private sector. Taxes on parking may provide the public sector with additional control over traffic flows. Raising the cost or restricting the supply of off-road parking while enforcing on-road parking constraints may be an effective way to reduce traffic flows, but the combined use of these measures would likely meet with opposition from local businesses. Restriction of off-street parking has been used effectively in Seoul (World Bank 1996b). In downtown Singapore parking fees have been significantly increased to discourage cars from entering the city.

ANNEX A
Vehicular Emission Standards in the United States

New Vehicles

Emission standards for new cars in the United States were first established by the 1968 Clean Air Act, which was amended in 1970. These standards limited CO and HC emissions from vehicle exhaust gases (Table A.1). In 1971 evaporative emissions were controlled and in 1973 NO_x was added to the list of regulated pollutants. The CO, HC, and NO_x standards were tightened starting with 1975 model-year cars. Compliance with the 1975 standards required car manufacturers to install oxidation catalysts and refiners to produce unleaded gasoline to service these cars. In 1977 the Clean Air Act was amended and required a 90 percent reduction in HC in 1980 and a 90 percent CO and 75 percent NO_x reduction in 1981. This led to the automotive industry to introduce three-way catalytic converter technology. Along with these standards, the authorities established a certification requirement for manufacturers to build vehicles in compliance with these standards for 80,000 kilometers or five years (whichever comes first), a manufacturer recall program for failing vehicle components, and a warranty program providing consumers with an effective recourse for noncomplying vehicles. Emission standards were tightened considerably in later years. In addition, the 1990 amendments to the 1968 Clean Air Act extended the certification requirement for 1996 and newer model-year vehicles to 160,000 kilometers or ten years (whichever comes first). The state of California, because of the poor air quality in the Los Angeles area, generally has adopted more stringent standards than the federal standards, which apply to the rest of the United States.

Separate emission standards for new light-duty trucks were first established by the U.S. Environmental Protection Agency (USEPA) for 1975 model-year (Table A.2).[1] These standards, which limited CO, HC, and NO_x emissions, were tightened starting with the 1979 model-year. PM was added to the list of regulated pollutants for 1982 model-year diesel-fueled vehicles. More stringent CO and HC standards for 1984 model-year vehicles required use of two-way catalytic converters. The more stringent NO_x standard for 1988 model-year vehicles required three-way catalytic converters. Separate emission standards were established for two different weight classes of light-duty trucks starting with 1991 model-year. The 1990 amendments to the Clean Air Act specified more stringent emission standards and certification requirements starting with 1994 model-year light-duty trucks.

U.S. emission standards for CO and HC exhaust gases from new heavy-duty vehicles[2] were established in 1970 (Table A.3). In addition, opacity[3] standards for diesel-fueled heavy-duty vehicles were set at 40 percent during acceleration and 20 percent during lugging. In 1974 exhaust emission standards were revised to substitute the sum of HC and NO_x emissions for HC emissions.

1. Light-duty trucks are trucks with gross vehicle weight below 2,722 kilograms. This weight limit was extented to 3,856 kilograms starting with 1979 model-year vehicles.

2. Heavy-duty vehicles are those with gross vehicle weight of 2,722 kilograms or more for model-years before 1979 and 3,856 kilograms for model-years 1979 and after.

3. Opacity measures the percentage of light blocked by smoke emissions.

Table A.1 U.S. emission standards for new passenger cars
(grams per kilometer)

Model-year	*CO*	*HC*	*NO_x*	*PM*	*Evap. (grams/test)*
Pre-control	56	9.3	3.9		6.0
1970[a]	21	2.6			
1971[a]	21	2.6			6.0[b]
1972[a]	17	1.9			2.0
1973–74[a]	17	1.9	1.9		2.0
1975–76	9.3	0.9	1.9		2.0
1977	9.3	0.9	1.2		2.0
1978–79	9.3	0.9	1.2		6.0[c]
1980	4.4	0.25	1.2		6.0
1981	2.1	0.25	0.62		2.0
1982–86[d]	2.1	0.25	0.62	0.37	2.0
1987–93	2.1	0.25	0.62	0.12	2.0
1994–95[e]	2.1	0.16[g]	0.25	0.05	2.0
1996–2003	2.6[f]	0.19[g]	0.37[h]	0.06	2.0[i]
2004 and newer[j]	1.1	0.078[g]	0.12	0.05	2.0

Note: A blank space indicates that no standard was established. National emission standards for cars were set in the 1968 Clean Air Act, which was amended in 1970.
a. Pre 1975 standards are expressed as equivalent 1975 test values.
b. Using the carbon canister trap method.
c. Using the sealed housing evaporative determination (SHED) method. 6.0 grams/test by SHED method represents approximately 70 percent less emissions than 2.0 grams/test by the carbon trap method.
d. High altitude standards for 1982–83 model-years are 4.8 g/km for CO, 0.35 g/km for HC, 0.62 g/km for NO_x, and 2.6 grams/test for evaporative emissions. Starting with 1984 model-year, all cars must meet standards at high altitude.
e. Standards apply to 40 percent of production for 1994 model-year and 80 percent of production for 1995 model-year.
f. Additional CO limit of 6.2 g/km at -7^0C.
g. Nonmethane hydrocarbons.
h. Diesel-fueled passenger cars have separate NO_x limits. The NO_x limit is 0.62 g/km for 5 years or 80,000 kilometers, and 0.78 g/km for 10 years or 160,000 kilometers.
i. Revised test procedures with additional test procedures are established.
j. Implementation of these standards are at USEPA's discretion.
Source: CONCAWE 1994.

In addition, more stringent opacity standards for heavy-duty diesel-fueled vehicles were adopted (20 percent during acceleration, 15 percent during lugging,[4] and 50 percent at maximum power). These opacity standards are still in effect. In 1979 exhaust emission standards were again revised and the testing procedure for HC emissions was changed for gasoline-fueled vehicles, resulting in higher readings for equivalent emissions. In 1984 a standard for NO_x emissions and a transient emissions testing procedure were introduced. In 1985 separate limits for diesel-fueled vehicles were implemented and the standard for the sum of HC and NO_x was eliminated. In addition, standards for evaporative emissions for gasoline-fueled heavy-duty vehicles were established. The 1987 revisions of CO and HC limits required use of two-way catalytic converters. Introduction of a PM limit and a more stringent NO_x limit for gasoline-fueled heavy-duty vehicles in 1990 required use of three-way catalytic converters in these vehicles. The certification requirement for manufacturers to comply with emission standards of 1991 and thereafter was set at 193,000 kilometers.

Effective April 1993, the USEPA has specified evaporative emission standards with new test procedures. These standards, phased in over the 1996–99 model-years, apply to both light-duty and heavy-duty vehicles (Table A.4).

In-Use Vehicles

Emission standards for in-use vehicles in the United States are established at the federal and

4. Lugging simulates the up hill movement of a fully loaded heavy-duty vehicle.

Table A.2 U.S. emission standards for new light-duty trucks
(grams per kilometer)

Model-year	*CO*	*HC*	*NO$_x$*	*PM* [a]
1970–74		Same as passenger cars		
1975–78	12.4	1.24	1.93	
1979–81	11.2	1.06	1.43	
1982	11.2	1.06	1.43	0.37
1983	11.2	1.06	1.43	
1984–86	6.2	0.50	1.43	0.37
1987	6.2	0.50	1.43	0.16
1988–90				
Less than 2,722 kg	6.2	0.50	0.75	0.16
2,722–3,856 kg	6.2	0.50	1.06	0.16
1991–93				
Less than 1,701 kg	6.2	0.50	0.75	0.16
1,702–3,856 kg	6.2	0.50	1.06	0.08
1994–2002[b]				
Less than 1,701 kg				
5 years or 80,000 km	2.1	0.16[c]	0.25	0.05
10 years or 160,000 km	2.6	0.19[c]	0.37	0.06
1,701–2,608 kg				
5 years or 80,000 km	2.7	0.20[c]	0.49	0.05
10 years or 160,000 km	3.4	0.25[c]	0.60	0.06
2,609–3,856 kg				
5 years or 80,000 km	3.1	0.24[c]	0.68	
10 years or 160,000 km	4.5	0.35[c]	0.95	0.07

Note: A blank space indicates that no standard was established.
a. PM standards apply to diesel-fueled trucks only and are relaxed for vehicles with gross vehicle weight over 1,701 kilograms. Limits are 0.31 g/km for 1987 model year and 0.28 g/km for 1988–90 model-years.
b. Standards are phased in over a three-year period starting with 1994 model-year.
c. Nonmethane hydrocarbons.
d. USEPA must decide by 1997 whether to apply these limits or set different standards.
Source: CONCAWE 1994.

state levels and vary by state (Table A.5). The 1990 amendments to the Clean Air Act called for the introduction of enhanced inspection and maintenance programs in polluted nonattainment areas for ozone with populations over 200,000 people as well as in “ozone transport regions” with populations over 100,000 people.[5] States were required to submit their inspection and maintenance programs by November 1993 and promulgate the necessary legislation. Of 181 areas of the United States identified to establish emissions testing programs, 95 moderately polluted areas were required to implement a basic inspection and maintenance program and 82 more polluted areas were required to implement an enhanced inspection and maintenance program. The standard for basic inspection and maintenance program was modeled on the use of a simple idle test. The USEPA’s standard for the enhanced inspection and maintenance program (commonly known as IM240) was based on annual testing of all 1968 and newer model-year passenger cars and light-duty trucks at centralized inspection stations. In these areas the scheme allowed a steady-state test for 1968–85 model-year vehicles but required the IM240 test for 1986 and newer model-year vehicles. Under the same act more stringent emission standards, known as “Tier 1,” were to be phased during 1994–96 and to be completely implemented for all 1997 and newer model-year vehicles (Table A.6). The inspection and maintenance procedures also require pressure and purge checks on the carbon canister and a visual inspection of the catalytic converter, fuel inlet, and evaporative emission control systems (CONCAWE 1994).

5. Nonattainment areas are those where national ambient air quality standards are not exceeded.

Table A.3 U.S. emission standards for new heavy-duty vehicles

(grams per break horsepower-hour)

Model-year	*CO*	*HC*	*NO_x*	*HC + NO_x*	*PM*	*Evap. (grams/test)*
1970–73[a]	63.6	6.55				
1974–78	40			16		
1979–83[b]	25	1.5[c]		10		
1984						
Gasoline-fueled vehicles						
Transient[d]	25	1.5	10.7	10		
Idle	0.5%					
Diesel-fueled vehicles	15.5	5	9.0			
1985–86						
Gasoline-fueled vehicles						
Option A[e]	37.1	1.9	10.6			3.0[f]
Option B[e]	40.0	2.5	10.7			3.0
Diesel-fueled vehicles	15.5	1.3	10.7			
1987–89						
Gasoline-fueled vehicles						
Less than 6,350 kg	14.4	1.1	10.6			3.0
Idle[g]	0.5%					
More than 6,350 kg	37.1	1.9	10.6			4.0
Diesel-fueled vehicles	15.5	1.3	10.7			
Idle[g]	0.5%					
1990						
Gasoline-fueled vehicles						
Less than 6,350 kg	14.4	1.1	6.0			4.0
Idle[g]	0.5%					
More than 6,350 kg	37.1	1.9	6.0			4.0
Diesel-fueled vehicles	15.5	1.3	6.0		0.6	4.0
Idle[g]	0.5%					
1991–92[h]						
Gasoline-fueled vehicles						
Less than 6,350 kg	14.4	0.9	5.0			
More than 6,350 kg	37.1	1.7	5.0			
Diesel-fueled vehicles	15.5	1.3	5.0		0.25	
1993[h]						
Buses	15.5	1.3	5.0		0.10	
1994–95[h]						
Diesel-fueled vehicles	15.5	1.3	5.0		0.10	
Buses	15.5	1.3	5.0		0.07	
1996–97[h]						
Buses	15.5	1.3	5.0		0.05	
1998 and newer[h]						
3,856–12,700 kg	15.5	1.3	3.15		0.10	
Buses	15.5	1.3	4.0		0.05	

Note: A blank space indicates that no standard was established.

a. Standards apply to gasoline-fueled vehicles only.

b. Alternative standards are 25 g/bhp-h for CO and 5 g/bhp-h for the sum of CO + NO_x.

c. HC measurement method changed starting with 1979 model-year gasoline-fueled vehicles. The new method (FID) results in higher readings for equivalent emissions measured with the former method (NDIR).

d. A new transient test procedure is introduced. The standard for NO_X is interim.

e. Different dynamometer schedules are used for options A and B. Option A and B limits apply at the beginning and end of the durability test schedules.

f. For heavy-duty vehicles with gross vehicle weights of 3,856–6,350 kilograms. For heavier vehicles the limit is 4.0 grams/test.

g. For heavy-duty gasoline-fueled vehicles using the catalyst technology.

h. From 1991 on, the NMHC limit of 1.2 g/bhp-h applies for natural gas engines instead of the HC limit.

Source: CONCAWE 1994; CONCAWE 1995.

Table A.4 U.S. Federal evaporative emission standards for new vehicles

Implementation schedule[a] *Year*	*Share of production (percent)*	*GVW*[b] *(kilograms)*	*Durability (kilometers)*	*Three-day diurnal hot soak test (grams/test)*	*Supplementary two-day diurnal test (grams/test)*	*Running loss (grams/km)*	*Spitback test (grams liquid/test)*
1996	20	< 2,727	[c]	2.0	2.5	0.031	1.0
1997	20	2,727–3,864	192,000	2.5	3.0	0.031	1.0
1998	90	3,865–6,364	192,000	3.0	3.5	0.031	1.0
1999	100	> 6,364	192,000	4.0	4.5	0.031	

Note: A blank space indicates that no standard was established. Diurnal losses occur when the vehicle is stationary with the engine off. These losses are due to vapor emissions from the fuel tank at ambient temperature changes during a 24-hour period. Evaporative losses are measured after three-day ambient temperature cycles of 22.2–35.6^{0}C using the Sealed Housing for Evaporative Determination (SHED) method which is supplemented by two-day diurnal test with similar temperature cycles. Running losses occur while the vehicle is normally driven. The spitback test simulates fuel losses during vehicle refueling.

a. Methanol-fueled vehicles are required to comply the implementation schedule starting with the 1998 model-year. However, manufacturers selling less than 10,000 vehicles a year do not have to comply until the 1999 model-year.

b. GVW is gross vehicle weight.

c. Durability for 1996 model-year vehicles is defined as follows: light-duty vehicle two years or 38,400 kilometers if the evaporative emission control device costs less than $200; eight years or 128,000 kilometers if deemed "specified major emission components." For light-duty trucks the durability requirements are specified as ten years or 160,000 kilometers for vehicles less than 1,705 kilograms, and 192,000 kilometers for heavier vehicles.

Source: CONCAWE 1994.

Table A.5 U.S. emission standards for in-use vehicles

Jurisdiction/vehicle type	*CO (percentage)*	*HC (ppm)*	*Smoke (percent opacity)*
Federal (USEPA inspection and maintenance program)			
Passenger cars (1981and newer models)	1.2	220	
State of Arizona			
Gasoline-fueled passenger cars and light-duty trucks			
1967–71	5.5	500	
1972–74	5.0	400	
1975–78	2.2	250	
1979	2.2	220	
1980 and later model-years	1.2	220	
Diesel-fueled vehicles			50
State of Florida			
Gasoline-fueled vehicles			
Less than 2,722 kilograms			
1975–77	5.0	500	
1978–79	4.0	400	
1980	3.0	300	
1981 and later model-years	1.2	220	
2,722–4,536 kilograms			
1975–77	6.5	750	
1978–79	5.5	600	
1980	4.5	400	
1981–84	3.0	300	
1985 and later model-years	1.2	220	
Diesel-fueled vehicles			
Cruise mode			20
Idle mode			5

Note: A blank space indicates that no standard was established. CO and HC emission standards for gasoline-fueled vehicles apply both at idle and 2,500 rpm. Smoke measurements of diesel-fueled vehicles are made at free acceleration (in this test the engine is rapidly accelerated from idle to full speed).

Source: Adapted from Faiz, Weaver, and Walsh 1996.

Table A.6 U.S. emission standards for in-use vehicles based on the IM240 test
(grams per kilometer)

Vehicle type/model-year	*CO*	*HC*	NO_x
Light-duty vehicle			
1986–1993	12.4	0.5	1.2
1994–1996[a]	12.4/9.3	0.5/0.4[b]	1.2/0.9
1997 and later model-years	9.3	0.4[b]	0.9
Light-duty truck			
Less than 2,722 kilograms			
1986–1993	12.4	0.7	2.2
1994–1996[a]	12.4/9.3	0.7/0.4[b]	2.2/1.2
1997 and later model-years	9.3	0.4[b]	1.2
Light-duty truck			
More than 2,722 kilograms			
1986–1993	12.4	0.5	2.2
1994–1996[a]	12.4/9.3	0.5/0.4[b]	2.2/1.6
1997 and later model-years	9.3	0.4[b]	1.6

a. During the 1994–96 phase-in period, a percentage of vehicles designated by each state is required to comply with the standards for the 1986–93 model-year vehicles and the remaining vehicles are required to comply with the standards for the 1997 and newer model-year vehicles.
b. Non-methane hydrocarbons.
Source: Adapted from Faiz, Weaver, and Walsh 1996.

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4

CASE STUDIES

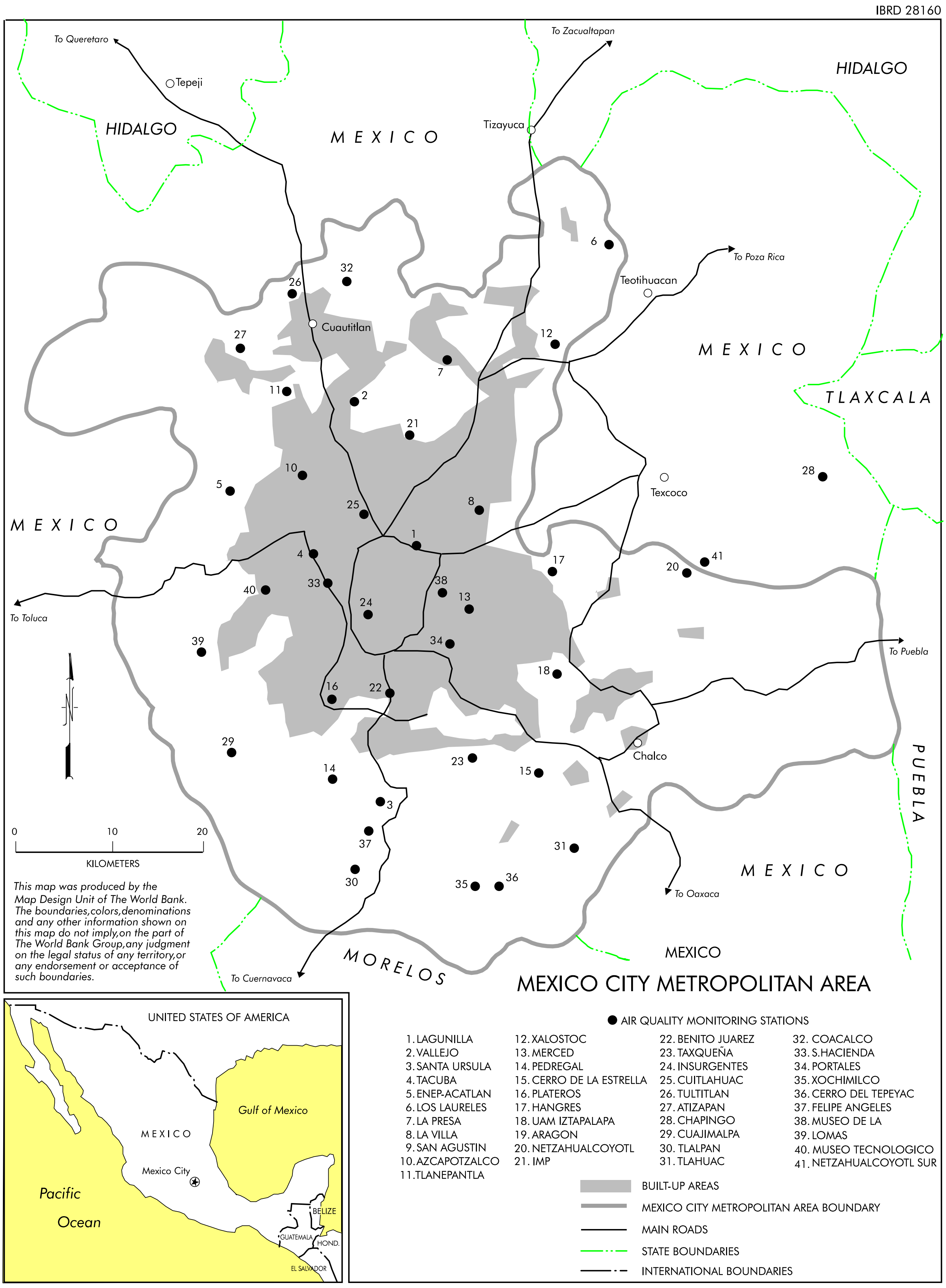
An increasing number of urban centers in Latin America are beset with vehicular air pollution. Despite efforts to alleviate them, ambient levels of air pollutants are rising as vehicle fleets grow, posing a health risk to urban populations and damaging natural resources. Three urban centers in Latin America—Mexico City, Santiago, and São Paulo—have particularly bad air pollution problems. Several air pollutants in these urban centers exceed the national ambient air quality standards and World Health Organization (WHO) guidelines. In other urban centers—Belo Horizonte, Buenos Aires, Rio de Janeiro, and Santafé de Bogotá—national ambient air quality standards and WHO guidelines are exceeded for at least one pollutant.

This chapter presents case studies of the vehicular air pollution problem in seven Latin American urban centers:

- Mexico City
- Santiago
- São Paulo
- Belo Horizonte
- Buenos Aires
- Rio de Janeiro
- Santafé de Bogotá.

Each study analyzes ambient air quality, sources of air pollution, institutional responsibilities (at the national, regional, and local levels), measures implemented to curtail vehicular air pollution, and evaluation of these measures. These measures are described in terms of vehicle emission standards and inspection programs, fuel-targeted measures, and transport management.

Mexico City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Cuautitlan
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T L A X C A L A
Texcoco
M E X I C O
To Toluca
To Puebla
Chalco
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KILOMETERS
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UNITED STATES OF AMERICA
Gulf of Mexico
M E X I C O
Mexico City
Pacific
Ocean
BELIZE
GUATEMALA
HOND.
EL SALVADOR
MEXICO CITY METROPOLITAN AREA
AIR QUALITY MONITORING STATIONS
1. LAGUNILLA
2. VALLEJO
3. SANTA URSULA
4. TACUBA
5. ENEP-ACATLAN
6. LOS LAURELES
7. LA PRESA
8. LA VILLA
9. SAN AGUSTIN
10. AZCAPOTZALCO
11. TLANEPANTLA
12. XALOSTOC
13. MERCED
14. PEDREGAL
15. CERRO DE LA ESTRELLA
16. PLATEROS
17. HANGRES
18. UAM IZTAPALAPA
19. ARAGON
20. NETZAHUALCOYOTL
21. IMP
22. BENITO JUAREZ
23. TAXQUEÑA
24. INSURGENTES
25. CUITLAHUAC
26. TULTITLAN
27. ATIZAPAN
28. CHAPINGO
29. CUAJIMALPA
30. TLALPAN
31. TLAHUAC
32. COACALCO
33. S.HACIENDA
34. PORTALES
35. XOCHIMILCO
36. CERRO DEL TEPEYAC
37. FELIPE ANGELES
38. MUSEO DE LA
39. LOMAS
40. MUSEO TECNOLOGICO
41. NETZAHUALCOYOTL SUR
BUILT-UP AREAS
MEXICO CITY METROPOLITAN AREA BOUNDARY
MAIN ROADS
STATE BOUNDARIES
INTERNATIONAL BOUNDARIES
JULY 1997

The Mexico City Metropolitan Area (MCMA) is the most populated urban area in Latin America and the Caribbean. Located at the southern end of the Valley of Mexico at an average altitude of about 2,240 meters, the MCMA has expanded to fill the full width of the valley, and now comprises about 1,200 square kilometers administered by the Federal District and seventeen municipalities. High mountains constrain further growth, except to the north and southeast. The average height of the surrounding mountain ranges is about 3,200 meters, with some peaks exceeding 5,000 meters. The city was originally situated on a series of artificial islands in a shallow lake surrounded by pine forests. But today, as a result of uncontrolled urban growth, 99 percent of the original lake and 75 percent of the forests have disappeared, exposing more than 40,000 hectares of land to wind erosion, a major source of PM in ambient air.

Urban expansion in the MCMA has been caused by high rates of population growth and migration from rural areas. From less than 1 million people at the beginning of the century, the MCMA's population had grown to more than 17 million in 1994, representing 18 percent of Mexico's population. Between 1930 and 1980 the MCMA became the center for Mexico's rapid industrial growth, with the number of industrial establishments increasing by about twelve-fold. The MCMA's good infrastructure and educated work force attracted industry, and migrants came because of its employment opportunities. The MCMA now accounts for 36 percent of Mexico's domestic production and consumes 17 percent of domestic energy production.

Emissions from about 3 million vehicles, 31,000 industries, and 12,000 service-related facilities in the MCMA are the principal anthropogenic source of air pollution. The area's topography and climate also play a key role in making the pollution levels unusually severe. Because of its high altitude, air in the MCMA is 23 percent less dense than at sea level. This reduces the combustion efficiency of fuels in internal combustion engines that are not adjusted to account for the altitude and results in higher levels of CO and HC emissions. The mountains surrounding the MCMA tend to limit air circulation as well, trapping pollutants within the Valley of Mexico. During the daytime winds carry industrial emissions from the north and northwest to populated areas in the city.

Thermal inversions limit air circulation even further. A thermal inversion occurs when a layer of cold, dense, thermally stable air prevents pollutants emitted at ground level from dispersing upward and produces high pollutant concentrations, frequently reaching critical levels. Inversions occur in the MCMA throughout the year but are especially severe during the dry winter season (from November to March). On most days the trapped pollutants are released when the sun heats the cold air and destroys the thermal inversion at around 9 A.M. to 11 A.M.

Some of the short-term health effects of air pollution in the MCMA include eye irritation, migraine, and irritation and inflammation of the upper respiratory tract resulting in shortness of breath, sore throat, coughing, and hoarseness. Documentation by Mexican authorities shows a clear positive correlation between the level, duration, and frequency of air pollution episodes and the incidence of the symptoms (DDF 1996).

Ambient Air Quality

The most critical air pollutants in the MCMA are ozone and its precursors NO_2 and NMHC, and PM. In addition, ambient CO concentrations exceed the Mexican standard in traffic-congested streets. Although SO_2 and lead were of concern in the late 1980s and early 1990s, their ambient concentrations have been below the Mexican air quality standards since 1992.

Ambient ozone concentrations in the MCMA have consistently exceeded the Mexican 1-hour standard of 0.11 ppm (220 $\mu g/m^3$) despite significant control efforts of NO_x and NMHC emissions. Violations of the standard have been observed year round because the number of daylight hours and the direct angle of the sun in the MCMA are not heavily affected by seasonal variations.[1] Since 1988 ambient ozone concentrations have exceeded the 1-hour standard on 89 to 97 percent of the days of the year (Table 4.1). Although the number of days with very high ambient ozone concentrations increased during 1988–92, the situation substantially stabilized during 1992–95. For example, the number of days with ozone concentrations above 710 $\mu g/m^3$ peaked in 1992 with eleven days, but none occurred in 1994 or 1995. The highest ozone concentration ever recorded in the MCMA was on

1. By contrast, in many other Latin American urban centers violations of 1-hour ozone standards occur only seasonally.

Table 4.1 Number of days with high ozone concentrations in the MCMA, 1988–95

Year	*Greater than 220 μg/m³*	*Greater than 465 μg/m³*	*Greater than 588 μg/m³*	*Greater than 710 μg/m³*
1988	329	67	11	1
1989	329	15	3	0
1990	328	84	27	3
1991	353	173	56	8
1992	333	123	37	11
1993	324	80	14	1
1994	344	93	4	0
1995	324	88	6	0

Note: The Mexican standard is 220 μg/m³ (0.11 ppm) for 1-hour averaging time. The 220 μg/m³, 465 μg/m³, 590 μg/m³, and 710 μg/m³ measures used here correspond to IMECA values (described later) of 100, 200, 250, and 300, respectively.
Source: DDF 1996.

March 6, 1992, with a value of 955 μg/m³ (DDF 1996). In 1995 the two highest ozone concentrations in the MCMA were 698 μg/m³ (Pedregal) in the southwestern section and 690 μg/m³ (Benito Juarez) in the central section. The highest concentrations in each of the other sections were 588 μg/m³ (Azcapotzalco) in the northwest, 562 μg/m³ (Uam Iztapalapa) in the southeast, and 552 μg/m³ (Xalostoc) in the northeast (DDF 1997a). In 1995 ozone concentrations were above the Mexican 1-hour standard on 89 percent of the days, above 465 μg/m³ on 24 percent of the days, and above 588 μg/m³ on 2 percent of the days (see Table 4.1).

Besides its adverse health effects and ozone and nitrate forming characteristics, NO_2 pollution in Mexico City produces a brownish color smog that reduces visibility. Ambient concentrations of NO_2 in the MCMA are lower during April through September because of more frequent rain which transforms NO_2 into nitrates and nitric acid, and because of increased solar radiation and higher temperatures which promote conversion of NO_2 to ozone. In 1992 the peak 1-hour NO_2 level at a downtown station was 602 μg/m³, a concentration well over the Mexican standard of 395 μg/m³ (0.21 ppm; LANL and IMP 1994). In 1995 the highest 1-hour concentration in the MCMA was 835 μg/m³ (Enep-Acatlán) in the northwestern section. The highest concentrations in each of the other sections were 658 μg/m³ (Benito Juarez) in the center, 624 μg/m³ (Plateros) in the southwest, 525 μg/m³ in the northeast (Xalostoc), and 466 μg/m³ in the southeast (Taxquéna). The 1-hour Mexican standard was exceeded from one day in the northwestern section to thirteen days in the central section (DDF 1997a).

In 1992 the annual average concentration of NO_2 at a downtown station (244 μg/m³) was more than twice the USEPA's annual average standard of 100 μg/m³ (there is no corresponding Mexican standard; LANL and IMP1994). In 1995 the annual average NO_2 concentrations in the MCMA ranged from 56 μg/m³ (Xalostoc) in the northeastern section to 87 μg/m³ (Benito Juarez) in the central section (DDF 1997a).

Ambient monitoring of HC conducted in 1992 and 1993 indicates that the highest concentrations were observed in the northeastern industrial section (Xalostoc), the central section (Merced), and the northwestern industrial, commercial, and commuter section (Tlalnepantla). In March 1992, HC concentrations ranged between 2.0 and 7.2 parts per million carbon (ppmC) in Xalostoc, between 2.4 and 6.2 ppmC in Merced, and between 1.6 and 4.7 ppmC in Tlalnepantla (LANL and IMP 1994). HC concentrations were higher during morning hours and averaged about 3.5 ppmC. This average concentration exceeds those observed in Los Angeles in the late 1970s and early 1980s (2 ppmC and 1 ppmC, respectively; DDF 1996).

Although the photochemical ozone formation potential of benzene is much smaller, it has carcinogenic effects on humans. At Merced and Xalostoc, 3-hour average concentrations of benzene averaged between 50 and 60 parts per billion (ppb), with a maximum of 86 ppb. Concentrations higher than those monitored at these stations would be expected at street level (LANL and IMP 1994).

TSP is considered another air pollutant of concern in the MCMA. Since 1986 ambient TSP concentrations have exceeded the Mexican 24-hour standard of 260 µg/m^3, especially in the northeastern and southeastern sections, with day time concentrations nearly twice as high as those at night. During 1990 and 1991 the highest 24-hour average TSP concentrations recorded varied between 1,100 µg/m^3 and 1,300 µg/m^3 in an industrial area located in the northeastern section (LANL and IMP 1994). These concentrations are among the highest recorded in any city of the world. In 1993 ambient TSP concentrations exceeded the Mexican 24-hour standard on about 64 percent of the sampling days in the southeastern section, 30 percent of the sampling days in the northeastern section, and 10 percent of the sampling days in the central section. In 1995 the highest 24-hour average TSP concentration in the MCMA was 727 µg/m^3 (Xalostoc) in the northeastern section. The highest concentrations in each of the other sections of the MCMA were 597 µg/m^3 (Cerro de la Estrella) in the southeast, 555 µg/m^3 (Tlalnepantla) in the northwest, 390 µg/m^3 (Lomas) in the southwest, and 357 µg/m^3 (Merced) in the center. The Mexican 24-hour standard was exceeded on 82 percent of the sampling days in the northeastern section, 46 percent of the sampling days in the southeastern section, 18 percent of the sampling days in the central section, 12 percent of the sampling days in the northwestern section, and 2 percent of the sampling days in the southwestern section (DDF 1997a).

In 1993 annual average TSP concentrations in all sections of the MCMA exceeded the Mexican standard of 75 µg/m^3. These concentrations were about 340 µg/m^3 at a southeastern station, about 200 µg/m^3 at central, northern, and northeastern stations, and about 120 µg/m^3 at a southern station. Annual average TSP concentrations in 1993 were 28 percent less than those registered in 1988 but were slightly higher than those in 1992 (CMPCCA 1995a). In 1995 annual average TSP concentrations were still higher than the Mexican standards: 375 µg/m^3 (Xalostoc) in the northeastern section, 244 µg/m^3 (Cerro de la Estrella) in the southeastern section, 173 µg/m^3 (Merced) in the central section, 172 µg/m^3 (Tlalnepantla) in the northwestern section, and 119 µg/m^3 (Lomas) in the southwestern section (DDF 1997a).

Ambient PM-10 concentrations over the Mexican 24-hour standard of 150 µg/m^3 have been recorded since 1988. Ambient PM-10 concentrations are highest in the northeastern and southeastern sections of the MCMA, where industry is concentrated, and lowest in the southwestern section. Ambient PM-10 concentrations over the standard decreased from 40 percent of the total measurements in 1988 to 16 percent in 1994 and 13 percent in 1995 (DDF 1996). The 24-hour PM-10 concentrations for the entire MCMA during 1990–92 were considerably lower than those during 1988–89, increased slightly in 1993, but decreased again in 1994. In 1995 the Mexican 24-hour standard was exceeded in all sections of the MCMA except in the southwest. The highest PM-10 concentrations in the MCMA were 252 µg/m^3 (Xalostoc) in the northeastern section, 238 µg/m^3 (Tláhuac) in the southeastern section, 206 µg/m^3 (Tlalnepantla) in the northwestern section, 187 µg/m^3 (Merced) in the central section, and 143 µg/m^3 (Pedregal) in the southwestern section. The Mexican 24-hour standard was exceeded on 16 percent of the sampling days in the northeastern section, 6 percent of the sampling days in the southeastern section, and 3 percent of the sampling days in the central and northwestern sections. Ambient PM-10 concentrations did not exceed the PM-10 standard in the southwestern section (DDF 1997a). PM-10 concentrations were lower during the nights and rainy months.

In 1995 annual average PM-10 concentrations exceeded the Mexican standard of 50 µg/m^3 in all sections of the MCMA, except the southwestern section. The highest annual average PM-10 concentrations were 87 µg/m^3 (Netzahualcóyotl) in the northeastern section, 67 µg/m^3 (Cerro de la Estrella) in the southeastern section, 60 µg/m^3 (Tultitlán) in the northwestern section, 51 µg/m^3 (Merced) in the central section, and 44 µg/m^3 (Pedregal) in the southwestern section (DDF 1997a).

Ambient concentrations of CO vary according to time of day and traffic flow. In 1992 8-hour ambient CO concentrations were measured as high as 27.5 mg/m^3 at a monitoring station heavily influenced by local traffic (Cuitlahuac) in the northwest of the MCMA. This concentration is more than twice the Mexican 8-hour average standard of 12.6 mg/m^3 (11 ppm). Since 1992 ambient CO concentrations in the MCMA have been showing a decreasing trend (CMPCCA 1995a). The monitoring data for 1995 show that the Mexican 8-hour average standard was exceeded in the northeastern section on three

days, the central section on one day, and the northwestern section by at least one day. The highest 8-hour CO concentrations in the MCMA were 18.9 mg/m^3 (Netzahualcóyotl) in the northeastern section, 17.1 mg/m^3 (Merced) in the central section, 13.6 mg/m^3 (Vallejo) in the northwestern section, 12.5 mg/m^3 (Taxquena) in the southeastern section, and 9.2 mg/m^3 (Plateros) in the southwestern section (DDF 1997a). Because most ambient concentrations are measured by monitoring stations located at roof tops, however, the resulting data may not be representative of the higher concentrations that people are exposed to on canyon-type streets (LANL and IMP 1994).

Ambient levels of SO_2 in the MCMA have been declining as a result of the lower sulfur content of conventional fuels and use of alternative fuels. During the second half of the 1980s the annual average ambient concentration of SO_2 decreased from 165 μg/m^3 to 130 μg/m^3 but was still well over the Mexican standard of 78 μg/m^3 (0.03 ppm; LANL and IMP 1994). In 1995 the maximum annual average SO_2 concentrations were within the Mexican standard and ranged from 44 μg/m^3 in the southwestern section (Santa Ursula) to 62 μg/m^3 (Aragón) in the central section of the MCMA (DDF 1997a).

Since March 1991 ambient SO_2 levels have been lower than the Mexican 24-hour standard of 338 μg/m^3 (0.13 ppm; CMPCCA 1995a; DDF 1996). In 1995 the maximum 24-hour average SO_2 concentrations were 224 μg/m^3 (Aragón) in the northeastern section, 200 μg/m^3 (Lagunilla) in the central section, 182 μg/m^3 (Vallejo) in the northeastern section, 179 μg/m^3 (Uam Iztapalapa) in the southeast section, and 130 μg/m^3 (Santa Ursula) in the southwestern section (DDF 1997a).

In 1988 some ambient lead concentrations in the MCMA exceeded 10 μg/m^3 in the northwestern, northeastern, and southeastern sections and 2.5 μg/m^3 in the southeastern and central sections of the MCMA (DDF 1996). Between 1988 and 1992, however, quarterly average concentrations of lead in ambient air decreased by 83 percent in the northwestern section (from 3.0 μg/m^3 to 0.5 μg/m^3 at Tlalnepantla), 79 percent in the southeastern section (from 2.4 μg/m^3 to 0.5 mg/m^3 at Cerro de la Estrella), 71 percent in the northeastern section (from 3.9 μg/m^3 to 1.1 mg/m^3 at the Xalostoc), 60 percent in the center (from 1.5 μg/m^3 to 0.6 μg/m^3 at Merced), and 43 percent in the southwestern section (from 1.05 μg/m^3 to 0.6 μg/m^3 at Pedregal; LANL and IMP 1994). Since 1992 ambient lead concentrations have been below the Mexican lead standard of 1.5 μg/m^3 for quarterly average (CMPCCA 1995a). The average lead concentration for the fourth quarter of 1994 was about 0.15 μg/m^3 (Pedregal) in the southwestern section and 0.6 μg/m^3 (Xalostoc) in the northeastern section (DDF 1996). Ambient lead concentrations in air have decreased significantly as a result of reduction of lead in regular gasoline and introduction of unleaded gasoline (Figure 4.1).

Sources of Pollutants

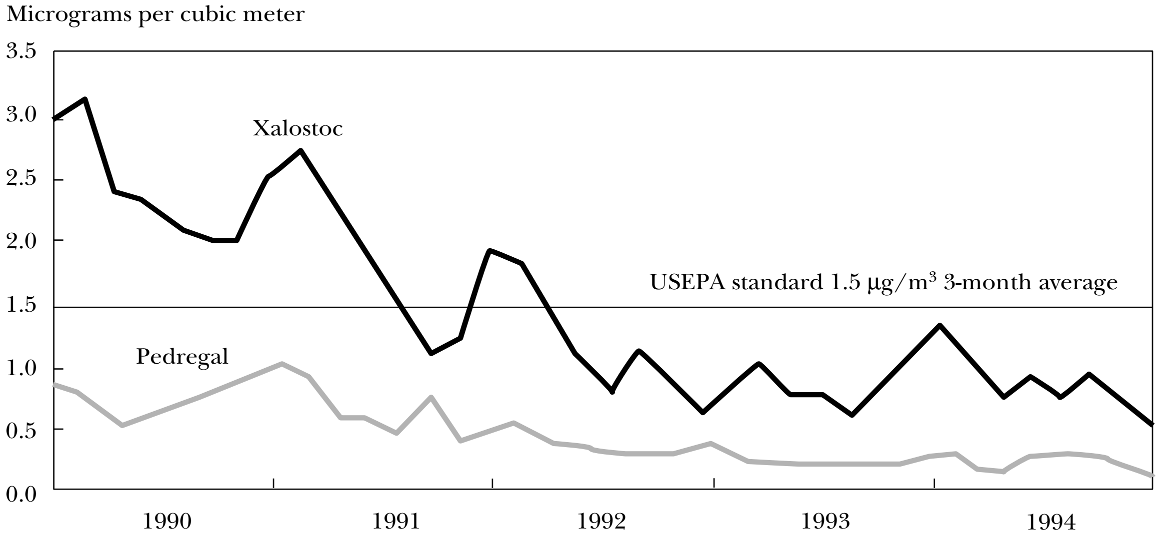
Main sources of pollutant emissions in the MCMA are road transport, industry, service-related facilities, and wind-blown dust. Based on the emissions inventory for 1994, motor vehicles are by far the most important source of pollutant emissions. In 1994 road-based motor vehicles contributed to 99 percent of CO, 54 percent of HC, 70 percent of NO_x, 27 percent of SO_2, and 4 percent of PM emissions in the MCMA (Figure 4.2). As shown in Table 4.2, which details the sources of pollutant emissions, private cars alone emit about 44 percent of CO, 25 percent of HC and NO_x, 39 percent of non-dust PM, and 13 percent of SO_2 in the MCMA.

Most CO emissions from vehicles are caused by incomplete fuel combustion, especially in vehicles that are poorly maintained, uncontrolled (for example, vehicles not equipped with catalytic converters) or not adapted for operation at high altitudes. After motor vehicles, industry is the second largest emission source for NO_x. In addition to motor vehicle exhaust emissions, major anthropogenic sources of HC include evaporative emissions from gasoline, industrial processes, distribution and use of LPG, and use of solvents.

The HC to NO_x ratio in ambient air is important for identifying the limiting pollutant for ozone formation. For the MCMA this ratio was determined as varying between 13 and 50 ppmC/ppm NO_x (DDF 1996).[2] Based on Mexican Petroleum Institute plots that relate maximum concentrations of ozone to the concentrations of HC and NO_x in ambient air

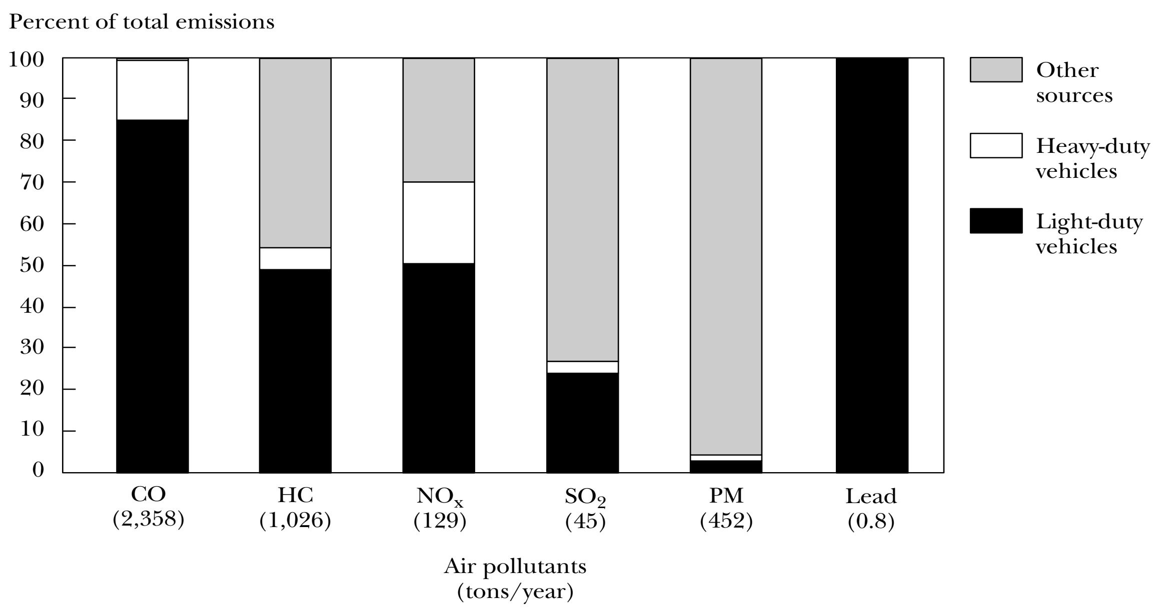
2. By contrast, in the South Coast Basin of California this ratio was about 12 in the late 1970s and mid-1980s, and about 9 in the 1990s.

Figure 4.1 Ambient lead concentrations in the MCMA, 1990–94



Source: DDF 1996.

Figure 4.2 Share of pollutant emissions from motor vehicles and other sources in the MCMA, 1994



Source: DDF 1996.

Table 4.2 Pollutant emissions by source in the MCMA, 1994

	CO		*HC*		*NO_x*		*PM*		*SO_2*	
Emission source	*Tons/year*	*Percent*	*Tons/year*	*Percent*	*Tons/year*	*Percent*	*Tons/year*	*Percent*	*Tons/year*	*Percent*
Road transport	2,346,811	99.5	554,749	54.1	89,784	69.8	18,779	4.2	12,138	26.7
Private cars	1,044,008	44.3	253,866	24.8	31,913	24.8	10,321	2.4	6,062	13.3
Taxis	529,530	22.5	126,575	12.3	15,982	12.4	613	0.1	3,073	6.8
Vans, pick-ups, and microbuses	432,451	18.3	120,955	11.8	16,989	13.2	1,488	0.3	1,832	4.0
Ruta-100 buses	5,655	0.2	2,337	0.2	6,751	5.3	1,900	0.4	366	0.8
State of Mexico buses	59,110	2.5	2,837	0.3	5,077	3.9	2,195	0.5	502	1.1
Trucks	276,057	11.7	48,179	4.7	13,072	10.2	2,262	0.5	303	0.7
Other transport[a]	1,686	0.1	570	0.1	2,003	1.6	63	0.0	62	0.1
Industry	8,696	0.4	33,099	3.2	31,520	24.5	6,358	1.4	26,051	57.3
Service facilities	948	0.0	398,433	38.8	5,339	4.1	1,077	0.2	7,217	15.9
Vegetation	0	0.0	38,909	3.8	0	0.0	0	0.0	0	0.0
Natural dust	0	0.0	0	0	0	0.0	425,337	94.2	0	0.0
Total	2,358,141	100.0	1,025,760	100.0	128,646	100.0	451,614	100.0	45,468	100.0

a. Includes rail and air transport modes.
Source: DDF 1996.

(Figure 4.3), formation of ozone in the MCMA can be more effectively controlled by reducing concentrations of NO_x than HC. For this reason the MCMA's recent air quality control strategy for ozone emphasizes control of NO_x emissions from motor vehicles, which are responsible for about 70 percent of total NO_x emissions. However, high concentrations of HC in the MCMA are likely to be correlated with extensive nonautomotive use of LPG, which consists mainly of propane and butane. Because propane and butane are less reactive for ozone formation than most of the volatile HC present in gasoline, control of HC emissions (especially from gasoline production, storage, distribution, and use) is probably more important than the HC to NO_x ratio suggests.

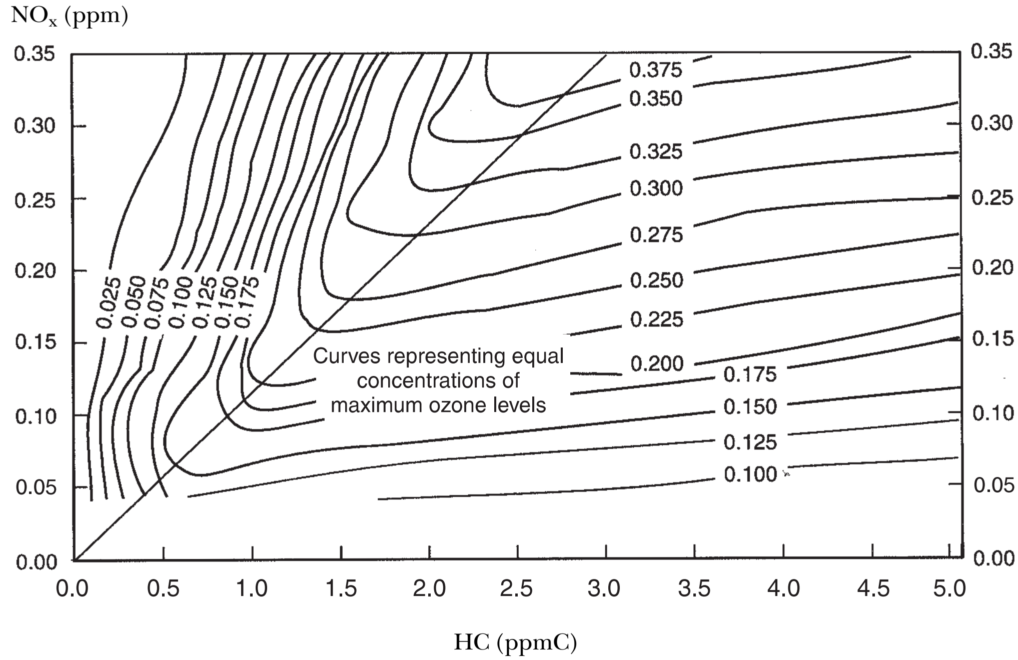
Industry contributes 57 percent and service-related facilities contribute 16 percent of SO_2 emissions in the MCMA. SO_2 emissions from these sources originate from sulfur in industrial gas oil, which is limited to 2 percent by weight. Industrial gas oil constitutes only 2 percent of total energy consumption in the MCMA. SO_2 emissions from the transport sector are from sulfur in gasoline and diesel fuel, which together make up 53 percent of total energy consumption in the MCMA (DDF 1996).

About 94 percent of PM in air is believed to originate from natural sources, mainly soil erosion and dust from unpaved and paved surfaces. However, the main contributor to PM-10 is anthropogenic sources, especially motor vehicles. PM-10 also includes secondary particles that form in the atmosphere in the presence of solar radiation.

The main source of lead exposure in the MCMA is through inhalation of lead in ambient air, which results largely from combustion of leaded gasoline in motor vehicles. People also ingest lead from metal salts leached from metal cans containing acidic food products (such as chili sauces and fruit juices) and lead enamel pottery used for eating and drinking.

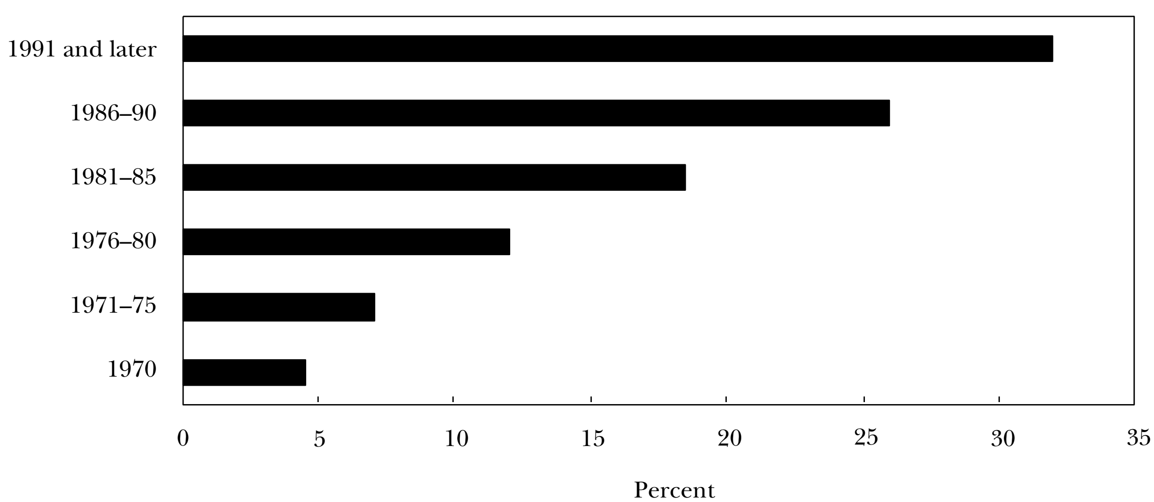
About 3 million motor vehicles are estimated to circulate and contribute to air pollution in the MCMA. Of the vehicles registered in Mexico City, 71.2 percent are private cars, 17.8 percent are freight vehicles, 5.4 percent are taxis, 1.9 percent are buses, 1.1 percent are government vehicles, and 2.6 are other vehicles (DDF 1996). About 42 percent of the vehicle fleet in the MCMA is more than ten years old, and 68 percent of the vehicle fleet was manufactured before 1991 and thus is not equipped with catalytic converters (Figure 4.4). The deep recession Mexico experienced during the 1980s partly explains the large proportion of older vehicles in the MCMA. Tax exemptions for vehicles older than ten years and low repair costs also have encouraged prolonged vehicle ownership. These older vehicles emit a considerable proportion of pollutants, and poor maintenance greatly contributes to air pollution. For example, based on the results of remote sensing tests conducted on

Figure 4.3 Relation between ambient HC, NO_x, and maximum ozone concentrations in the MCMA



Source: DDF 1996.

Figure 4.4 Distribution of vehicles by model-year in the MCMA, 1994



Source: DDF 1996.

Table 4.3 Pollutant emission rates from various transport modes in the MCMA
(grams of pollutant per passenger-kilometer)

	CO		*HC*		NO_x	
Vehicle type	*With catalytic converter*	*Without catalytic converter*	*With catalytic converter*	*Without catalytic converter*	*With catalytic converter*	*Without catalytic converter*
Private cars	4.70	45.20	0.47	4.47	0.40[a]	1.00
Taxis	10.00	96.85	1.00	9.57	0.86[a]	2.14
Vans	1.11	13.40	0.14	1.30	0.08[a]	0.20
Gasoline-fueled microbuses	0.04	0.79	0.02	0.09	0.06[a]	0.16
LPG-fueled microbuses	0.11	0.91	0.01	0.06	0.03	0.07
Urban buses	—	0.70	—	0.20	—	0.60

— Not available.
a. Three-way catalytic converter.
Source: DDF 1996.

motor vehicles in 1991, the highest emitting 25 percent of the fleet in the MCMA was found to be responsible for 47 percent of CO emissions from mobile sources. Twelve percent of the fleet contributed 50 percent of HC emissions, and 25 percent of the fleet accounted for 62 percent of HC emissions (CMPCCA 1995a; Beaton, Bishop, and Stedman 1992).

While the older vehicles have remained in circulation, sales of new vehicles in the MCMA have increased considerably since 1987. For example, the annual increase for vehicle sales was 19.8 percent between 1987 and 1992, a result of lower interest rates and more attractive financing conditions, as well as of simplification of licensing formalities and slight increases in vehicle prices (CMPCCA 1995a). During the past few years the size of the MCMA's vehicular fleet has been growing by nearly 10 percent a year (DDF 1996).

Pollutant emission rates for typical private cars, taxis, vans, microbuses, and urban buses in the MCMA are presented in Table 4.3. Among these, taxis and private cars have much higher emission rates than road-based mass transport vehicles. Table 4.3 also shows pollutant emission rates for typical vehicles equipped with catalytic converters.

About 36 million person-trips are made every day in the MCMA, of which 21.4 percent are by private cars. Unimodal trips represent about 80 percent of the total and consist of about 60 percent by buses, 29 percent by private cars, 5 percent by taxis, 4 percent by metro, and 2 percent by the combination of trolleybuses, bicycles, and motorcycles. Although private cars make up 71.2 percent of the fleet, they are used by only 15 percent of the population (CMPCCA 1995a).[3] Taxis are estimated to carry more than 1 million passengers a day (World Bank 1992). Vans and microbuses consume about 18 percent of gasoline.

Buses carried 991 million passengers in 1993. The MCMA's electricity-driven public transport system—which consists of the metro, trolleybuses, and light trains—does not emit pollutants. The metro provides public transport services on a 175-kilometer network. Trolleybuses and light trains together transport only 1 percent of the city's passengers. About 350 trolleybuses operate on 13 lines with a coverage of 429 kilometers, 69 kilometers of which are elevated. Trolleybuses carry an average of 310,000 passengers a day and light trains, about 42,000 passengers a day. The light train system consists of 15 trains that operate on the 12.5-kilometer line between Taxqueña and Xochimilco (CMPCCA 1995a).

Institutional Responsibilities

The institutions responsible for controlling vehicular air pollution in the MCMA are shown in Table 4.4 and discussed below.

Federal institutions. Over the past twenty years Mexico has developed a comprehensive legal framework for environmental protection. The original approach, reflected in the 1971 federal

3. About 75 percent of the private cars in the MCMA are estimated to be operational on any given day.

Table 4.4 Institutional responsibilities for vehicular air pollution control in the MCMA

Responsibility	*SEMARNAP*	*State of Mexico*	*Federal District Department (DDF)*
Fuel standards	SEMARNAP in collaboration with the Secretariat of Commerce and Industrial Development (SECOFI), the Mexican Petroleum Company (Pemex), and the Mexican Petroleum Institute		
Emissions standards for new vehicles and certifying their observance by automotive industry	SEMARNAP in collaboration with SECOFI, Secretariats of Energy, Mines, and State-Owned Industries (SEMIP), and Pemex		
Emissions limit for circulating vehicles in critical pollution areas and the rest of the country and determining procedures and equipment to verify observance of such limits	SEMARNAP in collaboration with DDF, State of Mexico, and Mexican Petroleum Institute		
Observance of emission limits for private cars and public transport; limiting circulation of vehicles; setting up or authorizing the setting up of obligatory inspection centers, supervising the operation of these inspection systems and limiting the circulation of vehicles which do not comply with emission standards		State of Mexico in 17 MCMA municipalities, except for federal public vehicles, considering the opinions of SEMARNAP. The Federal Ministry of Transport and Communications is responsible for federal public vehicles	DDF in the Federal District, except for federal public vehicles, considering the opinions of SEMARNAP. The Federal Ministry of Transport and Communications is responsible for federal public vehicles
Air monitoring system	SEMARNAP is responsible for certifying air quality monitoring systems set up by local governments outside the MCMA	State of Mexico is responsible for air monitoring in the State, excluding the 17 MCMA municipalities. System is subject to certification by SEMARNAP	In 1986 the former SEDUE established an automatic air quality monitoring network in the MCMA. In 1990 the responsibility for its expansion, operation, maintenance, and quality certification became DDF's responsibility
Implementing emergency measures		State of Mexico in 17 MCMA municipalities	DDF in Federal District

Source: General Law of Ecological Balance and Protection of the Environment; Menéndez 1996.

law dealing with environmental protection, had a relatively narrow focus on pollution prevention and control as well as on the negative health impacts of pollution. In line with this focus, various secretariats of the federal government were made responsible for setting and enforcing environmental standards, with the Secretariat of Health and Public Assistance playing a coordinating role. An undersecretariat within the Secretariat of Health and Public Assistance was made responsible for formulating, implementing, and monitoring air pollution control measures.

A significant shift in the approach to environmental protection occurred in 1982 with the creation of the Secretariat of Urban Development and Ecology (SEDUE) as the federal environmental institution. In December 1988 the General Law of Ecological Balance and Protection of the Environment, which constitutes the current legal framework for environmental management in Mexico, was adopted. This law made SEDUE responsible for formulating Mexico's environmental policy and setting national standards, in close collaboration with other federal secretariats. The law also allowed a gradual shift of air pollution control responsibilities from the federal level to state and municipal agencies. It gave authority to the State of Mexico and Federal District Department (DDF) to enforce environmental standards in the MCMA, although there have been some exceptions to this basic scheme (for example, control of industrial air pollution in the MCMA originally was assigned to SEDUE).

Within a year of the creation of SEDUE, Mexico entered a period of economic recession and debt restructuring that required severe fiscal austerity. As a result SEDUE's professional staff was reduced and its nonsalary operating budget was cut, severely weakening its capacity to carry out the functions assigned to it by law. As of early 1992, SEDUE had not been able to establish emission standards for heavy-duty diesel-fueled vehicles or for in-use vehicles retrofitted with catalytic converters, had not conducted an independent analysis of the quality of fuels produced by Petroleos Mexicanos (Pemex, the state-owned petroleum company), and had not been able to enforce industrial pollution standards (World Bank 1992). In December 1992 SEDUE's functions were legally transferred to the Secretariat of Social Development (SEDESOL). Thus SEDESOL became responsible for environmental protection and natural resource management in Mexico at the federal level. As a cabinet-level department of the Mexican federal government, it oversaw programs related to environmental protection, conservation of natural resources, regional and urban development, housing, and indigenous people. SEDESOL developed a network of state and local vehicle inspection and maintenance programs and, with the assistance of other agencies, managed the inspection and maintenance program for federal public transport vehicles. It was also responsible for setting fuel specifications for the automotive sector (Rowley 1994).

Two semiautonomous agencies within SEDESOL were responsible for environmental protection in Mexico: the National Institute of Ecology (INE) and the Office of the Federal Attorney for Environmental Protection (PROFEPA). INE was responsible for overall environmental policy formulation and implementation, research, natural resource conservation and forestry, hazardous waste cleanup, ecosystem management, environmental regulation, and standards development (including setting fuel quality specifications and developing vehicle emission standards). It also assisted the State of Mexico and Federal District Department in enforcing environmental standards and operating the air quality monitoring system in the MCMA. PROFEPA, the environmental enforcement arm of SEDESOL, was responsible for monitoring environmental compliance and enforcement of environmental regulations in cases in which such authority had not been vested in other Mexican federal, state, or local government agencies (Rowley 1994).

In December 1994 SEDESOL was divided into the Secretariat of the Environment, Natural Resources, and Fisheries (SEMARNAP) and the Secretariat of Social Development. SEMARNAP became responsible for industrial pollution control, natural resources (mines, soil erosion, forests, bulk water distribution, sanitation) management, fisheries, federal environmental standards setting, and enforcement of industrial solid and hazardous waste regulations. Urban planning and infrastructure were assigned to the Secretariat of Social Development. Along with these changes, INE was totally integrated with SEMARNAP. PROFEPA has remained a semiautonomous agency reporting to SEMARNAP.

State of Mexico institutions. The Ecological Law approved by the State of Mexico legislature in

September 1991 has expanded the responsibilities and powers of the State's Secretariat of Ecology. The Secretariat of Ecology contributes to the MCMA's air pollution control program and supervises private vehicle inspection stations through a private contractor. It has delegated responsibility for the inspection of public service vehicles to the State of Mexico Transport Commission (COTREM). The Secretariat of Ecology is also responsible for strengthening the MCMA's inspection and maintenance system and extending it to the rest of the State of Mexico. In addition, it is responsible for monitoring air, except in the seventeen municipalities of the MCMA. State transport-related institutions include:

- Metropolitan Commission, which oversees the operation of urban and suburban buses.
- COTREM, which is involved in the promotion, operation, and maintenance of the State toll road system.
- Ministry for Urban Development and Public Works, which is involved in the formulation of transport policy and planning; infrastructure for urban and suburban buses and parking; planning and construction of transport infrastructure; and issuing bus, microbus, and taxi licenses.
- Local municipalities, which issue drivers licenses.

Federal District institutions. The Secretariat of the Environment is the key environmental agency in the Federal District. It serves as the city's environmental authority and acts as the coordinating body for the Technical Secretariat of CMPCCA. The Secretariat of the Environment includes the General Directorate of Environmental Projects and the General Directorate of Environmental Protection and Control. The General Directorate of Environmental Projects identifies and prepares environmental projects. It is the basic support group for the Technical Secretariat of CMPCCA. It is made up of about forty experts in such areas as environmental and civil engineering, chemistry, biology, sociology, communications, economics, and law. The General Directorate of Environmental Protection and Control provides the enforcement function in the Federal District and includes thirty inspectors and administrative personnel (Menéndez 1996).

The specific responsibilities of the main Federal District transport management and air quality control agencies are as follows:

- The General Directorate of Pollution Prevention and Control is responsible for public and private vehicle emissions testing, *hoy no circula* (the one-day driving ban), and gasoline station vapor recovery programs.
- The General Directorate of Urban Automobile Transport oversees vehicle registration grants and controls drivers licenses and bus and taxi licenses.
- The General Directorate of Operations is responsible for traffic management and traffic signal systems.
- The General Transport Coordinating Office regulates public transport and parking lots (including tariffs) and coordinates the operation of the metro, bus, and trolleybus systems.
- The General Planning Secretariat carries out overall transport planning for the Federal District Department.
- The General Directorate of Public Works prepares, constructs, and supervises public works.
- The General Directorate of Urban Services sets criteria and standards and maintains public works.
- The Commission for Highways and Urban Transport constructs metro, bus infrastructure, and parking lots.

In the MCMA the Collective Transport Service operates the metro, the Electric Transport Service runs the trolleybus and light rail services, and Metropolitan Services manages the parking infrastructure (World Bank 1992). Ruta-100 buses, which had been operated by the Electric Transport Service within Federal District, ceased operation in 1995. In the future, the private sector will provide this service.

Metropolitan institutions. Designing and implementing of a program to reduce transport air pollution in the MCMA is complicated because national, regional, and local institutions are involved and coordination among them is difficult. The problem is local in the sense that issues like vehicle inspection, traffic management, and public transport are in the hands of Federal District Department, state, and municipal authorities. The problem is regional because the metropolitan area, as currently defined, includes the Federal District and seventeen municipalities in the neighboring State of Mexico. With the rapid urbanization and growth of industry throughout

the entire Valley of Mexico, the problem is regional in a broader sense and requires common action across jurisdictional boundaries. From an institutional and legal standpoint, the subject is national because the Federal District is not only the national capital, but its city government is also a direct arm of the federal government. As such its mayor is not elected, but is nominated by the president of Mexico and functions as a delegate of the president.[4]

The Federal District mayor took the first metropolitan air quality management initiative when he established an informal institutional arrangement in response to the president of Mexico's December 1988 inaugural address. Under this arrangement the Federal District Department took the lead in planning an air quality program for the MCMA without creating new bureaucratic structures and by relying on private sector expertise. The mayor appointed the chief of his General Coordination for Environmental Programs to prepare an air pollution control program. To help develop the program, two intergovernmental groups were formed: a steering committee consisting of senior officials of the Federal District Department, State of Mexico, SEDESOL, some federal secretariats, Pemex, Mexican Petroleum Institute, and the Federal Power Commission; and a technical secretariat consisting of staff members of the agencies making up the steering committee, working on a part-time or temporary basis. Members of the technical secretariat and teams of local and foreign experts, directed by Mexican consultants prepared the program. Although these arrangements worked relatively well for program preparation, an effective long-run air quality management program required that institutional arrangements be strengthened, complemented, and made more permanent.

On January 8, 1992, the president of Mexico issued a decree creating CMPCCA as a permanent entity to define, coordinate, and monitor implementation of public policies, programs, and projects to control pollution in the MCMA. The agencies comprising the CMPCCA include the Secretariats of Health, Treasury and Public Credit, Social Development (currently SEMARNAP), Public Education, Commerce and Industrial Development, Communications and Transport, Federal Comptroller, and Energy; the Mexican Petroleum Institute; the State of Mexico; and the Federal District Department. Although the commission is responsible for preventing and controlling all aspects of environmental degradation in the MCMA, its primary focus has been on air pollution. CMPCCA's main functions are:

- To define antipollution policies, programs, projects, and actions to be carried out by federal entities in the MCMA
- To establish criteria and guidelines to prevent and control pollution in the MCMA
- To give its views on programs, projects, and budgetary allocations of federal government entities, State of Mexico, the Federal District and its municipalities, and affected interest groups and individuals
- To propose to the authorities actions to prevent and control environmental emergencies in the MCMA
- To support environmental research, technological development, and training programs
- To define ways to secure resources to form a fund to finance the programs, projects, and actions approved by CMPCCA
- To develop CMPCCA's internal rules and regulations
- To carry out other actions related to its objectives, as directed by the president of Mexico.

CMPCCA comprises a president, a technical secretariat, and an advisory council. CMPCCA's presidency was established for a two-year term rotating among the mayor of the Federal District, the governor of the State of Mexico, and the secretary of SEMARNAP. Although the mayor and governor have both served as president of the commission, the secretary of SEMARNAP recently declined the presidency. This decision, which will make local jurisdictions responsible for solving their own environmental problems, is in line with a national trend toward decentralization of responsibilities and resources from federal to local institutions.

CMPCCA's technical secretariat comprises a technical secretary and one technical representative from each member agency. It is responsible for identifying measures to curtail air pollution in the MCMA and specifying schedules, budgets, and institutional responsibilities for implementing these measures. The Department of Environmental Projects within the Fed-

4. In 1997 the mayor of Mexico City is scheduled to be elected.

eral District Department's Environment Secretariat is the coordinating body for the CMPCCA's technical secretariat. By presidential decree, the costs of this coordinating group are assumed by the Federal District Department.

The Federal District's environmental secretary has been appointed by the president of Mexico as CMPCCA's technical secretary for a two-year term. The key functions of the technical secretary are to prepare programs and projects to obtain and administer grant, loan, and budget funds; ensure that these funds are used in an effective and timely manner; coordinate the activities of the working groups; and train technical personnel to ensure the quality and continuity of actions to deal with pollution problems. The representatives from member agencies are mid-level government officials backed by their institutional resources. This arrangement secures the necessary participation and contribution of all involved agencies. These technical personnel have accrued considerable experience from working together to solve MCMA's complex environmental issues, and are exposed to the experiences of the world's most advanced environmental agencies and to international environmental information (Menéndez 1996).

CMPCCA has established an advisory council to ensure citizen participation in the design and implementation of air pollution control measures for the MCMA. The advisory council consists of representatives of the scientific, environmental, industrial, business, and NGO communities. Representatives from the federal, Federal District, and State of Mexico governments are also invited as needed to participate in advisory council discussions. The advisory council can suggest air pollution control measures to the CMPCCA's technical secretariat, and evaluates and approves the secretariat's proposed measures before implementation.

The MCMA's jurisdictional complexity had resulted in overlapping transport management responsibilities until 1989. The sharp division between the Federal District Department and the State of Mexico government in planning, coordinating, and supplying transport services resulted in a disparate, inefficient, and costly (to users) transport network, demonstrated by the massive interchanges at the Federal District's boundaries. In 1989 a Metropolitan Transport Council was formed by the federal secretary for transport and communications, the governor of the State of Mexico, and the mayor of the Federal District to provide a framework for coordinated policy development and implementation. The council consisted of a president, a technical secretary, a full-time technical team, and working groups. One of the working groups was charged with developing a transport master plan for the MCMA (defined as the Federal District and twenty-one instead of seventeen municipalities). Critical to this plan was formulation of a program of travel demand management to help achieve both transport and air management objectives. Through the council's efforts, transport services started across the Federal District's boundary in July 1991.

To better address transport issues between the State of Mexico and the Federal District, in July 1994 the Metropolitan Transport Council was replaced by the Metropolitan Commission for Transport and Highway Administration (COMETRAVI) in accordance with an agreement signed by the Ministry of Communications and Transport, the State government of Mexico, and the Federal District Department. COMETRAVI's organizational structure is similar to CMPCCA's except that it has fewer professional staff (about ten members), it does not have a advisory council (so all its study proposals are only technical), its technical secretary does not have executive authority, and its staff operates independently of federal agencies and local governments. Authority lies with the secretaries of transport from the local governments in the State of Mexico and the Federal District (Menéndez 1996). COMETRAVI developed a 1995-96 work program that includes homogenizing transport laws and regulations; developing technical standards for vehicle manufacturing; regularizing vehicle permitting, improving bus routes, and modernizing license plates; tariffing and financing public and freight transport for fleet renewal; supervising traffic and enforcing; developing road infrastructure; saving energy and protecting the environment; regulating freight transport; developing a master plan for public transport and roads; and preventing accidents. A working group has been formed for each element of this program. The working group on the environment includes the technical secretariat of the CMPCCA. Because COMETRAVI does not have any executive authority or the ability to commit budgets to implement proposed projects, COMETRAVI's technical secretary relays important recommendations made by the working group to the local governments' transportation secretaries for negotiation.

Implemented Measures

Although efforts to control air pollution in the MCMA go back many years, it was only in 1989 that an emergency program was initiated after widespread public concern over increasing levels of air pollution. The program was coordinated by a steering committee and a technical secretariat, established by the federal government and consisting of the representatives from Federal District Department; State of Mexico; Secretariats of Ecology and Development, Finance, Programming and Planning, and Industry and Agriculture; Pemex; Mexican Petroleum Institute; and National Bank of Public Works and Services (BANOBRAS). The following measures were directed toward curtailing vehicular air pollution:

- Tighter emission standards for vehicles, effective from model-year 1991.
- A rotating driving ban called "don't drive today" (hoy no circula) aimed at prohibiting circulation of one-fifth of the vehicles each weekday.
- Addition of 5 percent MTBE to gasoline to make up for the reduction in the lead content of gasoline and to reduce HC and CO emissions.
- A vehicle inspection and maintenance program.
- Replacement of some bus engines with engines meeting the California 1990 emission standards and rehabilitation of these buses to improve their comfort, appearance, and mechanical condition.
- Expansion and improvement of the air quality monitoring network.

Some of these measures were implemented through a $22 million World Bank loan, Mexico First Urban Transport Project (for example, purchase of some Ruta-100 bus engines and of air quality monitoring equipment).

In September 1990 the Mexican government announced an expanded program called the Integrated Program Against Air Pollution in the MCMA. This program consisted of forty-two specific measures (including continuation of measures under the 1989 Emergency Program), grouped into the following categories: oil industry and fuels; transport sector; private industry and services; thermoelectric plants; reforestation and sanitary measures; and research, education, and communication. Of these, the measures dealing with oil industry and fuels and the transport sector were the most relevant for curtailing vehicular air pollution. Many of the components of the integrated program have been financed through a $220 million World Bank loan for the MCMA Transport Air Quality Management Project.

The oil industry and fuels component of the integrated program included two types of measures: changes in the refining and distribution infrastructure to reduce emissions from these sources, and changes in fuel composition to reduce pollutant emissions from other sources. The first set of measures was aimed at reducing pollutant emissions directly by shutting down a refinery located in the MCMA, adding floating roofs to fuel storage tanks, and installing vapor recovery systems for filling stations to reduce HC vapor emissions. The second set of measures included supplying unleaded gasoline for catalytic converter-equipped vehicles, reformulating leaded gasoline to reduce pollutant emissions, and desulfurizing diesel fuel and fuel oil.

The program's transport-related emission control measures involved steps to reduce pollutant emissions per kilometer traveled and encourage use of public transport while limiting private car use. Specific measures included developing new emission standards for gasoline-fueled vehicles, requiring emission controls by catalytic converters; replacing high-use vehicles (taxis and microbuses) with new vehicles meeting emission standards; converting gasoline-fueled cargo trucks to LPG or CNG; expanding and improving the inspection and maintenance program; continuing the "don't drive today" program for private vehicles and expanding it to taxis and public transport vehicles; improving parking and traffic management systems; expanding the metro and surface electric transport systems; and authorizing of new private bus routes.

At the end of 1995 CMPCCA prepared a Program to Improve the Quality of Air in the Valley of Mexico for 1995–2000 (hereafter referred to as the new program). The new program includes a diagnosis of the air pollution problem in the MCMA and considers strategic actions in the following areas: improving and using new technologies and cleaner fuels in motor vehicles, industry, and the service sector; providing safe and efficient public transport services; integrating metropolitan policies for urban development, transport, and environment; providing eco-

Table 4.5 Exhaust emission standards for new cars in Mexico
(grams per kilometer)

Model-year	*CO*	*HC*	*NO_x*
1975	29.0	2.5	
1976	24.0	2.1	
1977–88	24.0	2.6	2.3
1989	22.0	2.0	2.3
1990	18.0	1.8	2.0
1991–93	7.0	0.7	1.4
1994 and newer	2.11	0.25	0.62

Note: A blank space indicates that no standard was established. Evaporative hydrocarbon emissions were not regulated before 1995. Subsequently, all cars were required to meet the 2.0 grams/test emission standard.
Source: World Bank 1992; *Diario Oficial* of October 19, 1988.

Table 4.6 Exhaust emission standards for new light-duty commercial vehicles in Mexico
(grams per kilometer)

Vehicle weight/model-year	*CO*	*HC*	*NO_x*
Gross vehicle weight below 2,727 kg			
1990–93	22.0	2.0	2.3
1994 and newer	8.75	0.63	1.44
Gross vehicle weight from 2,728–3,000 kg			
1990–91	35.0	3.0	3.5
1992–93	22.0	2.0	2.3
1994 and newer	8.75	0.63	1.44

Source: Diario Oficial of October 19, 1988.

nomic incentives; inspecting and enforcing motor vehicles and industry; and encouraging information, environmental education, and social participation. The new program identifies specific measures that include estimated benefits and costs, budgets, and institutions responsible for implementation.

Vehicle emission standards. Since 1975 new cars sold in Mexico have been subject to exhaust emission standards that include CO, HC, and NO_x (Table 4.5). In general, these emission standards have been based on U.S. standards. Before model-year 1991, Mexican standards were lenient enough to be met without use of a catalytic converter or other advanced emission control technologies. The standards for 1991–93 model-years represented a transition period because they were sufficiently stringent to require use of catalytic converters but did not include the full range of emission controls required in the United States. Beginning with the 1994 model-year all new cars were subject to exhaust emission standards equivalent to those of the United States. These standards necessitated the installation of three-way catalytic converters and computerized engine control systems but lacked requirements for evaporative emission controls, emission warranties, or recall of vehicle parts that did not comply with emission standards. During the 1991–93 transition period most Mexican car manufacturers still equipped their vehicles with U.S.-equivalent emission controls. Even the absence of formal evaporative emission standards, they agreed to install evaporative control systems compatible with those in the United States. Starting in 1995 all cars were required to meet the evaporative emission standard of 2.0 grams/test. As part of NAFTA, the United States, Canada, and Mexico are harmonizing vehicle emission standards.

In 1988 emission standards were established for new commercial vehicles with a gross weight below 2,727 kilograms and for vehicles between 2,728 and 3,000 kilograms (Table 4.6). Manufacturers were allowed to comply with these standards through an "average fleet emission" until the 1992 model-year. This average allowed the marketing of some new vehicles with emissions higher than the standard as long as other vehicles marketed by the same manufacturer had lower emissions, therefore achieving compliance with the average fleet emission. In 1993 emission standards for these two weight categories were merged for 1994 and subsequent model-year vehicles. In addition, the weight limit of light-duty commercial vehicles was extended to 3,857 kilograms.[5] In 1995 evaporative emissions for light-duty commercial vehicles were limited to a maximum of 2.0 grams/test.[6]

Exhaust emission standards for new urban transport microbuses were proposed for polluted

5. The regulation NOM-CCAT-004-ECOL/1993 was published in the *Diario Oficial* of October 22, 1993. Commercial vehicles are defined as light-duty trucks designed for commercial, multiple, or service use and fueled with gasoline or alternative fuels (such as LPG and CNG).

6. Evaporative emissions were not regulated until 1995.

Table 4.7 Proposed exhaust emission standards for new urban microbuses in Mexico (3,000–5,000 kilograms)
(grams per kilometer)

Model-year	*CO*	*HC*	*NO_x*
1991	10.0	0.6	1.5
1992	3.0	0.3	1.0

Source: World Bank 1992.

Table 4.8 Exhaust emission standards for new heavy-duty commercial vehicles using gasoline or alternative fuels in Mexico
(grams per break horsepower-hour)

Vehicle weight/model-year	*CO*	*HC*	*NO_x*
Gross vehicle weight from 3,858–6,350 kg			
1995–97	14.4	1.1	5.0
1998 and newer	14.4	1.1	4.0
Gross vehicle weight above 6,350 kg			
1995–97	37.1	1.9	5.0
1998 and newer	37.1	1.9	4.0

Note: All model-year vehicles indicated in this table should meet the 3.0 grams/test for evaporative emissions.
Source: Menéndez 1996.

areas but have not been enacted (Table 4.7). Because of the critical air quality levels in the MCMA, however, vehicle manufacturers agreed to comply with these standards one year earlier than is indicated in Table 4.7. In practical terms, that meant that microbuses sold in the MCMA had to incorporate a catalytic converter starting with the 1992 model-year (Menéndez 1996). In October 1995 emission standards were established for new commercial vehicles using gasoline or alternative fuels with gross weights ranging from 3,858 kilograms to 6,350 kilograms and greater than 6,350 kilograms (Table 4.8).

Until 1993 new diesel-fueled vehicles were subject only to smoke opacity testing.[7] Exhaust emission standards for CO, HC, NO_x, and PM were established starting with the 1993 model-year diesel-fueled vehicles. These standards were further tightened first for the 1994–97 and then for the subsequent model-years (Table 4.9).

Emission standards were established for in-use gasoline-fueled cars, trucks, and commercial, multiple-use, and service vehicles with a gross vehicle weight below 2,727 kilograms. These standards, which limit CO and HC emissions in exhaust, were tightened in 1996 (Table 4.10). In addition, in 1996 emission standards were established for in-use commercial, multiple-use, and service vehicles and for trucks fueled with LPG, CNG, methanol, and mixtures of these fuels with gasoline or diesel fuel (Table 4.11).

In 1993 standards limiting smoke emissions were established for in-use diesel-fueled vehicles. The smoke opacity (expressed by absorption coefficient) was limited according to the nominal flow of a vehicle's exhaust gas. These standards were revised in 1996 and limited smoke emissions based on the vehicle weight category, model-year, and gas flow from the exhaust (Table 4.12).

Vehicle inspection programs. The Mexican government views inspection of in-use vehicles as a crucial element in controlling air pollution in the MCMA. Inspection of in-use vehicles was initiated in the 1970s. At that time the main objective was to detain vehicles that were emitting excessive amounts of smoke based on visual inspections. In August 1988 a voluntary periodic inspection and maintenance program was introduced as a measure to curtail air emissions from gasoline- and diesel-fueled in-use vehicles in the MCMA. In January 1989 periodic inspection of in-use vehicles was made compulsory, with one test per year charged at a cost equivalent to one day of the minimum wage. In 1990 the number of periodic inspections was increased to two per year, with the second test free of charge. In 1991 one annual inspection was established, but subsequently increased to two inspections a year.

Emission testing of in-use gasoline-fueled vehicles involves determining CO and HC concen-

7. The opacity standard for heavy-duty vehicles was set at 70 units using the Hartridge method. However, with the establishment of the Permanent Program for Correcting Excessive Black Smoke in early 1992, this standard was lowered to 40 units for Ruta-100 buses. The Hartridge method draws a continuous sample of the vehicle exhaust into a chamber to measure the attenuation of a light-shining beam. This method can measure the smoke level contributed by soot (through light absorption) and oil or fuel droplets (through light scattering).

Table 4.9 Exhaust emission standards for new diesel-fueled vehicles in Mexico
(grams per break horsepower-hour)

Vehicle type/model-year	*CO*	*HC*	NO_x	*PM*
1993	15.5	1.3	5.0	0.25
1994–97				
Heavy-duty urban buses	15.5	1.3	5.0	0.07
Medium-duty urban buses and others	15.5	1.3	5.0	0.10
1998 and newer				
Heavy-duty urban buses	15.5	1.3	4.0	0.05
Medium-duty urban buses and others	15.5	1.3	4.0	0.10

Note: These standards apply to diesel-fueled vehicles with gross weight greater than 3,857 kilograms. Heavy-duty urban buses have a gross weight greater than 15,000 kilograms and an engine power greater than 250 hp, and carry 15 or more passengers. All diesel-fueled vehicles should also meet the opacity test of 15 percent at idle, 20 percent at acceleration, and 50 percent at peak power.
Source: Walsh 1996; NOM-CCAT-007-ECOL/1993 published in *Diario Oficial* of October 22, 1993.

trations in the tailpipe exhaust at 2,500 rpm without load. Although this procedure is commonly used and very effective in identifying high emissions from older vehicles, it cannot reliably identify emission-related defects in late-technology vehicles equipped with electronic air-fuel control systems. For diesel-fueled vehicles the inspection consists of measuring smoke opacity as the engine is accelerated rapidly without load. This test procedure is capable of detecting high PM and HC emissions from diesel engines.

To test high-use passenger and freight vehicles, government-operated inspection stations are equipped with dynamometers that simulate driv-

Table 4.10 Exhaust emission standards for in-use light-duty gasoline-fueled vehicles in Mexico

	CO (% by volume)		*HC (ppm)*	
Vehicle type/model-year	*Before January 1996*	*After January 1996*	*Before January 1996*	*After January 1996*
Cars and commercial vehicles				
1979 and older	6.0	4.0	700	450
1980–86	4.0	3.5	500	350
1987–93	3.0	2.5	400	300
1994 and newer	2.0	1.0	200	100
Multiple-use and service vehicles and light-, medium-, and heavy-duty trucks				
1979 and older	6.0	5.0	700	600
1980–85	5.0	4.0	600	500
1986–91	4.0	3.5	500	400
1992–93	3.0	3.0	400	350
1994 and newer	2.0	2.0	200	200

Note: These standards apply to gasoline-fueled in-use vehicles with gross weight below 2,727 kilograms. The maximum oxygen content is limited to 6.0 percent by volume for model-years before 1994 and 15.0 percent by volume for model-years 1994 and newer. The minimum and maximum $CO+CO_2$ dilution limits for all model-years are 7.0 and 18.0 percent by volume.
Source: Walsh 1996; NTE-CCAT-003/88 published in *Diario Oficial* of June 6, 1988; NOM-EM-102-ECOL-1966 published *in Diario Oficial* of July 24, 1996.

Table 4.11 Exhaust CO and HC emission standards for in-use commercial, multiple-use, and service vehicles and for trucks fueled with LPG, CNG, methanol, and mixtures of these fuels with gasoline or diesel fuel in Mexico

Model-year	*CO (% by volume)*	*HC (ppm)*
1986 and older	2.0	200
1987–93	1.0	150
1994 and newer	0.75	100

Note: The maximum oxygen content is limited to 6.0 percent by volume, and the minimum and maximum $CO + CO_2$ dilution limits for all model-years are 7.0 and 18.0 percent by volume.
Source: NOM-EM-102-ECOL-1966 published in *Diario Oficial* of July 24, 1996.

Table 4.12 Exhaust smoke emission standards for in-use diesel-fueled vehicles in Mexico

Vehicle weight/model-year	*Absorption coefficient (m^{-1})*
Gross vehicle weight below 2,727 kg	
1995 and older	1.99
1996 and newer	1.07
Gross vehicle weight above 2,727 kg	
1990 and older	1.99
1991 and newer	1.27

Source: NOM-045-ECOL-1995 published in *Diario Oficial* of January 8, 1996.

ing conditions in the MCMA under load. In 1993 these stations were modernized with computerized equipment that included high-precision gas analyzers and a data processing system that can immediately print out emissions test results and compare them with applicable emissions standards. Along with this procedure, stickers are issued to passing vehicles to allow circulation for a period of six months. A central verification center equipped with dynamometers allows measurements of pollutant emissions from heavy-duty passenger or freight vehicles under simulated driving conditions in the MCMA. Furthermore, since 1994 nine emission evaluation centers in the Federal District have been used to provide drivers with a technical assessment of their vehicles free of charge.

Until 1996 emissions testing of private vehicles in the MCMA was carried out at 1,650 authorized private and twenty-six high-volume government-operated inspection stations. The periodic inspection and maintenance program with the private garage system, however, proved ineffective. Although the failure rate was 16 percent at the centralized government-operated inspection centers, it was only about 9 percent at private garages. Performance monitoring of a large number of private inspection stations was also virtually impossible with available resources. Stations conducting improper or fraudulent inspections were taken to court on several occasions with the courts usually agreeing to shut them down. As part of MCMA's new air pollution control program and in recognition of the critical role of inspection and maintenance, at the end of 1995 the Federal District Department decided to close all private garage inspection stations in favor of a completely centralized inspection system.

Since January 2, 1996, all periodic inspections in the Federal District have taken place at one of the existing centralized facilities. Twenty-six such facilities maintain about 142 lanes, resulting in serious congestion. This problem is expected to be overcome, however, when the expanded system becomes operational in 1997. The inspection frequency has been reduced to once per year to relieve congestion at inspection centers, but taxis and other high-use vehicles continue to be tested twice a year.

In close coordination with vehicle manufacturers, the Federal District Department has been moving to expand the existing centralized inspection network by adding thirty-six centralized stations. A bidding document has been prepared for the construction and operation of these facilities in 1997 using accelerated simulation mode (ASM) testing.[8] The bidding documents do not put any restrictions on the maximum number of lanes (with the minimum being three) or facilities any one company will be able to win. In addition, any company winning a bid must have as part of its team a former owner of one of the private garages that carried out inspections. Funding for the centralized facilities will be entirely private, with the payback coming out of the fee

8. The ASM tests, which require dynamometer loading of vehicles, yield good correlations with Federal Test Procedures (FTP) for pollutants emitted in the exhaust, especially NO_x.

for each test. Fees will be 70 pesos ($9.40) for cars and 100 pesos ($13.50) for high-use vehicles, and 10 pesos ($1.35) of the fee will be submitted to the government to pay for the stickers. A special committee has been set up with prominent industrialists and academics, who will help select the winning bidders.

The existing stations are being upgraded so that all will have a dynamometer and be capable of running the ASM test in 1997. Existing stations equipped with the necessary equipment ASM began testing in mid-1996. Test results are not used to pass or fail vehicles but rather to gather necessary data for setting new emission standards for in-use vehicles, as well as standards that will exempt in-use vehicles from the one-day and two-day driving ban programs (see below). The test procedure includes the two-stage idle test for private cars and steady-state loaded test for high-use vehicles. Independent auditors are present at each inspection station during tests. These auditors change stations monthly, and their contracts are funded by companies operating the stations. Each test is recorded on a video in real time, and tapes and computer printouts are spot checked to assure that tests are valid. Evaporative test procedures will be developed later. The State of Mexico plans to use the same inspection approach as the Federal District, with about a one-year delay.

Roadside inspections complement periodic vehicle inspections. Since December 1, 1992, the Federal District Department, the State of Mexico, and the Federal Secretariat of Communications and Transport have been jointly conducting an on-the-road inspection program under PROFEPA's supervision. This program, which targets excessively polluting in-use vehicles in the MCMA, is staffed by fifty inspectors who use eleven patrol vehicles and twenty mobile emission testing instruments. Vehicles barred from circulation are taken to one of thirty-six detention centers (CMPCCA 1995a).

Fuel-targeted measures. In 1994, 56 percent of the fuel consumed in the MCMA (44.4 million liters a day) was for the transport sector, mostly in the form of leaded gasoline (called *Nova*), unleaded gasoline (called *Magna Sin*), and diesel fuel. All gasoline and diesel fuel sold in Mexico is produced by Pemex. Alternative fuels used in the MCMA include LPG and CNG.

Fuel quality has improved as a result of Pemex's refinery investments. The lead content of Nova consumed in the MCMA was gradually reduced from 0.14–0.28 g/liter in 1986 to 0.08–0.15 g/liter in 1991, 0.06–0.08 g/liter in 1992, and 0.03–0.06 g/liter in the winter of 1994 (Berumen 1996). Production of Magna Sin began in 1988 to meet the fuel requirements of new light-duty vehicles equipped with catalytic converters. In 1995 the lead content of Magna Sin was 0.00017 g/liter. The share of Magna Sin in total gasoline sales in the MCMA was only 2 percent in 1989, but it increased to 37 percent in 1994, 44 percent in 1995, and 48 percent in May 1996 (CMPCCA 1995a, DDF 1996, Berumen 1996).[9] Magna Sin's market share is increasing as more catalytic-converter equipped vehicles are marketed and some of the old vehicles in circulation are retiring.

One component of Pemex's production of Magna Sin involved increasing the production capacity of the Madero refinery from 15,000 to 20,000 barrels a day. In addition, the octane deficiency caused by reduced lead content in gasoline was made up for by converting the catalytic reforming units for naphtha from a semi-regenerative to a continuous catalytic regenerative system at various Pemex refineries. Investment requirements were $12 million at each of the Salamanca, Cadereyta, and Minatitlan refineries (in August 1993), $36 million at the Salina Cruz refinery (in July 1994), $32 million at the Tula refinery (in August 1994), and $54 million at the Madero refinery (in September 1995). Three isomerization units were also constructed to convert low-octane n-pentanes and n-hexanes to higher-octane hydrocarbons. The conversions were performed at the La Cangrejera Petrochemical Complex at a cost of $52 million (in August 1994), at the Minatitlan refinery at a cost of $28 million (in December 1994), and at the Cadereyta refinery at a cost of $36 million (in December 1994; Rosas 1996). The closure of Pemex's 18 de Marzo refinery in the MCMA in March 1991 somewhat lowered production of transport fuels, but it also considerably reduced air emissions.

The 23 percent lower air density at MCMA's altitude adversely affects combustion of fuels in internal combustion engines, resulting in higher

9. The share of Magna Sin in gasoline sales in May 1996 was 59 percent nationwide, 51 percent in Guadalajara, 88 percent in Monterrey, and 98 percent in the northern border area (Berumen 1996).

CO emissions. To reduce CO emissions from vehicles and boost the octane number of gasoline, since 1989 Pemex has produced leaded and unleaded gasoline containing 5 percent MTBE by volume. The MTBE raises the oxygen content in gasoline to the legally required range of 1 to 2 percent. National production of oxygenates started with the construction of MTBE plants at three refineries: Salina Cruz (at a cost of $15 million in December 1994 for a 30,000 metric ton a year capacity), Cadereyta ($12 million in December 1994 for a 30,000 metric ton capacity), and Tula ($12 million in September 1995 for a 90,0000 metric ton capacity). In addition, TAME plants were constructed at Salina Cruz ($13 million for a 60,000 metric ton capacity) and Cadereyta ($19 million for a 90,000 metric ton capacity) to supply additional oxygenates for gasoline (Rosas 1996).

To limit air emissions of ozone-forming HC and carcinogenic benzene, in December 1992 Pemex established reformulated fuel specifications for Magna Sin and Nova (CMPCCA 1995a). Based on these specifications, the Mexican gasoline quality standards were established (Table 4.13). Controlled parameters include vapor pressure, aromatics, olefins, benzene, sulfur, lead, and oxygen.

For the high-pollution winter seasons, starting with the 1993–94 winter season, Pemex tightened gasoline specifications. For both Magna Sin and Nova the olefins content was limited to a maximum 12 percent by volume and the benzene content to a maximum 1.5 percent by volume. In addition, the aromatics content of Nova was limited to a maximum 25 percent by volume. In 1997 Pemex will begin producing Magna Sin with aromatics content limited to a maximum 25 percent by volume, olefins content to a maximum 10 percent by volume, benzene content to a maximum content 1.0 percent by volume, and Reid vapor pressure to a maximum 7.8 psi (Rosas 1996). To ensure compliance with gasoline specifications, CMPCCA has been inspecting refineries and gas stations.

CMPCCA is considering further improvements in the quality of motor vehicle fuels using a cost-effective approach. Currently, an experiment is being conducted in Monterrey with a new, high quality “premium” gasoline. This fuel, which was introduced in several stations as a replacement for Nova, has the following characteristics: 92 research octane number, maximum limits of 1 percent benzene, 32 percent aromatics, 12 percent olefins and an oxygenate content of between 1 and 2 percent, and no lead. This fuel costs about 20 percent higher than Nova.

In 1986 the sulfur content of the Mexican diesel fuel marketed in the MCMA was reduced from 1 percent to 0.5 percent by weight with the introduction of Special Diesel fuel. Pemex later initiated a program to further reduce SO_2 emissions by supplying a lower sulfur diesel fuel to meet the fuel quality requirements of diesel-fueled vehicles equipped with advanced emission controls. As a result the sulfur content of the diesel fuel was reduced to 0.05 percent by weight with the introduction of Diesel Sin fuel in October 1993. On December 2, 1994, fuel standards for the Special Diesel were published in *Diario Oficial.* These standards limit the sulfur content to 0.05 weight percent and specify the requirements for other parameters as well (for example maximum aromatics content of 30 percent by vol-

Table 4.13 Gasoline quality standards in Mexico

Fuel parameter	*Magna Sin*	*Nova*
Reid vapor pressure (psi)	6.5–8.5[a]	6.5–8.5[a]
Aromatics (maximum percent by volume)	30	30
Olefins (maximum percent by volume)	15[b]	15
Benzene (maximum percent by volume)	2	2
Oxygen (percent by weight)	1–2	1–2
Sulfur (maximum percent by weight)	0.10	0.15
Lead (g/liter)	0.0026	0.06–0.08

Note: Fuel standards for Magna Sin and Nova include other parameters not included in this table.
a. The Reid vapor pressure of Magna Sin and Nova prior to these standards was specified at 7.0–9.5 psi.
b. After January 1998, the maximum permissible value will be 12.5 percent by volume.
Source: Diario Oficial of December 2, 1994.

ume and minimum cetane number of 48). To provide this low sulfur fuel, three hydrodesulfurization plants were constructed: two at Tula refinery with 20,000 barrel a day capacity and one in the Salamanca refinery with 25,000 barrel a day capacity. Total investment for this project was $115 million. In addition, desulfurization units at other Pemex refineries (such as Salina Cruz) have been producing low-sulfur diesel fuel (CMPCCA 1995a). In February 1997 the sulfur content of diesel fuel used throughout Mexico was reduced to 0.05 percent.

Pemex's future investments to meet the stringent motor vehicle fuel quality requirements in Mexico will total about $1 billion. These investments involve construction of alkylation, isomerization, and hydrodesulfurization plants at various refineries (Berumen 1996).

In the MCMA the use of LPG as a transport fuel began in February 1992 with the conversion of some buses operated by the public sector or by the private sector under a concessioning agreement. Since then Pemex has been supplying LPG for high-use vehicles. Six main and four provisional LPG fueling stations were constructed to service about 8,000 vehicles a day. In addition, most commercial companies, which converted their fleet from petroleum-based fuels to LPG, have their own storage and fueling facilities. About 27,000 buses and trucks have been now converted to LPG. In addition, about 1,300 LPG-fueled microbuses equipped with three-way catalytic converters are circulating (Sánchez 1996). More than 200 conversion kit models have been certified. Each fuel conversion and catalytic converter installation costs to vehicle owners between $2,000 and $3,000 (Viola 1996). Vehicles that have converted to LPG and installed a catalytic converter are exempt from the circulation ban in the MCMA.

Use of CNG in the MCMA was initiated in 1992 through a pilot program. This program included an additional supply of 2.5 million cubic meters of natural gas by Pemex, enough to fuel about 45,000 high-use vehicles; rehabilitation of an existing service station owned by the Mexican Petroleum Institute and construction of a new service station for CNG fueling in the northern section of the city; and retrofitting of forty-seven private and commercial vehicles, microbuses, and police cars for CNG.

An LNG plant was also constructed to fuel buses and trucks. However, the new plant could not be operated because of legal and financial problems. Two vehicles converted to use LNG were tested. These vehicles received the fuel in liquid form and evaporated it before combustion (Sánchez 1996).

Measures are being adopted to reduce HC emissions from gasoline storage, distribution, and sales activities in the MCMA. Four Pemex gasoline storage distribution terminals have installed vapor recovery systems. In addition, all gasoline stations and Pemex's gasoline distribution trucks have been required to install vapor recovery systems. Gas stations collect the stored vapors and return them to Pemex's distribution centers.

The federal government controls fuel pricing in Mexico. The retail price of motor vehicles is the same at any location in Mexico. It includes the producer price (which is determined according to a reference price based on international price to reflect the opportunity cost of the fuel), a specific tax, and a value added tax (which is charged on the producer price). Since the retail price is fixed to control inflation and the producer price changes according to market conditions, the specific tax is adjusted each month so that the desired retail price is obtained. Since January 1995 each state can collect a charge on fuel prices based on environmental considerations to finance specific pollution control measures (O'Ryan 1996).

Before November 1991 the retail prices of Nova and Magna Sin were set at $0.24 a liter and $0.33 a liter, respectively. The high price for Magna Sin was intended to restrict its use because it was in limited supply. However, the large price difference between the two gasoline grades encouraged misfueling of catalyst-equipped vehicles with leaded gasoline, which impairs pollution control efficiency. In November 1991 the government raised the prices of Nova by 55 percent and Magna Sin by 25 percent, bringing them to $0.37 a liter and $0.42 a liter, respectively. In April 1992, the price of Magna Sin was lowered to $0.40 a liter. In January 1995 a uniform gasoline surcharge of $0.01 a liter was introduced in the MCMA. The funds generated by this surcharge are channeled to an Environmental Trust Fund to finance CMPCCA's programs.[10] Since May 1996 the surcharge has been increased and differenti-

10. Since its initiation in January 1995 the gasoline surcharge program has raised more than $11 million for the Environmental Trust Fund.

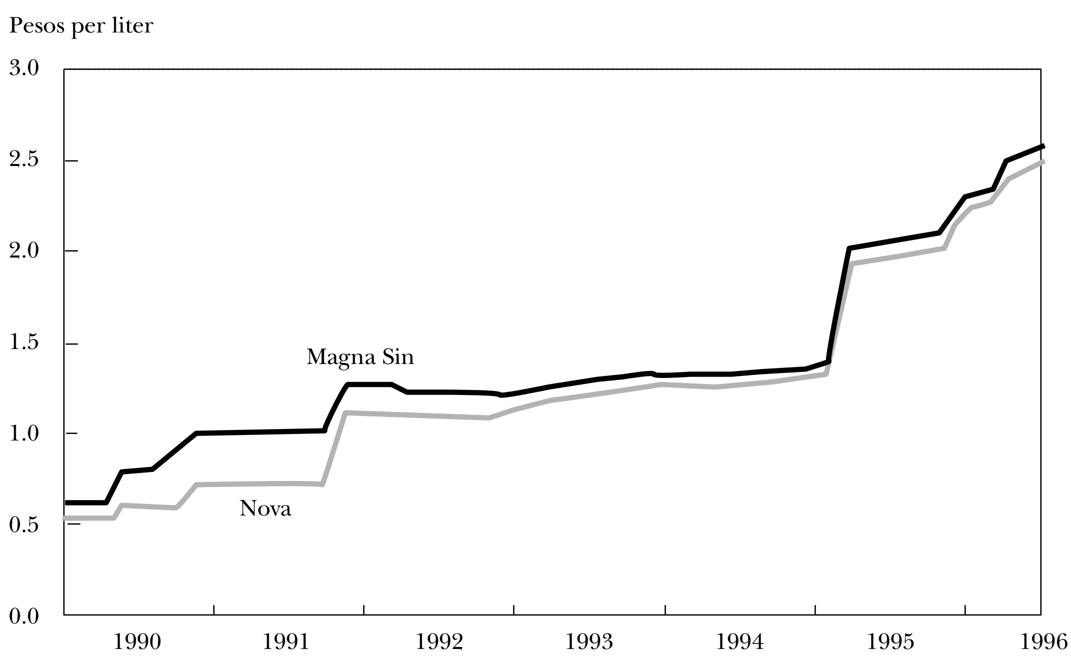
ated by gasoline type. The surcharge was raised from \$0.01 to \$0.04 for Nova and to \$0.02 for Magna Sin, reducing the price difference between unleaded and leaded gasoline grades. Magna Sin is now only 2.4 percent more expensive than Nova (Menéndez 1996). Retail prices of Magna Sin and Nova in the MCMA since 1990 are shown in Figure 4.5.

The fuel taxing policy used to result in higher prices for CNG than gasoline, which discouraged use of CNG by motor vehicles. However, recently the policy was revised to maintain the CNG price at 35 percent of the gasoline price.

Transport management. The modernization of high-use vehicles (taxis, trucks, buses, microbuses, and vans) has been an important component of traffic management policy in the MCMA.

- In 1990 taxis were estimated to emit high levels of pollutants per passenger-kilometer traveled. The taxi fleet was old, with 60 percent of vehicles more than ten years old and 93 percent more than six years old. The taxi modernization program was initiated in 1991 based on an agreement among the Federal District, State of Mexico, taxi associations, car manufacturers, and the National Bank of Public Works and Services. In the Federal District the program sought to replace all pre-1985 taxis over a two-year period with newer vehicles meeting 1991 emission standards (or 1993 standards if vehicles are replaced after October 1991). In the State of Mexico the program sought to replace all pre-1982 model-year taxis with 1982 or later model-year vehicles. By December 1993 about 47,000 taxis had been replaced by new model vehicles equipped with catalytic converters.
- A Federal District regulation required that all pre-1977 model-year trucks be replaced. About 15,000 trucks were replaced by emission-controlled vehicles meeting the new emission standards under financing by the World Bank. Priority was given to replacement by LPG- and CNG-fueled trucks.
- Between 1991 and 1995 about 4,100 Ruta-100 buses were retrofitted with new engines to reduce emissions. About 75 percent of these buses were operating during weekdays and 50 percent on Sundays and holidays. The remaining ones were being kept for maintenance. With establishment of the

Figure 4.5 Prices of Magna Sin and Nova in the MCMA, 1990–96



Source: Berumen 1996.

Permanent Program for Correcting Excessive Black Smoke in early 1992, Ruta-100 buses exceeding the 40-Hartridge-unit standard were taken from service for revision. Fuel injection pumps were also recalibrated and injectors were replaced to reduce other air emissions from Ruta-100 buses. Since Routa-100 buses ceased operation in 1995, private sector will provide this service in the future. Among the former 2,500 Routa-100 buses, only those complying with the 1994 emission standards will be sold to the private sector for circulation in the Federal District and the rest of the MCMA.
- By December 1993 there were about 10,000 microbuses replaced with vehicles equipped with catalytic converters in the MCMA.
- In 1993 vans equipped with catalytic converters were substituted for more than 27,000 old polluting vans. In 1994 there were an average of 400 substitutions a month.

The 1995 economic crisis in Mexico adversely affected the vehicle modernization program because high interest rates reduced demand for financing and development banks discontinued credit programs. The vehicle modernization program is being revitalized by emphasizing attractive financing conditions for replacement of microbuses by large buses.

Another component of the transport management policy in the MCMA includes circulation bans. One type of circulation ban is based on the model-year of certain vehicle classes. For example, since 1992 circulation of taxis older than model-year 1986 and microbuses older than model-year 1984 have been prohibited in the Federal District. In addition, in November 1989 an emergency measure for traffic management was implemented in the MCMA. Called *hoy no circula* (don't drive today), it prohibited circulation of vehicles in the MCMA one workday of the week based on the last digit of the vehicle's license plate. The program was designed to reduce gasoline consumption, traffic congestion, and emission of pollutants from mobile sources. Initially, all vehicles except high-use vehicles, fire trucks, ambulances, and police cars were prohibited from circulation one workday per week. In late 1991 the program was extended to include vans, taxis, and microbuses. Circulation of taxis was also prohibited on alternate Saturdays.

In December 1995 the government introduced a new program called *doble no circula* (don't drive for two days), which is used when emergency air pollution levels (above IMECA 250) are reached. When in place, the program prohibits 40 percent of the vehicles from circulation. Buses, low-emission vehicles, and trucks equipped with an oxidation catalyst are exempted from the ban. As a result of this measure about 1,000 diesel-fueled heavy-duty vehicles have been retrofitted (Viola 1996). The emergency measure has generated a quite negative public opinion.

The following measures have been implemented in the 1990s for rail-based mass transport vehicles in the MCMA:

- Between 1989 and 1994 the metro system was extended by 37 kilometers to provide services on a line that runs from Iztapalapa to Garibaldi. Metro construction on Line 10 is also under way. This new line will provide transport services from Guerrero in downtown Mexico City to the municipality of Catepec in the State of Mexico.
- Modernization of the Federal District trolleybus fleet was carried out in 1991–94.
- Twelve new trains equipped with modern technology were purchased for the light train system (CMPCCA 1995a).

To reduce congestion in the MCMA, 200 kilometers of roads (including the beltway and main interior roads) were modernized. Lanes of access roads from the city center to five different highways were widened, and nine bridges on major roads and eight underpasses on Line 8 of the metro system were constructed. Furthermore, between 1990 and 1994, 1.7 million square meters of road surface were paved in an effort to reduce dust levels.

Air quality monitoring. Air quality monitoring in the MCMA began in the mid-1970s with measurement of TSP and SO_2. At that time the main air quality problems were perceived to be dust storms and combustion of high sulfur fuels at industrial sources. Since 1986 air quality monitoring has been conducted by manual and automatic networks. Both networks were designed and operated to conform with criteria established by the WHO, and the U.S. and German environmental protection agencies.

Until recently the automatic network consisted of twenty-five stations in five different sec-

tions of the MCMA (southwest, northwest, southeast, northeast, and center). These stations continuously monitor ozone (in sixteen stations), SO_2 (in seventeen stations), NO_x (in ten stations), CO (in seventeen stations), PM-10 (in eleven stations), and atmospheric parameters such as temperature, wind direction and speed, and relative humidity (in ten stations). These stations are connected to a central data processing facility. Seven new automatic stations were recently added to this network, bringing the total number to thirty-two. The automatic air monitoring network is verified every six months by the USEPA.

The manual system consists of nineteen stations that monitor ambient TSP and PM-10 concentrations. The TSP samples are also analyzed for such parameters as nitrates, sulfates, lead, and other heavy metals. According to criteria established by USEPA standards, samples are collected once every six days for a 24-hour period. During winter, however, sampling frequency increases to once every three days.

Ambient concentrations of HC are measured through special programs jointly conducted by Pemex and the USEPA. In addition, there are two mobile air monitoring units and a remote detection system used for research and siting of new air monitoring stations.

Air quality data in the MCMA are expressed as IMECA values (Tables 4.14 and 4.15). IMECA values are calculated from hourly averages of pollutant concentrations using a scale from zero to 500, with a reference value of 100 for the air quality standard of the pollutant. These values are displayed at electronic billboards located next to principal roads of the city and transmitted by radio stations. They are also published every day by local newspapers and in monthly and yearly reports of the CMPCCA.

Evaluation of Implemented Measures

Despite a fast growing vehicle fleet, the urban air quality management strategy in the MCMA has effectively reduced ambient concentrations of some pollutants (such as lead, SO_2, and CO) and somewhat stabilized the upward trend of ambient concentrations of other pollutants (such as ozone and PM-10). Successful formulation and implementation of this strategy can be attributed to a coordinated effort that has involved government institutions representing the various jurisdictions in the MCMA, research agencies, and the nongovernmental community.

Vehicle emission standards. As a result of exhaust emission standards, all new vehicles that have entered into traffic in the MCMA since 1991 are equipped with catalytic converters. These newer vehicles constitute about 32 percent of road-based motor vehicles in the MCMA. Installation of catalytic converters has enabled a 90 to 95 percent reduction in CO and HC emissions and a 60 to 65 percent in NO_x emissions from gasoline-fueled cars, taxis, vans, and microbuses (see Table 4.3).

The Mexican emission standards for new vehicles, however, are less stringent than those in effect in the United States, and this gap may widen unless standards are tightened to keep pace with technological advances (Walsh 1996). Emission standards for in-use gasoline-fueled vehicles with model-year 1994 and older are relatively lenient compared with those in the United States.

Emission tests conducted on new vehicles at sea level would not yield the same results at high-altitude locations like the MCMA. Because the MCMA does not have a vehicle testing laboratory, new vehicles or engines are not certified

Table 4.14 IMECA values for the MCMA

	Pollutant (time-weighted average)					
IMECA value	*CO (8-hour) (mg/m³)*	*NO_2 (1-hour) (μg/m³)*	*O_3 (1-hour) (μg/m³)*	*SO_2 (24-hour) (μg/m³)*	*TSP (24-hour) (μg/m³)*	*PM-10 (24-hour) (μg/m³)*
100	12.6	395	220	338	260	150
200	23.8	1,236	465	695	445	350
300	34.9	2,077	710	1,469	630	420
500	57.2	3,760	1,200	2,600	1,000	600

Source: DDF 1997b.

Table 4.15 Significance of the IMECA values

IMECA value	*Air quality*	*Human health effects*
0–100	Satisfactory	A favorable situation for physical activities
101–200	Unsatisfactory	Some annoyance to sensible people
201–300	Bad	Increased annoyance and intolerance for people who exercise and have some respiratory problems
301–500	Very bad	General increase in intolerance among the public

Source: LANL and IMP 1994.

for emissions. Testing for certification of new vehicles and engines is carried out by manufacturers with some oversight by government officials. Occasional certification tests are carried out at the Mexican Petroleum Institute's laboratory at the request of either government or industry (Walsh 1996).

Exempting low-emission vehicles from the one-day or two-day driving ban provides a good incentive to have only clean vehicles for use on high pollution days. This measure may also stimulate the modernization of the fleet by encouraging people to replace their old, high-polluting vehicles with new ones that could qualify for the exemption. Emission standards for exemption needs to be announced sufficiently in advance to allow vehicle owners to adjust their behavior accordingly.

Vehicle inspection programs. During the second half of 1993 about 2.8 million vehicles were inspected at private and government-operated inspection stations. Of these vehicles about 2.3 percent were barred indefinitely from circulation. Among vehicles passing the test, almost 25 percent needed maintenance and a second inspection within six months in order to comply with emission standards. For those vehicles permitted to circulate, 71 percent were private cars, 8 percent were public transport vehicles, 18 percent were freight vehicles, and 3 percent were emergency vehicles, official vehicles, or motorcycles. The average age of these vehicles was 8.5 years (CMPCCA 1995a).

The computerized system motivated many drivers to take their vehicles to maintenance before inspection. The fail rate in the first inspection of vehicles was 42 percent during the first six months after the introduction of the computerized inspection system in 1993. This rate dropped to 26 percent at the end of 1994. Based on test results at government-owned stations, the modernization of the inspection system resulted in a 61 percent reduction of CO emissions and a 71 percent in HC emissions (CMPCCA 1995a).

A noncomputerized inspection and maintenance system, such as the one used by private stations and the previously government-owned stations in the MCMA, leaves the pass-fail decision for each vehicle up to the individual mechanic, who must read the results and compare them with emission standards. Based on the U.S. experience, such a design was associated with a high percentage of improper inspections, rendering the periodic inspection and maintenance program ineffective. Anecdotal evidence and limited data available on failure rates in the Mexican program suggest that the same is true for the MCMA.

Procedures for vehicle inspection payments differed for government-operated stations and private stations. For testing at government-operated stations, vehicle owners paid the fee at one of the forty-one treasury offices located in the MCMA and presented the receipt at the testing station. Cash payments were made directly at private inspection stations. As such, testing at the government-operated stations was less time-consuming and more convenient.

Government-operated and private inspection stations also provided different type of services. Government-operated stations did not provide repair services, but private stations did. So, vehicles that failed the emissions test at government-operated stations had to be taken to private service stations for repair. Based on a survey of service receivers and inspection technicians in early 1990s, government-operated stations were perceived as being stricter and more straightforward than the private service stations. With the modernization of the government-operated inspec-

tion stations, human intervention in determining test results has been eliminated.

Federal District Department's recent decision to conduct periodic vehicle inspections at high-volume automatic inspection stations is based on the above-mentioned factors. This scheme would eliminate many of the problems encountered at private inspection stations. Considering previous private inspection station owners in bids would somewhat compensate those who lost their work and would also increase acceptability of the government's decision.

Emission testing of the actual motor vehicle fleet in the MCMA will allow the government to establish realistic standards for in-use vehicles and for the one-day and two-day driving ban programs. This approach will be more effective than adopting the in-use vehicle emission standards used in industrial countries, where motor vehicle fleets are likely to have substantially different characteristics, emission rates, and driving patterns.

The periodic inspection and maintenance program in the MCMA has increased public awareness about the contribution of vehicle emissions to air pollution and the importance of vehicle maintenance for curtailing these emissions. As a result ambient CO concentrations decreased by 68 percent between 1991 and 1994. Similarly, there were twenty-three air quality violations for CO registered in 1992, but none in 1993 or 1994 (CMPCCA 1995a).

Through the roadside inspection program, an average of 2,700 vehicles are fined and 700 vehicles are barred from circulation every month. About 73 percent of these vehicles are trucks and buses (CMPCCA 1995a).

Fuel-targeted measures. Between 1986 and 1991 the lead content of Nova was reduced by about 45 percent. This was achieved mainly by adding MTBE to boost the octane number of the gasoline. Since 1992 the lead content of Nova has been lower than the maximum allowable lead content in Mexico (0.08 g/liter) and the European Union countries that still use leaded gasoline (0.40 g/liter in Portugal and 0.15 g/liter in other European Union countries).

After Magna Sin was introduced in Mexico to meet the fuel requirements of catalytic converter-equipped vehicles, consumption of Nova in the MCMA decreased from 90,000 barrels a day in 1989 to 56,000 barrels a day in mid-1996. Consumption of Magna Sin increased to 52,000 barrels a day in mid-1996 and accounts for 48 percent of the gasoline consumed in the MCMA. Magna Sin accounts for a higher percentage of total gasoline sales in wealthier Mexican cities (88 percent in Monterrey) and in the northern border area (98 percent; Berumen 1996).

Because of the reduction of lead levels in leaded gasoline and higher market share of unleaded gasoline, the lead concentration in ambient air in the MCMA has decreased almost 90 percent during the past five years. Because there is less lead in ambient air, the average lead level in blood of children examined in the MCMA fell by 66 percent between 1991 and 1994 (from 17.5 μg/dl to 6.0 μg/dl of blood (CMPCCA 1995a).

Large price differences between Magna Sin and Nova in the early 1990s caused persistent misfueling of vehicles in the MCMA (that is, Nova was used in vehicles equipped with catalytic converters). Frequent supply problems with Magna Sin also resulted in misfueling. Misfueling damages the catalyst and oxygen sensor in catalytic converter-equipped vehicles, permanently increasing emissions. A survey carried out between January and March 1992 on 500 taxis and buses showed that 95 percent had misfueled. Another survey carried out that year by independent consultants detected lead in the tailpipes of 12 percent of the catalyst-equipped private vehicles and 13 percent of the public transport vehicles sampled (O'Ryan 1996). To reduce misfueling, a sufficient supply of Magna Sin was maintained to meet demand in the MCMA and the price difference between Magna Sin and Nova was reduced. The use of differential surcharges also helped reduce the retail price gap to 2.4 percent in mid-1996.

These surcharges provide revenue for the Environmental Trust Fund to implement pollution control projects with little or no financial recuperation. This arrangement illustrates a nice example of the "polluter pays" concept: those who pollute the environment by using fuels, especially the dirtier one, should pay for environmental improvement. At the start-up of the Environmental Trust Fund in 1995, one project being considered by CMPCCA involved financing the installation of vapor recovery systems in gasoline stations. Another project recently announced involves substituting microbuses for buses. The Trust Fund will provide financial guarantees to individual owners so that commercial banks will consider them creditworthy. The goal

Table 4.16 Typical fuel quality parameters of Magna Sin and Nova, 1995

Fuel parameters	*Magna Sin*		*Nova*	
	Quality	*Standard* [a]	*Quality*	*Standard* [a]
Reid vapor pressure (psi)	7.9–8.2	6.5–8.5	8.1	6.5–8.5
Aromatics (percent by volume)	24.7–28.6	30	22.4	30
Olefins (percent by volume)	8.3–12.3	15[b]	8.5	15
Benzene (percent by volume)	0.9–1.2	2	1.2	2
Oxygen (percent by weight)	0.92–1.19	1–2	0.78	1–2
Sulfur (percent by weight)	0.035–0.070	0.10	0.07	0.15
Lead (g/liter)	0.00017	0.0026	0.03	0.06–0.08

a. The lead standard for Magna Sin and the aromatics, olefins, benzene, and sulfur standards for Magna Sin and Nova specify the maximum values.
b. After January 1988, the maximum permissible value will be 12.5 percent by volume.
Source: Berumen 1996; DDF 1996.

of this project is to improve the public transport service by offering higher capacity vehicles. Financing of educational campaigns is also being considered (Menéndez 1996).

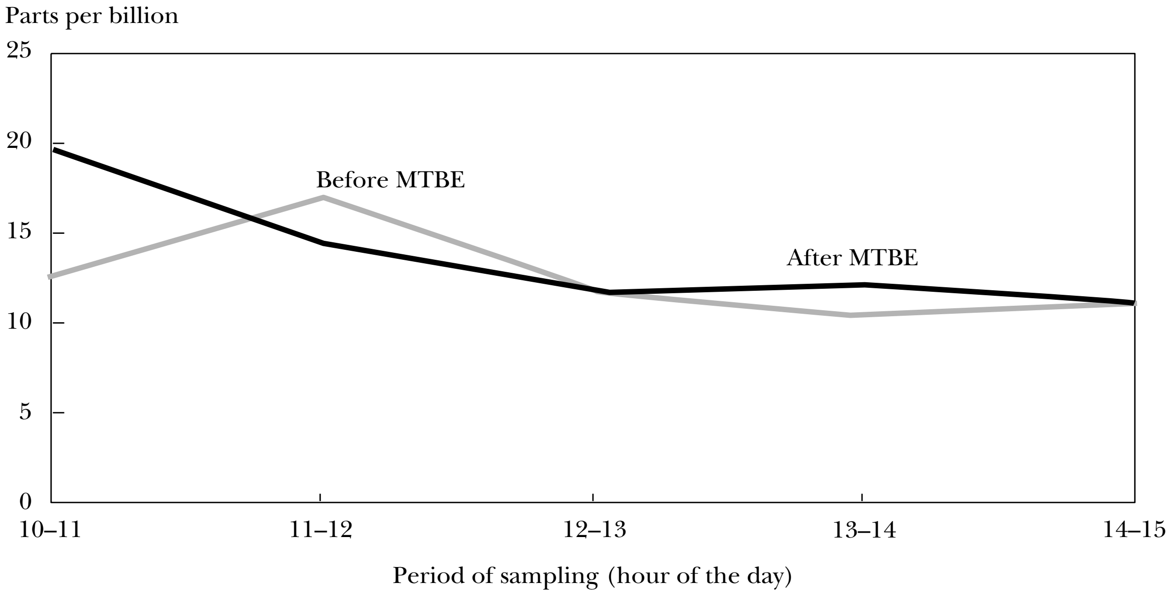
At a retail price for Nova of $0.373 a liter, the new fuel taxing policy would result in a retail price for CNG of $0.21 a liter (including a compression cost of $0.08 a liter) on a gasoline-energy equivalent basis. This price differential should promote CNG-conversion of gasoline-fueled vehicles, especially those that travel extensively (such as gasoline-fueled microbuses and taxis). However, assuming an annual consumption of 300,000 liter of diesel fuel per bus, the taxing policy would not provide sufficient incentive for a private investor to spend an additional $10,000 to $15,000 for a new CNG-fueled bus instead of a new diesel-fueled-bus. This assessment is based on a retail price of diesel fuel of $0.292 a liter for diesel fuel and taking account 11 percent greater fuel efficiency of diesel fuel compared to gasoline and 10 percent greater engine efficiency for diesel engines than CNG engines. Use of CNG instead diesel fuel can be promoted by imposing a surcharge on diesel fuel.

In 1995 typical Magna Sin and Nova fuel parameters all complied with the established standards, except for oxygen content (Table 4.16). Nevertheless, the Reid vapor pressure of gasoline marketed in Mexico is higher than in the southern United States (a maximum of 7.2 psi where use of reformulated gasoline is required and a maximum of 7.0 psi in the Los Angeles Metropolitan Area). Further reduction of unleaded gasoline volatility would help reduce ambient ozone levels in the MCMA. In addition, the sulfur content of the Magna Sin in Mexico (0.070 percent by weight) is higher than in the United States (1990 industry average of 0.0338 percent by weight). Unleaded gasoline with a high sulfur content reduces the efficiency of catalytic converters and promotes higher emissions of CO and ozone precursors (HC and NO_x).

Studies conducted by the Mexican Petroleum Institute indicate that leaded gasoline containing 5 percent MTBE by volume reduces exhaust emissions from noncatalytic gasoline-fueled vehicles by about 15 percent for CO and 11 percent for HC without increasing NO_x emissions (CMPCCA 1995a). However, Bravo and others (1991) found that adding 5 percent MTBE to gasoline increased ambient peak concentrations of formaldehyde in the southwestern section of the MCMA and shifted the peak from 11–12 A.M. to 10–11 A.M. (Figure 4.6). A slight increase in ambient ozone concentrations in the morning and evening hours was also observed after adding MTBE (Figure 4.7).[11] Further ambient air measurements in March 1992 indicate that formaldehyde concentrations were as high as 33 ppb in the northwestern section (Tlalnepantla) and 18 ppb at the center (Merced) of the MCMA (LANL and IMP 1994). Because Magna Sin has been reformulated since 1992, the effect on fuel's volatile and reactive HC emissions (which

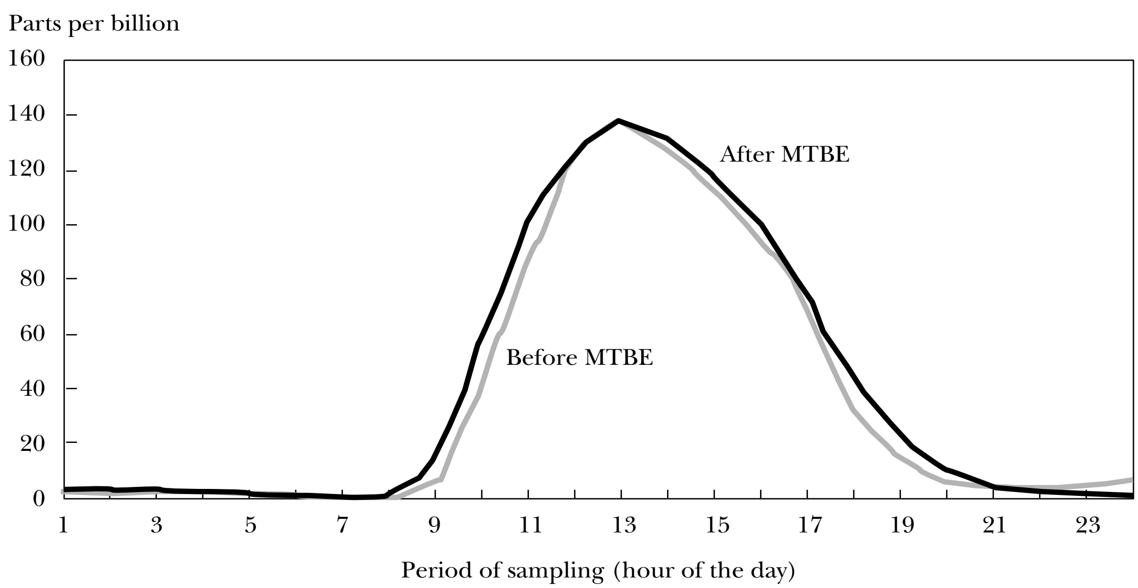
11. Sampling was conducted on 29 weekdays during the December 1998-February 1989 period when no MTBE was added to gasoline, and on 56 weekdays during the December 1989-February 1990 period when gasoline contained 5 percent MTBE. Meteorological conditions during both sampling periods were similar (Bravo and others 1991).

Figure 4.6 Ambient concentrations of formaldehyde in the MCMA before and after adding MTBE



Source: Bravo and others 1991.

Figure 4.7 Ambient concentrations of ozone in the MCMA before and after adding MTBE



Source: Bravo and others 1991.

contribute to formaldehyde and ozone concentrations in ambient air) caused by adding 5 percent oxygenates cannot be predicted without evaluation of the entire fuel matrix.

Diesel fuel quality parameters have complied with the Mexican standard. The typical sulfur content of Special Diesel sold in the MCMA in 1995 was 0.041 percent by weight. Elimination of the regular diesel fuel throughout Mexico (in February 1997) must have eliminated higher SO_2 emissions caused by misfueled vehicles circulating in the MCMA or intercity vehicles fueled with regular diesel fuel entering the MCMA. In 1995 Diesel Sin had a cetane index of between 55.0 and 59.0, and an aromatics content of 25.9 to 28.1 percent by volume (DDF 1996). The quality of Diesel Sin is similar to diesel fuel in the United States and better than the average diesel fuel in Europe. Further reformulation of diesel fuel should focus on reducing its aromatics content. This would reduce PM emissions in the form of soot, which has carcinogenic effects, reduces visibility, and causes soiling.

Limited data from testing of five in-use light-duty trucks converted to LPG indicate that none of the five vehicles met the emission standards to which they were originally certified. Conversion efficiencies were less than 20 percent for NO_x (for four of these vehicles) and 50 to 80 percent for CO and HC. The low NO_x efficiency suggests improper converter installation (Walsh 1996). In addition, although LPG is a more desirable motor vehicle fuel than gasoline or diesel fuel, it is not totally environmentally benign because its photochemical components contribute to ozone formation. Based on preliminary estimates, LPG losses during handling, distribution, and use are responsible for 20 to 30 percent of the ozone in the MCMA. A solution to this problem may be to reformulate LPG by reducing its butane and butylene content (DDF 1996).

The gasoline vapor recovery program is expected to reduce HC emissions by 29,000 tons to 36,000 tons a year. This would also reduce the formation of ozone in ambient air and recover gasoline, which would otherwise be lost to the atmosphere. The Environmental Trust Fund was to be used to finance the installation of a vapor recovery system in the gasoline stations operating in the MCMA. Despite collection of more than $11 million, the vapor recovery system has been installed in only nine of the MCMA's 360 gasoline stations. Significant delays in using the Environmental Trust Fund have occurred for two reasons. First, the National Institute of Ecology did not announce the mandatory requirement of installing a vapor recovery system until September 1995, although it was decided in October 1994. Second, the initial decision to provide nonrefundable funds for the installation of vapor recovery systems was replaced by the decision to provide interest-free loans. This decision was vehemently opposed by gasoline station owners, who argued that the low profit margin was not sufficient to pay back the credit. It was only when CMPCCA intervened and threatened to shut down all the gas stations not equipped with vapor recovery systems under the smog alert mandatory shut-down program that some gas stations applied for the credit. The Finance and Public Credit Secretariat has recently mandated interest payments on the credits provided by the Environmental Trust Fund. This is expected to further delay adoption of the vapor recovery project.

Transport management. Modernization of the motor vehicle fleet has reduced pollutant emissions by replacing some of the old, heavily polluting in-use vehicles in the MCMA. For example, the taxi replacement program to meet the 1991 standards is estimated to have reduced average emissions in the replaced vehicles by 76 percent for CO, 60 percent for HC, and 9 percent for NO_x. The average reduction in emissions from taxi replacement to meet the 1993 standards is estimated to be 96 percent for CO, 84 percent for HC, and 60 percent for NO_x. The replacement of old gasoline-fueled trucks with newer trucks meeting the 1993 standards is estimated to have lowered average emissions for replaced vehicles by 85 percent for NO_x, 81 percent for CO, and 49 percent for PM (World Bank 1992). Replacing engines in about 4,100 Ruta-100 buses reduced emissions of black smoke and eliminated 41,000 tons of air pollutants. Inspection and maintenance of all Ruta-100 buses further reduced black smoke emissions. Adjusting and replacing the injection system in these buses reduced their emissions by 67 percent for NO_x, 50 percent for HC, 25 percent for CO, and 14 percent for CO_2.

Despite the modernization efforts for these vehicles, no action has been taken for the old, highly polluting cars circulating in the MCMA. A vehicle taxing policy disfavoring older cars in the MCMA would create an incentive to export these vehicles outside the MCMA. Because this policy may be politically difficult to implement, a

scrappage program may be considered instead. Such a program, however, would bring a cost burden to the government and also create a demand for older vehicles in the local market. This demand may be controlled by prohibiting importation of older vehicles to the MCMA.

Circulation bans in the MCMA have had mixed results. Banning older microbuses and taxis from circulation has eliminated emission of pollutants from these highly polluting sources of the fleet in the Federal District. Despite its initial success based on reduced traffic congestion and curtailed air pollution, however, the one-day driving ban program did not achieve the desired results because households circumvented the ban by buying a second car. According a recent study, 22 percent of vehicle owners in the MCMA purchased a second vehicle just to bypass the requirement (CMPCCA 1995b). These included 170,000 inexpensive old vehicles brought in from surrounding regions were purchased, mostly by households having more driver's licenses than cars. The acquired second car was not only used as a one-day replacement for the principal vehicle but was also driven during the other (permitted) days of the week by other members of the family. As a result the total kilometers traveled by many households increased. Accelerated gasoline consumption and increased air pollution after this driving ban suggest that the intended results were not achieved.

The Mexican government has not entirely given-up the one-day driving ban, however, because it is estimated that eliminating this program will increase daily gasoline consumption by 132,000 liters and increase daily vehicle circulation by 385,000, resulting in a 756-ton increase in daily pollutant emissions. Thus the government is trying to use both the one-day and two-day ban programs as an incentive to modernize the fleet, switch to cleaner fuels, and install pollution control equipment. For example, since 1992 all freight, passenger, and service vehicles that have switched to CNG or LPG are exempt from the one-day driving ban. With the introduction of the two-day driving ban, there is an incentive for vehicles manufactured between 1980 and 1990 to retrofit with catalytic converters. For example, installation of an oxidation catalyst on in-use trucks, which exempts these vehicles from the ban, would reduce their average CO and HC emissions by up to 70 percent and PM emissions by up to 50 percent (through oxidation of the soluble organic fraction of PM; Viola 1996). Implementation of the driving ban programs is expected to reduce annual emissions from the most polluting vehicles by 71,100 tons for CO, 5,250 tons for HC, and 1,350 tons for NO_x (DDF 1996).

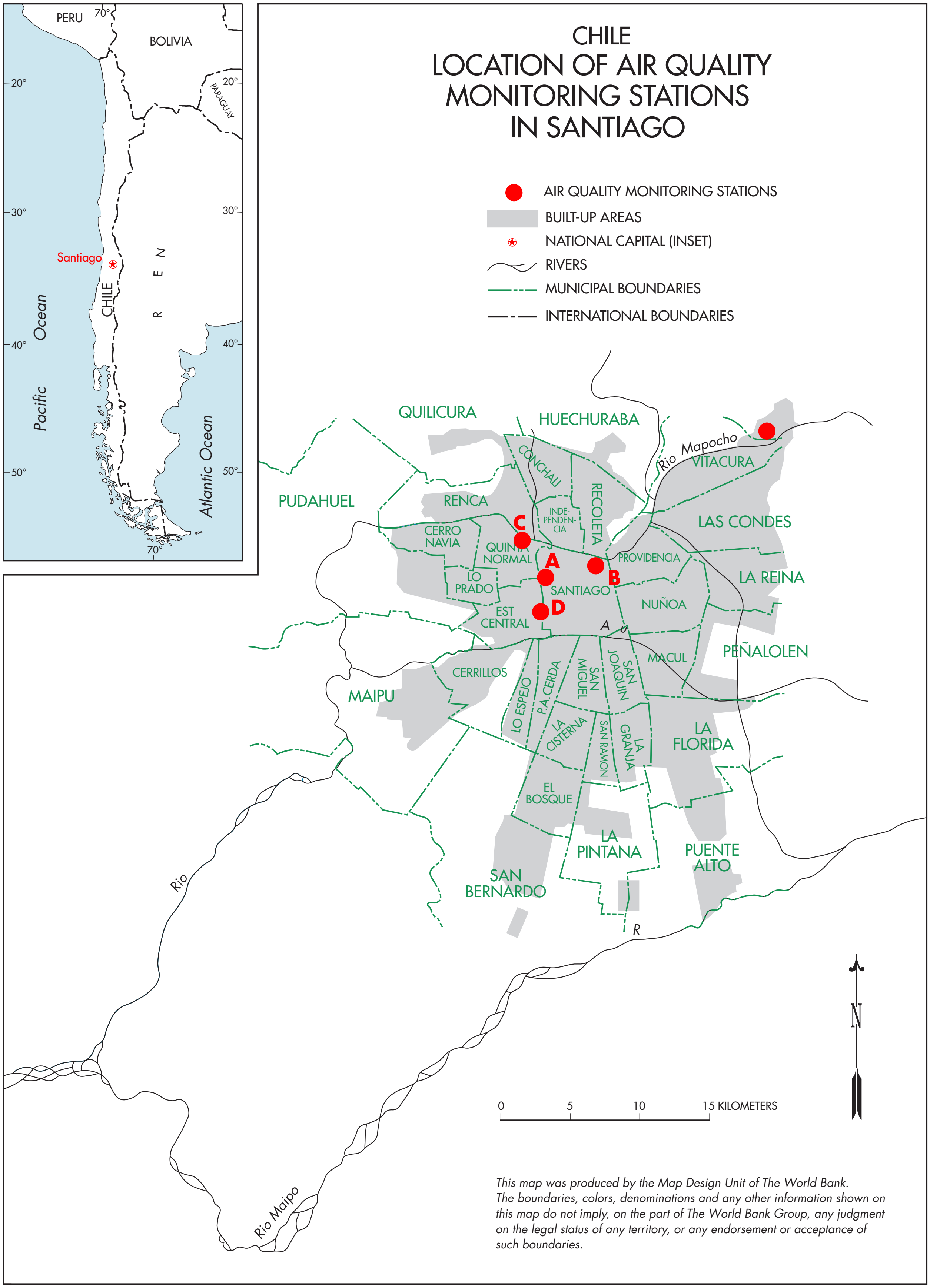
Other transport management measures in the MCMA have had the following effects:

- Opening the newly constructed 37 kilometers of Line 8 of the metro system has provided transport services to an additional 300 million passengers a year, eliminating about 100,000 vehicles a day from traffic and reducing pollutant emissions from mobile sources by about 22,000 tons.
- Constructing Line 10 of the metro system is expected to replace 230 buses, 1,160 microbuses and 18,000 private cars a day. This substitution is expected to reduce pollution in the MCMA by 4 percent.
- Renovating trolleybuses and purchasing fifteen new trains has improved public transport services in the MCMA. Each train can carry about 350 people and travel at an average speed of 50 kilometers an hour. Two trains can be coupled at peak hours to provide additional services. With the introduction of these trains, the wait for trains at rush hours was reduced to three minutes.
- Modernizing the road network should have reduced congestion, although no quantitative data are available (CMPCCA 1995a).

Privatization of Ruta-100 buses is expected to provide a more efficient mass transport service to the public. This would attract some additional riders who currently drive private cars, resulting in a net reduction in pollutant emissions.

Air quality monitoring. The automatic air quality monitoring network in the MCMA is one of the most sophisticated in the world in terms of coverage and quality. This network now includes thirty-two automatic stations supported by nineteen manual air monitoring stations and can provide hourly air quality information to the public through billboards placed next to major roads and radio stations. USEPA verifies the network twice a year.

Santiago



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JUNE 1997

The Santiago Metropolitan Area (SMA), Chile's most populated urban area and center for economic and industrial activities, has one of the worst air pollution problems of any urban center in Latin America. The main industries in the SMA are involved in food, textile, chemical, mineral, plastics, metal, paper, and rubber production.

The SMA is located in the Metropolitan Region[12] and comprises all of the thirty-two *comunas* (local administrative units) of the Santiago Province, the comuna of Puente Alto in the Cordillera Province, and the comuna of San Bernardo in the San Bernardo Province, for a total area of 493 square kilometers. Its population of about 4.8 million people represents 37 percent of Chile's total population. Since 1977 the SMA's population has grown by about 37 percent. This rapid growth and increased economic activities have expanded the urban periphery into rural areas at the expense of the central comunas (Santiago, San Miguel, San Joaquín, Ñuñoa, Providencia, Independencia, Conchali, Quinta Normal, and Estación Central). Urban growth has absorbed some of the country's most fertile lands, especially toward the south and southeast. Agricultural land in the SMA has decreased by more than 60 percent, mainly as a result of this highly deregulated urban growth. Population densities among the thirty-four comunas vary considerably from less than one person a hectare (Lo Barnechea) to almost 200 people a hectare (Lo Prado), with an average of 112 people a hectare (Hall, Zegras, and Rojas 1994).

Topography and climate play an important role in the high levels of pollution recorded in the SMA. The city lies at altitudes ranging from 400 meters to 900 meters in a valley surrounded by high mountains. These mountains—the Andes to the east and the Cordillera de la Costa to the west— restrict the flow of air into and out of the valley. The only natural outlets from the valley are to the south (Angostura de Paine) and southwest (Corredor de Melipilla; BKH Consulting Engineers and Universidad de Chile 1992). The entire annual precipitation, an average of about 400 millimeters, falls irregularly on about twenty days between May and August. Winds are weak, varying between 2 meters per second in the winter and 5 meters per second in the summer during the day, and falling to 1.0 meter to 1.5 meters per second at night. Moreover, a persistent thermal inversion holds contaminated air within the valley. The inversion layer, which forms at night, is destroyed in the morning hours. The height of the inversion layer ranges between 300 meters during the most polluted days in the winter (May through August) to about 1,000 meters in the summer when the sun's radiation is strongest.

The high levels of air pollution in the SMA have been linked to higher rates of respiratory problems (coughing, hoarseness) among children, upper respiratory diseases (asthma, pneumonia) among the general population, and air pollution-related mortality than in other parts of Chile (Belmar 1993).

Ambient Air Quality

Ambient air quality data for the SMA have been collected by the Metropolitan Region's Environmental Health Service (SESMA). Five automatic monitoring stations (the MACAM network) have been used to generate most of the data. Station A is located in the central part of the city; stations B, C, and, D are near the downtown area; and station M is in the northeastern section away from the downtown area. Semiautomatic stations, which were installed before the MACAM network, provide additional monitoring data.

TSP, PM-10, and PM-2.5 are the most critical air pollutants in the SMA, especially high during the colder months (April through September). Other air pollutants of concern are CO during the colder months and ozone during the warmer months (November through March). In addition, ambient NO_2 concentrations have been increasing since 1992.

TSP concentrations in the SMA are among the highest of any urban area in the world. In 1995 the maximum the 24-hour TSP concentration was 621 µg/m^3, much higher than the Chilean standard of 260 µg/m^3. Furthermore, at the same station the standard was exceeded on forty-five of ninety-one sampling days. The maximum 24-hour concentrations recorded by the other stations ranged between 311 µg/m^3 and 455 µg/m^3. In 1995 annual average TSP concentrations measured by four semiautomatic stations ranged between 146 µg/m^3 and 266 µg/m^3, much

12. Chile is divided into thirteen regions, one of which is the Metropolitan Region.

greater than the Chilean standard of 75 μg/m^3 (SESMA 1996a).

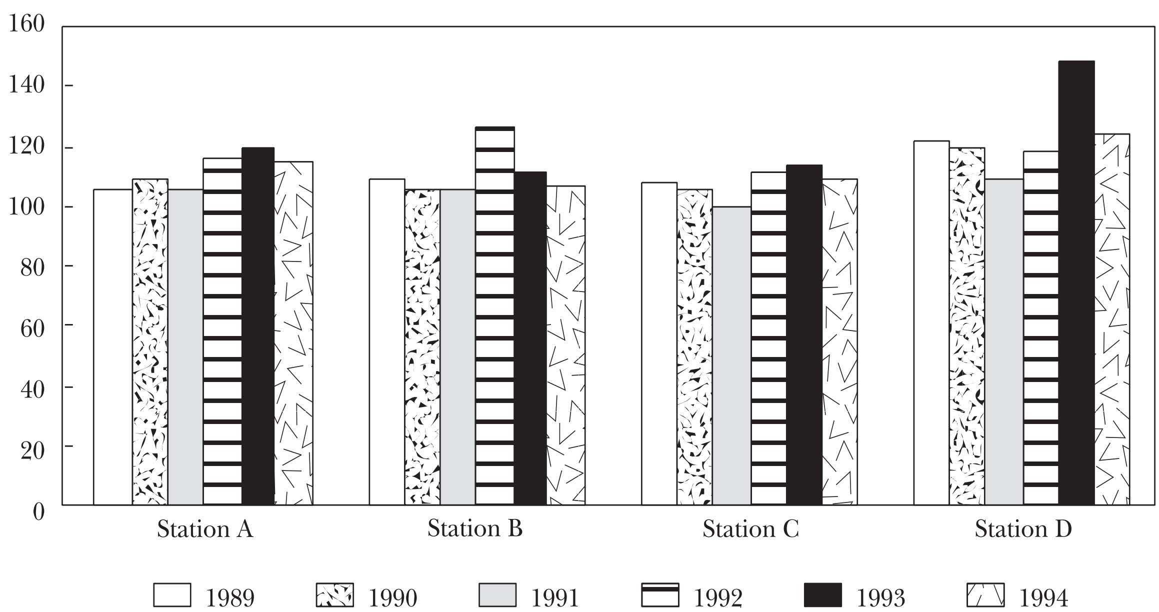
Between 1989 and 1994 annual average ambient PM-10 concentrations, as measured by the MACAM network around the downtown area, ranged from 100 μg/m^3 to 149 μg/m^3—far more than the USEPA's standard of 50 μg/m^3 (there is no corresponding Chilean standard; Figure 4.8). Station D recorded slightly higher levels than the other four monitoring stations; station M recorded lower levels. In 1995 annual averages were 88 μg/m^3 at stations A and C, 87 μg/m^3 at station B, 101 μg/m^3 at station D, and 71 μg/m^3 at station M (SESMA 1996b). The annual averages of PM-10 data measured by the semiautomatic stations in 1995 ranged between 88 μg/m^3 and 109 μg/m^3 (SESMA 1996a).

The 24-hour average PM-10 concentrations were above the Chilean standard (150 μg/m^3) on 100 days in 1990, 69 days in 1991, and 84 days in 1992. More than 98 percent of these violations occurred during the colder months (between April and September). During 1990–92, 24-hour average PM-10 concentrations were above the pre-emergency level (240 μg/m^3) on twenty to thirty-three days a year and above the emergency level (330 μg/m^3) on one to seven days a year (Escudero and Cofré 1993). In 1992 the three highest 24-hour average PM-10 concentrations were 470 μg/m^3, 440 μg/m^3, and 380 μg/m^3 (O'Ryan 1994). Since then PM-10 concentrations have fallen as a result of air pollution control measures. In 1995 the 24-hour PM-10 standard was exceeded on fifty-three days at station D with the highest observed concentration being 302 μg/m^3. At the other stations the number of days above the standard ranged from seven (at station M, where the highest observed concentration was 203 μg/m^3) to thirty-four (at station A, where the highest observed concentration was 279 μg/m^3; SESMA 1996b). The maximum 24-hour PM-10 concentrations recorded by the semiautomatic stations ranged between 275 μg/m^3 and 297 μg/m^3 (SESMA 1996a).

PM-2.5, although not regulated, is a major health concern. The PM-2.5 concentrations are higher around the downtown area than in the northeastern section of the SMA. In 1995 the maximum 24-hour average PM-2.5 concentrations were 164 μg/m^3 at station A, 146 μg/m^3 at stations B and C, 174 μg/m^3 at station D, and 121 μg/m^3 at station M (SESMA 1996b). These concentrations are 2.4 to 3.5 times higher than the USEPA's proposed 24-hour standard of 50

Figure 4.8 Annual ambient concentrations of PM-10 in the SMA, 1989–94

Micrograms per cubic meter



Note: There is no Chilean PM-10 standard for the 1-year average period. The corresponding USEPA standard is 50 μg/m^3.
Source: Escudero and Cofré 1993; Katz 1995.

μg/m³. The annual average concentrations were 44 μg/m³ at station A, 43 μg/m³ at stations B and C, 48 μg/m³ at station D, and 32 μg/m³ at station M (SESMA 1996b). These concentrations exceed the USEPA's proposed annual standard of 15 μg/m³ by 2.1 to 3.2 times. Comparison of the annual PM-2.5 and PM-10 data suggests that PM-2.5 constitutes 50 percent of PM-10.

The monthly distribution of ambient CO concentrations follows the same pattern as PM-10 with the highest ambient concentrations occurring between April and September. The highest concentrations are observed in the city center in areas where traffic volume is high and when a persistent inversion layer prevents the vertical mixing of pollutants. The Chilean 8-hour CO standard of 9 ppm (10.3 mg/m³) was exceeded on 108 days in 1990, 92 days in 1991, and 94 days in 1992. Ambient CO concentrations were above the pre-emergency level (34.4 mg/m³) on two days in 1990 and two days in 1991 (Escudero and Cofré 1993). In 1992 the highest 8-hour average concentration monitored was 29 mg/m³ (Ulriksen, Fernández, and Muñoz 1994). In 1995 the 8-hour average concentrations exceeded the standard on sixty days (at station D) and reached as high as 26 mg/m³ (CONAMA-RM 1996). The 8-hour average CO concentrations exceeded the standard on fewer days at stations A, B, and C and remained below the standard at all times at station M (SESMA 1996b).

Analysis of data collected at station B in 1992 indicates that 1-hour CO concentrations followed the same daily pattern during the four-month monitoring period and remained below the Chilean standard of 35 ppm (40 mg/m³). This pattern shows two daily peaks, the first one between 8 A.M. and 10 A.M. and the second one between 7 P.M. and 11 P.M. (Ulriksen, Fernández, and Muñoz 1994). Since 1994 the 1-hour CO concentrations have fallen. In 1995 the 1-hour CO concentrations were over the standard only once (41 mg/m³ at station D). The maximum 1-hour concentrations observed at other stations ranged from 7 mg/m³ (at station M) to 29 mg/m³ (at station A; CONAMA-RM 1996; SESMA 1996b).

Ambient ozone concentrations in the SMA exceed the Chilean 1-hour standard of 160 μg/m³ (80 ppb) on many days of the year. Although the highest ozone concentrations occur during the spring the most frequent violations of the standard are observed during the summer. Violations of the 1-hour ozone standard also occur during the rest of year, including the winter. The ozone standard is exceeded most frequently in the northeastern section of the city (station M) and, to a lesser extent, in the city center. In 1992 the maximum 1-hour ozone concentration monitored in the northeastern section was 540 μg/m³. The least frequent violations of the 1-hour standard occurred at station B and station D (Table 4.17). Since 1992 the 1-hour ozone concentrations have remained below 400 μg/m³ except during the spring of 1995. In addition, the high frequency of ozone concentrations above the 300 μg/m³ level observed in 1992 and 1993 fell in subsequent years except during the 1995 spring-summer period. In 1995 the maximum 1-hour ozone concentrations monitored were 304 μg/m³ at station A, 186 μg/m³ at station B, 280 μg/m³ at station C, 214 μg/m³ at station D, and 448 μg/m³ at station M. The 1-hour standard was exceeded 404 times (on 155 days) at station M, 78 times at station C, 58 times at station A, 42 times at station D, and 6 times at

Table 4.17 Ambient ozone levels exceeding the 1-hour Chilean standard in the SMA, 1992–93

	1992		*1993*	
Air monitoring stations	*Number of hours exceeding the standard*	*Number of days exceeding the standard*	*Number of hours exceeding the standard*	*Number of days exceeding the standard*
A	119	55	115	61
B	13	10	37	24
C	195	84	100	58
D	64	30	32	20
M	598	152	557	162

Note: The 1-hour ambient ozone standard is 160 μg/m³.
Source: Katz 1995.

Table 4.18 Annual average concentrations of SO_2 in the SMA, 1987–91
(micrograms per cubic meter)

Station	*1987*	*1988*	*1989*	*1990*	*1991*
Montijas and Mac-Iver	15	11	41	22	31
P. De Valdivia 963	16	16	22	23	17
Marathon 1000	13	9	8	11	10
Independencia 3540	20	10	12	12	8
Teniente Cruz 1087	14	9	11	12	7
La Pintana	28	19	17	16	8

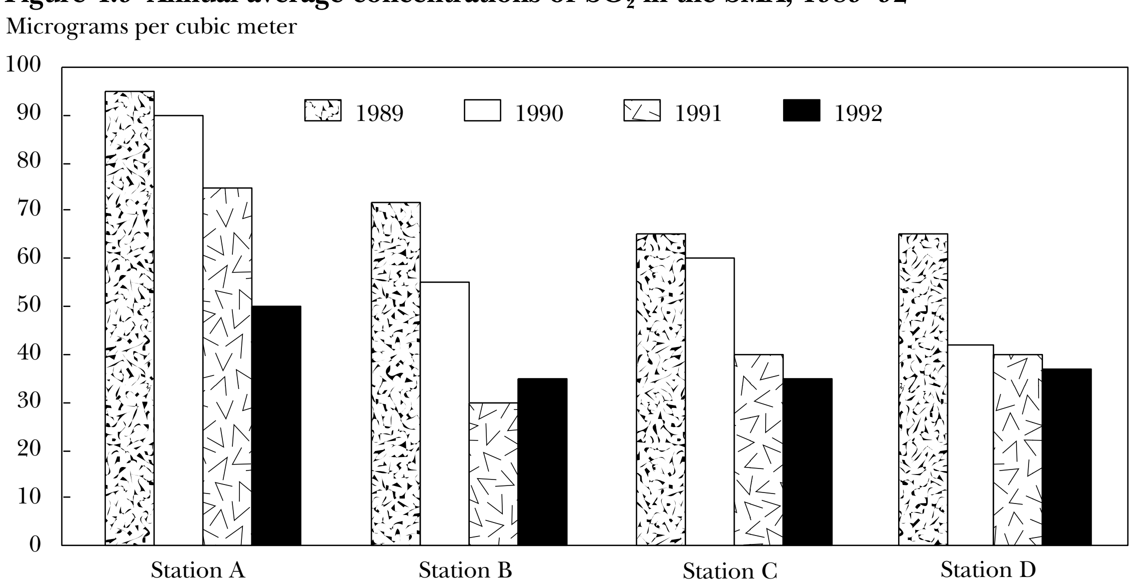
Source: INE 1993.

station B (CONAMA-RM 1996; SESMA 1996b).

Annual averages for ambient SO_2 concentrations during 1987–91, as measured by six semiautomatic monitoring stations, are shown in Table 4.18. Annual averages for 1989–92, as measured by the MACAM network, are shown in Figure 4.9. The concentrations measured by the semiautomatic monitoring stations were lower than the Chilean standard of 80 μg/m³ or the WHO guideline of 40 μg/m³ to 60 μg/m³. The concentrations measured by the MACAM network were also lower than the Chilean standard, except for station A during the 1989–90 period (Escudero and Cofré 1993). But average concentrations were over the WHO guideline at four stations in 1989, three stations in 1990, and one station in 1991 (Escudero and Cofré 1993). In 1995 annual average concentrations ranged between 9 μg/m³ and 34 μg/m³ for the semiautomatic network and between 21 μg/m³ and 37 μg/m³ for the MACAM network (SESMA 1996a; SESMA 1996b).

The maximum 24-hour ambient SO_2 concentration in 1992 was recorded at 105 μg/m³, much lower than the Chilean standard of 365 μg/m³ (Ulriksen, Fernández, and Muñoz 1994). In 1995 the maximum 24-hour average SO_2 concentrations measured by the MACAM network were 146 μg/m³ at station A, 110 μg/m³ at station B, and 133 μg/m³ at station C (SESMA 1996b). The maximum 24-hour average SO_2 concentrations measured by the semiautomatic stations ranged

Figure 4.9 Annual average concentrations of SO_2 in the SMA, 1989–92



Note: The Chilean standard is 80 μg/m³ and the WHO guideline is 50 μg/m³. Data are from the MACAM network.
Source: Escudero and Cofré 1993.

between 47 μg/m^3 and 161 μg/m^3 (SESMA 1996a). The highest concentrations observed were in the city center during the winter months (CONAMA-RM 1996). The installation of a desulfurization equipment at a metallurgical facility (Molymet) and changes in the operation of the Renca power plant helped reduce ambient SO_2 concentrations (Katz 1996).

Between 1988 and 1991 annual average concentrations of NO_2, as measured by the MACAM network, ranged between 33 μg/m^3 and 64 μg/m^3 and were below the Chilean standard of 100 μg/m^3 (Escudero and Cofré 1993). Since 1992 the peak (during the winter) and minimum (during the summer) NO_2 concentrations have increased slightly as a result of the growth of the motor vehicle fleet. In 1995 the annual average NO_2 concentrations ranged between 73 μg/m^3 and 79 μg/m^3 for the MACAM network and between 32 μg/m^3 and 98 μg/m^3 for the semiautomatic stations (SESMA 1996a; SESMA 1996b). The highest concentrations were measured in the city center during the winter months (CONAMA-RM 1996).

In 1995 the maximum 1-hour NO_2 concentrations measured by the MACAM network exceeded the WHO guideline of 400 μg/m^3 and the Chilean air quality index of 100 (470 μg/m^3; there is no corresponding Chilean standard). These concentrations were 681 μg/m^3 at station A, 540 μg/m^3 at station B, and 562 μg/m^3 at station C (SESMA 1996b).

In 1992 the highest 24-hour NMHC concentration in the SMA was 4.8 μg/m^3 near the downtown area. In the northeastern zone the highest 24-hour concentration was 1.9 μg/m^3 (Ulriksen, Fernández, and Muñoz 1994).

In 1993 monthly ambient lead concentrations in the SMA varied from 0.4 μg/m^3 in December to 2.1 μg/m^3 in June. Lead concentrations were above 1.5 μg/m^3 between April and July. The highest quarterly average was for the April-June period (1.8 μg/m^3), which exceeded the USEPA standard of 1.5 μg/m^3 (there is no ambient air quality standard for lead in Chile). Lead concentrations in blood among 12-month old children were measured at levels ranging from 5.3 μg/dl to 8.5 μg/dl (Ruiz 1996).

Sources of Pollutants

Most anthropogenic air emissions in the SMA are generated by combustion of gasoline, diesel fuel, kerosene, fuel oil (no. 5 and 6), LPG, city gas, coal, and wood. Incineration of solid waste, distribution of hydrocarbons, and road dust also produce emissions. In recent years consumption of wood and coal has fallen because of restrictions imposed on its use in residential boilers and large fixed combustion sources. Consumption of gasoline, diesel fuel, kerosene, fuel oil, and LPG has risen as a result of population growth, the growing vehicular fleet, and increased industrial activity.

Estimates of air pollutant emissions in the SMA for 1992 are shown in Figure 4.10. Among these pollutants, CO emissions (291,000 tons a year) are notable. Motor vehicles are the main contributors of CO (94 percent), HC (83 percent), and NO_x (85 percent) emissions (World Bank 1994). Gasoline-fueled vehicles are responsible for 98 percent of the CO emissions, 92 percent of the HC emissions, and 66 percent of the NO_x emissions from vehicular sources (Escudero and Cofré 1993). Among these pollutants, NO_x and HC emissions contribute to ozone formation.

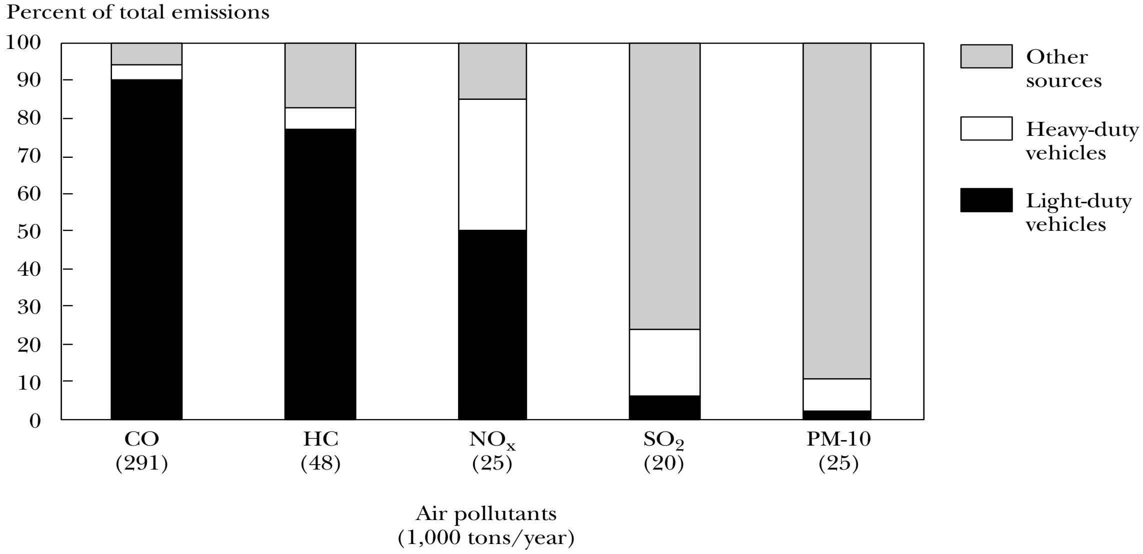
About half of the TSP in the SMA is of natural origin. This percentage is similar to that in other urban centers where the climate is semi-arid (for example, 35 to 45 percent in Los Angeles, California and 54 percent in Tuscon, Arizona).

PM-10 emissions originate from road dust (68 percent), point sources (15 percent), mobile sources (11 percent), and wood burning (6 percent; World Bank 1994). However, the biggest contributors to PM-10 concentrations in ambient air are motor vehicles and road dust (Katz 1996).[13] Among the motor vehicle types, diesel-fueled vehicles emit most of the PM-10; the contribution of gasoline-fueled vehicles is significantly smaller. PM-10 from these sources, which is more toxic than natural dust, can remain suspended in air for longer periods of time because of their smaller sizes, especially when unfavorable atmospheric conditions prevent their dispersion.

SO_2 emissions result from the combustion processes at point sources (75 percent), mobile sources (24 percent), and other sources (1 percent; World Bank 1994). The high sulfur content in coal and no. 5 and 6 fuel oils, as well as

13. In 1992 unpaved roads, mostly located in the less developed sections of the SMA, accounted for about 1,000 km of the SMA's road network or about 20 percent of the road network (Ulriksen, Fernández, and Muñoz 1994).

Figure 4.10 Share of pollutant emissions from motor vehicles and other sources in the SMA, 1992



Note: Other sources include point sources (industries, boilers, bakeries), road dust, and residential wood burning.
Source: World Bank 1994.

industries processing sulfurous minerals, largely contribute to the SO_2 emissions from point sources. Among mobile sources, SO_2 emissions originate mostly from diesel-fueled vehicles (especially buses and trucks).

The vehicle fleet in the SMA has grown at a much faster rate than the population. Between 1977 and 1991 the number of light-duty vehicles increased by 95 percent (from 208,000 to 405,000), while the population grew only 29 percent (from 3.5 million to 4.5 million people; Escudero and Cofré 1993). In 1992 the SMA's road-based vehicle fleet consisted of about 525,000 light-duty vehicles, 30,000 trucks, and 15,000 buses (of which 8,500 were urban buses and 4,500 were minibuses). The light-duty vehicles included 400,000 private cars, 25,000 taxis, and 100,000 vans, pickup trucks, and jeeps (Ulriksen, Fernández, and Muñoz 1994). In 1995 the fleet exceeded 700,000 vehicles, about 230,000 of which were equipped with three-way catalytic converters (Ruiz 1996; Santana 1995). Although the number of buses and minibuses has been falling since 1990, the total vehicle fleet has been growing by 10 percent a year and is expected to reach about 1 million by 2000 (Hall, Zegras, and Rojas 1994).

Buses are the most important mode of public transport in the SMA. Urban buses are owned and operated by the private sector on about 350 routes, most of which run from one end of the city to the other. Among the 9,500 registered buses and minibuses in 1995, 26 percent were model-years 1994–95, 42 percent were model-years 1990–93, and 32 percent were model-years 1989 and older. In 1995 taxis represented only 5 percent of the light-duty vehicles circulating in the SMA but registered 30 percent of the total distance traveled by light-duty vehicles (Ruiz 1996).

The metro system, owned and operated by Metro S.A. (a state company), consists of two lines with a total length of 27 kilometers and with thirty-seven stops. Line 1 runs east-west and Line 2 runs north-south. Construction of a third line, which is 5 kilometers long and runs from the city center to a middle-class neighborhood (La Florida) in the southeastern section, is near completion. About 79 percent of metro users are middle class. About 63 percent of station entries and 80 percent of station egresses are pedestrian trips (Hall, Zegras, and Rojas 1994). There is also commuter train run by National Railway to the southern suburbs. The privately owned

trolleybus company, which used to operate two lines in the downtown area, went bankrupt because of competition from bus companies.

Between 1977 and 1991 daily trips by motor vehicles increased 233 percent (from 3.6 million to 8.4 million). During the same period the share of transport accounted for by private cars increased 60 percent, while the share accounted for by buses and minibuses decreased 28 percent (Escudero and Cofré 1993). Of the 8.4 million daily trips in 1991, 48 percent were made by bus, 16 percent by car, 20 percent by foot, 4 percent by metro, and 13 percent by a combination of these and other modes (Hall, Zegras, and Rojas 1994). Given the trend toward increased private car use and the rising numbers of daily trips (estimated to rise to 9.9 million by 2001), congestion and traffic-related air pollution are expected to worsen if appropriate measures are not taken.

Institutional Responsibilities

Chile has a long history of air pollution control efforts. Legislation in this area dates back to 1916, when Law 3,133 was introduced to control emissions from industries. Subsequent legislative efforts can be grouped into four periods: 1916–60, 1961–77, 1978–89, and 1990–the present (Box 4.1).

The legal and institutional framework governing environmental protection efforts in Chile is highly centralized. The central government is responsible for most environmental matters and, through national and regional environment commissions, assigns functions to sectoral ministries and regional sectoral agencies. Institutional responsibilities for various air pollution control activities in the SMA are shown in Table 4.19.

National institutions. The National Environment Commission (CONAMA) is responsible for studying, analyzing, and evaluating matters related to environmental protection and natural resource management in Chile. It was created in 1990 by Decree 240 (superseded in 1991 by Decree 544) to facilitate, coordinate, communicate, and strengthen public sector environmental efforts both across sectors and at the regional and provincial, and local levels. The Basic Law of the Environment, enacted on March 9, 1994, makes CONAMA responsible for proposing the government's environmental policies, monitoring compliance and implementation of environmental legislation, maintaining a public information system for each region on environmental matters, administering the environmental impact assessment system at the national level, co-

Box 4.1 Air pollution control efforts in Chile, 1916–present

1916–60
- Qualitative and simple legislation
- Regulation by decree for fixed sources
- Authority centralized at the Ministry of Health
- Public health objectives

1961–77
- Specific regulations with objectives to control air pollution
- Regulation by decree for fixed and mobile sources, with more emphasis on fixed sources
- Authority centralized at the Ministry of Health
- First measurement of pollutants

1978–89
- Regulation by resolution started
- Primary standards for environmental quality established
- Air pollution concerns popularized
- Environmental monitoring stations installed
- Emission inventories developed
- Emission standards established for fixed and mobile sources
- Authority and control established by sectoral agencies other than the Ministry of Health
- Coordinated efforts started

1990–present
- Coordinated efforts in politics and public involvement
- Central control of emissions from mobile sources
- Legal framework oriented by executive actions
- Use of market instruments to regulate air pollution
- Emission standards and monitoring gaining high level of sophistication
- Sectoral agencies involved in norm making and control
- Ministry of Health losing importance in air pollution control

Source: Katz 1993.

Table 4.19 Institutional responsibilities for air pollution control in the SMA

Public institution/Department	*Area of responsibility*
Metropolitan Region's Environmental Health Service	Declaring pollution episodes and pre-emergency and emergency measures
Metropolitan Region's Environmental Health Service/ MACAM network	Monitoring ambient air and meteorological conditions
Metropolitan Region's Environmental Health Service/ PROCEFF[a]	Developing regulations and enforcing fixed source emissions
Ministry of Transportation and Communications/ Enforcement Department	Enforcing mobile source emissions
Ministry of Transportation and Communications/ Regional Ministerial Secretary	Developing regulations for mobile sources, emergency and pre-emergency measures
Ministry of Agriculture/CONAF[b]	Controlling agricultural waste burning, urban and suburban forestation
Metropolitan Intendancy	Street cleaning
Police/Ecological Brigade	Enforcement support to PROCEFF
Meteorological Department of Chile	Generating meteorological data
Ministry of Housing and Urban Development	Street paving, land use control, and urban park creation
National Energy Commission	Improving fuels and energy efficiency
Ministry of Education	Environmental education and information
Ministry of Public Works	Infrastructure development
CONOMA-RM[c]	Evaluating extent of pollution, deciding pollution episodes, proposing pollution control plans and policies

a. PROCEFF is the Program to Control Fixed Source Emissions.
b. CONAF is the National Forestry Corporation.
c. CONAMA-RM is the National Environment Commission's office for the Metropolitan Region.
Source: Santana 1996; Katz 1996.

ordinating the development of environmental quality standards, and developing programs to meet these standards. CONAMA also helps prepare, approve, and develop environmental education and awareness programs, coordinate international assistance on environmental projects, and finance projects and activities aimed at environmental protection.

The commission has its own legal standing, budget, and resources, and falls under the authority of the ministry secretary general of the presidency. The various organs of CONAMA include a managing council of ministers, an executive office, an advisory council, and the regional environmental committees. In each of Chile's thirteen regions, including the Metropolitan Region, CONAMA is represented by a regional office.

CONAMA is controlled by a managing council that consists of the minister of the general secretary of the president (who also acts as the president of CONAMA) and the ministers of foreign relations, defense, economic development and reconstruction, planning and cooperation, education, public works, health, housing and urban development, agriculture, mining, transport and telecommunications, and national assets. The managing council implements CONAMA's actions, ensures coordination among ministries and public offices on environmental matters, oversees execution of the agreements and policies established by CONAMA, proposes environmental legislation to the president of Chile, and promotes environmental enforcement and control activities. The executive office coordinates CONAMA's work program. With the managing council's approval CONAMA's executive director can create and preside over operating committees and subcommittees comprising representatives from ministries and other institutions to study, advise, analyze, communicate, and coordinate specific environmental issues. CONAMA's advisory council, headed by the minister of the general secretary of the president, con-

sists of two scientists from Chilean universities, two representatives from NGOs, two representatives from academic centers, two representatives from the business community, two representatives from labor unions, and one representative of the president of Chile. Members of the advisory council are nominated by the president of Chile for a period of two years. The advisory council is responsible for evaluating the opinions formulated by the managing council. It provides views on draft laws and decrees that establish environmental quality standards, environmental protection, pollution prevention and control plans, and emission regulations. Each of the Chile's thirteen regions, including the Metropolitan Region, maintains a CONAMA office.

CONAMA is playing a catalytic role in defining Chile's environmental policies and in providing support services (such as environmental data collection and analysis and environmental impact assessment training) to the rest of the public sector. CONAMA's strategy involves strengthening key institutional functions and units in the line ministries rather than duplicating or replacing their functions. CONAMA has recently prepared regulations on environmental impact assessment procedures. In the near future CONAMA plans to prepare regulations on air, water, and soil pollution and on environmental liability.

The Ministry of Transport and Communications is responsible for transport operations; the Ministry of Public Works, for the construction and maintenance of interurban facilities, and the Ministry of Housing and Urban Development, for most large urban transport facility construction. The Commission for Transport Infrastructure Investment Planning, which includes representatives from these and other ministries, is responsible for strategic transport investment decisions at the national level. The commission is presided over by the minister of transport and communications. Decisions made by this commission are largely based on technical advice from an executive secretary (Hall, Zegras, and Rojas 1994).

Regional institutions. The environmental management structure in the Metropolitan Region is very similar to that at the national level and consists of CONAMA's regional office (CONAMA-RM), a regional environmental commission (COREMA), and a regional consultative council. CONAMA's regional office, which assumed the responsibilities of the Special Commission for Decontamination of the Metropolitan Region (CEDRM) in 1995, provides inputs for the environmental component of the regional development plan, evaluates environmental impact assessments, and coordinates environmental activities in the region. The office is headed by a regional director appointed by CONAMA's executive director and includes air quality, solid waste, environmental impact assessment, and natural resources units employing a total of twenty-seven people, twenty of which are professionals. The air quality unit is staffed by seven professionals.

The regional environmental commission is a decisionmaking body for work prepared by CONAMA's regional office. The commission coordinates health and transport services, reviews pollution control plans prepared by CONAMA's regional office, and has the authority to approve or reject environmental impact assessment studies in the region. It is presided over by the regional intendant. Commission members include a regional director, regional secretarial ministries, four regional counselors, and CONAMA's regional director, who acts as the executive secretary. The regional environmental commission also has a technical advisory committee, headed up by CONAMA's regional director. Members of the technical committee for each project are selected by the regional environmental commission from public services with environmental attributes.

The environmental consultative council, established by the Basic Law in each regional environmental commission, consists of two scientists, two representatives from NGOs, two representatives from the business community, two representatives from the labor force, and one representative of the regional intendant. All council members are nominated by the regional intendant for a period of two years. The council is responsible for evaluating the opinions formulated by the regional environmental committee and CONAMA's regional office.

Local institutions. At the local level, each of the thirty-four comunas within the SMA has its own government, headed by a mayor, and its own departments. Each comuna funds its own local road construction, maintenance, and public transport facilities (such as bus stops), and has direct control over local land uses (Hall, Zegras, and Rojas 1994).

Measures Implemented

The first regulatory measure for controlling vehicular emissions in Chile took effect in 1978, when Resolution 1,215 assigned the responsibility for enforcing vehicular emission controls to the Ministry of Health. In 1983 this responsibility was transferred to the Ministry of Transport and Communications, but until 1989 the ministry was unable to enforce most regulations because of pressure from the bus owners' association and car owners (Katz 1991). When the democratic government took office in 1990 there was a good information base about emissions from urban buses as a result of studies conducted by the regional intendants and the National Energy Commission. However, the Ministry of Transport and Communications lacked data vehicle registrations in the SMA, so it had to compile this information before it could start enforcing the regulations (Escudero and Cofré 1993).

In 1990 the Special Commission for Decontamination of the Metropolitan Region prepared a master plan to ensure long-term compliance with air quality standards in the SMA. The plan consisted of a monitoring plan to maintain, replace, and expand the air quality monitoring stations, an epidemiological program to evaluate effects of air pollution on human health, a program to treat people affected by acute respiratory problems, a program to strengthen control and enforcement of air emissions, and specific plans to reduce emissions from such sources as buses, cars, industries, residences, and natural dust.

The Basic Law of the Environment forms the legal basis for declaring a zone in Chile as *saturated* if the ambient concentration of any air pollutant exceeds the air quality standard or *latent* if the pollutant concentration is between 80 and 100 percent of the standard. Decree 131 of June 12, 1996, declared the Metropolitan Region as a saturated zone for ozone (for exceeding the 1-hour standard), PM-10 (for exceeding the 24-hour standard), TSP (for exceeding the 24-hour standard), and CO (for exceeding the 8-hour standard).[14] The decree also declared the Metropolitan Region as a latent zone for NO_2. According to the requirements of Regulation 94 of 1995, a pollution control plan for the Metropolitan Region should be prepared by April 1997. This involves preparation of a draft plan by CONAMA (although, in practice, this plan is prepared by CONAMA's regional office with some support from CONAMA) within 120 days of the declaration of the area as a saturated or latent zone. This plan should include scientific and technical data as well as economic and social impacts of proposed measures. The draft should then be presented to the public and consultative councils for review and comments during a 60-day period, and then finalized within 45 days for presentation to the president of Chile. Some of the anticipated measures of this plan include enforcement of fuel quality requirements, renewal of bids for bus services, implementation of projects for alternative transport modes (such as suburban train and bicycling), curtailing use of private cars (for example, by constructing toll roads), road paving, transport tariffing, and construction of new population centers and siting of new colleges to reduce trips to the downtown area. Additional emission standards for industrial sources and improved standards and procedures for in-use vehicles are also being considered.

Vehicle emission standards. Emission standards for new vehicles developed by the Ministry of Transportation and Telecommunications limit pollutant emissions from light- and medium-duty vehicles, urban buses operating in Santiago, and other heavy-duty vehicles (Table 4.20). These regulations restrict CO, HC, and NO_x emissions in the exhaust for all vehicle types and evaporative HC emissions for gasoline-fueled vehicle. In addition, these regulations limit PM emissions in the exhaust for all diesel-fueled vehicles.

- Emission standards for new light-duty vehicles were specified by Decree 211 of 1991. These standards—which became effective on September 1, 1992—are based on USEPA's 1987 vehicle emission standards.
- Emission standards for new medium-duty vehicles were specified by Decree 54 of 1994. These standards—which became effective on September 1, 1995—are based on USEPA's 1987 vehicle emission standards.
- Emission standards for new urban buses operating in Santiago were specified in 1993 by Decree 82. These standards have

14. The decree was published in *Diario Oficial* dated August 1, 1996.

two compliance schedules for diesel-fueled buses (September 1, 1993 and September 1, 1996) and one compliance schedule for gasoline-fueled buses (September 1, 1993). The 1993 limits are based on USEPA's 1991 (or European EURO1) standards and the 1996 limits are based on USEPA's 1994 (or European EURO2) standards.

- Emission standards for the remaining types of heavy-duty vehicles (for example, trucks and rural and intercity buses) were specified by Decree 55 of 1994. These standards have two compliance dates: September 1, 1994 limits based on USEPA's 1991 (or EURO1) standards and September 1, 1998 limits based on USEPA's 1994 (or EURO2) standards.

Emission standards for in-use vehicles have been established according to the effective dates shown in Table 4.20.

- In-use vehicles registered before these dates must comply with the Ministry of Transportation and Telecommunications' Decree 4 of 1994 (Table 4.21). Vehicles with spark-ignition engines must comply with CO and HC exhaust emission limits that vary based on vehicle age. Vehicles with diesel engines must comply with the limits for smoke emissions.
- Emission standards for in-use vehicles registered after these dates were established by Decree 211 of 1991 for light-duty vehicles, Decree 54 of 1994 for medium-duty

Table 4.20 Exhaust emission standards for new vehicles in Chile

Type of vehicle	*Effective date (registration)*	*Unit*	*Pollutant*			
			CO	*HC*	*NO_x*	*PM*
Light-duty vehicles						
Passenger vehicles	9/1/92[a]	g/km	2.11	0.25[b]	0.62	0.125[c]
Commercial freight vehicles	9/1/92[a]	g/km	6.21	0.50[b]	1.43	0.16[c]
Medium-duty vehicles						
Type 1	9/1/95	g/km	6.21	0.50[b]	1.43	0.16[c]
Type 2	9/1/95	g/km	6.21	0.50[b]	1.43	0.31[c]
Urban buses operating in Santiago						
Diesel-fueled buses[d]	9/1/93	g/kWh	4.5	1.1	8.0	0.36
Diesel-fueled buses[e]	9/1/96	g/kWh	4.0	1.1	7.0	0.15
Gasoline-fueled buses	9/1/93	g/bhp-h	37.1	1.9[f]	5.0	
Heavy-duty vehicles[g]						
Diesel-fueled vehicles[d]	9/1/94	g/kWh	4.5	1.1	8.0	0.36
Diesel-fueled vehicles[e]	9/1/98	g/kWh	4.0	1.1	7.0	0.15
Gasoline-fueled vehicles	9/1/94	g/bhp-h	37.1	1.9[f]	5.0	

Note: A blank space indicates that no standard was established. Light-duty vehicles are those with a gross weight (includes weight of the vehicle with its fuel, passengers, and freight) below 2,700 kg. Medium-duty vehicles (such as vans) are those with a gross weight between 2,700 kg and 3,860 kg. Type 1 vehicles are those with a net weight (includes weight of the vehicle with its fuel but excludes weight of passengers or freight) below 1,700 kg. Type 2 vehicles are those with a net weight above 1,700 kg. Heavy-duty vehicles and urban buses are those with a gross weight above 3,860 kg. Exhaust emissions are to be tested using USEPA's Method FTP-75 for light- and medium-duty vehicles, EEC's 13-mode test for diesel-fueled urban buses and heavy-duty vehicles, and transient acceleration test for gasoline-fueled urban buses and heavy-duty vehicles.

a. For the Metropolitan Region, and Regions V and VI. The effective date for other regions is September 1, 1994.

b. Evaporative emissions from gasoline-fueled vehicles are not to exceed 2.0 g/test according to the SHED Method. No crankcase emissions are allowed.

c. Applies only to diesel-fueled vehicles.

d. Diesel engines meeting the USEPA standard of 15.5 g/bhp-h for CO, 1.3 g/bhp-h for HC, 5.0 g/bhp-h for NO_x, and 0.25 g/bhp for PM are considered compliant with the Chilean standard.

e. Diesel engines meeting the USEPA standard of 15.5 g/bhp-h for CO, 1.3 g/bhp-h for HC, 5.0 g/bhp-h for NO_x, and 0.10 g/bhp for PM are considered compliant with the Chilean standard.

f. Evaporative emissions from gasoline-fueled vehicles are not to exceed 4.0 g/test according to the SHED Method. No crankcase emissions are allowed.

g. Excludes urban buses. Standards apply to heavy-duty vehicles operating in the Metropolitan Region (Region XIII) and Regions IV, V, VI, VII, VIII, IX, and the continental part of Region X.

Source: CONAMA-RM 1995.

Table 4.21 Exhaust emission standards for in-use vehicles registered before the effective dates in Chile

			Smoke[d]				
				Opacity under load (%)[e] Exhaust pipe diameter			Opacity at free acceleration (%)[e,f,g]
Type of vehicle	*CO*[a,b] *(%)*	*HC*[b,c] *(ppm)*	*Smoke index*	*3″*	*3 1/2″*	*4″ or more*	
Vehicles with spark-ignition engines							
Vehicle age							
6 years and less	3.0	300					
7 to 12 years	3.5	500					
13 years or older	4.5	800					
Diesel-fueled vehicles							
Engine power (hp)							
10 to 50			5.6				
51 to 100			5.3				
101 to 150			5.0				
151 to 200			4.6				
201 or greater			4.2				
Engine power (hp)							
80 to 120[h]				8	9	10	
121 to 165[i]					9	10	
166 or greater[j]					9	10	
Urban buses							18
Rural and intercity buses and trucks							25

Note: A blank space indicates that no standard was established. Effective dates are given in Table 4.20, except for opacity limits which became effective on January 1, 1995.
a. For two- and four-cycle engines.
b. These standards are to be met at idle/2,500 rpm.
c. For four-cycle engines.
d. Smoke emissions must meet either the smoke index or opacity requirement unless indicated otherwise.
e. Public service buses operating within the SMA as well as in the provinces of Cordillera and Maipú must meet the opacity requirements under load and at free acceleration. Since most long-distance routes start and end in Santiago, these standards cover most of the urban and long-distance buses in Chile.
f. Diesel-fueled trucks operating in the province of Santiago must meet the opacity measurement at free acceleration.
g. These limits are for naturally-aspirated engines. For turbocharged engines these limits are 50 percent higher.
h. Power applied to dynamometer during testing: 45 hp.
i. Power applied to dynamometer during testing: 60 hp.
j. Power applied to dynamometer during testing: 80 hp.
Source: CONAMA-RM 1995.

vehicles, Decree 82 of 1993 for urban buses, and Decree 55 of 1994 for other heavy-duty vehicles. These standards limit HC and CO emissions in the exhaust for all vehicles with spark-ignition engines and smoke emissions for all diesel-fueled vehicles (Table 4.22).

Vehicle inspection programs. Ministry of Transportation and Communications' Enforcement Department was created in 1993 to enforce vehicle emission standards. Staffed with thirty-five inspectors and six professionals—eight in environmental control units—the department is responsible for the following activities:

- Certification of catalytic converter-equipped new vehicles at a high-technology center in Maipú. This center, constructed at a cost of $2.6 million, includes a laboratory equipped with instruments capable of conducting standard exhaust and evaporative emission tests to follow USEPA methods. This center will be in operation in 1997.
- Periodic inspection of exhaust emissions from in-use vehicles is mandatory and is used to renew vehicle permits. Vehicle inspection stations are owned and operated by private concessionaires and supervised

Table 4.22 Exhaust emission standards for in-use vehicles registered after the effective dates in Chile

Type of vehicle	*CO*[a] *(%)*	*HC*[a] *(ppm)*	*Smoke* *Smoke index*	*Opacity at idle/2,500 rpm (%)*	*Opacity under load (%)*	*Opacity at free acceleration (%)*
Light-duty vehicles						
Gasoline-fueled vehicles	0.5[b]	100				
Diesel-fueled vehicles				0		
Medium-duty vehicles						
Gasoline-fueled vehicles	0.5	100				
Diesel-fueled vehicles[c]			3.5		6	15
Urban buses operating in Santiago						
Gasoline-fueled buses	0.5	100				
Diesel-fueled buses[c]			3.5		6	15
Heavy-duty vehicles[d]						
Gasoline-fueled vehicles	0.5	100				
Diesel-fueled vehicles[c]			3.5		6	15

Note: A blank space indicates that no standard was established. Vehicle classes and effective dates are defined in Table 4.20.
a. The limits are to be met at idle/2,500 rpm.
b. The minimum limit for CO + CO_2 is 6 percent.
c. Smoke emissions must meet either the smoke index or opacity requirement.
d. Excludes urban buses.
Source: CONAMA-RM 1995.

by the Enforcement Department. There are two inspection stations for buses, three for taxis and trucks, and twenty for private cars. Exhaust emissions of private cars and trucks are checked once a year, and taxis and buses twice a year. Because the accuracy of the test results obtained at the inspection stations has been challenged, the concession system for these stations is being reformulated and inspections are being automated to reduce human interference in test results.

- Roadside inspections of buses and cars circulating in the SMA. These inspections are conducted by eight different teams of inspectors equipped with opacimeters and gas analyzers and with the support of traffic police. The department is evaluating measures to raise the operational efficiency of the teams without necessarily increasing the number of inspectors.

Since 1994 the Enforcement Department has also been involved in a systematic public awareness campaign to curtail air pollution from vehicular sources.

Fuel-targeted measures. Two gasoline grades are sold in Chile: leaded gasoline (at RON of 93) and unleaded gasoline (at RON of 93, 95, and 97). Unleaded gasoline was introduced in January 1992 to meet the emission standards for new light-duty vehicles sold in the Metropolitan Region (as well as Regions V and VI) effective September 1992. Although the regulation did not specify the type of technology, the standards can only be met through use of three-way catalytic converters in vehicles with spark-ignition engines, which requires unleaded gasoline. Cars equipped with three-way catalytic converters are provided with a green label that exempt them from the circulation ban in the SMA on weekdays. Also measures are taken to avoid contamination of unleaded gasoline with lead during storage, transportation, and distribution. A different nozzle size is required on leaded and unleaded gasoline pumps to avoid misfueling. In addition a public awareness campaign about unleaded gasoline was initiated.

Since its introduction in January 1992, the share of unleaded gasoline in domestic gasoline consumption grew from 17 percent in July 1994 to 40 percent in June 1996 and is expected to

reach 65 percent by 2000. These percentages are even higher in the SMA. Leaded gasoline is projected to be completely eliminated in Chile by 2006 (Ruiz 1996).

The National Standards Institute has specified gasoline quality standards (Norm 64 of 1995) for summer and winter use (Table 4.23), and diesel fuel quality standards (Norm 62 of 1995) for the Metropolitan Region and the rest of the country. The maximum sulfur content of diesel fuel is limited to 0.3 percent by weight for the Metropolitan Region and 0.5 percent by weight for the rest of the country. In May 1998 these sulfur limits are to be lowered to 0.2 percent and 0.3 percent, respectively. For the entire country the cetane number of diesel fuel is limited to a minimum of 45 and density of diesel fuel is required to range between 830 kg/m^3 and 870 kg/m^3 (Ruiz 1996).

The government of Chile has a free policy for pricing, importing, and refining motor vehicle fuels but maintains its regulatory function. The Petrox Concepción and Petroleo Concón refineries, owned by the national petroleum company ENAP, are the only local producers of gasoline and diesel fuel sold in the SMA. At these refineries unleaded gasoline is produced without the addition of oxygenates. ENAP's projected refinery investments for the total elimination of lead from gasoline are presented in Table 4.24.

The price of motor vehicle fuels is set by the market. The price difference between unleaded and leaded gasoline was about 1.8 percent in September 1992. Since September 1994, however, both gasoline grades (at 93 RON) in the SMA have been sold at the same price (Ruiz 1996).

Table 4.23 Gasoline quality standards in Chile

Fuel parameter	*Summer*	*Winter*
Reid vapor pressure (maximum psi)	10.0	12.5
Lead (maximum g/liter)		
Leaded gasoline	0.6	0.6
Unleaded gasoline	0.013	0.013
Sulfur (maximum percent by weight)		
Leaded gasoline	0.15	0.15
Unleaded gasoline	0.10	0.10
Benzene (maximum percent by volume)	5.0	5.0

Note: The norm also specifies other parameters not included in this table.
Source: Ruiz 1996.

Transport management. To curtail emissions from vehicular sources, "normal" restriction measures are implemented between March and December regardless of air pollution levels. Accordingly, on weekdays 20 percent of cars not equipped with catalytic converters and 20 percent of buses that operate on auctioned routes and that do not comply with the Ministry of Transportation and Communications' Decree 82 of 1993 are banned from circulation based on the last digit of the vehicle's license plate number. On weekends the restriction applies to 50 percent of urban buses based on the same criteria.

In addition, Decree 32 of 1990 establishes pre-emergency and emergency measures to control air pollution from mobile and fixed sources in the SMA. These measures are implemented when the air quality index exceeds 300 (or ambient PM-10 concentrations exceed 240 $\mu g/m^3$) and 500 (or 330 $\mu g/m^3$), respectively, at any of the MACAM monitoring stations. Under pre-emergency situations the circulation of an additional 20 percent of cars and buses beyond the normal restriction is prohibited within the Américo Vespucio beltway. In addition, the most polluting 20 percent of fixed source PM-10 emitters are shut down, and combustion of coal and wood is restricted. In emergency situations the additional 20 percent restriction on car and urban bus circulation is extended to the entire SMA. In addition, the most polluting 50 percent of fixed source PM-10 emitters are shut down and combustion of coal and wood is prohibited.[15] The pre-emergency and emergency measures are announced and implemented based on evaluation of ambient monitoring data and meteorological forecasts. This involves a coordi-

15. The shutdown is applied only to industries and institutions that violate emission standards. It is based on cumulative emissions calculated starting with the highest emitter (in terms of pollutant concentration) and multiplying this concentration by the respective pollutant emission flow. Once the cumulative emissions reach 20 percent under pre-emergency situations or 50 percent under emergency situations, the process is stopped. The list of industries and institutions in violation of PM-10 standards is prepared by the Metropolitan Environmental Health Services in March of each year and updated every two months according to new information received.

Table 4.24 Projected refinery investments required to eliminate lead from gasoline

Company/refinery operation	*Year*	*Capacity (barrels per day)*	*Investment ($ million)*
Petroleo Concón Refinery			
Semiregenerative reforming	1996	10,000	33.7
Semiregenerative reforming (expansion)	1997	2,000	7.1
Isomerization	1997	5,000	14.1
DIPE production	1998	60,000[a]	21.8
Continuous reforming (conversion)	1999	1,800	20.4
MTBE production	2001	30,000[a]	11.6
Alkylation with hydrofluoric acid	2005	3,000	31.8
Petrox Concepción Refinery			
Semiregenerative reforming	1998	14,000	45.6
Isomerization	1998	5,000	13.1
Continuous reforming (conversion)	2000	2,100	20.4
MTBE production	2001	30,000[a]	11.6
Alkylation with hydrofluoric acid	2005	3,000	29.6

a. Tons per year.
Source: Ruiz 1996.

nated effort among CONAMA's regional office and the various enforcement agencies, which include SESMA's Program to Control Fixed Source Emissions, the Ministry of Transportation and Communications, the Ministry of Agriculture's National Forestry Corporation, and the Ecological Brigade.

Two additional transport management measures have been implemented to reduce congestion and air emissions from buses circulating in Santiago. First, buses operating in downtown Santiago were restricted to be less than 18 years old. Under a bus retirement program initiated in 1991, the Ministry of Transportation and Communications purchased urban buses 18 years or older. The second measure involved implementation of a bus route auctioning program. This program allowed the Ministry of Transportation and Communications to grant operation rights to formal bus companies that fulfilled certain conditions, including compliance with the Chilean environmental regulations. Bids from the bus companies had to specify the fare, average capacity of the fleet (passenger to bus ratio), average age of the fleet, appropriate number of vehicles needed for the required frequency, and availability of a money collector separate from the driver. In 1994 the bus route auctioning program was expanded to areas beyond the original business district.

In June 1994 empty taxis were prohibited from passing through any of the twelve access points to the forty-block area of the central business district between 10 A.M. and 8 P.M. All parking, loading, and unloading activities in this area were also prohibited during this period.

Other transport management measures introduced in the early 1990s included the creation of a registry for road-based public transport vehicles, establishment of new bus stops and bus lanes, computerization of traffic lights, optimization of the metro system, initiation of metro-train and metro-bus services to Rancangua and rural zones to the north, south, and west of Santiago, and promotion of bicycle use through a pilot plan that constructed bicycle routes in Estación Central. The municipality of Santiago also acquired new parking meters, improved taxi parking areas, and established loading and unloading periods for trash collection in the city center.

In 1987 the metro company (Metro S.A.) entered into agreements with a limited number of bus companies (operating blue buses) to provide intermodal transfers.[16] Since then the metro company has been selling a metro-bus pass for a reduced rate and sharing the revenues with the

16. The metro company is prohibited from operating nonelectric vehicles.

involved bus companies. The lack of fare integration with the vast majority of bus companies (operating yellow buses) creates one of the current problems of the public transport system. The metro company also provides a transfer service with the commuter train.

In 1991 the Ministry of Housing and Urban Development initiated efforts to control urban growth patterns through the Intercommunal Plan for Santiago. This plan established the urban growth boundary for the SMA and set the stage for growth through densification, setting aside certain areas for parks and green spaces (Hall, Zegras, and Rojas 1994).

Air quality monitoring. Ambient air quality in the SMA is monitored through an automatic network and a separate set of semiautomatic stations. In addition, two mobile monitoring stations donated by the government of the Netherlands are used for research. The mobile stations are capable of monitoring SO_2, NO_2, ozone, benzene, toluene, and formaldehydes. SESMA is responsible for operating and maintaining the air quality monitoring system in the SMA, as well as for processing the monitoring data.

Ambient air quality monitoring in the SMA was initiated in 1967 through a joint effort between the National Health Service and Pan-American Health Organization. Two stations located in the downtown commercial area measured SO_2, TSP, settleable PM, and index of corrosion. The first comprehensive ambient air monitoring effort came in 1976, when the U.S. Agency for International Development (USAID) helped install a network that consisted of one automatic station at the city center and ten semiautomatic stations located around the center. The pollutants monitored by these stations included SO_2, CO, NO, NO_2, HC, ozone, TSP, and settleable PM.[17] Most of this equipment is now nonoperational, and only six of these stations are used to support the automatic monitoring network. Every three days samples were collected during a 24-hour period and analyzed in SESMA's laboratories.

As part of a loan financed by the Inter-American Development Bank an air emissions inventory and dispersion model (which included simulation of ozone formation) were developed for Santiago, and an automatic air monitoring system, called the MACAM network, was installed in 1987. This system consists of five monitoring stations (A, B, C, D, and M) and one meteorological station. Station A is located at the city center, stations B, C, and D are located around the downtown area; and station M is located at the northeastern edge of the SMA, where the polluted air from the urban area is discharged in the evenings. All MACAM network stations monitor ambient concentrations of CO, SO_2, NO, NO_2, ozone, HC, PM-10, and PM-2.5. Among the five stations, only station M monitors ambient concentrations of methane. All MACAM stations (except station M) also collect meteorological data (wind direction and speed, temperature, and humidity).

In 1991 CEDRM organized an air monitoring campaign under an agreement with Sweden's Economic Cooperation Agency to validate the results obtained by the air monitoring network and to assess air quality management needs. The results from this effort indicated weaknesses in the monitoring network, especially with respect to the accuracy of air quality data. In addition, the meteorological stations were deemed to be insufficient to develop the necessary information to clearly understand the phenomena for atmospheric pollution in the SMA. These findings led to the formulation of the Swedish Meteorological and Hydrological Institute's technical assistance project for CONAMA's regional office.

This project, which has been under way since 1994, has improved the quality of data generated by meteorological and ambient air monitoring stations. Continuous monitors for PM-10 and PM-2.5, which allow real-time measurements using the tapered element oscillating microbalance (TEOM) technique, were acquired. An optic measurement system using the differential optical absorption spectroscopy (DOAS) technique was installed to determine hourly average concentrations of gaseous pollutants (SO_2, NO_2, ozone, benzene, toluene, formaldehyde) in ambient air at 200- to 1,000-meter segments. In addition, air monitoring equipment (passive tubes) was installed at twenty-five sites to collect pollutant samples (such as ammonia, SO_2, NO_2,

17. The monitoring results indicated serious CO problem in the downtown area and serious TSP pollution in the entire metropolitan area. NO_2 and SO_2 levels were found to be below the permissible limits.

Table 4.25 Air quality indices and pollutant concentrations

	Pollutant (time-weighted average)				
Index	*CO (8-hour) (ppm)*	*NO_2 (1-hour) (μg/m^3)*	*O_3 (1-hour) (μg/m^3)*	*SO_2 (24-hour) (μg/m^3)*	*PM-10 (24-hour) (μg/m^3)*
100	9	470	160	365	150
200	19	1,290	470	929	195
300	30	2,110	780	1,493	240
400	40	2,930	1,090	2,056	285
500	50	3,750	1,400	2,620	330

Source: Ministry of Health Resolution 369 of December 4, 1988.

benzene, toluene, xylene, and ozone), which are subsequently analyzed in a laboratory.[18] In addition, the MACAM monitoring stations were connected to a central computer at SESMA to provide hourly air quality data by telephone or cellular phone. The air quality data have been also provided to CONAMA's regional office.

The Swedish project has also created a meteorological station network and a forecasting system for predicting atmospheric conditions that result in high pollution episodes in the SMA. The meteorological network includes a main station capable of determining temperature and wind profiles up to a height of 24 meters, and six additional stations determining temperature and wind profiles up to a height of 10 meters. This monitoring network feeds a model that calculates wind fields, which are used for dispersion modeling of air pollutants.

The Swedish project has developed an information system for air quality management in the SMA. The information system consists of a meteorological and air quality database, an emissions inventory, and dispersion models. Air monitoring and meteorological data are entered into a database managed by SESMA. The emissions inventory includes 3,200 fixed sources, 4,000 primary routes for mobile source emissions, and 17 zones for area emission sources (gas stations, residences, street dust). The emissions inventory estimates characteristics and quantities of emissions from major fixed, mobile, and other sources on an hourly basis for each of the 2 × 2 kilometer grid of an entire 34 × 34 kilometer area. The database can predict air emissions by time interval, geographical area, type of emission-generating fixed source (heating boiler, industrial process), type of fuel, and type of vehicle. It also can estimate the air quality impacts of alternative pollution control measures, such as introduction of new fuel types, catalytic converter-equipped vehicles, and newly created industrial zones.

Three types of dispersion models are used to predict ambient concentrations of air pollutants in the SMA. The Eulerian grid (a three-dimensional model that includes time as one dimension) and Gaussian models are used to predict the horizontal distribution of pollutant concentrations, and the Street Section model is used to predict the vertical distribution of pollutants emitted by vehicles in streets sided by buildings. Inputs to these models include the hourly meteorological and emissions data as well as digitized topographical maps. The modeling results are validated using actual measurements by the monitoring stations.

Air monitoring data are also used to calculate the air quality index. Tables 4.25 and 4.26 show the air quality indices and the corresponding pollutant concentrations, human health effects, and air quality classifications. Information on the air quality index is disseminated to the public by the media on a daily basis. When the index exceeds 100 (health standard) for any pollutant, CONAMA's regional office alerts various enforcement agencies to strengthen their enforcement capabilities. When the index exceeds 300 or 500, CONAMA's regional office, in coordination with these agencies, declares and implements pre-emergency and emergency measures for the SMA.

18. The monthly average concentrations of SO_2 and NO_2 are calculated from these determinations.

Table 4.26 Air quality indices and human health effects

Index	*Air quality*	*Human health effects*
0–100	Good	None.
101–200	Regular	Mild effects on susceptible people. Mild irritation symptoms for healthy people.
201–300	Bad	Significant worsening of symptoms and lower tolerance to exercise for people with heart and lung problems. Widespread symptoms for healthy people.
301–400	Critical	Premature appearance of sicknesses, deterioration of symptoms, and decrease in the tolerance to exercise for healthy people.
401–500	Dangerous	Premature death among the sick and elderly. Adverse symptoms affecting normal activities of healthy people.

Source: Ministry of Health Resolution 369 of December 4, 1988.

Evaluation of Implemented Measures

Vehicle emission standards. The emission standards shown in Table 4.20 have affected the design of new vehicles in the following ways (Weaver 1995).

- Compliance with the standards for gasoline-fueled light- and medium-duty vehicles requires such measures as installation of a three-way catalytic converter in conjunction with exhaust gas recirculation and control of injection timing.
- Compliance with the 1993 standards for urban buses in Santiago requires major modifications to the engine design, including extensive use of variable fuel injection timing, increased fuel injection pressure, low temperature charge-air cooling, and combustion optimization. Compliance with the 1996 standards requires higher injection pressure and more extensive combustion optimization. Electronic fuel injection controls are probably also needed, although mechanical injection controls are technically feasible.[19] To meet the 1996 limits, smaller engines would also require use of oxidation catalytic converters to reduce the soluble organic portion of diesel PM.
- Compliance with the remaining heavy-duty vehicle standards requires major engine modifications.

In response to the promulgation of emission standards for new vehicles, the share of new vehicles registered in Chile that are equipped with catalytic converters increased from 21 percent in 1992 to 95 percent in 1995 (Table 4.27). Vehicles not equipped with catalytic converters are usually either diesel-fueled, or are gasoline-fueled and either registered before the effective dates or registered in areas not covered by the regulations. In the SMA all new gasoline-fueled private cars, taxis, and light-duty trucks registered since September 1992 have been equipped with three-way catalytic converters and electronic control systems to comply with Decree 211.

Turner, Weaver, and Reale (1993) estimated the emission benefits of replacing a typical 1991 in-use gasoline-fueled car in the SMA with a car meeting the limits specified by Decree 211. The exhaust emission reductions were found to be 68 percent for CO, 52 percent for HC, and 6 percent for NO_x on average. The same analysis conducted for gasoline-fueled light-duty trucks yielded exhaust emission reductions of 18 percent for CO and 17 percent for HC. In addition, lead emissions would be totally eliminated for both vehicle types, and evaporative emissions would be reduced by 72 to 90 percent in cars and by 80 to 83 percent in light-duty trucks. The cost of environmental compliance was estimated at $630 per vehicle. This estimate includes $25 for the crankcase and evaporative controls, $265 for the catalytic converter, $60 for the air injection system, and most of the remaining $280 for the fuel injection and electronic control systems (Turner, Weaver, and Reale 1993).

Turner, Weaver, and Reale (1993) also estimated the emission benefits of replacing a typical 1991 in-use heavy-duty truck in the SMA with a heavy-duty truck meeting the September 1994

19. In the United States some engines with mechanical injection controls have been manufactured. Engines of some 1994 model-year vehicles in the United States adopted electro-hydraulic fuel injection systems for even better control of injection characteristics (Weaver 1995).

Table 4.27 New vehicle registrations in Chile, 1992–95

Year	*Total new vehicles*	*Vehicles with catalytic converter*	*Percent of new vehicles with catalytic converter*
1992	119,652	25,000	20.9
1993	112,876	89,157	79.0
1994	108,327	94,841	87.6
1995	146,430	138,788	94.8

Source: Ruiz 1996.

(or USEPA 1991) emission standards (Table 4.28). The analysis was also extended to diesel-fueled buses to meet the September 1993 (or USEPA 1991) emission standards (see Table 4.28). The emission reductions for trucks were found to be 83 percent for CO, 52 percent for HC, 37 percent NO_x, and 69 percent for PM. The emission reductions for buses were found to be 45 percent for CO, 68 percent for HC, none for NO_x, and 72 percent for PM. The average cost of meeting the heavy-duty vehicle emission standards was estimated at $1,500 per vehicle. This cost includes engine modifications for variable fuel injection timing, increased fuel injection pressure, low-temperature charge-air cooling, and extensive combustion optimization in the engine (Turner, Weaver, and Reale 1993).

Vehicle inspection programs. During 1988–89 tests were conducted on 150 buses, 150 private cars, and 225 taxis to determine the levels of pollutant emissions from in-use vehicles in the SMA. Test results indicated high levels of emissions (Table 4.29). For example, PM emissions from buses averaged 2.27 g/km for Santiago, more than twice as high as for buses in São Paulo (Katz, Reinke, and Sáez 1993).

Inspection programs for in-use vehicles in the SMA have reduced air emissions by eliminating the most polluting vehicles. For example, in 1991 alone some 5,600 minibuses and taxis and 1,600 private cars were temporarily prohibited from circulating because they exceeded emission standards. In addition, these programs likely have encouraged vehicle owners to better maintain their vehicles. Emission reductions from improved maintenance were evaluated by testing four diesel-fueled buses with rebuilt engines. One of these buses was tested right after engine rebuilding, and the other three were tested after a period of use during which they were given different levels of maintenance (one was maintained according to the manufacturer's specifications, one according to average Chilean maintenance standards, and one received no maintenance). Tests were also conducted on a fifth bus that was in-use and poorly maintained. The buses that received poor or no maintenance had much higher CO and PM emissions and somewhat higher NO_x emissions than those that were better maintained or newly rebuilt. No maintenance also increased HC emissions (Figure 4.11). The buses that received poor or no maintenance had about 20 to 24 percent better

Table 4.28 Comparison of exhaust emissions between controlled and uncontrolled heavy-duty vehicles
(grams per kilometer)

Vehicle	*CO*	*HC*	*NO_x*	*PM*
Uncontrolled heavy-duty truck	18.8	4.29	12.5	1.28
Controlled heavy-duty truck	3.16	2.05	7.90	0.40
Uncontrolled bus	7.37	1.45	6.21	2.00
Controlled bus	4.07	0.46	6.21	0.57

Source: Turner, Weaver, and Reale 1993.

Table 4.29 Average pollutant emission factors for in-use vehicles in the SMA, 1988–89
(grams per kilometer)

Vehicle type	*CO*	*HC*	*NO_x*	*PM*	*PM-10*
Private cars	6.42	1.05	1.22	0.07	0.06
Taxis	8.06	1.51	1.43	0.08	0.04
Buses	6.71	1.43	5.29	2.27	2.07

Note: Exhaust emissions were measured following the USEPA's FTP-75 test method for private cars and taxis. A special operating cycle was developed for buses.
Source: Katz, Reinke, and Sáez 1993.

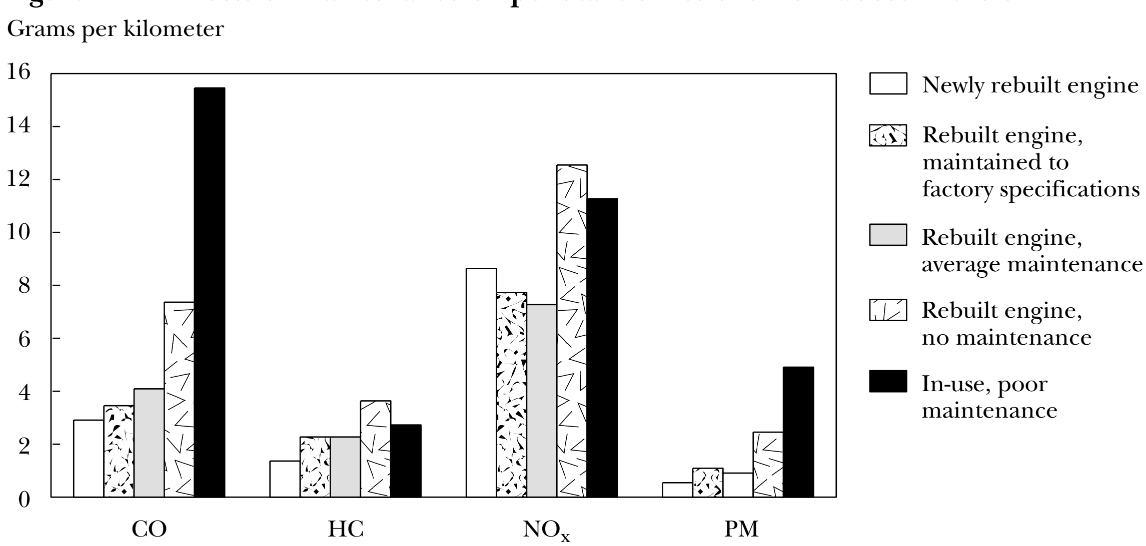
fuel economy than the bus that was not maintained (McGregor and Weaver 1994).

Another study of Chilean buses, tested on a chassis dynamometer using a driving cycle typical of urban bus operations, found that the average PM emission was 2.5 g/km. The study also found that the most polluting 10 percent of buses were responsible for 25 percent of PM emissions, and 20 percent of buses contributed more than 40 percent of PM emissions. The least-polluting, well-maintained 20 percent of buses contributed only 7 percent of PM emissions (McGregor and Weaver 1994).

Inspections conducted by the Ministry of Transportation and Communications found that in 1995 the average CO concentration in exhaust emissions was 0.28 percent for catalytic converter-equipped vehicles and 2.93 percent for vehicles lacking this technology. The average HC concentration in the exhaust emissions was 42 ppm for catalytic converter-equipped vehicles and 437 ppm for vehicles lacking this technology (Ruiz 1996). Based on these results, uncontrolled vehicles—which constitute about two-thirds of the SMA's fleet—contribute about 95 percent of the CO and HC emissions from motor vehicles.

Fuel-targeted measures. Typical leaded and unleaded gasoline quality parameters for 1995 and 1996 in Chile are shown in Table 4.30. Based on 1996 data, leaded and unleaded gasoline appear to have high levels of vapor pressure and olefinic and aromatics content that promote ozone

Figure 4.11 Effects of maintenance on pollutant emissions from buses in the SMA



Source: McGregor and Weaver 1994.

Table 4.30 Typical gasoline quality parameters in Chile, 1995–96

	Leaded gasoline		*Unleaded gasoline*	
Fuel parameter	*1995*	*1996*	*1995*	*1996*
Reid vapor pressure (psi)	9.7	7.6–13.5	9.7	7.0–13.5
Aromatics (percent by volume)	—	19.2	—	25.3–49.0
Olefins (percent by volume)	—	23.2	—	15.3–34.6
Benzene (percent by volume)	—	1.4	—	1.5–1.8
Sulfur (percent by weight)	0.050	0.030	0.020	0.030
Lead (g/liter)	0.26	0.31	< 0.003	0.002

— Not available.
Source: Ruiz 1996 for 1995 data; Alconsult International Ltd. 1996 for 1996 data.

formation. The Chilean standards for these parameters and for benzene also less stringent than the U.S. standards.

- The high end of the range for Reid vapor pressure of leaded and unleaded gasoline (13.5 psi) exceeds the Chilean norm (12.5 psi for winter and 10.0 psi for summer), which is more lenient than the U.S. standard (the 1992 limits for unleaded gasoline during summer months is 9.0 psi for the northern states and 7.8 psi for most of the southern states; the limits for reformulated gasoline are even stricter). Lowering the vapor pressure in both gasoline grades would reduce volatile HC emissions that contribute to ozone formation.
- The olefinic contents in leaded gasoline (23.2 percent by volume) and medium-octane unleaded gasoline (34.6 percent by volume) are much higher than allowed by emission standards in Mexico (15 percent by volume) or the United States (the 1990 baseline value for reformulated gasoline is 10.8 percent by volume). Reduction of olefinic compounds in these gasoline grades would reduce emissions of highly reactive HC that contribute to ozone formation.
- The aromatics content of the high-octane unleaded gasoline (49.0 percent by volume) is much higher than allowed in Mexico (30 percent by volume) or the United States (the 1990 baseline value for reformulated gasoline is 28.6 percent by volume). Reduction of aromatics in high-octane unleaded gasoline would reduce emissions of ozone-forming NO_x and HC, as well as carcinogenic benzene.

The lead content of leaded gasoline in Chile was reduced from 0.84 g/liter in 1981 to 0.80 g/liter in 1990, 0.34 g/liter in 1994, and 0.26 g/liter in 1995 (NRDC 1995; Lacasaña and others 1996; Ruiz 1996). While the 1996 lead content (0.31 g/liter) was about half the limit (0.61 g/liter) established by Chile's National Standards Institute, it still was much higher than in Mexico (0.11 g/liter in 1996) or most European Union countries (0.15 g/liter). No long-term studies are available on the effect that lowering lead content in gasoline has on the level of lead in blood.

The short-term measures adopted by refiners in Chile for lead reduction include remodeling the existing catalytic conversion units, constructing low-pressure catalytic reforming units, and remodeling the existing high-pressure catalytic reforming units for isomerization units.[20] To eliminate lead by 2006 the refiners are planning to add continuous regeneration units to the new catalytic reforming units and produce oxygenates (MTBE and DIPE; Ruiz 1996). The emission benefits of using 15 percent MTBE (by volume) as an octane enhancer and oxygenate on pollutant emissions in the SMA were estimated for light-duty vehicles. The study found that introduction of MTBE would lower CO emissions by 17 percent, HC emissions by 12 percent, and NO_x emissions by 9 percent. The 15 percent MTBE addition would increase the cost of gasoline by about $0.0077 to $0.016 a liter (Turner, Weaver, and Reale 1993).

20. Remodeling the existing catalytic conversion units includes operation at conditions that would yield the highest possible octane blendstocks, and replacement of catalysts.

Table 4.31 Estimated emissions from diesel- and CNG-fueled buses
(grams per kilometer)

Fuel type	*CO*	*HC*	*NO_x*	*PM*
Diesel	4.07	0.46	6.21	0.57
CNG	3.40	1.05	2.39	0.12

Source: Turner, Weaver, and Reale 1993.

In 1995 typical values for diesel fuel parameters observed in the Metropolitan Region were 0.2 percent by weight for sulfur, 49 for cetane number, and 850 kg/m^3 for density (Ruiz 1996). These values complied with the Chilean norm for diesel fuel.

The use of CNG as an alternative fuel to diesel was evaluated for heavy-duty vehicles. The conversion to CNG in urban buses in Santiago was estimated to result in a 79 percent reduction for PM emissions, 62 percent reduction for NO_x emissions, and 17 percent reduction for CO emissions. Practically all the sulfur emissions from CNG-fueled vehicles would also be eliminated. However, HC emissions would increase by a factor of 2.3, although most of this increase would be associated with methane emissions (Table 4.31). Converting a diesel-fueled bus to CNG would cost between $3,000 and $4,000. Any possible savings on the use of CNG as a substitute for diesel fuel could not be estimated because CNG is not yet available in Santiago (Turner, Weaver, and Reale 1993).

Transport management. Diesel-fueled buses in the SMA are responsible for a large percentage of PM emissions from mobile sources. Liberalization of the bus system in 1975 has increased both the supply and coverage of bus services but also has resulted in an oversupply of buses. For example, in 1991 nearly 4,000 more buses than necessary were in operation in the SMA, causing congestion and resulting in slow and unreliable services. These buses were estimated to consume an extra $24.4 million a year in fuel and emit 10 percent more PM into the atmosphere (Hall, Zegras, and Rojas 1994).

The structure of bus ownership has also affected pollutant emissions in the SMA. In 1990, for example, 4,800 bus proprietors owned one bus, 1,200 owned two to four buses, and 400 owned five or more buses, for an average of 1.7 buses per proprietor (BKH Consulting Engineers and Universidad de Chile 1992). The competition and low occupancy rates that resulted from deregulation have caused serious economic hardship for most single-bus owners. As a result these owners have reduced maintenance on their buses to a minimum and operated them as long as they covered their operating costs. These poorly-maintained buses emit more pollutants than the newer and better-maintained buses owned by proprietors of large fleets (Hall, Zegras, and Rojas 1994).

Although the imposition of the 20 percent traffic restriction during the winter months reduced the supply of the excess bus fleet somewhat, this measure also resulted in a 5 percent increase in the number of bus riders per vehicle-kilometer (Escudero and Cofré 1993). However, some families purchased a second or even a third car to evade the restriction (Hall, Zegras, and Rojas 1994).

The Ministry of Transportation and Communication's bus retirement program has eliminated the oldest and most polluting 20 percent of the urban bus fleet from circulation. Since the initiation of the route auctioning program for buses in the central business district, cleaner and more modern buses have been providing public transport services. As a result the average bus operating in the SMA is five years old. About 74 percent of the fleet has a model-year of 1990 or later only 9 percent are older than 15 years. Improved bus services resulted in an increase in bus ridership between 350 and 400 passengers per bus per day in 1990 to about 600 passengers per bus per day in 1994 (Hall, Zegras, and Rojas 1994).

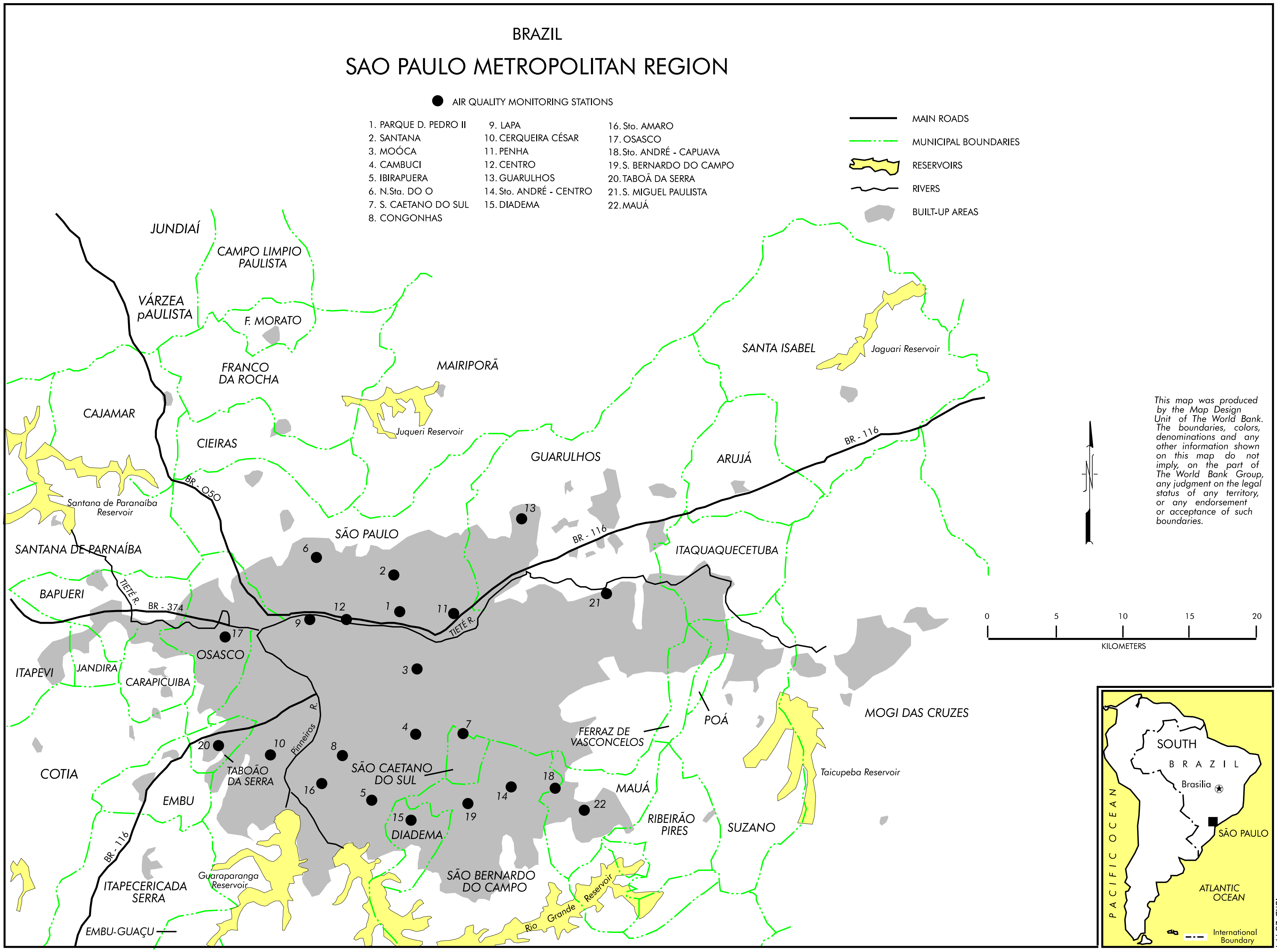
As a result of the traffic ban on empty taxis in a forty-block area of the business district of Santiago, traffic flow has dropped 30 percent. This measure should also have improved the air quality in the restricted area.

Attractive features of the metro include its short wait time, safety, speed, competitiveness with bus fares, comfort, and overall quality. However, its area of coverage is limited to a small portion of the SMA. Its operational and fare integration with yellow buses also has been a drawback. Only 17 percent of the metro's riders originate from metrobuses and regular buses, and 10 percent of its egresses go to buses. These riders account for only 1 percent of the surface public transport ridership (Hall, Zegras, and Rojas 1994).

Air quality monitoring. Since pollution control measures were implemented in the SMA in 1989 the number of days with high air quality indexes (exceeding 300) has decreased. During the first six months of 1989 the 300 mark was exceeded on four days; in the first six months of 1996 this only happened once. Similarly, the number of days exceeding the 500 mark dropped from nine to zero for the same period.

The MACAM network is unique in Latin America for PM-2.5 monitoring. Still the monitoring system in the SMA has not yet been used effectively for air quality management. First, the monitoring system provides data for only the downtown area and the northwestern zone of the SMA, leaving great most of the SMA without adequate information on air quality. The semiautomatic system that supports the MACAM network has been in operation for more than 15 years, is subject to frequent breakdown, and requires replacement. Although considerable progress has been made through the Swedish government's technical assistance project on air quality management, the dispersion models developed under this project lack photochemical reactions to predict ambient ozone concentrations. Technical studies are also needed to understand ozone formation in the Metropolitan Region as well as types and sources of the volatile organic chemicals that act as critical precursors for ozone formation. Air quality management in the SMA could be improved by expanding the existing models to include photochemical reactions. The health effects of air pollution could be reduced by using billboards or other means to disseminate air quality information and raise public awareness.

São Paulo



BRAZIL
SAO PAULO METROPOLITAN REGION
AIR QUALITY MONITORING STATIONS
1. PARQUE D. PEDRO II
2. SANTANA
3. MOÓCA
4. CAMBUCI
5. IBIRAPUERA
6. N.Sta. DO O
7. S. CAETANO DO SUL
8. CONGONHAS
9. LAPA
10. CERQUEIRA CÉSAR
11. PENHA
12. CENTRO
13. GUARULHOS
14. Sto. ANDRÉ - CENTRO
15. DIADEMA
16. Sto. AMARO
17. OSASCO
18. Sto. ANDRÉ - CAPUAVA
19. S. BERNARDO DO CAMPO
20. TABOÃ DA SERRA
21. S. MIGUEL PAULISTA
22. MAUÁ
MAIN ROADS
MUNICIPAL BOUNDARIES
RESERVOIRS
RIVERS
BUILT-UP AREAS
JUNDIAÍ
CAMPO LIMPIO PAULISTA
VÁRZEA pAULISTA
F. MORATO
FRANCO DA ROCHA
MAIRIPORÃ
CAJAMAR
CIEIRAS
Juqueri Reservoir
Santana de Paranaíba Reservoir
SANTA ISABEL
Jaguari Reservoir
GUARULHOS
ARUJÁ
BR - 116
BR - 050
SÃO PAULO
SANTANA DE PARNAÍBA
BAPUERI
TIETÊ R.
BR - 374
ITAQUAQUECETUBA
OSASCO
ITAPEVI
JANDIRA
CARAPICUIBA
COTIA
EMBU
TABOÃO DA SERRA
Pinneiros R.
SÃO CAETANO DO SUL
FERRAZ DE VASCONCELOS
POÁ
MOGI DAS CRUZES
Taicupeba Reservoir
MAUÁ
RIBEIRÃO PIRES
SUZANO
DIADEMA
SÃO BERNARDO DO CAMPO
Rio Grande Reservoir
Guaraparanga Reservoir
ITAPECERICADA SERRA
EMBU-GUAÇU
KILOMETERS
0 5 10 15 20
This map was produced by the Map Design Unit of The World Bank. The boundaries, colors, denominations and any other information shown on this map do not imply, on the part of The World Bank Group, any judgment on the legal status of any territory, or any endorsement or acceptance of such boundaries.
SOUTH
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Brasilia
SÃO PAULO
PACIFIC OCEAN
ATLANTIC OCEAN
International Boundary
IBRD 28414
JULY 1997

São Paulo, the largest city in Brazil, contains 9.5 million people. The São Paulo Metropolitan Region (SPMR), the second largest urban center in Latin America and the Caribbean (after the Mexico City Metropolitan Area), contains about 17 million people. The SPMR is an important economic center that generates about half of Brazil's gross national product (CETESB 1996). It spans 8,051 square kilometers and includes thirty-eight municipalities besides the Municipality of São Paulo (which occupies 1,577 square kilometers). The SPMR's population density averages 2,110 inhabitants per square kilometer, rising to an average of 6,380 in the city and reaching as high as 10,000 in certain downtown areas.

Ecologically, the surface of the SPMR consists of urbanized areas, forests, natural vegetation, and a hydrological system consisting of three rivers. The SPMR lies at altitudes ranging from 650 meters to 1,200 meters. The SPMR's climate is moderate, with dry and cold winters (averaging 8°C) and hot and humid summers (averaging 30°C). Annual precipitation averages 1,500 millimeters, with most rainfall occurring during October and March. Because of thermal inversions, ambient air quality in São Paulo worsens during the winter (May through September).

São Paulo's rapid industrialization and urbanization have caused serious environmental problems.[21] Federal and state authorities began addressing industrial pollution during the 1970s, with some success. Air pollution from motor vehicles is now the environmental priority for the SPMR.

Ambient Air Quality

Pollutants that exceed the ambient air quality standards in the SPMR are TSP, PM-10, smoke, NO_2, ozone, and CO. In 1995 annual average ambient TSP concentrations ranged from 65 μg/m³ to 131 μg/m³. The annual standard of 80 μg/m³ was exceeded at six of nine monitoring stations: Osasco (131 μg/m³), Parque D. Pedro II (116 μg/m³), S.B. do Campo (94 μg/m³), Santa Amaro (85 μg/m³), São C. do Sul (85 μg/m³), and Parque Ibirapuera (84 μg/m³). The 24-hour TSP standard (240 μg/m³) also was exceeded at these six stations. The frequency of violation ranged from 2 percent of the sampling days at Penha and 20 percent at Osasco. The 24-hour "alert" level of 625 μg/m³ was exceeded once at Parque Ibirapuera with a concentration of 685 μg/m³ and the 24-hour "attention" level of 375 μg/m³ was exceeded once at S.B. do Campo with a concentration of 387 μg/m³(CETESB 1996).

In 1995 annual average ambient PM-10 concentrations in the SPMR, monitored by twenty-one monitoring stations, ranged from 60 μg/m³ (at Mauá) to 105 μg/m³ (at Guarulhos). The annual standard of 50 μg/m³ was exceeded at all twenty-one stations. The highest 24-hour average concentrations, which ranged between 184 μg/m³ (at Cerqueira César) and 298 μg/m³ (at Cambuci), also exceeded the 24-hour standard (150 μg/m³) at all twenty-one stations. At Cambuci and Osasco violations of the 24-hour standard occurred on 16 and 17 percent of the sampling days. The 24-hour "attention" level of 250 μg/m³ was exceeded at S.B. do Campo five times, and at Cambuci and Parque Ibirapuera once each (CETESB 1996).

In 1995 two of the seven stations monitoring smoke in the SPMR recorded average ambient levels above the annual standard of 60 μg/m³ (103 μg/m³ at Campos Eliseos and 68 μg/m³ at Tatuapé). The 24-hour standard of 150 μg/m³ was exceeded at five of these stations, with the highest concentration being 245 μg/m³ at Campos Eliseos. At this station the 24-hour standard was exceeded on 12 percent of the sampling days (CETESB 1996).

The latest ambient NO_2 data for the SPMR are from 1993 when average concentrations were below the annual standard of 100 μg/m³. Annual average concentrations were 99 μg/m³ at Congonhas, 85 μg/m³ at Parque D. Pedro II, and 62 μg/m³ at Cerqueira César. However, the 1-hour standard of 320 μg/m³ was exceeded at Congonhas (on 125 of the 214 monitored days, with a maximum 1-hour concentration of 784 μg/m³), Parque D. Pedro II (on 57 of the 158 monitored days, with a maximum 1-hour concentration of 1,097 μg/m³), and Cerqueira César (on 9 of the 180 monitored days, with a maximum 1-hour concentration of 568 μg/m³). These concentrations were below the 1-hour "attention" level of 1,130 μg/m³ (CETESB 1994b).

In 1995 the 1-hour ozone standard of 160 μg/m³ was exceeded three times at Moóca, thirty

21. There are about 30,000 industries in the SPMR (Romano and others 1992).

times at Lapa, and twenty times at Parque D. Pedro II. Maximum 1-hour ambient ozone concentrations were 763 μg/m^3 at Lapa, 269 μg/m^3 at Parque D. Pedro II, 218 μg/m^3 at Moóca, and 131 μg/m^3 at Congonhas. The 1-hour "attention" level of 200 μg/m^3 for ozone was exceeded on six days at Lapa and on one day each at Parque D. Pedro II and Moóca. The highest ozone levels are observed during September and October. Ozone levels are relatively low during the winter (CETESB 1996).

In 1995 ambient CO concentrations exceeded the 8-hour standard of 9 ppm (10 mg/m^3) at four stations in the SPMR: Parque D. Pedro II on forty-two days (with a maximum of 18 ppm), Congonhas on thirty-four days (maximum 19 ppm), Cerqueira César on twenty-four days (maximum 17 ppm), and Centro on fourteen days (maximum 18 ppm). The 8-hour "attention" level of 15 ppm was exceeded at Centro on five days, Congonhas on four days, Parque D. Pedro II on three days, and Cerqueira César on one day (CETESB 1996).

In 1995 ambient SO_2 concentrations in the SPMR, monitored by twenty-nine stations, were below the annual (80 μg/m^3) and 24-hour (365 μg/m^3) standards. The highest annual average concentration (46 μg/m^3) was at Campos Eliseos and the highest 24-hour average concentration (179 μg/m^3) was at Guarulhos (CETESB 1996).

Average ambient concentrations of TSP, PM-10, smoke, and SO_2 in the SPMR for the 1983–95 period are presented in Figure 4.12. During this period annual average ambient concentrations dropped by 29 percent for TSP (from 125 μg/m^3 to 89 μg/m^3), 18 percent for smoke (from 83 μg/m^3 to 68 μg/m^3), and 69 percent for SO_2 (from 61 μg/m^3 to 19 μg/m^3). These reductions were the result of industrial pollution control measures and the Proalcohol Program, which promoted the use of alcohol as a motor vehicle fuel (see Chapter 3). Annual average PM-10 concentrations, which fluctuated between 50 μg/m^3 and 80 μg/m^3 during 1983–95, have been increasing since 1992.

No major changes were observed in ozone, NO_2, and CO levels for the 1983–95 period. Although no recent data are available, monitoring in 1983–87 found high ambient concentrations of NMHC. For example, annual average NMHC ambient concentrations at Parque D. Pedro II increased from 0.74 μg/m^3 in 1983 to 1.51 μg/m^3 in 1987 (CETESB 1996).[22] Ambient concentrations of lead, which used to be a serious environmental problem in the SPMR, have fallen to about 0.10 μg/m^3 as a result of the Proalcohol program as well as the elimination of lead from gasoline (Branco 1995).

Sources of Pollutants

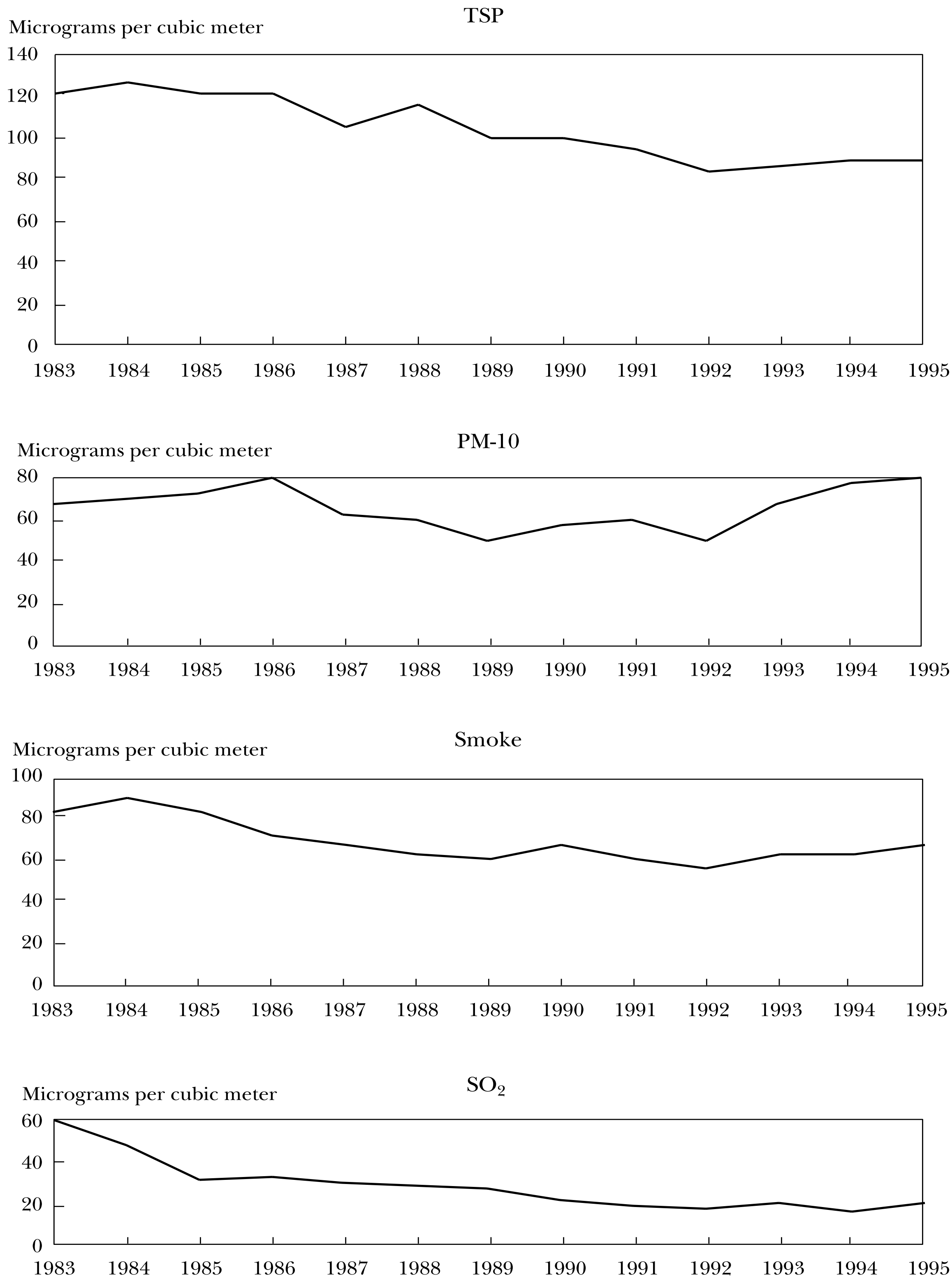
The main source of air pollution in the SPMR is motor vehicles. In 1995 the fleet consisted of about 5.16 million vehicles (3.3 million gasohol-fueled light-duty vehicles, 1.5 million ethanol-fueled light-duty vehicles, and 360,000 diesel-fueled heavy-duty vehicles). These vehicles were responsible for 96 percent of CO, 90 percent of HC, 97 percent of NO_x, 86 percent of SO_2, and 42 percent of PM emissions (Figure 4.13). The light-duty vehicles, which are mostly cars, contributed 68 percent of CO and 69 percent of HC emissions. Gasohol-fueled vehicles were responsible for higher emissions than ethanol-fueled vehicles. In addition, diesel-fueled heavy-duty vehicles contributed 82 percent of NO_x and 77 percent of SO_2 emissions.

In 1995 industry contributed 46 percent of all PM emitted in the SPMR, but its estimated contribution to ambient PM-10 concentrations at monitoring stations was only 10 percent mainly because emissions from industrial stacks are dispersed before reaching the stations' receptors (CETESB 1996). By contrast, street-level emissions may expose the public to very high PM-10 concentrations. And because the PM in vehicle emissions are toxic and within the inhalable range, they pose greater risks to the public than those generated by most industrial sources (Szwarc 1993). In 1995 PM-10 in ambient air was contributed mostly by diesel-fueled vehicles (30 percent), resuspended dust (25 percent), and aerosols (25 percent). The contribution of gasohol-fueled vehicles was much less (10 percent; CETESB 1996).

The 1986–87 data from four monitoring sites in the SPMR show that PM-10 constitutes 49 to 61 percent of TSP and is largely contributed by motor vehicles and road dust (Table 4.32). The data also show that fine particles (PM-2.5), which are not regulated but constitute a major health

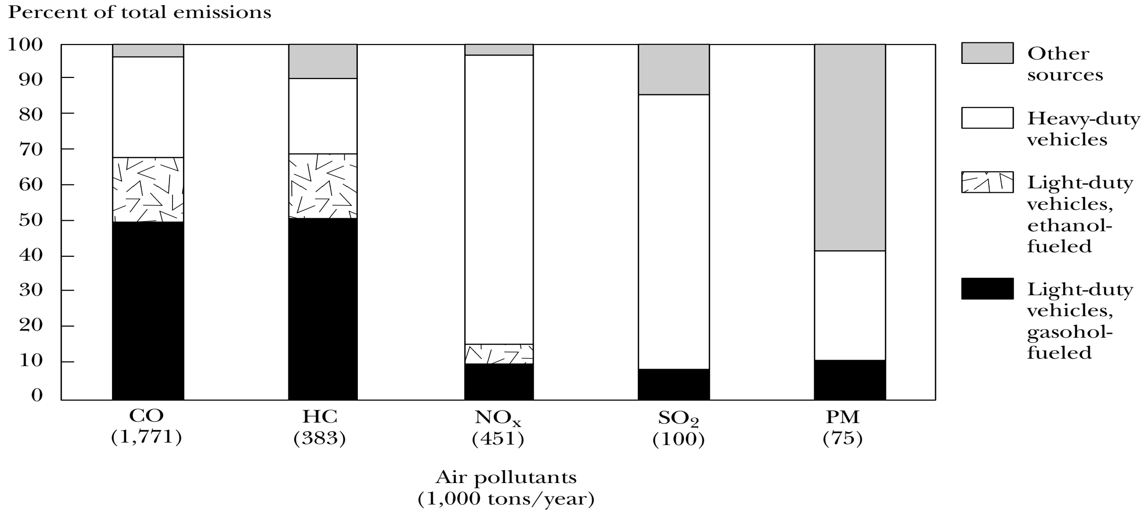
22. Both concentrations are expressed as propane equivalent.

Figure 4.12 Average ambient pollutant concentrations in the SPMR, 1983–95



Source: CETESB 1996.

Figure 4.13 Share of air pollutant emissions from road-based motor vehicles and other sources in the SPMR, 1995



Note: Other sources include industrial processes, fuel transfer, resuspended particles, secondary aerosols, two- and three-wheelers. Two- and three-wheelers contributed 1.7 percent of CO, 2.3 percent of HC, and less than 0.3 percent of NO_x, SO_2, and PM emissions.
Source: CETESB 1996.

risk, make up 52 to 61 percent of PM-10 and are largely contributed by motor vehicles and secondary pollutants containing sulfates and carbon (Alonso and others 1992).

In 1990 about 30 million trips a day were made in the SPMR. Of these, 10 million were walking trips (Table 4.33). Of the remaining 20 million, cars accounted for 40 percent, buses for 38 percent, metro for 14 percent, metropolitan train for 6 percent, and other modes for 2 percent. Of the 12 million trips by public transport modes, one-third required the use of more than one vehicle: 78 percent of all metro trips, 61 percent of all train trips, and 16 percent of all bus trips required one or more transfers to be completed (Rebelo and Benvenuto 1995).[23] Despite a 250-kilometer rail network, limited integration between the metro and suburban trains discourages rail-based trips in favor of trips by cars and buses, resulting in heavy congestion during peak hours. The economic and fuel loss due to traffic congestion is estimated at $6.2 million a day. In addition, congestion caused by road-based motorized vehicles has significant impacts on the SPMR's air quality and the health of its population (World Bank 1994).

Economic conditions in Brazil strongly affect people's driving behavior and therefore air pollution in the SPMR. During 1980–85, when Brazil was experiencing an economic crisis, many car owners used public transportation during weekdays for commuting to work. During this period air pollution in the SPMR remained relatively stable. But when the economy stabilized and inflation leveled off for about seven months in 1986, a surge in air pollution from motor vehicles occurred due to extensive use of private cars. A subsequent rise in inflation triggered a shift from private to public transport modes. Since 1993, with the stabilization of the economy, the situation has been the similar to that experienced in 1986: more cars in circulation, more congestion and fuel consumption, and more

23. The metro and train lines are managed by the State Government of São Paulo because these lines extend over various municipalities.

Table 4.32 Sources of TSP and PM-10 in ambient air at four stations in the SPMR, November 1986–November 1987

	Ambient concentration ($\mu g/m^3$)			*Percentage of TSP emitted by*			*Percentage of PM-10 emitted by*			*Percentage of PM-2.5 emitted by*		
Monitoring station	*TSP*	*PM-10*	*PM-2.5*	*Vehicles*	*Road dust*	*Other sources*	*Vehicles*	*Road dust*	*Other sources*	*Vehicles*	*Road dust*	*Other sources*
São Caetano	179	87	45	27	55	18	40	30	30	42	9	49
Osasco	121	63	50	30	50	20	41	25	34	38	6	56
Ibirapuera	75	46	28	23	49	28	35	23	42	28	7	65
D. Pedro II	138	82	36	38	45	17	50	23	27	54	4	42

Note: São Caetano is located southeast SPMR in an industrial-commercial area. Osaco is located northwest SPMR in an industrial-commercial area. Ibirapuera is located in a park- residential area. D. Pedro II is located in downtown.
Source: Alonso and others 1992.

vehicular air pollution (Branco 1995). This recent increase in circulation has resulted not only from a change in commuting behavior but also from new cars added to the motor vehicle fleet. The light-duty motor vehicle fleet in the SPMR grew about 5 percent a year during 1990–93, but has grown by about 10 percent a year since 1993. Nearly 90 percent of this growth has been contributed by gasohol-fueled vehicles (CETESB 1996).

Transport infrastructure in the SPMR is concentrated in areas close to the city center. It also connects centers of employment with high-and middle-income neighborhoods, where private cars are the principal mode of transport. This arrangement encourages the use of private cars, resulting in traffic congestion (especially in the central area) and significant emissions of air pollutants. By contrast, public transport services to the periphery of the city, where low-income populations live, are limited. And even though the maximum capacity of most buses is 36 persons seated and 40 standing, during peak hours more than 90 passengers—and in some cases up to 120—are admitted. These buses are forced to compete with cars for limited road space (World Bank 1994). Other factors exacerbating the traffic problem in the SPMR include unplanned land use, poor traffic management, inadequate parking enforcement (specially during rush hours), and limited flexibility of the outdated traffic sign system to manage variable traffic flows (Szwarc 1993).

Table 4.33 Daily trip distribution in the SPMR, 1990

Mode	*Trips a day (million)*	*Percent*
Individual motorized transport		
Car	8.2	27
Motorcycle and other	0.2	1
Public transport		
Bus	7.8	25
Metro	2.8	9
Train	1.2	4
Other	0.2	1
Nonmotorized transport (on foot)	10.0	33
Total	30.4	100

Source: World Bank 1994.

Institutional Responsibilities

The key institutions determining environmental policy in São Paulo are the federal government, state authorities, municipal government agencies, private enterprises, and NGOs. The division of responsibilities across the levels of government is well defined. Policy guidelines, basic laws (such as emission and ambient standards and licensing requirements for new projects), and budgetary decisions are made by the federal government. Water supply, pollution control, sewerage, and power supply are under the control of state governments. Municipalities are involved with solid waste management, noise pollution, streets, parks and recreation, education, health care, and public transportation. The trend toward decentralization, embodied in the 1988 Constitution is increasing the role of local governments in the provision of public goods (Leitmann 1991).

Federal institutions. Federal environmental institutions and pollution control laws were established in 1973. Brazil's current environment strategy dates to 1981, when the National Environmental System (SISNAMA) was created to implement the National Environmental Policy (PNMA). The Ministry of Interior's Secretariat of the Environment (SEMA) made the National Environmental System responsible for strengthening state environmental agencies. In 1984 the system's policy making functions were assigned to the National Environmental Council (CONAMA). In 1988 the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA) replaced the Secretariat of the Environment and integrated all federal executive agencies with environmental authority.

The current institutional arrangements emerged in 1989 as a result of the National Environmental System's reorganization. The system now consists of a government council from all ministries; an advisory and policy council (CONAMA), with representatives from the states, unions, and NGOs; a central agency, the Secretary of the Environment (SEMAM), which chairs CONAMA and is linked to the presidency; other public agencies involved in environmental issues; and the state environmental agencies.

The Brazilian Transport Planning Agency (GEIPOT) was created in 1976 to help prepare urban and inter urban transport policies and investment plans. At the same time the Brazilian Urban Transport Company (EBTU) was established to implement urban transport policy and finance urban transport investments. In 1984 the Brazilian Urban Train Company (CBTU) was formed to separate nationwide rail-based goods and commuter services, and was empowered to take over the planning, operation, and financing of most suburban rail systems in metropolitan regions. In 1985 the Ministry of Urban Development and the Environment (MDU) was established to formulate urban development and environmental policies. In 1986 the ministry took over the Urban Transport Company. In addition, the urban divisions of the Transport Planning Agency were merged with the Brazilian Urban Transport Company. The Urban Train Company remained within the Ministry of Transportation. In 1989, to shrink the public sector, the Government of Brazil abolished both the Ministry of Urban Development and the Environment and the Brazilian Urban Transport Company. In doing so it eliminated the main federal agency in charge of preparing guidelines and negotiating financing for the urban transport sector. Thus a first step towards decentralization of responsibility from the national to sub national levels was made, although the Brazilian Urban Train Company continued as the only federal urban transport agency in the Ministry of Transportation, which was incorporated into the Ministry of Infrastructure in March 1990.

State institutions. The Environmental Sanitation Technology Company (CETESB) is the state environmental protection institution responsible for monitoring air pollution in São Paulo. CETESB, a part of the state Secretariat of the Environment, is a public entity with administrative authority that allows it to earn profits. Among other things, it is responsible for licensing new industrial installations, monitoring pollution control activities, and enforcing state pollution control legislation. With regard to vehicular air pollution, CETESB has been monitoring ambient air levels and disseminating the results to the public, conducting research on alternative fuels, enforcing smoke emission regulations for diesel-fueled vehicles, and preparing and delivering training programs. In 1995 CETESB was asked to design a program to control air pollution from motor vehicles in the State of São Paulo. The objective of this program was to integrate the air pollution control efforts of CETESB, the São Paulo Metro Company (responsible for operation of the São Paulo metro), the association of public transportation companies (ANTC), and municipalities within the SPMR.

CETESB also supports federal environmental agencies in reducing vehicular air pollution. For example, CETESB helped prepare CONAMA Resolution 18/86, which established the Program to Control Air Pollution from Motor Vehicles (PROCONVE) at the national level, and its complementary Federal Law 8723 of October 1993 (CETESB 1994a). CETESB also prepared the national resolution (CONAMA 7/93) that established emission limits for used cars and associated testing procedures. As a technical arm of the Brazilian Institute of the Environment and Renewable Natural Resources, it is responsible for implementing PROCONVE at the national level, including controlling pollutant and noise emissions from imported and domestically produced new vehicles.

Two state institutions are responsible for overseeing the urban transport sector in the SPMR: the State Secretariat of Metropolitan Transport (STMSP) and the State Secretariat of Road Infrastructure Works (SENIV). The State Secretariat of Metropolitan Transport, created in 1991, is responsible for urban transport in the SPMR outside the Municipality of São Paulo. It oversees the São Paulo metro as well as the São Paulo metropolitan train and bus companies (CPTM and EMTU). It also regulates the licensing of intermunicipal bus services owned and operated by the private sector. The State Secretariat of Road Infrastructure Works is responsible for roads and railways (other than suburban railways) in the State of São Paulo, and oversees the agency in charge of planning, building, and maintaining the roads in the SPMR (DERSA).

Until November 1993 suburban commuter train services were the responsibility of the São Paulo State Railways and the Brazilian Urban Train Company. This responsibility has since been assumed by the São Paulo Metropolitan Train Company.

Local institutions. Municipalities in the SPMR are not directly involved in environmental management but are responsible for managing traffic, operating bus lines, and licensing taxis.[24] The Municipality of São Paulo will be responsible for managing the city's inspection and maintenance program.

The Municipality of São Paulo, through the Municipal Public Bus Company (CMTC), owns and operates about 20 percent of municipal bus passenger services. It also regulates the remaining 80 percent, which is owned and operated by the private sector. The municipality's Traffic Engineering Company (CET) is in charge of traffic management and control in the municipality. Other municipalities in the SPMR regulate the bus services operating exclusively within their territories.

Implemented Measures

For many years the SPMR lacked an integrated air pollution control program that included the environmental and transport institutions in the State of São Paulo and municipalities within the region. In recent years, however, two initiatives have been undertaken. First, CETESB began preparing the Program for the Control of Pollution from Vehicles (PCPV) for the State of São Paulo. In addition to integrating the air pollution control effort of CETESB, São Paulo Metro Company, the association for public transportation companies, and municipalities, the PCPV supports the inspection and maintenance program and promotes alternative transport fuels and public transport modes (for example, it is extending two metro lines, constructing two metro lines, and encouraging the use of trolleybuses). The program makes the municipalities responsible for implementing land use and traffic control measures.

In addition, the State Secretariat of Metropolitan Transport has created the Permanent Group for Integrated Planning (GPPI) and has started preparing an integrated urban transport, land use, and air quality strategy for the SPMR. With support from the Municipality of São Paulo, the planning group has launched studies to define the role, responsibilities, and funding of the Regional Transport Coordination Commission (RTCC).

Vehicle emission standards. In 1986 national legislation (CONAMA Resolution 18/86) established PROCONVE to cope with Brazil's worsening vehicular air pollution problem. This legislation was subsequently complemented by nine other resolutions and Federal Law 8723 of October 1993. PROCONVE sought to reduce pollutant emissions from vehicles to comply with ambient air quality standards, especially in urban centers; promote and develop technology for sampling and analyzing pollutants; create inspection and maintenance programs for in-use vehicles; promote public awareness of the vehicular air pollution problem; establish evaluation criteria for results obtained; and improve fuel characteristics to reduce vehicular air pollution. The program, based on the experiences of industrial countries with enforcing emission standards for motor vehicles using standardized testing procedures and referenced fuel types, defines phased and increasingly rigorous emission limits and standardized emissions testing procedures for all new gasoline-, alcohol-, and diesel-fueled engines used in cars, trucks, and buses. This program requires reduction of car

24. However, license plates for the entire vehicular fleet are controlled by the State Department of Transportation (DETRAN).

exhaust emissions (including CO, HC, and NO_x) to occur in stages. PROCONVE also requires that new model and prototype vehicles be approved for emission standards.

The emission standards for light-duty vehicles specified in PROCONVE and subsequent legislation are presented in Table 4.34. The first set of standards, which applied to new model light-duty vehicles produced and marketed after June 1988, regulated emissions of CO, HC, and NO_x. More stringent emission standards, comparable to those adopted in the United States in 1975, became effective on January 1, 1992. Starting with the 1994 model-years PM emissions from diesel-fueled vehicles were limited to the same level for 1994 model-year U.S. diesel-fuel vehicles. Exhaust emission standards equivalent to those adopted in the United States in 1981 and used until 1993 for gasoline-fueled vehicles are scheduled to take effect on January 1, 1997.

Uncontrolled combustion of ethanol results in higher aldehyde emissions than combustion of gasoline. To avoid additional air pollution from ethanol combustion, the aldehyde emission standard for light-duty ethanol- and gasohol-fueled vehicles was established equal to that for gasoline-fueled light-duty vehicles—0.15 gram/kilometer, starting with model-year 1992 (see Table 4.34). A stricter aldehyde limit (0.03 gram/kilometer) was set starting with model-year 1997 given more advanced emission control systems. In addition, PM emissions from diesel-fueled light-duty vehicles were limited to 0.05 gram/kilometer effective March 1994. Crankcase emissions have not been allowed since January 1988, and evaporative emissions have been limited to 6 grams/test since January 1990.

Emission standards for new diesel-fueled vehicles were set by CONAMA Resolution 18/86 and its complementing resolutions. Among these, Resolution 8/93 is especially important since it established the most comprehensive and stringent compliance program for diesel-fueled vehicles (Table 4.35). PROCONVE limits on smoke emissions from diesel-fueled urban buses became effective in October 1987 and from other diesel-fueled vehicles in January 1989. Effective January 1988, PROCONVE also limits to negligible levels crankcase emissions from urban buses equipped with naturally-aspirated diesel engines.

As Table 4.35 shows, CO, HC, NO_x, and PM emission standards have been established for the following types of new diesel-fueled vehicles: imported vehicles, domestically produced urban buses, and other domestically produced vehicles. The first set of standards was set for all imported vehicles and 80 percent of domestically pro-

Table 4.34 Exhaust emission standards for new light-duty vehicles in Brazil
(grams per kilometer)

Year effective	*CO*	*HC*	*NO_x*	*PM*[a]	*Aldehydes*[b]	*CO at idle (percent)*
1988[b]	24	2.1	2.0			3.0
1989[c]	24	2.1	2.0			3.0
1990[d]	24	2.1	2.0			3.0
1992[e]	24	2.1	2.0			3.0
1992[f]	12	1.2	1.4		0.15	2.5
1994	12	1.2	1.4	0.05[g]	0.15	2.5
1997	2	0.3	0.6	0.05[g]	0.03	0.5

Note: A blank space indicates that no standard was established. Crankcase emissions were eliminated effective January 1988. Effective January 1990 evaporative emissions were limited to 6.0 grams/test, expressed as ethanol when the fuel is ethanol and as propanol if the fuel is gasohol. Test procedures are USEPA's FTP-75 for exhaust emissions and SHED method for evaporative emissions.
a. For diesel-fueled vehicles only.
b. For vehicles with spark-ignition engines only.
c. New models only.
d. For 50 percent of production.
e. For all models, except those not derived from cars.
f. For models not derived from light-duty vehicles.
g. For models not covered in note f.
Source: CETESB 1994a; CETESB 1996.

Table 4.35 Exhaust emission standards for new diesel-fueled vehicles in Brazil
(grams per kilowatt-hour)

<table>
<tr><th>Effective date</th><th>Applied to</th><th>CO</th><th>HC</th><th>NO_x</th><th>PM</th><th>Smoke[a]</th></tr>
<tr><td>January 1987</td><td>Urban diesel buses</td><td></td><td></td><td></td><td></td><td rowspan="6">2.5</td></tr>
<tr><td>January 1989</td><td>All diesel vehicles</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">January 1994</td><td>All imported vehicles[b]</td><td rowspan="2">4.9</td><td rowspan="2">1.2</td><td rowspan="2">9.0</td><td>0.7/0.4[c]</td></tr>
<tr><td>80% of domestically produced urban buses[b,d]</td><td rowspan="3"></td></tr>
<tr><td>20% of urban diesel-fueled buses and 80% of all other domestically produced diesel-fueled vehicles[d]</td><td rowspan="2">11.2</td><td rowspan="2">2.4</td><td rowspan="2">14.4</td></tr>
<tr><td rowspan="2">January 1996</td><td>20% of domestically produced vehicles[b,d]</td></tr>
<tr><td>80% of domestically produced vehicles[b,d]</td><td rowspan="2">4.9</td><td rowspan="2">1.2</td><td rowspan="2">9.0</td><td rowspan="2">0.7/0.4[c]</td><td rowspan="7"></td></tr>
<tr><td rowspan="3">January 1998</td><td>20% of domestically produced urban buses[b,d]</td></tr>
<tr><td>80% of domestically produced urban buses[b,d]</td><td rowspan="3">4.0[e]</td><td rowspan="3">1.1[e]</td><td rowspan="3">7.0[e]</td><td rowspan="3">0.15[e]</td></tr>
<tr><td>All imported vehicles[b]</td></tr>
<tr><td>January 2000</td><td>80% of domestically produced vehicles[b,d]</td></tr>
<tr><td rowspan="2">January 2002</td><td>20% of domestically produced vehicles[b,d]</td><td>4.9</td><td>1.2</td><td>9.0</td><td>0.7/0.4[c]</td></tr>
<tr><td>All vehicles[b]</td><td>4.0[e]</td><td>1.1[e]</td><td>7.0[e]</td><td>0.15[e]</td></tr>
</table>

Note: A blank space indicates that no standard was established. Test procedures are based on EEC's 13-mode cycle for gaseous emissions and EEC's full-load steady-state test for smoke.
a. Absorption coefficient $k = c\sqrt{G}$, where c is carbon concentration (grams per cubic meter) and G is rated flow of exhaust gas (liters per second).
b. All vehicles (with spark-ignition and diesel engines).
c. 0.7 g/kWh for motors up to 85 kW and 0.4 g/kWh for motors above 85 kW. Valid only for diesel-fueled vehicles.
d. There are no criteria to determine which vehicle model shall comply with one or the other set of emission limits, but the manufacturer must certify that at least one engine model complies with the most stringent standards and ensure that its sales volume will be maintained over a specified percentage during the year. This strategy ensures that vehicular emissions are reduced among the best-selling engine models, covering at least the specified percentage of the market, with minimum investment and engineering effort. It also allows initial development of emission control technologies on one or a few models and subsequent application of these technologies to other models. The vehicle models sold in any geographic region are not restricted. In the case of urban buses local governments may require the use of the lowest emission models available.
e. To be confirmed by CONAMA.
Source: CETESB 1994b.

duced urban buses in 1994. These standards were expanded in scope and made more stringent for subsequent years. By 2002 all new diesel-fueled vehicles will be required to comply with emission limits similar to current U.S. standards.

A system of prototype and production certification of new vehicles has been established based on the U.S. model. Certification takes about sixty days. All manufacturers must submit statements specifying the emissions of all the models they produce. PROCONVE requires a written emission compliance certification by the manufacturer for five years or 80,000 kilometers (whichever comes first) for light-duty vehicles and five years or 160,000 kilometers (whichever comes first) for heavy-duty vehicles. Alternatively, this certification may be replaced by a 10 percent reduction in the emission levels specified in Tables 4.34 and 4.35, except for the CO emission limit at idle.

CONAMA Resolution 7 of August 1993 and São Paulo Sate Decree 38,789 of July 1994 estab-

lished CO and HC emission limits and associated testing procedures for in-use light-duty vehicles with spark-ignition engines (Table 4.36). Implementation of this legislation is left to the discretion of state and local governments, however.

Vehicle inspection programs. In 1993 CETESB prepared a periodic inspection and maintenance program for the SPMR according to the requirements of the São Paulo State decree regarding implementation of CONAMA Resolution 7/93. A key component of this program involved a two-stage inspection of in-use vehicles. The first stage included annual CO and HC emissions testing of in-use light-duty vehicles. This measure was important because previous test data had indicated that 75 to 90 percent of in-use light-duty vehicles were not in compliance with manufacturers' specifications for CO emissions (Szwarc 1993). The second stage of CETESB's program included measurement of exhaust emissions from in-use heavy-duty vehicles. CETESB also drafted the request for proposals for this program, which divided the SPMR in four areas, each to be operated by a single contractor under the same bidding process.

Despite this effort, in April 1994 the newly formed Environmental Secretariat of the Municipality of São Paulo published Municipal Decree 34,099/94, establishing the regulatory requirements for the city's inspection and maintenance program. This followed Decree 38,769/94 of the State of São Paulo, which set the regulatory requirements for the SPMR's inspection and maintenance program according to CETESB's recommendations. The September 1994 agreement between the state governor and the city mayor transferred the bidding process and contract administration responsibilities for the inspection and maintenance program to the city of São Paulo. This agreement represented a breakdown of the inspection and maintenance program concept that had been proposed by CETESB for the SPMR. In March 1995 Municipal Law 11,733/95 established the city of São Paulo's inspection and maintenance program based on the terms of Decree 34,099/94. In December 1995 the São Paulo State governor confirmed the September 1994 agreement, maintaining the municipality's administrative control over the city of São Paulo emission inspections and using CETESB's technical support to supervise and audit the inspections. In January 1996, following the bidding process, the city administration chose a consortium of three companies as the contractor for the inspection of the city's entire fleet at centralized inspection stations for a fee of $18. The inspections are expected to start in 1997, and vehicle owners not submitting to annual emission inspections will be fined about $200. The bidding process, however, was the subject of public complaints and was delayed pending resolution of a court case.

In December 1995 the National Council of Transit's (CONTRAN) Resolution 809/95 established an in-use vehicle inspection and maintenance program for the entire country based on integrated safety and emission inspections. This program requires every state transit department to initiate an inspection and maintenance program effective January 1998 but excludes municipalities from inspecting in-use vehicles except public transport vehicles under the authorization of state transit departments. To comply with this resolution, the Brazilian Association of State Transit Departments (ABDETRANS), which also includes the São Paulo Transit Department, is preparing a general outline for the country's integrated inspection program. Thus vehicles owners in the city of São Paulo will be subject to two separate inspections, one by the city and the other by the state of São Paulo.

CETESB has been enforcing smoke emissions from diesel-fueled vehicles since 1976. In addition to routine roadside inspections, CETESB

Table 4.36 Exhaust emission standards for in-use light-duty vehicles with spark-ignition engines in the SPMR

Model-year	*CO (percent by volume)*[a]	*HC (parts per million)* Gasoline, gasohol, LPG, and CNG	*HC (parts per million)* Alcohol and tertiary mixtures
1979 and older	6.0 (7.0)	700	1,100
1980–88	5.0 (6.5)	700	1,100
1989	4.0 (6.0)	700	1,100
1990–91	3.5 (6.0)	700	1,100
1992–96	3.0 (5.0)	700	1,100
1997 and newer	1.0 (1.5)	700	1,100

Note: Angular velocity at low gear is 600–1,200 rpm for all vehicles. The minimum dilution is 6 percent for CO + CO_2 for all vehicles. CO and HC measurements are made at idle/2,500 rpm.

a. Numbers in parentheses indicate optional limits during inspection and maintenance program initiation.

Source: CETESB 1995.

has been inspecting the bus and truck fleets of major transportation companies and promoting training courses. CETESB has provided technical school instructors with a mechanical training course for servicing light-duty vehicles that fail inspections. These instructors have, in turn, provided certified training to mechanics from 140 service stations. By 1997 about 500 service stations are expected to be certified.

Fuel-targeted measures. The main types of motor vehicle fuels used in Brazil are gasohol, ethanol, and diesel fuel. Gasoline is not marketed as a motor vehicle fuel, but is blended with ethanol to formulate gasohol. Ethanol and gasohol are used by light-duty vehicles and diesel fuel is used by heavy-duty vehicles. In addition, CNG is used on a limited basis by some taxis and urban buses.

Gasohol was introduced as a substitute for gasoline in light-duty vehicles following implementation of the 1975 Proalcohol Program, which was aimed at reducing Brazil's dependence on imported oil and supporting sugar cane growers facing a depressed sugar market. In 1977 gasohol contained 4.5 percent anhydrous ethanol and 95.5 percent gasoline by volume. The ethanol content of gasohol was increased to 8.5 percent in 1978, 15 percent in 1979, 20 percent in 1980, and 22 percent in 1985 (Romano and others 1992). During the 1989–92 alcohol crisis (caused by a decline in sugar cane production) the ethanol content of gasohol was temporarily lowered to 13 percent, but was subsequently raised to 22 percent, where it has remained to date.

Ethanol (which contains 4 percent water) was introduced as a motor vehicle fuel in 1979 with the launching of the second phase of the Proalcohol Program. The use of ethanol in light-duty vehicles increased steadily until the beginning of the alcohol crisis in 1989. At that time ethanol-fueled vehicles made up 49 percent of the light-duty fleet in the SPMR (Murgel 1990). To overcome the ethanol shortage another type of fuel called MEG—consisting of a mixture of 33 percent methanol, 60 percent ethanol, and 7 percent gasoline by volume—was introduced in late 1990. This fuel, which is fully compatible with ethanol (similar viscosity, density, and air-fuel ratio), was used as a substitute for ethanol in original equipment manufacture vehicles without any special engine calibration or modification. Thus MEG replaced 40 percent of ethanol use in such vehicles. Between March 1990 and November 1993 about 7 billion liters of MEG were consumed in the SPMR (Branco and Szwarc 1993). After the alcohol crisis ended MEG was no longer used in place of ethanol.

All light-duty vehicles in Brazil use lead-free fuels. The average lead content of gasoline, which is used to formulate gasohol, fell from 0.25 g/liter in 1977 to 0.15 g/liter in 1979, 0.09 g/liter in 1983, and 0.06 g/liter in 1987 (Romano and others 1992). Since 1991 no lead has been added to the gasoline produced in Brazil.

Nearly all the heavy-duty vehicles in the SPMR are diesel-fueled. Because 80 percent of the commercial transport of goods in Brazil is by road, the demand for diesel fuel (equivalent to 35 percent of the country's crude oil consumption)[25] is higher than the diesel fraction of crude processed by Brazilian refineries. To meet this demand, Petrobrás produces a reformulated diesel fuel by blending heavier and lighter petroleum fractions with the diesel fraction.

Sulfur in diesel fuel is the main source of ambient SO_2 pollution from motor vehicles in the SPMR. In October 1996 the sulfur content of diesel fuel sold in the SPMR was reduced from 0.5 to 0.3 percent by weight after the hydrotreating unit of Petrobrás' Paulínia refinery came on line. The sulfur content of the diesel fuel marketed for intercity transport is limited to 0.5 percent by weight. Both grades of diesel fuel are sold at the same price. Petrobrás is planning to introduce a new low-sulfur diesel fuel with a maximum sulfur content of 0.05 percent by weight. This fuel is expected to be used by urban buses starting in 2000 (Szwarc 1997).

In 1994 transport fuel consumption in Brazil was 55 billion liters for diesel fuel, 13 billion liters for gasoline, and 18 billion liters for ethanol. Both ethanol and diesel are heavily subsidized to support the Proalcohol Program (see Chapter 3) and promote road transportation. In 1994 the price of diesel fuel, which had been set at 50 percent of the price of gasoline, was sharply increased. In October 1996, service stations in the SPMR charged about $0.65 a liter for gasohol, $0.54 a liter for alcohol, and $0.36 a liter for diesel fuel.

CNG is used on a limited basis in the SPMR. In addition to the 3,000 taxis equipped with dual-

25. In comparison, diesel fuel accounts for 18 percent of crude oil refined in the United States, 22 percent in Japan, and 26 percent in Canada.

fuel systems, about 80 CNG-fueled urban buses are circulating. Two vehicle manufacturers (General Motors and Volkswagen) are offering ethanol-fueled vehicles that can be dual-fueled with CNG. The use of CNG in buses is also promoted by the City of São Paulo by requiring private bus companies to acquire CNG-fueled buses. To comply with this requirement bus companies operating in São Paulo have ordered about 500 CNG-fueled buses (Szwarc 1997).

Transport management. The State Secretariat of Metropolitan Transport is preparing an integrated urban transport, land use, and air quality strategy for the SPMR. This plan will guide future transport investment as well as the planning, coordination, and evaluation of the effects of private and public investment proposals. To test different scenarios, the secretariat has developed a model that integrates urban transport, land use, and environmental impacts to assess the overall costs and benefits of different urban transport programs (World Bank 1994).

Bus services on about 100 kilometers of high-density corridors in the SPMR have been given high priority through the use of reserved bus lanes and exclusive bus routes. About 62 kilometers of four trunk-line bus routes are in operation in the SPMR, three of them in the Municipality of São Paulo. These corridors were designed and constructed by the state or municipal government using public funds. In some cases private companies have taken over the provision of the bus fleet and corridor operations at an agreed tariff (Rebelo and Benvenuto 1995).

In terms of peak hour capacity, the SPMR contains some of the most efficient bus lanes and routes in the world. However, some bus corridors have reached their capacities, as indicated by a drop in average bus speeds (World Bank 1994).

São Paulo's state government has created a high-level commission in charge of promoting private participation in the development of major infrastructure projects. It also has been active in forcing the metro to become more cost-conscious and commercially oriented.

A new effort aimed at bringing private participation into the reserved bus lanes and exclusive bus routes is being implemented on two corridors of the SPMR, one in the Municipality of São Paulo and one in the State of São Paulo. The private sector is expected to improve the street system and facilities (including bus stop shelters) on these corridors with its own funds and to operate the system exclusively at an agreed tariff that is periodically reviewed. The operation period will be long enough to allow investors to recoup their investment (Rebelo and Benvenuto 1995). This is one of the few instances worldwide where private sector contractors or operators have been chosen by a public bid to build and operate bus routes.

In 1993 subsidies of municipal public buses operating within the Municipality of São Paulo were running at $1.5 million a day as a result of low tariffs and subsidies being paid on a vehicle-kilometer rather than passenger-transported basis. The municipality then renegotiated and considerably reduced the subsidy, which is now paid on the basis of passenger-kilometer transported. In 1994 a decision was made to privatize buses and maintenance installations that had been operated by the Municipal Public Bus Company.

The São Paulo metro is technically comparable with the world's leading metros. Revenues cover 100 percent of working costs, a level surpassed by only a few East Asian metros (where riders have considerably higher incomes). Increasing tariffs could raise serious affordability issues because many metro users are low-wage earners (World Bank 1994).

To reduce traffic congestion, the City of São Paulo is working to establish staggered work schedules and to control access of trucks to congested inner-city areas. The State of São Paulo is expanding the metro system and has plans to link railways and rail-metro lines, increase the number of exclusive bus lanes, and build an "outer ring" to link major highways and to avoid circulation of trucks within the city (Szwarc 1993).

Air quality monitoring. CETESB operates forty-five automatic and manual air quality monitoring stations in the State of São Paulo. The automatic network has been in operation since 1981 and the manual network since 1973. The automatic network, which monitors ambient pollution levels and meteorological conditions, has twenty-five stationary stations and two mobile laboratories. Data collected by the automatic monitoring stations are immediately transferred to the central station for processing by a computer. The automatic network measures PM-10, SO_2, NO_x, ozone, CO, HC, wind direction, wind velocity, humidity, and temperature. Of the twenty-five stationary stations, twenty-two are in the SPMR and three are in Cubatão. Data collected by the mobile laboratories are stored on perforated tapes that are later processed by the

Table 4.37 Ambient air quality indices for the SPMR

Air quality index	*Air quality standard and levels*	*Pollutant (time-weighted average)* *CO (8-hour) (ppm)*	*SO_2 (24-hour) ($\mu g/m^3$)*	*TSP (24-hour) ($\mu g/m^3$)*	*TSP × SO_2 (24-hour) ($\mu g/m^3$)^2*	*PM-10 (24-hour) ($\mu g/m^3$)*	*Smoke (24-hour) ($\mu g/m^3$)*	*Ozone (1-hour) ($\mu g/m^3$)*	*NO_2 (1-hour) ($\mu g/m^3$)*
50		4.5	80	80		50	60	80	100
100	Air quality standard	9.0	365	240		150	150	160	320
200	Attention level	15.0	800	375	65,000	250	250	200	1,130
300	Alert level	30.0	1,600	625	261,000	420	420	800	2,260
400	Emergency level	40.0	2,100	875	393,000	500	500	1,000	3,000
500	Critical level	50.0	2,620	1,000	490,000	600	600	1,200	3,750

Note: A blank space indicates that no limit was established.
Source: CETESB 1994b.

central computer. The mobile laboratory is used on an as-needed basis to cover areas not monitored by the stationary stations (CETESB 1994b).

The manual network comprises seven sampling stations that measure SO_2 and smoke and eleven stations that measure TSP. Unlike the automatic stations, which automatically transmit the monitoring data every minute, the manual stations require a technician to handle samples at regular intervals during a 24-hour period.

Air quality data gathered by automatic and manual networks are evaluated and immediately disseminated to the public by CETESB. In addition, CETESB provides the media with air quality data and pollution dispersion forecasts on a daily basis. Air quality data are evaluated according to an index established by CETESB in 1981 (Table 4.37). This index is based on the Pollutant Standard Index developed by the USEPA to disseminate air quality information. Air quality data are expressed in a qualitative form as good, regular, inadequate, bad, very bad, or critical and presented to the public using twenty billboards placed near major roads (Table 4.38).

In 1988, through CETESB's leadership, a one-day voluntary vehicle ban in the city center of São Paulo was implemented to simulate the "state of alert" measure that would be taken under extremely high levels of vehicular air pollution. The ban was supported by Civil Defense and public officials. Nearly 200,000 vehicles, representing 90 percent of traffic circulation in the area, participated in the ban. Ambient CO concentrations on that day were about 60 percent lower than normal CO levels (Szwarc 1993).

Evaluation of Implemented Measures

Vehicle emission standards. Pollutant emissions from new vehicles have decreased considerably over the years as a result of Brazilian regu-

Table 4.38 Air quality categories for the SPMR

Index	*Air quality*	*Description of health effects*
0–50	Good	
51–100	Regular	
101–199	Inadequate	Small aggravation of symptoms in susceptible people with symptoms of irritation in healthy people.
200–299	Bad	Diminishing physical resistance and significant aggravating symptoms in people with cardio-respiratory diseases. General symptoms in healthy people.
300–399	Very bad	Premature appearance of certain diseases, aside from significant aggravating symptoms.
More than 400	Critical	Premature death in ill and elderly people. Normal activity of healthy people affected.

Source: CETESB 1994b.

lations.Average pollutant emission factors for new light-duty vehicles in the SPMR are shown in Table 4.39. The reduction in CO and HC emissions between the pre-1980 years and 1985 can be attributed to the shift in motor vehicle fuels (from gasoline to gasohol or ethanol) and improvements in engine design. The 1988-90 emission standards for new light-duty vehicles were lenient enough to be met by manufacturers through engine modifications alone (Branco 1995). For example, on average the 1991 model-year gasohol-fueled vehicles emitted 59 percent less CO, 46 percent less HC, 19 percent less NO_x, and 20 percent less aldehydes in their exhaust than 1985 model-year vehicles.

To comply with the 1992 standards for light-duty vehicles, most manufacturers installed open-loop catalytic converters on engines manufactured in Brazil. General Motors, however, met the standard by manufacturing cars with an electronic fuel injection system (without any catalytic converter; Branco 1995). Exhaust emissions ranged from 3.6 grams/kilometer to 6.3 grams/kilometer for CO, 0.6 gram/kilometer to 0.7 gram/kilometer for HC, 0.5 gram/kilometer to 0.8 gram/kilometer for NO_x, and 0.013 gram/kilometer to 0.042 gram/kilometer for aldehydes. The 1995 model-year alcohol-fueled vehicles emitted 73 percent less CO, 56 percent less HC, and 42 percent less NO_x in their exhaust than the 1985 model-year alcohol-fueled vehicles. Exhaust emission reductions between the 1985 and 1995 model-year gasohol-fueled vehicles were even greater (83 percent for CO, 75 percent for HC, and 62 percent for NO_x). The reductions in exhaust emissions of aldehydes were 77 percent for alcohol-fueled vehicles and 50 percent for gasohol-fueled vehicles (see Table 4.39)

Compliance with the 1997 exhaust emission standards for light-duty vehicles will require the use of a three-way catalytic converter and electronic fuel injection with feedback control of the air-fuel ratio. The 1997 emission limit of 0.03 gram/kilometer for aldehydes is expected to be met through such measures as the use of a palladium catalyst and relocation of the catalyst closer to the engine to enhance adsorption efficiency at higher temperatures (Branco 1995).

Evaporative emissions from light-duty vehicles also have fallen. For example, in 1985, when no control measures were in place, evaporative emissions were 23 grams/test for gasohol-fueled cars and 10 grams/test for ethanol-fueled cars. In 1990, to comply with PROCONVE requirements, evaporative emissions from cars were reduced to less than half the 6.0 grams/test limit through installation of a charcoal canister near the front wheels. In 1992 and 1993 even better results were achieved through design improvements such as installation of thermal insulation between the carburetor and engine (Branco 1995). By 1995 evaporative emissions had been reduced by about 92 percent compared to the 1985 level (see Table 4.39).

To comply with the emission requirements specified in PROCONVE, manufacturers reduced smoke emissions from new diesel engines. In 1992 the production of polluting diesel-fueled engines (those with an absorption coefficient *k* greater than 2.5) was discontinued, and 89 percent of engine models had a low smoke level (with an absorption coefficient *k* lower than 2.0). The rest had an absorption coefficient in the range of 2.0 to 2.5. By comparison, in 1986, 74 percent of diesel-fueled engines had an absorption coefficient lower than 2.0, 16 percent were in the 2.0 to 2.5 range, and 10 percent were above 2.5 (Szwarc 1993).

Vehicle inspection programs. Implementation of a periodic inspection and maintenance program in the SPMR has been delayed by complexities in administrative systems and by politics. In addition, uncoordinated efforts by various levels of government have resulted in inefficiencies in developing inspection and maintenance programs. As a result, if current plans are not altered, separate inspection and maintenance programs by the city and state of São Paulo will require vehicle owners in the city of São Paulo to undergo two annual inspections (one by the city for emissions and the other by the state for emissions and safety). Coordination between these government levels will reduce public confusion and help ensure that resources for vehicle inspections are not wasted.

Periodic inspection of in-use vehicles in the SPMR is expected to ensure compliance with emission standards by improving maintenance. The success of Mexico City's inspection and maintenance program suggests that similar results can be achieved in São Paulo because of the similarities between the vehicle types and technologies used and the quality of vehicle maintenance in the two cities (World Bank 1994). The inspection and maintenance program in the SPMR is expected to reduce CO

Table 4.39 Average emission factors for new light-duty vehicles in the SPMR

Model-year	*Fuel type*	*Exhaust emissions (g/km)* CO	HC	NO_x	Aldehydes	*Evaporative emissions (grams/test)*
Pre-1980	Gasoline	54.0	4.7	1.2	0.050	—
1985 (no control)	Ethanol	16.9	1.6	1.2	0.180	10.0
	Gasohol	28.0	2.4	1.6	0.050	23.0
Limit		24.0	2.1	2.0	—	6.0
1990 (1st phase)	Ethanol	10.8 (36)	1.3 (19)	1.2 (0)	0.110 (39)	1.8 (82)
	Gasohol	13.3 (53)	1.4 (42)	1.4 (13)	0.040 (20)	2.7 (88)
1991 (1st phase)	Ethanol	8.4 (50)	1.1 (31)	1.0 (17)	0.110 (39)	1.8 (82)
	Gasohol	11.5 (59)	1.3 (46)	1.3 (19)	0.040 (20)	2.7 (88)
Limit		12.0	1.2	1.4	0.150	6.0
1992 (2nd phase)	Ethanol	3.6 (79)	0.6 (63)	0.5 (58)	0.035 (81)	0.9 (91)
	Gasohol	6.2 (78)	0.6 (75)	0.6 (63)	0.013 (74)	2.0 (91)
1993 (2nd phase)	Ethanol	4.2 (75)	0.7 (65)	0.6 (50)	0.040 (78)	1.1 (89)
	Gasohol	6.3 (77)	0.6 (75)	0.8 (50)	0.022 (56)	1.7 (93)
1994 (2nd phase)	Ethanol	4.6 (73)	0.7 (56)	0.7 (42)	0.042 (77)	0.9 (91)
	Gasohol	6.0 (79)	0.6 (75)	0.7 (56)	0.036 (28)	1.6 (93)
1995 (2nd phase)	Ethanol	4.6 (73)	0.7 (56)	0.7 (42)	0.042 (77)	0.9 (91)
	Gasohol	4.7 (83)	0.6 (75)	0.6 (62)	0.025 (50)	1.6 (93)

— Not available.
Note: Numbers in parentheses are the percentage reduction relative to 1985 model-year vehicles.
Source: CETESB 1996.

emissions by 11 percent, HC by 19 percent, and PM-10 by 20 percent (Table 4.40).

Fuel-targeted measures. Brazil has the world's largest renewable alternative fuel program, which involves extensive use of sugar cane ethanol either as a pure motor vehicle fuel in dehydrated form or as a 22 percent blend (in hydrated form) with gasoline. This program, which was developed primarily to address the energy needs of the country, has had consequences for the vehicle manufacturing industry, fuel production, and the urban environment. Following initiation of the Proalcohol Program in 1975 ethanol production was geared toward supplying gasohol as a substitute for gasoline in light-duty vehicles. During 1975–82 the motor vehicle fleet grew through addition of gasohol-fueled vehicles. However, between 1982 (shortly after the introduction of hydrated ethanol as a motor vehicle fuel) and 1990, when both alcohol and gasohol were marketed, ethanol-fueled vehicles accounted for most of the growth of the fleet in the SPMR. Since 1990 the pattern has reversed, with less than 4 percent annual growth in the fleet of ethanol-fueled vehicles and about 9 percent for gasohol-fueled vehicles. This latest shift in fuel type can be attributed mainly to the 1989–92 alcohol crisis. Public confidence in ethanol as a reliable motor vehicle fuel was broken by the shortage of sugar cane ethanol, and was further eroded by the poor performance of synthetic ethanol imported to overcome the shortage. These factors, combined with the lower fuel economy of ethanol-fueled vehicles, created a 20 percent price gap between ethanol- and gasohol-fueled cars in the second-hand market (Szwarc 1997).

Use of these alternative fuels rather than gasoline in light-duty vehicles has resulted in lower CO and HC exhaust emissions. Tests conducted on pre-1991 model-year in-use vehicles using gasohol show that greater reductions in CO and HC exhaust emissions can be obtained by increasing the ethanol content in the blend (Table 4.41). For example, a 12 percent ethanol blend gasohol reduces CO emissions by 25 to 67 percent compared to gasoline, and a 22 percent blend reduces CO emissions by 50 to 78 percent. For HC emissions the reduction is 21 percent

Table 4.40 Estimated reductions in pollutant emissions due to the inspection and maintenance program in the SPMR, 1994

(thousands of tons a year)

Emission source	*CO*	*HC*	NO_x	SO_2	*PM-10*
Cars	1,251	310.7	65.4	7.4	7.0
Exhaust emissions—gasohol-fueled private cars	888	86.9	40.0	7.1	6.7
Exhaust emissions—alcohol-fueled private cars	312	35.4	22.9	—	—
Exhaust emissions—gasohol and alcohol-fueled taxis	51	5.0	2.5	0.3	0.3
Evaporative and crankcase emissions—gasohol-fueled vehicles	—	131.6	—	—	—
Evaporative and crankcase emissions—alcohol-fueled vehicles	—	36.3	—	—	—
Refueling emissions—gasohol-fueled vehicles	—	12.2	—	—	—
Refueling emissions—alcohol-fueled vehicles	—	3.3	—	—	—
Motorcycles	30	8.8	0.2	0.3	0.1
Heavy-duty diesel-fueled vehicles	499	81.3	364.5	76.2	22.7
Dust from tires (all vehicles)	—	—	—	—	9.3
Total, road vehicles	1,780	400.8	429.9	83.9	39.1
Reduction due to inspection and maintenance	196	76	0	0	8
Reduction in emissions (percent)	11	19	0	0	20

— Not available.
Source: CETESB 1995; World Bank 1994.

and 29 percent, respectively. Other test data show that before the use of catalytic converters, new ethanol-fueled vehicles emitted substantially less CO and HC than similar gasohol-fueled vehicles (see Table 4.39). However, beginning with the 1992 model-year, new vehicles equipped with catalytic have sharply reduced CO and HC emissions regardless of fuel type. Yet largely because of the age of the motor vehicle fleet, in 1995 only 21 percent of the light-duty vehicle fleet in the SPMR was equipped with catalytic converters (about 850,000 of the 3.3 million gasohol-fueled vehicles and about 150,000 of the 1.5 million ethanol-fueled vehicles).

Table 4.41 Effect of the ethanol content of gasohol on vehicle exhaust emissions

(percent reduction compared to gasoline-fueled vehicles)

Gasohol composition[a]	*CO*	*HC*	NO_x
12% ethanol + 88% gasoline	25 to 67	21	–25
18% ethanol + 82% gasoline	49 to 73	25	–58
22% ethanol + 78% gasoline	50 to 78	29	–67

Note: Negative value indicates increase in emissions.
a. All percentages are by volume.
Source: Derived from CETESB 1996.

The ozone formation potential of HC emissions from the exhaust of alcohol- and gasohol-fueled vehicles depends on the emission rates and photochemical reactivities of various HC constituents. For either fuel type the older model-year vehicles not equipped with catalytic converters are the major polluters. In 1995 ethanol-fueled vehicles in the SPMR were estimated to emit 33,400 tons of HC from their exhaust and contribute 9 percent of HC pollution in the ambient air, whereas gasohol-fueled vehicles emitted 72,600 tons of HC and contributed 19 percent of HC in the ambient air (CETESB 1996). As to the composition of HC emissions from uncontrolled vehicles, those that are ethanol-fueled contain about 70 percent ethanol, 10 percent aldehydes, and 20 percent other organics (Murgel 1990). These aldehyde emissions consist of 85 percent acetaldehyde, 14 percent formaldehyde, and 1 percent other aldehydes. By contrast, HC emissions from gasohol-fueled vehicles contain less than 10 percent each ethanol and aldehydes, and more than 80 percent other organics (such as benzene and 1,3-butadiene). Formaldehyde constitutes about 60 percent of these aldehydes and has a higher toxicity and photochemical reactivity for ozone formation than either acetaldehyde or ethanol (Szwarc 1993). Aldehydes also contribute to the formation of compounds such as peroxide-acetyl nitrates (CETESB 1994b).

Table 4.42 Ambient concentrations of aldehydes in São Paulo and four U.S. cities
(parts per billion)

City (year)	*Formaldehyde*		*Acetaldehyde*	
	Maximum	*Average*	*Maximum*	*Average*
São Paulo-Moóca (1990)	17.0	8.5	26.0	16.2
São Paulo-Moóca (1993)	25.0	4.2	24.0	6.1
São Paulo-Cesar (1990)	41.0	16.8	47.0	21.8
São Paulo-Cesar (1993)	33.0	7.6	40.0	10.6
Los Angeles (1988/89)	25.1	6.1	9.3	3.8
Chicago (1981)	15.6	11.3	3.4	2.1
Houston (1984)	22.5	3.8	6.7	2.2
Atlanta (1992)	8.3	2.9	8.4	3.0

Source: CETESB 1994b.

Formaldehyde and acetaldehyde levels in São Paulo were monitored in 1990 and 1993. Formaldehyde levels in São Paulo are about the same as in four U.S. cities, but acetaldehyde levels are much higher (Table 4.42). The acetaldehyde levels are associated with the extensive use of ethanol as a motor vehicle fuel in São Paulo (CETESB 1996).

The use of ethanol instead of gasoline in light-duty vehicles has helped reduce evaporative (HC) emissions and thereby control ambient ozone levels in the SPMR to a certain degree. The reasons are twofold: first, ethanol's lower vapor pressure means that in the absence of evaporative controls ethanol-fueled vehicles have lower evaporative emissions than similar gasoline-fueled vehicles;[26] second, ethanol has lower photochemical reactivity for ozone formation than most of the volatile HC emitted by gasoline. However, evaporative emissions from uncontrolled gasohol-fueled vehicles in the SPMR have contributed substantially to ozone formation because the addition of ethanol to gasoline increases the vapor pressure of the blend, and the olefinic compounds in the gasoline fraction have higher atmospheric reactivity than ethanol. In 1995 the evaporative emissions from gasohol-fueled vehicles in the SPMR (119,500 tons) were estimated to contribute 31 percent of HC in ambient air. This compares with 34,100 tons of evaporative emissions from ethanol-fueled vehicles, which contribute 9 percent of HC in ambient air.

In 1996 the Reid vapor pressure of gasohol in Brazil ranged from 9.9 psi to 10.9 psi (Alconsult International Ltd. 1996). The high end of this range exceeded the Brazilian standard of 10 psi (69 kPa), which is more lenient than the U.S. standard for gasohol (the 1992 limit during the summer months is 8.8 psi in the southern states, except in the Los Angeles area where it is 8.0 psi; the limits for reformulated gasoline are even stricter). Lowering the vapor pressure of gasoline would reduce evaporative emissions from gasohol-fueled vehicles that lack evaporative controls.

The use of ethanol instead of gasoline has brought environmental benefits in terms of PM emissions because only negligible amounts of PM are emitted from ethanol combustion. In addition, ethanol-fueled vehicles not equipped with catalytic converters have lower NO_x emissions than similar gasoline- or gasohol-fueled vehicles. However, the use of three-way catalytic converters in post-1991 model-year vehicles has reduced considerably the difference in NO_x emissions from the various types of fuels.

Ethanol blending avoids the need to increase the aromatics content of gasoline to maintain the required octane levels. The use of ethanol-based fuels in Brazil has helped accelerate the complete phase-out of lead in gasoline. The shift from leaded to unleaded gasohol has not caused any major mechanical problems in light-duty vehicles. As a result of the Proalcohol Program, between 1977 and 1983 ambient lead concentrations dropped by 80 percent.[27] After lead was

26. However, the lower vapor pressure of ethanol also causes cold-starting problems in ethanol-fueled vehicles in cold weather, which contributes to higher exhaust emissions.

27. In 1977 the ambient lead concentration in the SPMR was 1.4 μg/m3.

eliminated from gasoline in 1991, ambient lead concentrations were 87 percent lower than in 1983.

Alternative fuels have reduced SO_2 emissions from light-duty vehicles in the SPMR because combustion of ethanol does not produce SO_2 and gasohol has lower SO_2 emissions than gasoline because of its ethanol content. Although the sulfur content of gasohol complies with the limit established by national Decree 43 of 1994 (a maximum of 0.2 percent by weight), it is still rather high (about 0.1 percent by weight) for use in catalytic converter-equipped vehicles (Alconsult International Ltd. 1996).[28] The high sulfur content of gasohol reduces the efficiency of catalytic converter-equipped light-duty vehicles, resulting in higher emissions of CO, HC, and NO_x. Emission of sulfur compounds from gasohol-fueled vehicles not equipped with catalytic converters (in 1995 there were about 2.2 million pre-1992 gasohol-fueled vehicles in the SPMR) would increase both ambient PM-10 (through formation of acid aerosols) and SO_2 concentrations.

The alcohol crisis led to the development of MEG, an important new alternative fuel. Use of MEG during the alcohol crisis of 1989–92 helped avoid fuel rationing. MEG's performance and fuel economy made it a viable alternative fuel when the use of pure ethanol was not possible. Its full compatibility with ethanol avoided the need for special engine calibrations or modifications for in-use vehicles (Szwarc 1993). Most exhaust emissions from the combustion of MEG are similar to those from ethanol. MEG emits the same amount of CO, 10 percent less HC, 10 percent more NO_x, 5 percent more formaldehyde, 50 percent less acetaldehyde, and 20 percent less alcohols (Branco 1995; CETESB 1996).

Addition of lighter and heavier fractions to meet the high demand for diesel fuel has negative emission impacts. Addition of the lighter fraction increases NO_x emissions because its low cetane number delays ignition and increases the flame speed. The minimum cetane number (40) requirement specified in CONAMA's Resolution 8 of 1993 is also lower than in other Latin American countries (45 in Chile and Colombia, 45 to 48 in Mexico, and 50 in Argentina). Addition of the heavier fraction increases PM emissions. Giving priority to policies that curtail NO_x and PM emissions from diesel-fueled vehicles is important because diesel-fueled vehicles contribute about 82 percent of NO_x and 30 percent of PM-10 in ambient air in the SPMR.

The lower sulfur content in urban diesel in the SPMR must have reduced SO_2 and sulfate emissions as well as formation of secondary sulfates.[29] The government's policy in setting the same price for both diesel grades should reduce misfueling of diesel-fueled vehicles circulating in the SPMR provided that low-sulfur diesel is not in short supply.

The use of CNG in taxis and buses in the SPMR has not been a complete success, although it has resulted in lower emissions of sulfur compounds, PM, and toxic HC. CNG-fueled buses have shown poor performance and yielded high emissions of CO and NO_x. CO emissions at idle from CNG-converted taxis were also found to be higher than before conversion (Szwarc 1993). To control these emissions CETESB and the state gas company (Comgas) considered certifying conversion kits and conversion shops, but they have not implemented this program because of the lack of demand for CNG-fueled vehicles (Szwarc 1997). This low demand can be explained by the inadequate infrastructure for supplying CNG in the SPMR and the difficulty in selling CNG-fueled vehicles in the second-hand market, especially outside of the SPMR (Tetti 1997). Presently, conversion of alcohol-fueled light-duty vehicles to an alcohol-CNG dual-fuel system is being done by authorized dealers with a warranty (Szwarc 1997). The City of São Paulo's requirement for private companies to acquire CNG-fueled buses instead of diesel-fueled buses will result in emissions benefits.

Transport management. Although improved traffic flows in the SPMR would reduce air pollution and fuel consumption, few efforts had been made in this area until recently. For many years the implementation of necessary actions was hindered by insufficient investment in urban infrastructure, transport systems, and traffic

28. By comparison, the 1990 average sulfur content of unleaded gasoline in the United States was 0.0338 percent by weight (338 ppm).

29. Secondary sulfates constituted 4 to 14 percent of TSP, 10 to 20 percent of PM-10, and 7 to 14 percent of PM-2.5 in the SPMR when higher-sulfur diesel fuel with a sulfur content of 0.5 percent by weight was being used (Alonso and others 1993).

management coupled with managerial discontinuity due to political disputes and poor interaction among the public entities responsible for transport, traffic, and environmental protection. Preparation of the integrated urban transport, land use, and air quality strategy is expected to be a major step forward in planning and implementing projects in the SPMR in accordance with policy objectives that encompass transport, urban planning, and the environment.

Because of congestion, the average traffic speed in the SPMR is 19 kilometers an hour. This compares with 31.5 kilometers an hour when no congestion is present. Congestion is estimated to increase air pollutant emissions from vehicles by 25 percent for CO and 20 percent for HC. In addition, fuel consumption increases by about 20 percent (Szwarc 1993).

Bus operations on many routes in the SPMR are hampered by the traffic signal timing logic, which favors the flow of cars. In addition, bus operations are delayed by excessive waits at stops caused by the ticket collection system and poor accessibility for bus passengers. As a result the average speed of buses operating in the SPMR is 13 kilometers an hour (Rebelo and Benvenuto 1995).

Still, a number of advances have been made. For example, the establishment of exclusive and priority bus lanes has segregated buses from cars and improved traffic flow to the extent that bus trips have been shortened by up to 30 percent, resulting in lower air emissions.

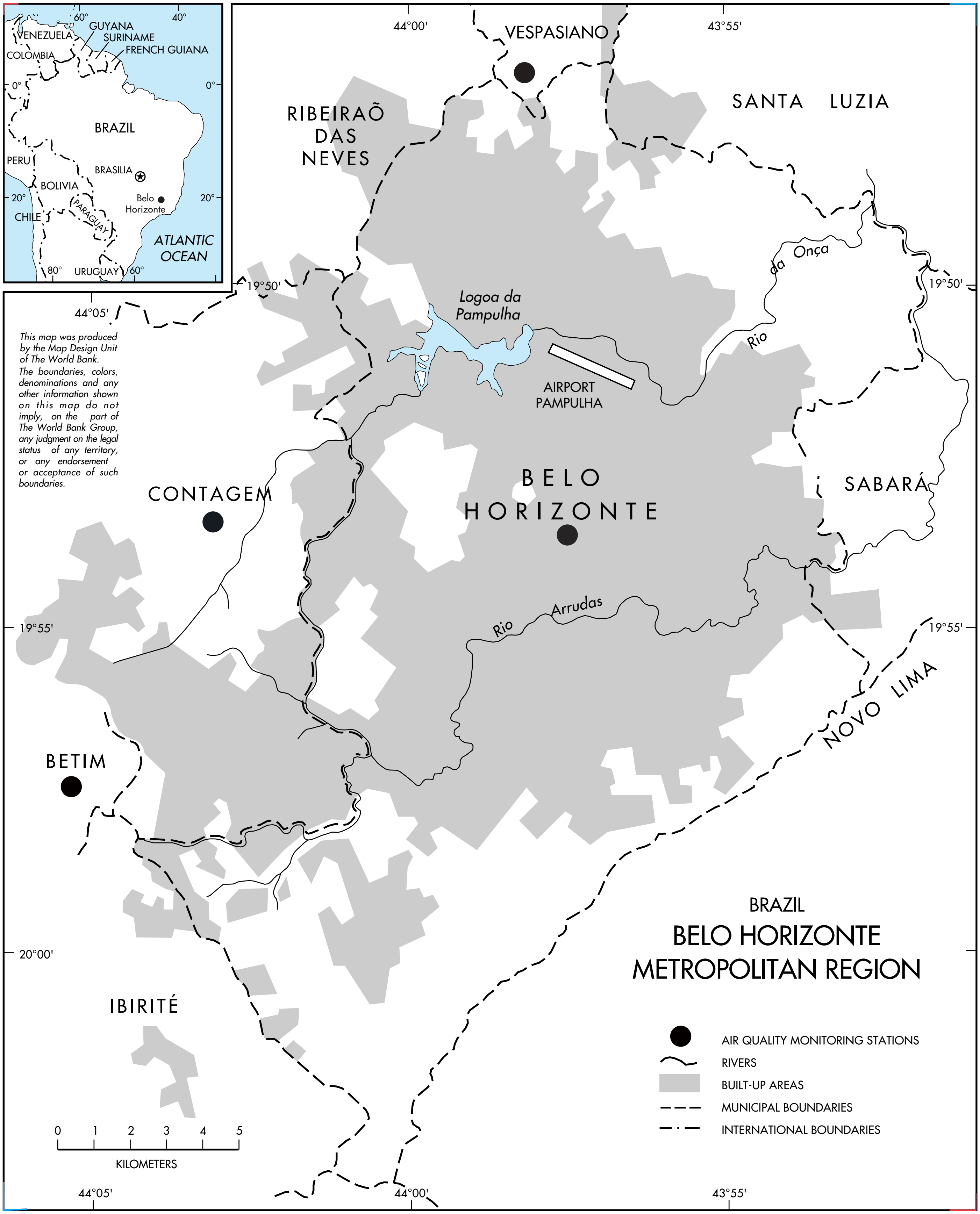
The provision of public transport services considerably reduces air pollutant emissions in the SPMR. For example, in areas where traffic jams occur during metro or bus personnel strikes, the 8-hour average for CO ambient concentrations are within the "attention level" range of 15 ppm to 30 ppm. In addition, integration of train, metro, and bus services has taken a large number of vehicles, particularly highly polluting older ones, out of circulation (Szwarc 1993). Still there is room for further improvement. For example, installing a six-kilometer link between the Roosevelt and Barra Funda stations of the suburban rail system and about a ten-kilometer link between the Paulista and Vila Sônia stations of the metro system would integrate the suburban rail and metro systems. These connections would lower bus trips by 41 million a year and 81 million a year, respectively, in favor of rail-based systems. Such a reduction in bus travel would lower PM-10 emissions by 20 percent, CO emissions by 12 percent, and ozone-forming HC emissions by 19 percent (World Bank 1994).

A small number of trolleybuses operating in the SPMR have recently been privatized by the state. Due to the lack of incentives for their use, however, trolleybuses are not expected to play an important role in curtailing air pollution in the SPMR.

Air quality monitoring. The SPMR's air quality monitoring network is one of the best in the region. The network includes twenty-two stations supported by seven manual stations and two mobile laboratories. The automatic network, which is connected to a central data processing system, disseminates air quality information to the public in real time at billboards placed throughout the SPMR.

Belo Horizonte

IBRD 28161



JULY 1997

Belo Horizonte, the capital of the State of Minas Gerais and third largest city in Brazil, had a population of 2.06 million people in 1993. The Belo Horizonte Metropolitan Region (BHMR) comprises the city of Belo Horizonte and twenty-two other municipalities. In 1993 the BHMR's population was 3.57 million people, spread over an area of 5,824 square kilometers (Almanaque Abril 1995). By 2000 the population of Belo Horizonte is expected to reach 2.95 million and the BHMR 5.16 million. The BHMR generates about half the gross domestic product of the State of Minas Gerais and is considered Brazil's third most important economic region (World Bank 1995).

The BHMR is located at an altitude of about 850 meters in the foothills of the Serra do Curral mountains which extend from southwest to the northeast. Belo Horizonte is located in a lower area, with well-demarcated openings through the hills to the municipalities of Contagem, Betim, and Ibirite to the west and the municipality of Santa Luzia to the northeast. The municipalities of Pedro Leopoldo and Vespasiano are located on an open plain in the northern part of the BHMR (Leme Engenharia 1991).

The BHMR has a subtropical climate, with monthly average temperatures of 19°C during the winter and 23°C during the summer. The annual precipitation, about 1,450 millimeters, falls almost entirely between December and March. Winds are predominantly from the east and northeast, with an annual average speed of 2.1 meters per second. Thermal inversions occur during the dry season (June through September; Leme Engenharia 1991).

Ambient Air Quality

Ambient air quality data for the BHMR is limited. The available data show that ambient TSP and PM-10 concentrations are in violation and SO_2 concentrations are in compliance with Brazil's air quality standards. No ambient monitoring data is available for other air pollutants such as CO, NO_2, and ozone.

Between 1984 and 1988 ambient TSP concentrations were monitored in Belo Horizonte, Betim, Contagem, Lagoa Santa, Pedro Leopoldo and Vespasiano. On at least one day during this period the 24-hour national and state TSP standard of 240 μg/m³ was exceeded at all municipalities except Belo Horizonte (at stations 71 and 82) and Lagoa Santa. The highest monitored 24-hour TSP concentrations were 474 μg/m³ in Belo Horizonte, 253 μg/m³ in Betim, 361 μg/m³ in Contagem, 337 μg/m³ in Pedro Leopoldo, and 521 μg/m³ in Vespasiano. Between 1984 and 1988 annual average TSP concentrations exceeded the 80 μg/m³ national and state standard in Betim (with a maximum annual average of 123 μg/m³ in 1987), Contagem (181 μg/m³ in 1985–86), Pedro Leopoldo (96 μg/m³ in 1991–92), and Vespasiano (118 μg/m³ in 1987). Annual average TSP concentrations in Belo Horizonte and Lagoa Santa were in compliance with the standard (Table 4.43).

Ambient monitoring of TSP resumed in 1991 at five monitoring stations in Belo Horizonte, Contagem, and Pedro Leopoldo. During a twelve-month period in 1991-92 ambient 24-hour TSP concentrations at all the stations exceeded the standard at least once and, in some cases, up to three times. The highest monitored 24-hour TSP concentrations were 293 μg/m³ at station 75 in Belo Horizonte, 604 μg/m³ at station 35, 561 μg/m³ at station 37, and 345 μg/m³ at station 44 in Contagem, and 299 μg/m³ at station 124 in Pedro Leopoldo (FEAM 1992). Ambient TSP concentrations were highest during the dry months (June through September) and lowest during the rainy months (December through February; Liu, de Morais, and da Silveira 1992). The annual TSP standard was exceeded in Contagem (107 μg/m³ at a commercial site and 101 μg/m³ at a residential site) and Pedro Leopoldo (96 μg/m³ at a residential site). Annual average TSP concentrations were high at another residential site in Contagem and at a curbside in Belo Horizonte, although they did not exceed the standard (see Table 4.43).

In a study conducted by the municipality of Belo Horizonte, ambient TSP and SO_2 concentrations were monitored at five stations on eight different days in 1992. The 24-hour TSP standard was exceeded at two stations, with a concentration of 253 μg/m³ at Praça da Estação (the Station Square) and 243 μg/m³ at a school site (Colégio Marconi). The geometric average of the 8-day TSP concentrations for these five stations ranged from 80 μg/m³ to 156 μg/m³. During the same period maximum 24-hour SO_2 concentrations for the five stations remained below the national and state standard of 365 μg/m³ (ranging between 55 μg/m³ at the Colégio Marconi and 292 μg/m³ at the Station Square).

Table 4.43 Annual average TSP concentrations in the BHMR, 1985–92
(micrograms per cubic meter)

		Year			
Municipality	*Station*	*1985–86*	*1987*	*1988*	*1991–92*
Belo Horizonte	43	68	—	—	—
	71	49	52	41	—
	75	—	—	—	80
	82	—	63	58	—
Betim	33	92	123	112	—
Contagem	35	96	90	90	76
	37	—	—	—	101[a]
	44	—	—	—	107
	45	181	—	—	—
	63	—	—	85	—
Lagoa Santa	113	29[b]	—	—	—
Pedro Leopoldo	123	97	98	82	—
	124	—	—	—	96[c]
Vespasiano	112	98	118	—	—

— Not available.
Note: Except where indicated, the sampling period varies from ten to twelve months and the number of 24-hour sampling days varies from thirty-seven to fifty-two.
a. Sampling period is nine months, and the number of 24-hour sampling days is twenty-eight.
b. Data are for 1985. Sampling period is ten months, and the number of 24-hour sampling days is thirty-two.
c. Sampling period is eight months, and the number of 24-hour sampling days is thirty.
Source: Data derived from FEAM 1992.

The arithmetic average of 24-hour SO_2 concentrations ranged from 19 μg/m^3 to 38 μg/m^3 for four of the stations but was 120 μg/m^3 at the Station Square (the national and state SO_2 standard for the annual average is 80 μg/m^3; Fundação Christiano Ottoni 1992). At the Station Square contributors to the SO_2 levels include emissions from buses, trucks, and trains.

In 1995-96 ambient PM-10 and SO_2 concentrations were continuously monitored during various months at Belo Horizonte, Contagem, and Betim. During the five months monitored at the Belo Horizonte station, where air quality is affected by local traffic, the 24-hour PM-10 standard (150 μg/m^3) was exceeded once with a concentration of 174 μg/m^3. At the Betim station, located in an area remote from the local traffic but close to Petrobrás' Gabriel Passos refinery, the maximum 24-hour PM-10 concentration during an eight-month monitoring period was 119 μg/m^3. At the Contagem station, where air quality is affected mostly by local traffic (especially diesel-fueled vehicles) and to a certain extent by local industries, the 24-hour PM-10 standard was exceeded ten times during a ten-month monitoring period. The maximum 24-hour PM-10 concentration monitored at this station was 276 μg/m^3 (Table 4.44). The 24-hour SO_2 standard (365 μg/m^3) was not exceeded at any of the stations. The maximum SO_2 concentrations measured were 130 μg/m^3 at Belo Horizonte, 74 μg/m^3 at Contagem, and 87 μg/m^3 at Betim (FEAM 1996).

Sources of Pollutants

Air emission inventories for the BHMR, last compiled in 1986 for fixed sources and 1991 for mobile sources (Table 4.45), indicate that industry and motor vehicles are the main emission sources (Leme Engenharia 1991). Since 1986 some industries have installed air pollution control equipment and since 1991 the vehicle fleet has expanded considerably. Although the amounts and sources of emissions have changed, most air pollution is still caused mainly by industry and vehicles (Liu 1995).

Contagem and Belo Horizonte are the municipalities most affected by vehicular air pollution. Air quality in Contagem also suffers from the emissions of local industries as well as from air pollution drifting from Belo Horizonte. The main industrial activities affecting air quality in

Table 4.44 Ambient PM-10 concentrations in the BHMR, 1995–96
(micrograms per cubic meter)

		Belo Horizonte		*Betim*		*Contagem*	
Year	*Month*	*24-hour maximum*	*Monthly average*	*24-hour maximum*	*Monthly average*	*24-hour maximum*	*Monthly average*
1995	July	70	28	102	38	129	51
	August	99	46	119	66	212	67
	September	174	57	102	43	231	76
	October	—	—	53	19	133	64
	November	—	—	83	32	96	49
	December	—	—	45	26	116	52
1996	January	44	23	71	48	87	44
	February	47	29	58	36	47	36
	March	—	—	—	—	—	—
	April	—	—	—	—	—	—
	May	—	—	—	—	135	59
	June	—	—	—	—	276	105

— Not available.
Source: FEAM 1996.

the BHMR are located in the municipalities of Contagem and Betim, west of Belo Horizonte. These industries include automotive, ceramics, glass, and cement manufacturing. The main air pollutants from these industries are TSP and SO_2. In addition, NO_x emissions from Petrobrás' refinery in Betim are a concern. Other major air emission sources include an iron and steel plant located in the municipality of Belo Horizonte near Contagem (with SO_2 and PM emissions) and a cement plant in the municipality of Pedro Leopoldo north of Belo Horizonte (with PM emissions). A cement plant located in Vespasiano recently reduced its PM emissions by installing control equipment.

Air emissions from the transport sector have increased with the rapidly growing number of vehicles in the BHMR. For example, between 1980 and 1991 the number of buses, cars, and trucks in Belo Horizonte increased by 71, 72, and 90 percent, respectively (Figure 4.14). In 1991 motor vehicles circulating in the city accounted for 88 percent of the vehicles in the BHMR. About 60 percent of the vehicle fleet and 50 percent of the urban buses in circulation are more than eight years old (Liu 1995).

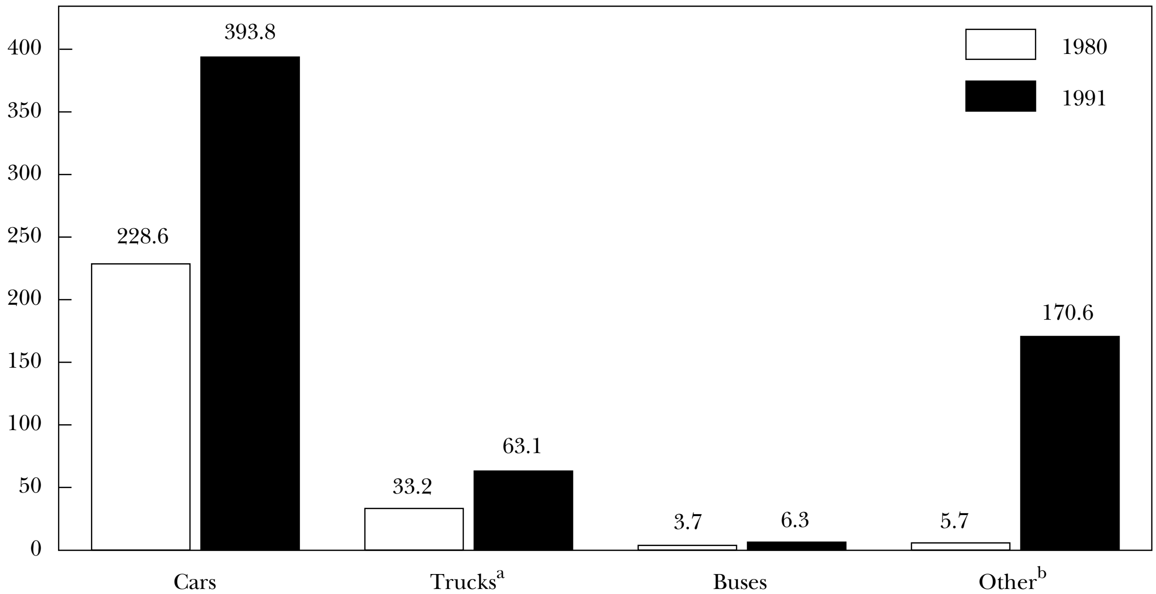
Table 4.45 Estimates of transport-related pollutant emissions in the BHMR, 1991
(thousand tons per year)

Emission source	*CO*	*HC*	*NO_x*	*SO_2*	*PM*	*Aldehydes*
Exhaust emissions						
Ethanol-fueled vehicles	22.5	2.3	1.9			2.0
Gasohol-fueled vehicles	122.6	7.2	4.7	0.2	0.8	1.0
Diesel-fueled vehicles	25.0	4.7	25.4	3.2	1.5	1.9
Evaporative emissions		12.6				
Crankcase emissions		2.8				
Road emissions (from tires)					1.7	
Transfer operations[a]		2.9				
Total	170.1	32.5	32.0	3.4	4.0	4.9

Note: A blank space indicates insignificant emissions.
a. From fuel stations.
Source: Leme Engenharia 1991.

Figure 4.14 Road-based vehicles in Belo Horizonte

Number of vehicles (thousands)



a. Includes light- and heavy-duty trucks.

b. Includes vans, agricultural and construction vehicles, motorcycles, and bicycles.

Source: IBGE 1980 and 1991.

Motor vehicle fuels in the BHMR include ethanol (which contains 4 percent water) and gasohol (a blend of 22 percent anhydrous ethanol and 78 percent gasoline) for light-duty vehicles and diesel fuel for buses, trucks, and some other vehicle types. In 1991, 55 percent of the motor vehicles in the BHMR were fueled with gasohol, 28 percent with ethanol, and 17 percent with diesel fuel (Leme Engenharia 1991). PM and SO_2 were emitted mostly by diesel- and gasohol-fueled vehicles (see Table 4.45). Diesel-fueled vehicles accounted for 38 percent of PM emissions and 94 percent of SO_2 emissions from transport-related sources. Gasohol-fueled vehicles were responsible for 20 percent of PM and 6 percent of SO_2 emissions. PM emissions caused by tire movement on the roads were also significant (43 percent).

Some 3.2 million person-trips take place each day in the BHMR. Of these, 68 percent are by bus, 25 percent are by private car, 1.7 percent are by urban train, and 5.3 percent are by other modes (mainly bicycling and walking). At peak periods the main roads in the BHMR are congested. This level of urban transport activity, dominated by road-based motorized modes, adversely affects the BHMR's environment (World Bank 1995).

The BHMR's road network is radial, and all ten of its main corridors intersect the beltway that surrounds it. The three busiest corridors are Amazonas Avenue, António Carlos Avenue, and Cristiano Machado Avenue. Municipal and inter municipal bus services are provided by 3,949 vehicles that are privately operated by 74 companies on 425 routes (CBTU-Demetrô 1995). Bus service is generally of low speed, unreliable, and infrequent at peak hours because of congestion. In 1991, 5,655 taxis were registered in Belo Horizonte, carrying 75,000 passengers a day (IBGE 1991).

The suburban train, known as Demetrô, began operating in 1986. The system consists of a single 16.1-kilometer line that runs parallel to the main east-west highway. This line carries about 50,000 passengers a day, considerably less than the 250,000 originally planned. Ridership is low because of the network's length, which is far shorter than was originally planned because of budget problems. Demetrô is integrated with

seventy-four bus lines at just one terminal (Eldorado), that generates about 60 percent of its demand. For passengers who are able to walk to and from the stations, Demetrô offers a comfortable and reliable mode of transport. But if their origins and destinations are beyond a reasonable walking distance, the lack of stations and limited integration with bus services make the system impractical and expensive. The lack of integration with buses discourages rail trips and encourages bus and car use adding to congestion and transport air pollution during peak hours (World Bank 1995).

Institutional Responsibilities

Federal institutions. The federal environmental institutions are described in the section on São Paulo. The Brazilian Urban Train Company (CBTU), through its Belo Horizonte subsidiary (STU-BH), operates Demetrô. Although the subsidiary is currently under the jurisdiction of the federal government, it is expected to be transferred to the State of Minas Gerais in 1997.

State institutions. The State Secretariat of Science, Technology and the Environment was created in 1987 to plan, organize, direct, coordinate, execute, and control all sectoral activities related to scientific and technological development and environmental protection. In the environmental area, the secretariat's responsibilities include formulating state policies and directives, elaborating plans and programs to improve the environment, stimulating, sponsoring basic and applied research, coordinating activities by entities under the secretariat, and initiating and coordinating the execution of state environmental policies and programs. The entities under the secretariat are the State Council for Environmental Policy (COPAM), State Council of Science and Technology (CONECIT), and Cartographic Coordination Council (CONCAR). The entities affiliated with the secretariat are the State Foundation for the Environment (FEAM), Foundation for Technology Center of Minas Gerais (CETEC), Institute of Weights and Measurements of Minas Gerais (IPEM), and Research Support Foundation of Minas Gerais (FAPEMIG).

The State Council for Environmental Policy was created in 1977. Its responsibilities include developing the state's environmental policies; formulating environmental legislation; helping municipalities with environmental protection, conservation, and improvement efforts; establishing environmental priority areas; enforcing (directly or through delegation of authority) environmental policies; and fostering public awareness of environmental issues. The council's twenty-five members are drawn from various parts of society, including government offices, civic associations, and universities. Before FEAM was established the council directed the Foundation for Technology Center of Minas Gerais to conduct air pollution research for the BHMR.

FEAM was established in 1987 to conduct studies and research on the environment and to help ensure its protection, conservation, and improvement in accordance with the council's directives. FEAM is responsible for conducting research on pollution control and standard setting; proposing measures for environmental protection, conservation, and improvement; offering specialized environmental services, including environmental training; developing public education activities on environmental issues; supporting municipalities in developing and implementing local environmental programs; and enforcing environmental legislation on behalf of the State Council for Environmental Policy. It also monitors air quality in the BHMR.

The Roads Directorate of Minas Gerais regulates intermunicipal bus services and the road network in the BHMR.

Metropolitan institutions. In 1993 the State of Minas Gerais established the BHMR Metropolitan Council (AMBEL) to foster integration of metropolitan transport services, approve and supervise implementation of the BHMR master plan and its budget, establish guidelines for tariffs on metropolitan public services (including transport), and administer the Metropolitan Development Fund. The council has a number of sectoral technical committees, including the Water Resources and Environmental Committee, Intermunicipal Transport and Road Committee, and Land Use Committee.

For the implementation of the World-Bank financed Belo Horizonte Metropolitan Transport Decentralization Project, the State of Minas Gerais and the municipalities of Belo Horizonte, Betim, and Contagem signed an agreement to create a permanent integrated planning group that will function as a precursor to a regional transport coordination commission (World Bank 1995).

Local institutions. Municipalities are the most important environmental institutions at the local level. The Municipality of Belo Horizonte has a Motor Vehicle Pollution Branch within the Municipal Secretariat of Environmental Control. This secretariat has been involved in signing agreements with the state government, conducting air quality monitoring studies, passing local environmental legislation, and enforcing laws and regulations within its jurisdiction.

The Belo Horizonte Transport and Transit Company, a municipal agency, regulates bus services within the Municipality of Belo Horizonte. It is also responsible for traffic management and control in the municipality.

Implemented Measures

Vehicle emission standards. The national regulatory measures for light-and heavy-duty vehicles are described in the São Paulo section. These measures, which include emission standards for light-and heavy-duty vehicles, also apply to the BHMR.

In 1988 the Environment Secretary of the Municipality of Belo Horizonte signed the "Oxygen Operation" agreement with the State of Minas Gerais to reduce air emissions from diesel-fueled vehicles. This agreement required compliance with Municipal Law 4253/1985 and its Decree 5893/1988. Article 25 of this decree limits smoke emissions from diesel-fueled vehicles to No. 2 on the Ringelmann scale or its equivalent.[30]

Vehicle inspection programs. Since 1988 the Municipality Belo Horizonte's Environment Secretariat has been testing buses circulating in Belo Horizonte as part of the Oxygen Operation program. The tests are performed at bus terminals and involve measurement of smoke emissions using the Ringelmann scale for vehicles equipped with naturally-aspirated diesel engines and the filtration method (through an equipment inserted directly into the tailpipe) for turbocharged vehicles. A notice is given during the first inspection if a bus does not comply with standards. If the problem is not corrected within a certain period, fines are imposed. Three technicians and two policemen conduct the inspections. The Oxygen Operation program was recently extended to trucks and intercity buses. The Municipality of Contagem's Environmental Secretariat plans to initiate a similar testing program for buses and trucks.

The BHMR does not have a periodic inspection and maintenance program that measures emissions at inspection stations. However, such a program is being prepared under the World Bank-financed transport management project for Belo Horizonte, mentioned earlier.

Fuel-targeted measures. Fuel policies—including type, quality, supply, and price—are determined at the national level. For the most part the discussion in the São Paulo section is valid for the BHMR.

Most cars in the BHMR use either ethanol or gasohol. The average lead content of gasoline was reduced from 0.25 g/liter in 1977 to 0.15 g/liter in 1979, to 0.09 g/liter in 1983, and to 0.06 g/liter in 1987. Since 1991 gasohol has been lead-free.

Most heavy-duty vehicles (buses and trucks) use diesel fuel. Two grades of diesel fuel, with different sulfur contents, are available. The low-sulfur grade is used by diesel-fueled vehicles circulating in the BHMR. In October 1996 the sulfur content of this diesel fuel was reduced from 0.5 to 0.3 percent by weight. The high-sulfur grade is allowed for vehicles operating outside the BHMR. The sulfur content of this fuel was reduced from 0.9 to 0.5 percent by weight. Both grades of diesel fuel are sold at the same price.

Transport management. Of the ten main roads in the BHMR, only Cristiano Machado Avenue has a reserved bus lane. Buses in the segregated busway move at about 25 kilometers/hour, although this speed drops to 9 kilometers/hour in the central business district.

Bus routes are allocated to private operators on the basis of competitive bidding and regulated (including the setting of tariffs) by the Belo

30. Smoke opacity measurement using the Ringelmann scale is an old technique that relies on visually matching the color of a smoke with a series of shades, ranging from white (Ringelmann No. 0) to black (Ringelmann No. 5), printed on a white card. By looking through a hole in the card at a smoke plume, the user can judge which shade of gray the smoke is closest to, and thus assign a Ringelmann number to the smoke. Ringelmann No. 1 corresponds to roughly 20 percent opacity, No. 2 to 40 percent opacity, No. 3 to 60 percent opacity, No. 4 to 80 percent opacity, and No. 5 to 100 percent opacity.

Horizonte Transport and Transit Company in the Municipality of Belo Horizonte and by the Roads Directorate of Minas Gerais across the municipalities within the BHMR. Both entities, which have a clearinghouse (Câmara de Compensação) for bus tariffs, pay for bus services according to a standard cost formula that they approve. This approach is used to compensate bus companies that charge tariffs below the cost estimated with the standard formula. No subsidies are paid to bus operators, however (World Bank 1995).

The World Bank-financed transport project will extend the urban rail system by 12 kilometers, construct nine new rail stations and improve an existing station, integrate the rail system with urban buses serving the BHMR by constructing three terminals, and introduce traffic engineering measures (signals, signs, busways, bus lanes, and shelters for bus passengers) and a road traffic control system (such as a centralized signal control system). In addition, the project will upgrade the BHMR's master plan and prepare an integrated land use, urban transport, and air quality strategy (World Bank 1995).

Air quality monitoring. Air quality monitoring in the BHMR was initiated in 1984 with a monitoring network established by the Foundation for Technology Center of Minas Gerais at commercial, industrial, curbside, and residential locations. The pollutants of concern were TSP and SO_2. Because SO_2 monitoring equipment was not available, total sulfation rates were measured instead. TSP concentrations were measured using high-volume samplers and analyzed gravimetrically. The number of stations in operation varied from twenty-three to thirty-four a year for total sulfation and from seven to twelve for TSP. Many of the stations suffered operational difficulties. The operation of the network was suspended in 1988 because of lack of funding.

In 1991 FEAM introduced a new air quality monitoring network that used high-volume equipment to sample TSP in the BHMR. This network included five monitoring stations; three were in Contagem (stations 35, 37, and 44) and one each in the municipalities of Belo Horizonte (station 75) and Pedro Leopoldo (station 124). All field and laboratory work as well as evaluation of the results were conducted by the Foundation for Technology Center of Minas Gerais, with the results sent to FEAM each month. The monitoring network was suspended in early 1993 because of insufficient funding.

Between February 1992 and February 1993 the municipality of Belo Horizonte contracted the Federal University of Minas Gerais to monitor ambient TSP and SO_2 concentrations. Five monitoring stations in Belo Horizonte were used for this purpose.

Air monitoring in the BHMR, which for many years had been hampered by lack of funding, started again in May 1995 as a result of a 1994 legal agreement between Petrobrás, the State Council for Environmental Policy, and FEAM. The investment cost of the monitoring network ($400,000)—which includes the automatic stations in Belo Horizonte, Betim, and Contagem—was financed by Petrobrás. These three stations are capable of continuously monitoring ambient SO_2 and PM-10 levels and meteorological parameters (wind direction and speed, temperature, and relative humidity). The monitoring data are sent by telephone lines to FEAM and Petrobrás. The system generates real-time data as well as daily, weekly, monthly, and annual averages. FEAM is responsible for operating the monitoring network (FEAM 1996).

Evaluation of Implemented Measures

Vehicle emission standards. The evaluation of emission standards in the São Paulo section is also valid for the BHMR. In summary, the emission limits imposed on manufacturers of new light- and heavy-duty vehicles have helped reduce vehicular emissions.

Vehicle inspection programs. Between June 1988 and July 1993, 65 percent of the 25,515 buses inspected were found to be in compliance, 12 percent were brought to compliance after the first failure, and 23 percent were fined. With the implementation of the Oxygen Operation program the noncompliant buses were reduced from 53 percent in 1988 to 19 percent in 1993 (Table 4.46). The increase in compliance is associated with a reduction in pollutant (especially PM) emissions.

The inspection and maintenance program being developed under the World Bank-financed project is expected to establish an inspection scheme for in-use vehicles in the BHMR. Such a program would reduce emissions by encouraging proper maintenance of these vehicles.

Fuel-targeted measures. The evaluation of fuel types presented in the São Paulo section also

Table 4.46 Bus inspection results for Belo Horizonte, 1988–93

Year	Total number inspected	In compliance		Notified-corrected		Fined	
		Number	Percent	Number	Percent	Number	Percent
1988	6,899	3,231	47	1,227	18	2,441	35
1989	2,618	1,827	70	257	10	534	20
1990	4,788	3,080	65	482	10	1,216	25
1991	4,622	3,358	73	450	10	814	18
1992	4,155	3,124	75	389	10	642	15
1993	2,443	1,974	81	179	7	290	12
Total	25,515	16,594	65	2,984	12	5,937	23

Note: Data for 1993 only cover January–June.
Source: Prefeitura Municipal de Belo Horizonte 1993.

holds for the BHMR. In summary, the use of ethanol and gasohol in place of gasoline has reduced CO, HC, PM, and SO_2 emissions but increased aldehyde emissions in the exhaust of light-duty vehicles that are not equipped with catalytic converters. Evaporative (HC) emissions have decreased for ethanol-fueled vehicles, but have increased for gasohol-fueled vehicles. The shift from leaded to unleaded gasoline undoubtedly has reduced lead emissions. Because of the lack of reliable ambient air quality data in the BHMR, the effects of these measures cannot be quantified.

Based on fuel quality data for 1996 the Reid vapor pressure and sulfur content of gasohol appear to be high. Lowering the vapor pressure would reduce evaporative emissions from gasohol-fueled vehicles not equipped with evaporative controls, and lowering the sulfur content would reduce CO, HC, and NO_x emissions from gasohol-fueled vehicles equipped with catalytic converters.

The addition of lighter and heavier fractions to meet market demand for diesel fuels increases NO_x and PM emissions from diesel-fueled vehicles. Lowering the sulfur content of the urban diesel fuel must have reduced SO_2 and sulfate emissions as well as the formation of secondary sulfates in the BHMR. Although the government's policy of setting the same price for both diesel grades is intended to reduce misfueling, the requirement to use low-sulfur diesel is not observed by all trucks and buses circulating in the BHMR because it is not enforced. Therefore, the health and environmental benefits of these regulatory measures have not been fully attained (Liu 1995).

Transport management. Because the BHMR Metropolitan Council was formed only recently, policies and regulations affecting urban transport are developed without a formal coordinating arrangement among different government agencies. As a result there has been a lack of consistency in the fares charged by similar or competing transport modes, an absence of criteria to prioritize investments, duplication of investments, and limited modal integration. At times these shortcomings have resulted in bus services operating in corridors served by Demetrô, expensive and time-consuming disagreements on the construction of a light rail transport system, and widely varying subsidy policies that are often based on non economic considerations. Creation of a regional transportation coordination commission would ensure that the recently established cooperation among the Belo Horizonte Transport and Transit Company, the Roads Directorate of Minas Gerais and the Belo Horizonte Subsidiary of the Brazilian Urban Train Company continue irrespective of the political parties in power.

The World Bank-financed transport project is expected to alleviate traffic congestion, which is growing by 20 percent a year. The greatest anticipated benefit of this project will result from the reduction in car and bus traffic due to the new train links. In addition, the traffic management, control, and safety components of this project will reduce accidents and vehicle emissions.

Air quality monitoring. During the 1980s ambient air monitoring in the BHMR focused on TSP instead of PM-10 because the Brazilian PM-10

standards were not established until June 1990. In addition, it was expensive to import PM-10 monitoring equipment, and Brazilian manufacturers did not fabricate it because there was little domestic demand (FEAM 1996).

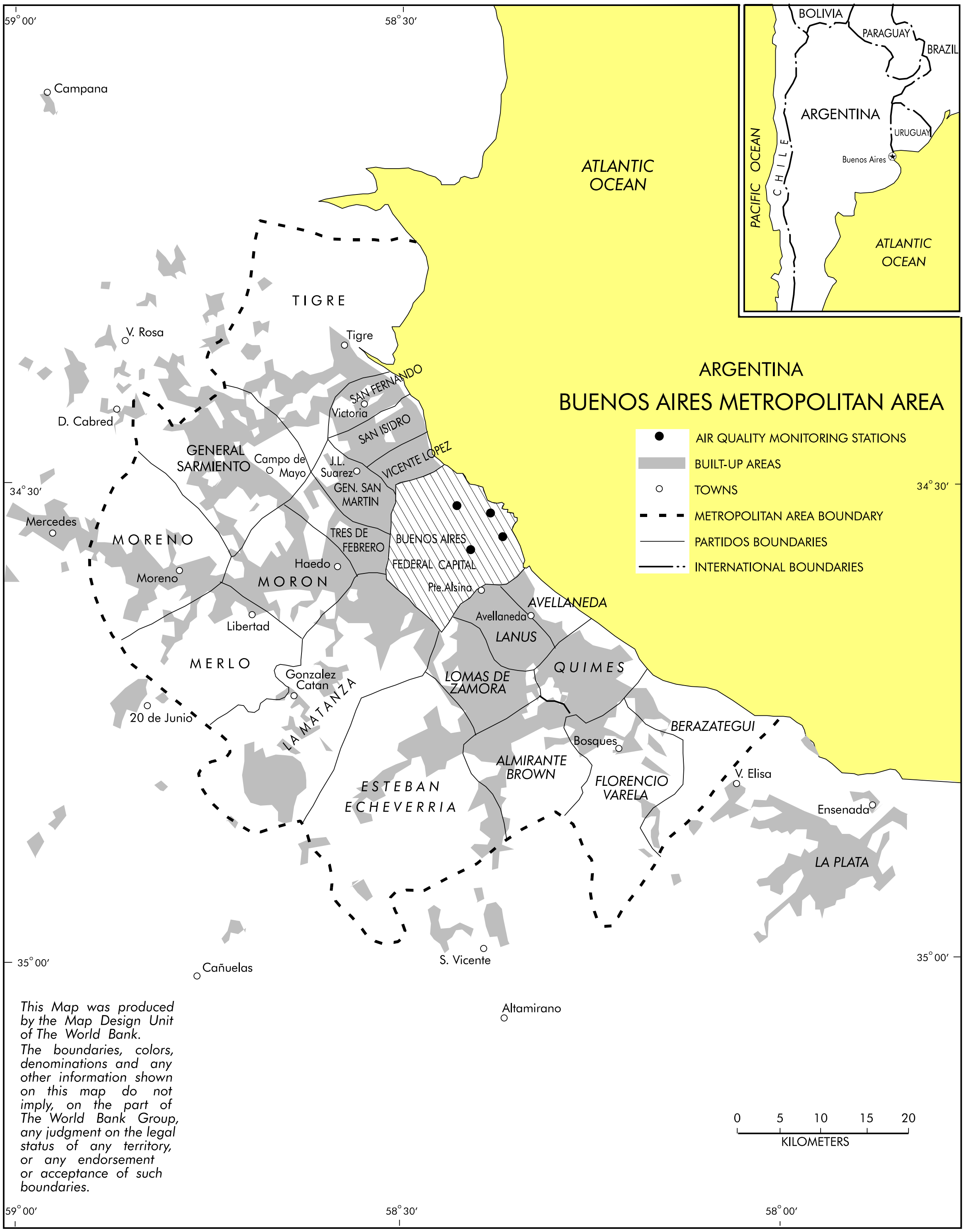
During the 1980s and early 1990s technical problems and a lack of financial resources hampered the operation of the air monitoring network in the BHMR. The quality of the available data is also suspect because no quality control and quality assurance procedures were used. The available data indicate that Belo Horizonte, Betim, Contagem, and Pedro Leopoldo are most affected by industrial and vehicular air pollution, mostly during the dry season. TSP levels in Belo Horizonte originate mainly from vehicles, especially diesel-fueled vehicles. Emissions from diesel-fueled vehicles are also an important source of the high ambient SO_2 levels observed at the Station Square. In Betim, Contagem, and Pedro Leopoldo industries are also important emission sources.

Continuous operation of the three air monitoring stations installed in 1995 has not been possible because maintenance-related problems have caused frequent shutdowns. For example, during March–April 1996 the stations were shut down because of an electrical discharge which damaged microcomputers. Also the local representative of the equipment's foreign manufacturer was deemed not competent to provide the technical assistance necessary to quickly resolve the maintenance-related problems (FEAM 1996).

Because of its remote location , the air quality data from the Betim station does not accurately reflect the level of human exposure to air pollutants in that municipality. Relocation of the station to a populated part of the municipality would provide a better information about pollutant exposure levels. The BHMR also needs a more widespread, permanent air quality monitoring network that would at least measure ambient concentrations of PM-10 and SO_2, and which could be expanded to monitor ambient concentrations of NO_2, CO, ozone, and aldehydes. In addition, the BHMR's outdated emissions inventory needs to be updated to provide data for planning the expansion of the monitoring network and devising pollution control measures. Furthermore, because industrial sources in some parts of the BHMR are believed to be important contributors to air pollution, a joint strategy for industrial and vehicular pollution control needs to be considered. Funds to develop and implement pollution control strategies are currently lacking, but are essential for improving ambient air quality in the BHMR.

Buenos Aires

IBRD 28882



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JULY 1997

The Buenos Aires Metropolitan Area (BAMA) comprises twenty-five municipalities in the Province of Buenos Aires and the city of Buenos Aires (the Federal Capital of Argentina).[31] In 1991 the BAMA contained 10.9 million people, 3.7 times the population of the Federal Capital and about one-third of Argentina's population (Pre-ATAM 1994b). Argentina's economic center, it is located on the southern bank of the Plata River, 160 kilometers from the Atlantic Ocean at an altitude of about 25 meters on a flat topography. The BAMA covers 3,880 square kilometers, of which 200 square kilometers are in the Federal Capital, and has a humid subtropical climate with average temperatures ranging from 10^0C during the winter (June–August) to 24^0C during the summer (December–February). Precipitation averages 1,000 millimeters annually, and varies from 60 millimeters in July to 120 millimeters in March. Air emissions are generally well dispersed by southeasterly and southwesterly winds. However, the winds are not sufficient to disperse vehicular air pollution in narrow, heavily traveled streets during weekday commuting and business hours.

Ambient Air Quality

Limited ambient air quality data are available for Buenos Aires. These data are based on daily manual samples of NO_x, lead, TSP, and SO_2 collected by the Municipality of Buenos Aires at one monitoring station, continuous samples of CO collected by Fundación Argentina Siglo 21 at another monitoring station, and short-term samples of CO collected by Xilix at roadside areas in the downtown business district and three other areas in the Federal Capital.[32] These data indicate that CO, NO_x, and TSP are the pollutants of concern for Buenos Aires. No information is available on ambient ozone or PM-10 levels.

Ambient CO concentrations at a traffic-dense location in downtown Buenos Aires are highest between 8 A.M. and 4 P.M. and lowest between 12 A.M. and 8 A.M. on weekdays. In 1994 the highest 8-hour average concentration was 17.3 ppm and in 1995, 12.4 ppm. These concentrations exceeded the national standard of 10 ppm and the WHO guideline of 9 ppm. The highest 1-hour CO concentration observed at this location was 30 ppm in 1994 and 33 ppm in the first five months of 1995 (FAS21 1995). In 1996, 1-hour concentrations as high as 68 ppm were recorded in the La Recoleta district, 43 ppm in the downtown business area, 40 ppm in the Once district, and 38 ppm in the Palermo district were recorded (Table 4.47). Ambient CO concentrations exceeded the 1-hour WHO guideline (26 ppm) at all these locations, but exceeded the 1-hour national standard (50 ppm) only at La Recoleta.

In 1994 short-term NO_x concentrations varied from 26 $\mu g/m^3$ to 447 $\mu g/m^3$. During November and December the short-term concentrations exceeded the city's 20-minute NO_x standard of 400 $\mu g/m^3$. The annual average NO_x concentration was 157 $\mu g/m^3$ (DVA 1995). This level exceeds the annual NO_x standard of 94 $\mu g/m^3$ for the Province of Buenos Aires.[33]

In 1994 short-term ambient TSP concentrations, which varied from 62 $\mu g/m^3$ (in September) to 335 $\mu g/m^3$ (in November), were below the city's 20-minute standard of 500 $\mu g/m^3$. Monthly average TSP concentrations were between 111 $\mu g/m^3$ (in September) and 218 $\mu g/m^3$ (in November). The city's 30 day standard of 150 $\mu g/m^3$ was exceeded only in November. The annual average (146 $\mu g/m^3$) was higher than the WHO guideline of 60 $\mu g/m^3$ to 90 $\mu g/m^3$ (DVA 1995).[34]

Limited monitoring data indicate that ambient lead used to be an environmental concern, especially in downtown Buenos Aires, where traffic is dense. Evidence of lead pollution in Buenos Aires was reported in the late 1980s (Table 4.48). Short-term lead concentrations monitored during five months in 1994 varied from 1.1 $\mu g/m^3$ to 9.2 $\mu g/m^3$. These concentrations complied with the city's 20-minute standard of 10 $\mu g/m^3$ (DVA 1995). However, ambient lead concentra-

31. Some other studies define BAMA to cover forty-three municipalities in the Province of Buenos Aires and the city of Buenos Aires in an area spanning 16,770 square kilometers. In 1991, the population of this area was 12.4 million (Pre-ATAM 1994b).

32. NO_x is used instead of NO_2 as the pollutant parameter in air quality standards and monitoring data in Argentina.

33. There is no corresponding local or national NO_x standard.

34. There is no corresponding local, provincial, or national TSP standard.

Table 4.47 Ambient CO concentrations in Buenos Aires
(parts per million)

Time	*Location*	*August 1993*	*June 1994*	*October 1995*	*May 1996*
9 A.M.	Downtown (Corrientes & Madero)	18	21.5	19.3	24.2
6 P.M.	Downtown (Corrientes & Madero)	26	22.4	26.1	28.2
9 A.M.	Downtown (Corrientes & Pellegrini)	23	27.2	21.6	26.5
6 P.M.	Downtown (Corrientes & Pellegrini)	17	25.6	27.1	27.8
9 A.M.	Downtown (Esmeralda & Córdoba)	25	22.4	31.2	27.4
6 P.M.	Downtown (Esmeralda & Córdoba)	20	24.8	29.4	30.5
9 A.M.	Downtown (Corrientes & Leandro N. Alem)	26	24.3	29.3	28.3
6 P.M.	Downtown (Corrientes & Leandro N. Alem)	26	33.1	31.8	42.5
9 A.M.	Downtown (San Martín & Tucumán)	28	29.2	26.5	24.3
6 P.M.	Downtown (San Martín & Tucumán)	33	30.5	27.6	36.3
9 A.M.	Palermo (Sta. Fé & Juan B. Justo)	28	26.7	31.5	32.4
6 P.M.	Palermo (Sta. Fé & Juan B. Justo)	28	37.2	33.4	37.8
9 A.M.	Once (Bmé. Mitre & Pueyrredón)	22	31.8	35.6	33.2
6 P.M.	Once (Bmé. Mitre & Pueyrredón)	30	39.1	36.3	40.3
9 A.M.	La Recoleta (F. Alcorta & Pueyrredón)	31	34.2	30.6	35.4
6 P.M.	La Recoleta (F. Alcorta & Pueyrredón)	62	58.0	67.1	68.2

Source: Cantini 1996 (based on monitoring data from Xilix).

tions must have fallen considerably since lead was eliminated from gasoline in late 1995.

In 1994 the highest recorded short-term SO_2 concentration was 31 $\mu g/m^3$, much lower than the city's 20-minute standard and WHO's 10-minute guideline of 500 $\mu g/m^3$. The annual average SO_2 concentration of 10 $\mu g/m^3$ was also lower than the WHO's guideline of 40 $\mu g/m^3$ to 60 $\mu g/m^3$ (DVA 1995).

Sources of Pollutants

Motor vehicles are the main source of air pollution in downtown Buenos Aires and the BAMA's major traffic corridors. Between 1994 and 1995 the motor vehicle fleet increased by 5.4 percent in the Federal Capital and by 3.0 percent in the Province of Buenos Aires, largely because of increased numbers of private cars. In 1995 the BAMA contained about 2.6 million private cars, 46,000 taxis, and 16,000 buses.[35] About 19 percent of the 5.9 million motor vehicles in circulation in Argentina were in the Federal Capital. These included 953,000 cars, 134,000 trucks, and 11,000 buses (ADEFA 1996). In the BAMA gasoline-fueled vehicles emitted about 85 percent of CO, 80 percent of HC, and 40 percent of NO_x from road-based sources, and diesel-fueled vehicles emitted 98 percent of SO_2 and 63 percent of PM (Table 4.49). Gasoline-fueled vehicles contributed to a higher share of CO, HC, and NO_x emissions in the Federal Capital than the BAMA because they constitute a higher proportion of the vehicle fleet in the Federal Capital.

Public transport services in the BAMA are provided by buses, metro, and suburban trains. In 1994 about 15,000 buses operated on 299 lines and were run by 240 privately owned companies. About 2,000 of these buses (on 93 lines) operated exclusively within and were regulated by a specific municipality in the Province of Buenos

Table 4.48 Ambient lead concentrations in Buenos Aires
(micrograms per cubic meter)

Location	*Sampling period*	*Concentration*
Downtown (heavy traffic)	8 A.M. – 5 P.M.	3.9
Downtown (heavy traffic)	7 P.M. – 8 A.M.	1.7
Downtown (medium traffic)	24 hours	1.5
Suburban (medium traffic)	24 hours	1.0
Suburban (low traffic)	24 hours	0.3
Standard for the City of Buenos Aires	24 hours	1.0

Source: Caridi and others 1989.

35. Estimated based on data from pre-ATAM 1994 and ADEFA 1996.

Table 4.49 Estimates of emissions from gasoline- and diesel-fueled vehicles in the Federal Capital and the BAMA, 1993
(thousands of tons)

	CO		*HC*		NO_X		SO_2		*PM*	
Vehicle Type	*FC*	*BAMA*	*FC*	*BAMA*	*FC*	*BAMA*	*FC*	*BAMA*	*FC*	*BAMA*
Gasoline-fueled	247.7	861.7	9.5	36.9	6.8	26.4	0.4	1.6	1.3	5.0
Diesel-fueled	27.2	156.1	1.6	9.2	6.8	39.0	11.7	67.2	1.5	8.6
Total	274.9	1,017.8	11.1	46.1	13.6	65.4	12.1	68.8	2.8	13.6

Note: FC is the Federal Capital and BAMA is the Buenos Aires Metropolitan Area.
Source: Derived from World Bank 1995.

Aires. Another 3,000 (on 59 lines) operated across municipality boundaries within the Province of Buenos Aires and were regulated by the province. The remaining 10,000 buses were run by 123 companies (on 147 lines) within the Federal Capital and on routes extending from it. Besides providing regular bus services, these bus companies also operate express buses (*diferenciales*) on many lines in the BAMA. Buses operating within and through the Federal Capital are regulated by the National Commission of Transport Control under the jurisdiction of the Municipality of Buenos Aires and the Secretariat of Public Works and Transportation, a national entity formed in June 1996.[36] In addition, charter buses have recently become popular for commuters living in suburbs 20 kilometers to 30 kilometers outside of the downtown area.

The fully electrified 44-kilometer metro network is owned by the Municipality of Buenos Aires and operated by a private firm under a twenty-year concession. Only 18 percent of the suburban railway, which has a total length of 900 kilometers on six different systems, is electrified. It is owned by the state and operated by four private firms under ten-year concessions.

The taxi fleet includes about 38,600 registered and 7,000 illegally operated taxis. In addition, chauffeured short-term cars (*remises)* have captured an increasing share of the taxi market. About 155 agencies, with about five remises each, operate legally, and about 750 agencies operate illegally. The share of taxis in the vehicle fleet decreases with further distance from the city center. In the microcenter area taxis represent more than 50 percent of all circulating vehicles, followed by private cars (25 percent) and buses (less than 15 percent). But in the macrocenter area private cars account for 46 percent of traffic, followed by taxis (40 percent) and buses (6 percent; World Bank 1995).

On a typical workday in 1994 about 17.6 million passenger trips took place in the BAMA. In addition, about 200,000 daily trips were made by trucks transporting more than 600,000 tons of goods. Of the passenger trips, 56.5 percent were made by public transport modes, consisting of buses (47.1 percent), suburban train (4.9 percent), and metro (4.5 percent). The share of private cars was 32.4 percent. About 71 percent of the bus commuters used the federal bus system; the rest used the provincial and municipal bus systems.

Institutional Responsibilities

National institutions. The Secretariat of Natural Resources and Sustainable Development, a cabinet-level agency reporting directly to the president, formulates national environmental policy in Argentina.[37] The secretariat, which includes subsecretariats for human environment and natural resources, is the national institution responsible for setting minimum environmental standards—including emission standards for vehicles—in Argentina. Provincial authorities establish their own standards based on this minimum.

A number of other institutions also deal with environmental issues at the national level in co-

36. In 1996 the National Commission of Transport Control was formed to replace the National Commission of Automotive Control (CONTA), and the Secretariat of Public Works and Transportation was formed to replace the Secretariat of Energy and Transportation.

37. In 1996 the Secretariat of Natural Resources and Sustainable Development was formed to replace the Secretariat of Natural Resources and Human Environment.

ordination with the Secretariat of Natural Resources and Sustainable Development. These institutions include the Secretariat of Industry, Commerce, and Mining (industry and mining), Ministry of Education (environmental education), Ministry of Health and Social Action (environmental standard setting, resettlement, environmental impact assessment of infrastructure projects), Secretariat of Public Works and Transportation (inspection of commercial vehicles), Ministry of External Relations and International Trade (international aspects of the environment), and Secretariat of Agriculture, Cattle, and Fisheries (environmental research). This fragmentation of responsibilities constrains the efficiencies of Argentina's environmental management framework and sometimes causes coordination conflicts and disputes over the allocation of resources (World Bank 1995).

The Secretariat of Natural Resources and Sustainable Development hosts the Federal Counsel of the Environment, the forum in which all national and provincial governments discuss common themes. In 1993, the Secretariat negotiated the Federal Environmental Pact with all the provinces. However, few provincial congresses have ratified this pact, a political instrument that signals a willingness to coordinate provincial and national efforts.

The Secretariat of Public Works and Transportation finances, constructs, and maintains national highways, subsidizes the operation of suburban railway lines, regulates the national bus lines operated by private bus companies, and inspects commercial vehicles operating under the national jurisdiction. The traffic police division of the federal police department is responsible for traffic control and enforcement in the Federal Capital.

Provincial institutions. In principle, most environmental matters that are not expressly delegated to the national government are the responsibility of the provinces. The Province of Buenos Aires has one of the best environmental management systems in Argentina. The provincial Secretariat of Environmental Policy is responsible for environmental matters within the province, including air pollution from fixed and mobile sources. The provincial Ministry of Public Works and Services regulates the operation of bus lines that cross municipalities within the province. It is also responsible for constructing and maintaining the principal roads in the province.

Metropolitan institutions. A number of unsuccessful attempts have been made to improve coordination among the federal government, the Province of Buenos Aires, and the Municipality of Buenos Aires on transport-related issues in the BAMA. One such attempt occurred in 1991 with the signing of an agreement between the economy minister and the mayor of Buenos Aires to create a temporary planning unit, called "pre-ATAM", to define and develop an independent and autonomous Transit Authority for the Metropolitan Area. The Transit Authority was conceived as consisting of representatives from all three government jurisdictions and was to be responsible for the planning, regulation, and control of all activities involving the urban transport system in the BAMA. Although the legislation to create the authority passed in the Senate, it failed to gain broad political support. In late 1996 it was converted into a new planning unit for Urban Transport of the BAMA (called "TUAMBA").

Local institutions. The Municipality of Buenos Aires has established ambient air quality standards and emission standards for vehicles, and has been monitoring ambient air quality in the Federal Capital through the Atmospheric Monitoring Laboratory of its Environmental Hygiene Department. The municipality does not have any authority to regulate the national bus system. However, it maintains the road infrastructure and regulates the operation of taxi services within Federal Capital. It also owns the infrastructure of the Buenos Aires metro system. The operation of this system, which is under a twenty-year concession to a private firm, is subsidized by the national government. The other municipalities of the BAMA are responsible for air and noise pollution, traffic management, and regulation of bus and taxi services within their respective municipalities.

Implemented Measures

Vehicle emission standards. National Decree 875/94 of Regulation 2254/92 established emission and noise standards for new and used motor vehicles and made the Secretariat of Natural Resources and Human Environment responsible for implementing and updating these standards. For new light-duty vehicles, Decree 875/94 limited exhaust emissions for CO, HC, and NO_x

Table 4.50 Exhaust emission standards for new light-duty vehicles in Argentina

Vehicle type and effective date of standard	*CO*		*HC*		*NO_x*	*PM*
	(g/km)	*(percent)*[a]	*(g/km)*	*(ppm)*[a]	*(g/km)*	*(g/km)*[b]
Passenger vehicles						
Before July 1994[c]		3.0		600		
July 1994[c]	24.0	3.0	2.1	600	2.0	
November 1995[d]	12.0	2.5	1.2	400	1.4	
January 1996[d]	12.0	2.5	1.2	400	1.4	0.373
January 1997[d]	2.0	0.5	0.3	250	0.6	0.124
Commercial vehicles						
Before July 1994[c]			3.0		600	
July 1994[c]	24.0	3.0	2.1	600	2.0	
January 1998[d]	6.2	0.5	0.5	250	1.43	0.16/0.31[e]
January 1999[d]	2.0	0.5	0.3	250	0.6	0.124

Note: A blank space indicates that no standard was established. CO, HC, and NO_x emissions from the exhaust are to be tested using USEPA's Method FTP-75.

a. Measured at idle only for vehicles with spark-ignition engines.

b. Applicable only to diesel-fueled vehicles.

c. Applicable only to domestically produced vehicles.

d. Applicable both to domestically produced and imported vehicles.

e. The 0.16 g/km limit is applicable to light-duty diesel-fueled vehicles with reference weight (weight of the vehicle plus 136 kg) not more than 1,700 kg. The 0.31 g/km limit is applicable to light-duty diesel-fueled vehicles with reference weight more than 1,700 kg.

Source: Decree 875/94, published in *Boletín Oficial* 27,919 of July 27, 1994, and Decree 779/95, published in *Boletín Oficial* 28,281 of November 29, 1995.

from all domestically produced and imported effective June 1994.[38] The decree also set more stringent limits for these pollutants according to a timetable, eliminated crankcase emissions effective July 1994, and limited evaporative emissions from light-duty vehicles with spark-ignition engines to 6.0 grams/test effective January 1, 1995. This decree was superseded by Decree 779/95 of Law 24,449/94. The new decree established CO, HC, and NO_x standards for light-duty passenger and commercial vehicles based on a more stringent compliance schedule. In addition, the decree set PM standards for diesel-fueled vehicles (Table 4.50).[9] The requirements for crankcase and evaporative emissions remained the same. Decrees 875/94 and 779/95 also established a certification system for new light-duty vehicles that requires manufacturers of light-duty vehicles to comply with emission standards for 80,000 km or five-years (whichever comes first). Alternatively, this requirement can be replaced by a 10 percent reduction of emission levels from those specified in Table 4.50. Small light-duty vehicle manufacturers (all manufacturers producing less than 1,000 vehicles a year and some specialized manufacturers producing less than 2,500 vehicles a year) are exempted from the certification requirement.

For new diesel-fueled urban buses and other vehicles circulating on roads under the national jurisdiction, Joint Resolution 58/94 and 96/94 by the Secretariats of Transportation and Industry established CO, HC, and NO_x emission standards effective July 1994. The resolution tightened these standards according to a timetable, set additional standards for smoke emissions as a function of exhaust gas flow rate and PM standards based on engine power, and eliminated evaporative emissions. Decree 779/95 reconfirmed these standards for all new diesel-fueled heavy-duty vehicles in Argentina (Tables 4.51 and 4.52). The decree also requires that compliance with the standards be guaran-

38. Light-duty vehicles are those with a net weight (without load) up to 2,722 kilograms and gross weight (with passengers and maximum freight) up to 3,856 kilograms.

39. Light-duty passenger vehicles are those designed to carry up to twelve passengers or derived from those vehicles to carry freight. Light-duty commercial vehicles are those designed to carry freight . or derived from those vehicles. They also include all light-duty vehicles designed to carry more than twelve passengers.

Table 4.51 CO, HC, and NO_x exhaust emission standards for new diesel-fueled heavy-duty vehicles in Argentina
(grams per kilowatt-hour)

Vehicle type and effective date	*CO*	*HC*	*NO_x*
Urban buses			
July 1994	11.2	2.4	14.4
January 1995	4.9	1.23	9.0
January 1998	4.0	1.1	7.0
Other heavy-duty vehicles			
July 1994	11.2	2.4	14.4
January 1996	4.9	1.23	9.0
January 2000	4.0	1.1	7.0

Note: Exhaust emissions are to be tested using EEC's 13-mode cycle. On July 1, 1994, crankcase emissions were eliminated with the exception of turbocharged vehicles.
Source: Joint Resolution 96/94 and 58/94, published in *Boletín Oficial* 27,854 of March 21, 1994, and Decree 779/95, published in *Boletín Oficial* 28,281 of November 29, 1995.

Table 4.52 PM exhaust emission standards for new diesel-fueled vehicles in Argentina
(grams per kilowatt-hour)

Effective date	*Engine power below 85 kW*	*Engine power above 85 kW*
January 1996	0.680	0.400
January 2000	0.225	0.150

Note: Exhaust emissions are to be tested using EEC's 13-mode cycle.
Source: Joint Resolution 96/94 and 58/94, published in *Boletín Oficial* 27,854 of March 21, 1994, and Decree 779/95, published in *Boletín Oficial* 28,281 of November 29, 1995.

Table 4.53 Exhaust emission standards for in-use vehicles with spark-ignition engines in Argentina

Date manufactured	*CO (percent)*	*HC (ppm)*
January 1, 1983–December 31, 1991	4.5	900
January 1, 1992–December 31, 1994	3.0	600
After January 1, 1995	2.5	400

Note: Measured at idle.
Source: Decree 779/95, published in *Boletín Oficial* 28,281 of November 29, 1995.

Table 4.54 Exhaust emission standards for in-use vehicles with diesel engines in Argentina

Effective date	*Bacharach index*	*Absorption coefficient (m^{-1})*
November 1995	6	2.62
July 1997	5	2.62

Note: Measured at free acceleration.
Source: Decree 779/95, published in *Boletín Oficial* 28,281 of November 29, 1995.

teed by manufacturers for five years or 160,000 kilometers, whichever comes first. Alternatively, this requirement can be replaced by a 10 percent reduction of emission levels.

For in-use vehicles with spark-ignition engines (such as gasoline- or CNG-fueled vehicles), Decree 875/94 established distinct CO and HC emission standards for vehicles manufactured in 1983–91, 1992–94, and after 1994. Decree 779/95 reconfirmed these standards (Table 4.53).

For in-use diesel-fueled vehicles, smoke emissions are regulated by Decree 779/95. This decree, which supersedes Decree 875/94, requires diesel-fueled vehicles that enter circulation after July 1, 1994 to meet the meet the standards specified in Table 4.54.

Vehicle inspection programs. In 1995 national Law 24,449 and its Decree 779/95 established the requirement for periodic inspection of in-use vehicles in Argentina. Accordingly, local jurisdictions were given the responsibility of inspecting private and commercial vehicles providing intrajurisdictional services and the national jurisdiction of inspecting commercial vehicles providing interjurisdictional services.[40] About half the provinces in Argentina have adopted this decree, and the rest are doing so. Past and present measures taken in the BAMA—which includes jurisdictions that fall under the responsibility of the Secretariat of Transportation, the City of Buenos Aires, and the Province of Buenos Aires—are discussed below.

40. Vehicles that provide interjurisdictional services in Argentina are those operating between the Federal Capital and a province, or between two or more provinces.

The first legislation for periodic inspection of public transport vehicles operating under the national jurisdiction was adopted in 1944. This was followed by three national regulations (in 1974, 1980, and 1989) that required inspection at a central station located in the Federal Capital. This inefficient system required all public transport vehicles in Argentina to travel to Buenos Aires. Because the physical capacity of this central station was limited, the waiting period for inspections was long. Furthermore, since inspections were based on visual, manual, and auditive measures, the results were affected by the judgment of the inspectors. During the last phase of the centralized inspection program about 1,200 public transport vehicles were inspected each month (GCTVI 1994).

Inspection of in-use public transport vehicles operating under the national jurisdiction was decentralized in 1992 by the Secretariat of Transportation's Resolution 417, which also extended the inspections to cover trucks. These inspections included safety and mechanical checks as well as measurement of smoke emissions for vehicles with diesel engines and CO and HC emissions for vehicles with spark-ignition engines. Inspection frequency was set at six months for buses and twelve months for trucks, irrespective of the age of the vehicles. Management of the inspection system, including approval of private inspection centers, was assigned to the Executive Consultant for National Transport (GCTVI 1994).[41]

The first private station to inspect commercial vehicles operating under the national jurisdiction was opened in February 1993. By November 1994 there were sixty-eight approved private inspection stations in Argentina, each with an average investment cost for inspection equipment of about $80,000 (GCTVI 1994). By mid-1996 there were thirty approved private stations in the BAMA inspecting about 150,000 commercial vehicles operating under the national jurisdiction (Galuppo 1997).

Since October 1994 these periodic inspections have been supplemented by unannounced inspections—conducted at major bus terminals and public roads—of urban buses operating within the national jurisdiction. These unannounced inspections, which focus on smoke and noise emissions, are administered by the National Commission of Transport Control (the technical arm of the Secretariat of Transportation) and take into consideration public complaints made to the commission's customer service division. Buses that fail the inspection are prohibited from circulating until the problem is corrected and the vehicle has been reinspected at one of the thirty inspection stations.

All commercial vehicles registered in the City of Buenos Aires are required to have a periodic inspection at a station owned and operated by a private firm, Sociedad Argentina de Control Técnico de Automotores (SACTA), under a ten-year concession from the Municipality of Buenos Aires. These inspections aim to ensure compliance with the safety standards for the vehicles as well as environmental standards for emissions. Exhaust emission inspections are limited to measuring CO and HC for CNG- and gasoline-fueled vehicles and opacity for diesel-fueled vehicles. Compliance with all inspection requirements is required to renew the license for taxis and to renew registration for other commercial vehicles (both of which are issued by SACTA). Inspection fees are $37 for taxis, $42 for trucks, and $52 for buses (Galuppo 1997).

SACTA's inspection station, designed for 1,200 vehicles a day, cost $5 million. Operating since October 1991, the facility covers 12,600 square meters and includes 2,200 square meters of covered inspection area with nine inspection lanes (three for light-duty vehicles and six for heavy-duty vehicles) and 800 square meters for an administrative building. The facility will be returned to the Municipality of Buenos Aires (at no charge) when the concession ends (SACTA 1994).

Roadside inspections of commercial vehicles registered in the City of Buenos Aires are conducted by SACTA, supported by federal police. These inspections aim to verify that vehicles have undergone the required annual inspection and to ensure that they are in good operating condition (SACTA 1994).

Periodic inspection of private cars registered in the City of Buenos Aires has not started yet.

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41. The Executive Consultant for National Transport (CENT) is a consulting firm created by the National Technological University following an agreement between the university and the Secretariat of Energy and Transportation. CENT's management of inspection stations in Argentina is conducted through an executive director and twelve regional auditing entities located at the university's various academic units throughout the country. Currently, CENT's steering committee includes members from the Secretariat of Public Works and Transportation, the university, and the National Commission of Transport Control.

This service will be provided by a private firm concessioned from the Municipality of Buenos Aires. The bidding process for the periodic inspection of in-use vehicles is under way according to the requirements of national Law 24,449 although no specific legislation has been passed in the Federal Capital (Galuppo 1997).

The Province of Buenos Aires enacted provincial Law 11,430 and its complementary Law 11,787, and promulgated Decree 4,103 for the inspection of in-use vehicles. The basic requirements of this provincial legislation are the same as the national legislation. Private cars and trucks are scheduled for inspection once a year, while taxis, remises, and buses are scheduled for inspection twice a year. The inspection strategy entails dividing the province into eleven zones (five of which are in the BAMA) and concessioning construction and operation of twenty-five high-volume, high-technology stations to eleven private firms (one firm in each zone). Each station consists of four lanes. Only one of the concessioned stations is currently operational and the rest are under construction. Annual inspections for 1997 are scheduled between March and July according to the last digit of the vehicle's license plate number. Inspection fees are set at $36 for vehicles less than 2,500 kilograms in gross weight and $75 for heavier vehicles (Galuppo 1997).

Fuel-targeted measures. Gasoline, diesel fuel, and CNG are the transport fuels available in Argentina. In 1996 motor vehicles in the Federal Capital consumed about 14 percent of gasoline, 8 percent of diesel fuel, and 26 percent of CNG consumed in Argentina (Table 4.55). Although no statistics are available, the share of the BAMA in total fuel consumption in Argentina is estimated to be 37 percent for gasoline, 30 percent for diesel fuel, and 51 percent for CNG. Of the 313 fuel stations serving CNG in the BAMA 47 percent are located in the Federal Capital (*Prensa Vehicular*, February 15, 1997).

Unleaded gasoline was introduced in 1993. Addition of lead to gasoline was eliminated in late 1995 as a result of the Argentine government's tax incentive program for petroleum refiners. Unleaded gasoline production in Argentina has been achieved by refinery modifications, including installation of MTBE units at YPF's La Plata and Lujan de Cuyo refineries.[42] Various Argentine refiners (such as Eg3, Esso, Refisan, and YPF) have also used the imported MTBE as a source of oxygenate for increasing the octane number of gasoline. In 1996 the previous leaded gasoline storage, distribution, and transfer systems were used to sell unleaded gasoline under the label of "leaded gasoline" to avoid any potential damage to vehicle catalysts by residual lead that might have been left in these systems. Although tax incentives to refiners will be removed, unleaded gasoline production is expected to increase to satisfy the market demand (Alconsult International Ltd. 1996).

Regulation 54/96 of the Ministry of Economy and Public Works and Services specifies gasoline and diesel fuel quality standards in Argentina effective September 31, 1996. The parameters specified for gasoline include the research octane number, and oxygenates, oxygen, benzene, and lead content (Table 4.56). The regulation also limits the sulfur content of diesel fuel to a maximum of 0.25 percent by weight and the cetane number to a minimum of 48 according to ASTM Method D976 and 50 according to ASTM Method D613.

The Argentine transport sector began using CNG in response to a 1985 tax exemption program designed to encourage substitution of CNG for petroleum fuels. By the end of 1996, 395,800 vehicles in Argentina had their fuel systems converted to use CNG; 265,200 of those vehicles

Table 4.55 Fuel consumption in the Federal Capital, Province of Buenos Aires, and Argentina, 1996

(thousands of cubic meters)

Fuel type	*Federal Capital*	*Province of Buenos Aires*	*Argentina*
Regular gasoline[a]	190	921	2,402
Super gasoline[a]	702	1,635	3,943
Diesel fuel	818	4,085	10,706
CNG	278,000	462,000	1,080,000

a. Unleaded grades. Production of leaded gasoline was discontinued in late 1995.
Source: World Bank data.

42. MTBE production capacities are 1,433 barrels a day at the La Plata refinery and 1,110 barrels a day at the Lujan de Cuyo refinery. In 1995 the La Plata refinery produced 885 barrels a day of MTBE and the Lujan de Cuyo refinery produced 1,110 barrels a day (Alconsult International Ltd. 1996).

Table 4.56 Gasoline quality standards in Argentina

Fuel parameter	*Standard*
Research octane number (RON; minimum)	
For common, normal, or regular gasoline	83
For super, extra, or special gasoline	93
Oxygenates (maximum percent by volume)	
MTBE	15
Ethanol	5
Isopropyl alcohol	5
Tertiary-butyl alcohol	7
Isobutyl alcohol	7
Oxygen (maximum percent by weight)	2.7
Benzene (maximum percent by volume)	4
Lead (maximum gram/liter)	
In leaded gasoline	0.2
In unleaded gasoline	0.013

Source: Ministry of Economy and Public Works and Services 1996.

were in the BAMA (Table 4.57). During 1995–96, 62 percent of the conversions were for private cars, 19 percent for light-duty trucks, 13 percent for taxis, 0.7 percent for official vehicles, and 5 percent for other vehicles. Although most conversions have been for private cars, it is estimated that less than 7 percent of private cars in the BAMA are fueled with CNG. However, CNG is used by a larger fraction of taxis, remises, and other light-duty commercial vehicles. For example, an estimated 80 to 90 percent of taxis in the BAMA are CNG-fueled. The use of CNG in buses is very limited (less than 200 buses). The remaining taxis and urban buses, as well as intercity buses and most trucks, run on diesel fuel. Some trucks are also fueled with gasoline.

CNG and diesel fuel are less expensive motor vehicle fuels than gasoline. Both CNG and diesel fuel were exempt from fuel taxes until late 1996, when a 59 percent fuel tax was imposed on diesel fuel. The fuel tax on gasoline is the highest among the available motor vehicle fuels in Argentina. The fuel tax on various gasoline grades, which ranged from 127 to 136 percent in October 1994, has been increased to between 165 and 189 percent (Table 4.58).

Transport management. Buenos Aires has traffic problems common to large urban centers worldwide. Illegal parking of vehicles and the loading and unloading of delivery trucks on busy streets during unauthorized hours forces taxis, buses, tourist buses, and official vehicles to stop in the middle of the road to drop off and pick up passengers. The problem is aggravated by taxis cruising at slow speeds in search of passengers and by cars trying to enter parking lots during rush hours.

National Decree 2254 of 1992 required urban buses older than 10 years and operating in the Federal Capital to retire by January 1, 1996. In 1994 the national Congress declared a state of emergency for transit in the Federal Capital and ordered that solutions to the congestion prob-

Table 4.57 Conversion of vehicles to CNG in the BAMA and Argentina
(thousands)

	BAMA		*Argentina*	
Year	*Annual*	*Cumulative*	*Annual*	*Cumulative*
1984	0.1	0.1	0.1	0.1
1985	1.6	1.7	2.0	2.1
1986	1.8	3.5	3.4	5.5
1987	5.0	8.5	7.9	13.4
1988	5.3	13.8	7.4	20.8
1989	10.6	24.4	14.9	35.7
1990	23.2	47.6	31.9	67.6
1991	27.2	74.8	41.0	108.6
1992	25.9	100.7	40.5	149.1
1993	35.3	136.0	52.7	201.8
1994	44.3	180.3	67.3	269.1
1995	36.7	217.0	54.7	323.8
1996	48.2	265.2	72.0	395.8

Source: Prensa Vehicular, February 15, 1997.

Table 4.58 Typical fuel prices in Argentina, December 1996 and October 1994

Fuel type	*Unit*	*Net price*	*Fuel tax*	*Value added tax*	*Station profit*	*Typical station price*
December 1996						
Extra unleaded gasoline	$/liter	0.2940	0.4865	0.0617	0.1538	0.9960
Super unleaded gasoline	$/liter	0.2580	0.4865	0.0542	0.1473	0.9460
Regular unleaded gasoline	$/liter	0.2152	0.3878	0.0452	0.1078	0.5860
Diesel fuel	$/liter	0.2035	0.1200	0.0427	0.0628	0.4290
CNG	$/m^3	—	0.0000	—	—	0.3060
October 1994						
Unleaded gasoline	$/liter	0.2573	0.3496	0.0460	0.1401	0.7930
Super leaded gasoline[a]	$/liter	0.2660	0.3496	0.0480	0.1234	0.7870
Regular leaded gasoline[a]	$/liter	0.1975	0.2509	0.0360	0.2006	0.5850
Diesel fuel	$/liter	0.1800	0.0000	0.0320	0.0520	0.2640
CNG	$/m^3	—	0.0000	—	—	0.2620

— Not available.
a. Production of leaded gasoline was discontinued in late 1995.
Source: Prensa Vehicular, October, 15 1994 and February 15, 1997.

lem be investigated. Subsequently, an emergency committee comprising representatives of the national Secretariat of Transportation and the Municipality of Buenos Aires was created. To alleviate congestion, a weekday traffic restriction, based on the license plate numbers of private cars, was implemented in downtown Buenos Aires. This restriction was lifted in a few months, however, because it was ineffective.

The commission also developed a modal hierarchy for the microcenter area, that would give on-foot and metro modes the highest priority, followed by buses, taxis, and private cars. A key element of the proposed transport policy was the segregation of different transport modes to improve traffic flows. One measure introduced a bus lane program that was to be extended to the main arteries. The program was initiated by establishing two short bus lanes on a pilot basis (World Bank 1995). In addition, the circulation of private cars in the microcenter area was prohibited between 10 A.M. and 8 P.M. to encourage pedestrian travel on streets with narrow sidewalks. Since February 1995 a traffic restriction has prohibited taxis without passengers from entering the microcenter area of Buenos Aires.

Other traffic management measures considered for the microcenter included allowing bus traffic only on specified streets and avenues, promoting walking by expanding sidewalks and allowing only one lane for buses (except for stops), prohibiting special permits and parking privileges for official vehicles and limiting the waiting period of vehicles that transport money to or from financial institutions, and restricting the use of some streets to pedestrian traffic.

A number of traffic management measures were suggested to improve circulation of private cars, taxis, and buses in the macrocenter area of Buenos Aires; optimizing the traffic light system to improve traffic flow in the main arteries; creating a central traffic command center that can modify the programming of traffic lights in case of unanticipated events (such as accidents, demonstrations, or emergencies), inform motorists of traffic problems, and propose alternative routes; extending the recently implemented reversible lane system (use of the lanes is based on the main flow of traffic) to other arteries; separating the lanes used by buses and taxis; introducing exclusive bus routes and extending bus lanes to the main arteries; initiating a bus ticket purchasing system before boarding the buses, establishing differential parking tariffs to discourage long-term parking of private cars at the city center and, at the same time, creating parking facilities in the peripheral zones with good access to the city center; designing and implementing an effective traffic enforcement system; limiting parking of official, diplomatic, and medical vehicles to locations that do not significantly affect the flow of traffic; updating the traffic network for the truck fleet with proper signs, and eliminating freight loading

and loading activities during certain periods; and implementing a public education program for motorists.

Major infrastructure investments have been undertaken to link the Federal Capital to its suburbs in the Province of Buenos Aires. In 1996 construction of highways to the western and southeastern suburbs was completed. The highway to Pilar in the west has been operating as a toll road and the highway to La Plata in the southeast has opened to traffic, but the toll booths are yet to be installed. In addition, the highways to Cañuelas in the southwest and to Luján in west, both in the Province of Buenos Aires, are under construction. These highways also will be operated as toll roads. All four of these highways are interconnected.

Argentine Railways used to be the sole provider of rail-based passenger and cargo services in Argentina (except for the Buenos Aires metro, which was served by Subterraneos de Buenos Aires). In 1991 the Argentine government called for bids to award operating concessions for various rail packages in Argentina to encourage private participation in the railway sector. Passenger services within the BAMA, including the Buenos Aires metro, were reorganized under the Railway Restructuring Coordination Unit. In 1994 a twenty-year concession went into effect for the metro, combined with one suburban railway system, and ten-year concessions for some other suburban railway systems (World Bank 1995). With the concessioning of the two remaining railway systems in January and May 1995, the entire rail passenger system in the BAMA is now operated by the private sector.

Air quality monitoring. The first ambient air quality monitoring in the Federal Capital was conducted in 1964 by the Municipality of Buenos Aires. Until 1973 an ambient air monitoring program was jointly carried out by the Municipality of Buenos Aires and the national Ministry of Public Health. Initially, two indicator pollutants were monitored each day for about a year. Following evaluation of the monitoring results, a network of twelve stations for monitoring pollutant gases and twenty-one stations for monitoring TSP was designed and operated. SO_2, NO_x, CO, TSP, smoke, and HC were monitored on a daily basis. Lead, ozone, and aldehydes were monitored less frequently. In 1982 the monitoring program was considerably weakened by budget cuts and personnel reductions. As a result the number of functioning monitoring stations declined every year. In 1994 the effort included daily monitoring of NO, NO_2, and SO_2 at a monitoring station in the City of Buenos Aires (in Palermo) and periodic monitoring of TSP and lead by three mobile monitoring stations (DVA 1995).

Ambient CO concentrations in the Federal Capital have been monitored by Fundación Argentina Siglo 21 since 1992. Currently, this effort is being conducted at three automatic monitoring stations with continuous sampling at one-minute intervals. Two of these stations are located in the port area and the third one in a narrow street in downtown Buenos Aires. The sampling network is maintained by the University of Buenos Aires. Since December 1993 monitoring results from the downtown station have been disseminated to the public through local newspapers, television and radio stations, and news agencies.

In addition, since 1993 short-term ambient CO concentrations have been monitored by Xilix, a private environmental consulting firm, at the intersections of heavy traffic areas. Five of these monitoring locations are in the downtown business area, and one each in the La Recoleta, Palermo, and Once districts of the Federal Capital.

In 1994 Instituto Pro Buenos Aires, in an effort to develop an environmental map of the city, measured ambient air concentrations of TSP, CO, NO_2, and HC using a mobile laboratory. In addition, in 1996 Greenpeace conducted an ambient air quality monitoring study in Buenos Aires. The results of this study are not available.

Evaluation of Implemented Measures

Vehicle emission standards. The 1997 exhaust emission standards for light-duty vehicles, which are based on the USEPA's 1987 emission standards, will require that vehicles be equipped with three-way catalytic converters as well as exhaust gas recirculation and injection timing control technology. These standards are comparable to the 1992 Chilean and 1994 Mexican standards. The evaporative emission standard of 6 grams/test is the same as the Brazilian standard but not as stringent as the Chilean or Mexican standard (2 grams/test).

The 2000 emission standards for diesel-fueled urban buses and 1998 standards for other diesel-fueled vehicles, which are based on the

USEPA's 1994 emission standards, require extensive use of variable fuel injection timing, high injection pressure, low-temperature charge-air cooling, and combustion optimization. These standards are comparable to the 1996 Chilean standards.

The CO standards for in-use vehicles with spark-ignition engines are comparable to the Chilean or Mexican standards. The HC standards are more lenient, however.

Because there is no emissions monitoring laboratory to perform all the required emission tests in Argentina, nationally manufactured new vehicles are being tested in Brazilian state laboratories in the presence of personnel from the National Institute of Industrial Technology. For imported vehicles, Argentina requires certification of emissions from an official vehicle testing laboratory in the country of origin. Establishment of a certification laboratory is under consideration.

Vehicle inspection programs. A 1991 survey of gasoline-fueled vehicles on public roads in the Federal Capital found that 66 percent of the vehicles were in violation of the CO emission standard. A similar survey in 1992 found that 90 percent of gasoline-fueled vehicles had CO emissions over the standard (Moran 1992). Although gasoline-fueled private cars have been the main source of air emissions in the Federal Capital and certain parts of the BAMA, until recently they were excluded from the periodic inspection and maintenance program. The recent periodic inspection requirement for private cars should reduce pollutant emissions. The scheme adopted in the Federal Capital and the Province of Buenos Aires will allow for efficient provision of these services at highly automated, high-volume inspections by private concessionaires.

The regular and unannounced inspections and heavy fines have played a major role in reducing the number of noncompliant buses and trucks in circulation. Between February 1993 and November 1994, 33,500 buses and 82,000 trucks operating within the national jurisdiction were inspected at sixty-eight inspection stations approved by the Executive Consultant for National Transport. In the first nine months of 1994 an average of 3,015 buses and 8,570 trucks were inspected each month (GCTVI 1994). In addition, between October 1994 and May 1995, 7,268 urban buses operating within the national jurisdiction were inspected at bus terminals and on public roads. The buses inspected included 74 percent of the buses that had generated complaints from the public. Of the inspected buses, 1,148 (or 16 percent) were found to be noncompliant. The noncompliant buses represented 25 percent of the buses denounced by the public. During January–May 1995 the noncompliance rate of inspected buses dropped from 24 to 10 percent (GIIE 1995). Fines for noncompliant buses range from 10,000 to 30,000 times the passenger ticket.[43] The collected fines are incorporated into the National Commission of Transport Control's budget. The commission is considering lowering the fines, however.

The City of Buenos Aires' periodic inspection program has had mixed results. In 1994, although nearly all taxis were inspected, only 10 percent of the registered trucks and 8 percent of the registered passenger transport vehicles were inspected at SACTA's inspection station (SACTA 1994). To reduce noncompliance, the municipal Secretariat of Urban Planning and Environment, along with the municipal police, carry out sporadic road checks. In April 1994, 235 of 898 randomly selected vehicles (26 percent) failed to meet the emission standards. The rate of noncompliance was 17 percent for buses (80 of 483), 38 percent for trucks (96 of 252), and 36 percent for taxis (59 of 163; World Bank 1995). Strengthening inspections for heavy-duty vehicles would encourage compliance with the emission standards and improve air quality.

Fuel-targeted measures. Fuel quality standards in Argentina establish the quality requirements of gasoline and diesel fuel produced by Argentine refiners or imported to Argentina. These standards are intended to ensure supply of fuels capable of meeting the 1997 motor vehicle emission standards and to reduce pollutant concentrations in ambient air. In 1996 gasoline produced by different Argentine refiners contained 3 to 15 percent MTBE by volume, 0.47 percent to less than 3 percent benzene by volume, and a maximum of 0.013 g/liter of lead (Alconsult International Ltd. 1996). These parameters met the Argentine quality standards for gasoline (see Table 4.58).

43. The average ticket price buses operating between the Federal Capital and the suburbs in the Province of Buenos Aires is $0.65.

Elimination of lead from gasoline must have reduced ambient lead concentrations in the BAMA, especially in the Federal Capital where public exposure is highest. No recent ambient air quality data are yet available, however, to confirm this assumption.

To make up for the octane that previously was provided by tetraethyl lead, Argentine refiners have resorted to the addition of MTBE and, possibly, to some refinery modifications in reformulating gasoline.[44] Because no leaded gasoline is presently available in Argentina, vehicles not equipped with catalytic converters are using unleaded gasoline. YPF is investigating the emission effects of using unleaded gasoline in uncontrolled vehicles. Although this investigation is of major interest to YPF, a parallel study by an independent group would ensure the public credibility of the findings. Based on a 1996 study of gasoline quality in Argentina (Alconsult International Ltd. 1996), the following parameters are noted to have higher values than gasoline in the United States:

- The Reid vapor pressure of medium- and high-octane gasoline produced by YPF (11.5 psi) and Eg3 (10 psi) was higher than allowed in the United States (the 1992 limits for unleaded gasoline during summer months are 9.0 psi for the northern states and 7.8 psi for most of the southern states; the limits for reformulated gasoline are even stricter). Lowering the vapor pressure in gasoline would reduce volatile HC emissions that contribute to ozone formation.
- The olefinic content of low-octane gasoline produced by Eg3 (22.3 percent by volume) was higher than allowed in the United States (the 1990 baseline value for reformulated gasoline is 10.8 percent by volume). Reduction of olefinic compounds would reduce emissions of reactive HC that contribute to ozone formation.
- The aromatics content of medium-octane gasoline produced by Eg3 (44.4 percent by volume) and high-octane gasoline produced by most refiners (35.6 percent by YPF, 37.5 percent by Eg3, and 40.0 percent by Refsan) was higher than allowed in the United States (the 1990 baseline value for reformulated gasoline is 28.6 percent by volume). Reduction of aromatics content would reduce emissions of NO_x, HC, and benzene.
- Gasoline produced by Esso had a much higher sulfur content (1,000 ppm) than gasoline produced by Eg3 (181 ppm to 288 ppm) or YPF (less than 500 ppm), or the 1990 baseline value of gasoline in the United States (338 ppm). Higher sulfur content reduces the efficiency of catalytic converters.

As a result of the government's fuel taxing policy CNG is the least expensive motor vehicle fuel in Argentina, and is especially popular for use in taxis circulating in Buenos Aires (see Table 4.58). A typical fuel cost for a taxi is about $0.04/kilometer if operated with CNG and $0.11/kilometer if operated with gasoline. In addition, newer CNG-fueled taxis cost about 30 percent less than diesel-fueled taxis. This requires installing a CNG tank and associated connections and a new fueling system. More than half of the 40 or so conversion kits in the market are locally produced. The conversion costs $1,000 to $1,500, depending on the size and weight of the CNG tank.

Although gasoline is more expensive than CNG, mainly because of the differential tax policy applied to these two fuels, it still generally is not preferred by private car owners because the CNG tank is heavy (a minimum of 80 kilograms) and takes up space. Choosing to convert private cars to CNG is often associated with extensive travel needs, where the economy of CNG outweighs its inconvenience and conversion cost.

Although CNG-fueled buses are less polluting than diesel-fueled buses in terms of NO_x, CO, and PM emissions, not even 2 percent of the urban buses operating in the BAMA are fueled with CNG. CNG-fueled buses are not generally favored mainly because fuel price incentives to convert diesel-fueled buses to CNG were not created until recently (see Table 4.58). In addition, CNG-fueled buses have lower resale value than diesel-fueled buses (because CNG service stations are not very common outside of urban centers), companies operating CNG-fueled buses must invest about $1.5 million to have their own CNG filling stations, CNG tanks need to be filled daily, it is slower to fill a CNG tank than a diesel fuel

44. YPF is producing MTBE at its La Plata and Lujan de Cuyo refineries, and in the near future will produce TAME at its La Plata refinery. EG3, Esso, and Refisan are purchasing MTBE (Alconsult International Ltd.).

tank, CNG cylinders add extra weight to the bus (as much as 1,200 kilograms), and CNG-fueled buses cost more than diesel-fueled buses (by about 15 to 20 percent). Until 1995 the CNG program caused a 12 percent reduction in consumption of diesel fuel in favor of CNG in the BAMA, which should correspond to a 6 percent reduction in PM emissions (World Bank 1995). The fuel tax adjustment increasing the price of diesel fuel relative to CNG is expected to encourage more diesel-fueled vehicles to convert to CNG, and therefore result in lower PM, CO, and NO_x emissions.

Transport management. The overlapping jurisdiction of the federal government, the Province of Buenos Aires, and the Municipality of Buenos Aires complicates the traffic management in the BAMA. This situation has created inefficiencies in cooperation, planning, operation, administration, regulation, and control of the transport system, yielding high social costs in the form of congestion, pollution, suboptimal investment, and decreasing levels of services. Coordination and planning of transport services among the agencies responsible for road management and public transport provision from all three jurisdictions in the BAMA is necessary to improve transport management and reduce vehicular air emissions.

Although the number of passenger trips made in the BAMA in 1970, 1992, and 1994 did not change significantly, the number of trips made by private cars is increasing (Table 4.59). Passenger trips by private cars increased by 69 percent between 1970 and 1992 (2.4 percent a year) and by 26 percent between 1992 and 1994 (12.3 percent a year). The sharp increase in recent years can be attributed to greater ownership of private cars. Since 1991 the number of private cars in circulation in the BAMA has increased by about 100,000 a year because of higher incomes, a new financing system for cars (four-to five-year loans with an annual interest rate of 15 to 20 percent), and stable car prices resulting from an agreement among the government, car manufacturers, dealers, and automotive industry unions.

Between 1970 and 1992 the share of public transport in total passenger trips fell slightly, by about 1 percent (see Table 4.59). Although bus ridership increased by about 9 percent, metro and suburban train ridership decreased by 48 and 45 percent, respectively. This drop can be attributed to the deteriorating service provided by metro and suburban trains under public sector management. Between 1992 and 1994, however, the metro and suburban train ridership increased by 62 and 22 percent, respectively. Ridership increased further in 1995 and 1996. For example, ridership for the first nine months of 1996 was up by 38 percent for metro and 93 percent for the suburban railway system as compared to the same period in 1993. Although part of these increases is due to a reduction in fare evasion, privatizing these systems improved their service reliability and security (particularly at stations) at no increase in fares. This is confirmed by a 1995 government survey, which found that 96 percent of the riders on four suburban lines felt the service was as good as or better than before, with a majority stating that it was better.

Table 4.59 Passenger trips in the BAMA, 1970, 1992, and 1994
(percent)

Mode	*1970*	*1992*	*1994*
Private car	15.4	25.0	32.4
Taxi	6.7	3.2	4.0
Bus	54.3	56.7	47.1
Train	7.0	3.9	4.9
Metro	5.4	2.7	4.5
Other[a]	11.2	8.5	7.1
Total	100.0	100.0	100.0
Number of daily passengers (millions)	17.4	18.1	17.6

a. Includes trips by foot, charter and school bus, motorcycle, and bicycle.
Source: Pre-ATAM 1994a.

The 1994 traffic restriction based on the license plates of private cars was lifted because it did not yield the desired results. Although traffic restrictions in the microcenter area of Buenos Aires have reduced congestion, they have not been totally successful because cars with special permits and official vehicles continue to circulate, and traffic enforcement has not been strict. In addition, circulation of certain bus lines in the microcenter area has contributed to congestion. Pilot bus lanes have proved worthwhile and should be extended to other arteries. Expanding the restricted zone for private cars and strengthening enforcement also would help reduce congestion and air pollution in Buenos Aires. Furthermore, better traffic engineering measures (such as elimination of bottlenecks and

signalization) as well as measures to increase the attractiveness of public transport (such as rehabilitation of the metro and suburban trains) would achieve the same objectives.

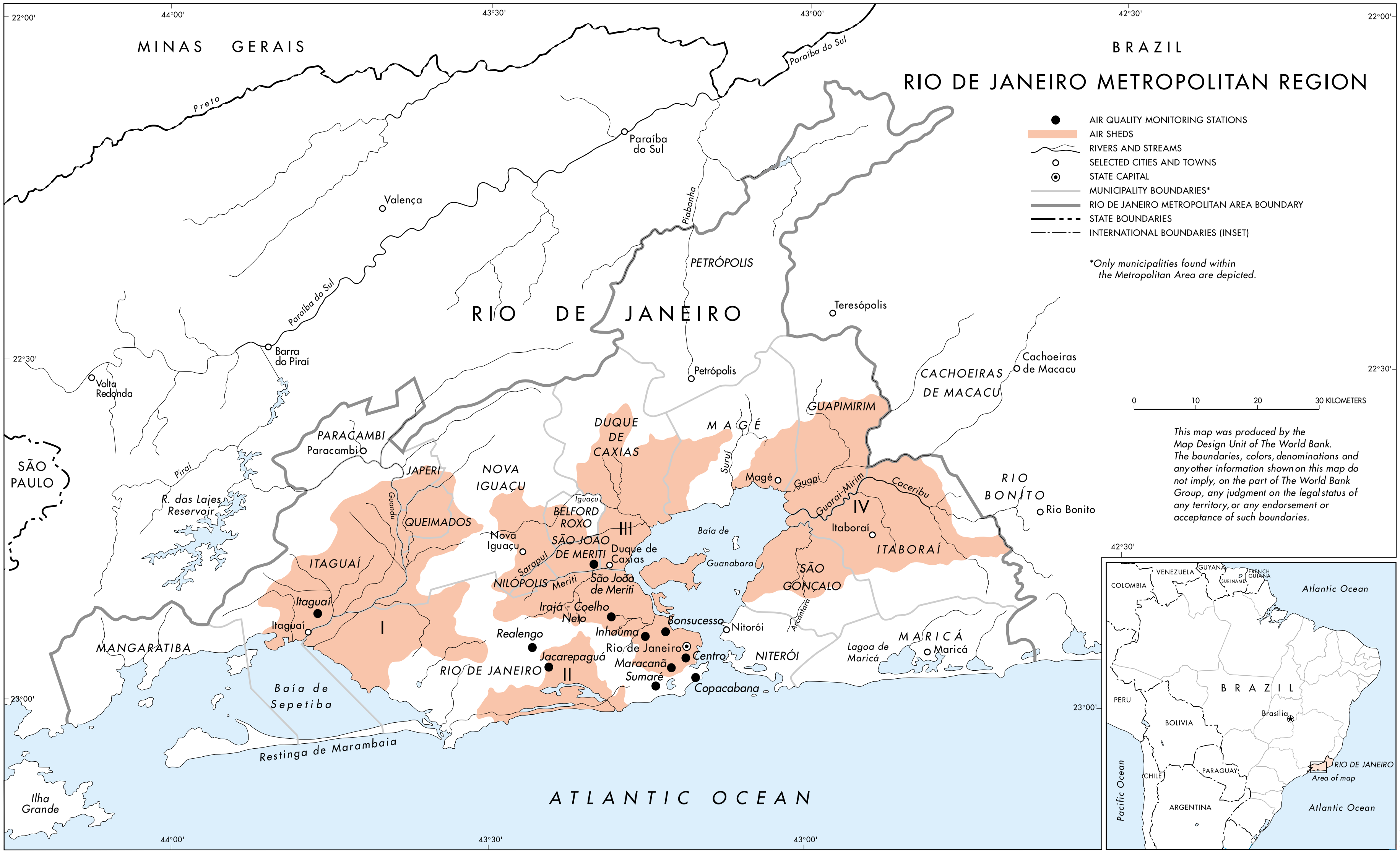
With the bus retirement program adopted in 1992, about 3,500 urban buses 10 years and older were taken out of circulation by January 1996. This measure has reduced air pollutant emissions from the bus fleet.

Compared with regular buses, diferencial buses offer faster and more comfortable service to commuters because they stop less frequently and guarantee a seat for every passenger. The fares for diferencial buses are higher than those for regular buses. For suburban commuters, charter buses provide faster and more convenient service because of reliable schedules and guaranteed seats.

The new toll road to Pilar and the highway to La Plata have increased travel speeds and relieved the traffic load on alternate roads. As a result, emission of pollutants from vehicular sources must have decreased. Establishing tolls on the highway to La Plata will allow traffic density to be controlled. When the toll road to the southwest and the second toll road to the west are completed, congestion and vehicular air emissions are expected to be further reduced in the BAMA.

Air quality monitoring. Air quality data for Buenos Aires is limited to manual sampling of NO_x, TSP, lead, and SO_2 at one monitoring station; continuous sampling of CO at three monitoring stations; and short-term monitoring of CO at heavy traffic intersections. In addition, air quality data for lead are available for certain months of the year. However, data is not collected for certain key air pollutants such as ozone. An air quality monitoring network needs to be established that includes all the above-mentioned pollutants and covers the entire BAMA. An emissions inventory for the Federal Capital and BAMA also needs to be developed. The data generated from these efforts would allow determination of potential exposure levels of air pollutants and design of a rational air pollution control strategy for the BAMA.

Rio de Janeiro


IBRD 28158
BRAZIL
RIO DE JANEIRO METROPOLITAN REGION
AIR QUALITY MONITORING STATIONS
AIR SHEDS
RIVERS AND STREAMS
SELECTED CITIES AND TOWNS
STATE CAPITAL
MUNICIPALITY BOUNDARIES*
RIO DE JANEIRO METROPOLITAN AREA BOUNDARY
STATE BOUNDARIES
INTERNATIONAL BOUNDARIES (INSET)
*Only municipalities found within the Metropolitan Area are depicted.
0 10 20 30 KILOMETERS
This map was produced by the Map Design Unit of The World Bank. The boundaries, colors, denominations and any other information shown on this map do not imply, on the part of The World Bank Group, any judgment on the legal status of any territory, or any endorsement or acceptance of such boundaries.
MINAS GERAIS
SÃO PAULO
RIO DE JANEIRO
ATLANTIC OCEAN
Paraíba do Sul
Preto
Piraí
Piabanha
Valença
Barra do Piraí
Volta Redonda
R. das Lajes Reservoir
PARACAMBI
Paracambi
JAPERI
QUEIMADOS
ITAGUAÍ
Itaguaí
MANGARATIBA
NOVA IGUAÇU
Nova Iguaçu
BELFORD ROXO
SÃO JOÃO DE MERITI
São João de Meriti
NILÓPOLIS
DUQUE DE CAXIAS
Duque de Caxias
PETRÓPOLIS
Petrópolis
Teresópolis
MAGÉ
Magé
GUAPIMIRIM
CACHOEIRAS DE MACACU
Cachoeiras de Macacu
RIO BONITO
Rio Bonito
ITABORAÍ
Itaboraí
SÃO GONÇALO
NITERÓI
Niterói
MARICÁ
Maricá
Lagoa de Maricá
Baía de Guanabara
Baía de Sepetiba
Restinga de Marambaia
Ilha Grande
Guandu
Iguaçu
Sarapuí
Meriti
Suruí
Guapi
Guapi-Mirim
Caceribu
Alcantara
I
II
III
IV
Realengo
Jacarepaguá
Irajá
Coelho Neto
Inhaúma
Bonsucesso
Rio de Janeiro
Maracanã
Centro
Sumaré
Copacabana
RIO DE JANEIRO
22°00'
22°30'
23°00'
44°00'
43°30'
43°00'
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VENEZUELA
GUYANA
SURINAME
FRENCH GUIANA
COLOMBIA
PERU
BOLIVIA
CHILE
PARAGUAY
ARGENTINA
BRAZIL
Brasília
Area of map
Atlantic Ocean
Pacific Ocean
JULY 1997

Rio de Janeiro, the capital of the State of Rio de Janeiro, covers an area of 1,171 square kilometers. With a population of 5.5 million people in 1991, Rio de Janeiro is Brazil's second largest city. The Rio de Janeiro Metropolitan Region (RJMR), which includes the City of Rio de Janeiro and fourteen other municipalities, covers 6,500 square kilometers, or 15 percent of the State of Rio de Janeiro. In 1991 the RJMR contained 9.8 million people, 77 percent of the state's population (IBGE 1991). During the 1980s annual population growth was 2.4 percent in the RJMR and 1.8 percent in Rio de Janeiro.

The RJMR borders the Atlantic ocean, but its topography includes hills reaching 800 meters in some urban areas. A tropical rain forest climate brings temperatures ranging from 21°C (July through September) to 27°C (January through April). Annual precipitation is about 1,200 millimeters, peaking between March and May (when the monthly average is 160 millimeters).

After the São Paulo Metropolitan Region, the RJMR has the second largest concentration of vehicles and industries in Brazil and a worsening urban air pollution problem. Its uneven topography, unplanned land use patterns, and the presence of the sea and Guanabara Bay affect the dispersion of pollutants. Air quality is worse in those parts of the RJMR that are affected by thermal inversions between May and September (mostly during June and July). Such is the case in the northern section of Rio de Janeiro, where air pollutants from major emission sources cannot easily be dispersed because incoming winds are blocked by the Carioca mountain range.

Ambient Air Quality

Air pollution monitoring efforts in the RJMR have concentrated on four airshed areas with different pollution characteristics. Airshed I, covering about 730 square kilometers, is in the western part of the RJMR, northeast of Sepetiba Bay. It consists of the Municipality of Itaguaí, the Queimados and Japeri districts of the Municipality of Nova Iguaçú, and the Santa Cruz and Campo Grande districts of the Municipality of Rio de Janeiro. Airshed II, covering about 140 square kilometers, is on the Atlantic coast between Guanabara Bay and Sepetiba Bay. It includes the Jacarepaguá and Barra da Tijuca districts of the Municipality of Rio de Janeiro. Airshed III, covering about 700 square kilometers, is to the west and northwest of Guanabara Bay. It includes many districts of the Municipality of Rio de Janeiro (including the downtown area), parts of the Municipality of Belford Roxo, the Municipalities of Nilópolis and São João de Meriti, the Nova Iguaçú and Mesquita districts of the Municipality of Nova Iguaçú, the Duque de Caxias, Xerém, Campos Elíseos, and Imbariê districts of the Municipality of Duque de Caxias, and the Guia de Pacoaíba, Inhomirim, and Suruí districts of the Municipality of Magé. Airshed IV, covering about 830 square kilometers, is to the east and northeast of Guanabara Bay. It includes the Municipalities of São Gonçalo and Itaboraí, and some districts of the Municipality of Magé (FEEMA 1989). In addition to the four airshed areas, air quality has been monitored in the coastal districts of Copacabana and Realengo, which are separated from Airshed III, to the north, by mountains.

Except for TSP and NO_2, the most recent ambient air quality data for the RJMR is more than five years old. More than fifteen stations have been used to monitor ambient TSP levels in the RJMR's residential, commercial, and industrial districts (Tables 4.60 and 4.61). Ambient TSP concentrations were found to be below the national and state primary annual standard (80 $\mu g/m^3$) in Airshed I, about twice the standard in Airshed II, above the standard in Airshed III, and around or above the standard in Airshed IV. In Airshed III average annual TSP concentrations were above the standard in industrial districts as well as in residential and commercial districts such as the Maracanã district of Rio de Janeiro, Nilópolis, and São João de Meriti, where PM emissions can be attributed mostly to vehicular sources. In 1994, however, the national and state primary 24-hour standard of 240 $\mu g/m^3$ was exceeded mostly in industrial neighborhoods (such as Inhaúma and Coelho Neto).

During May–October 1994 a separate air monitoring effort was conducted as part of the Brazilian-German cooperation agreement. This effort found that the national and state primary 24-hour TSP standard was exceeded by many air monitoring stations located in Airshed III: in São João de Meriti the standard was exceeded on 70 percent of the days monitored with a maximum value of 634 $\mu g/m^3$; in Bonsucesso and Inhaúma it was exceeded on 32 percent of the days, with maximum values of 290 $\mu g/m^3$ and 284 $\mu g/m^3$; in Irajá, 23 percent of the days with a maximum

Table 4.60 Annual average concentrations of TSP in the Municipality of Rio de Janeiro and the RJMR, 1987–93

(micrograms per cubic meter)

Station	*Contributors to TSP emissions*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*
Airshed I								
Itaguaí	Light traffic	—	—	26	32	35	32	33
Airshed III								
Municipality of Rio de Janeiro								
Benfica	Heavy traffic, refinery	101	—	76	81	81	—	#
Bonsucesso	Heavy traffic, industry	151	189	188	206	204	236	191
Centro II	Heavy traffic	—	—	—	—	102	—	#
Coelho Neto	Regular traffic, industry	—	—	—	145	—	—	—
Inhaúma II	Light traffic, industry	—	—	—	—	132	179	153
Maracanã UERJ	Heavy traffic	114	—	110	105	93	107	106
Gonçalo II	Regular traffic, industry	80	—	72	72	63	69	67
S. Cristovão	Regular traffic, industry	87	—	96	97	91	91	96
Santa Teresa	Light traffic	45	48	33	55	53	46	61
Other RJMR municipalities								
Duque de Caxias	Traffic, refinery	114	#	141	121	112	92	116
Nilópolis	Regular traffic	100	#	92	93	86	90	88
S. João de Meriti	Regular traffic	123	#	134	139	122	210	194
Airshed IV								
Niterói	Regular traffic	76	82	74	81	#	♓	♓
São Gonçalo	Heavy traffic	114	#	—	—	#	123	♓
Other								
Copacabana	Heavy traffic	66	81	73	74	70	84	#
Realengo	Light traffic	—	—	—	87	—	—	—

— Not available.

♓ Station inactive.

Insufficient data to calculate annual geometric mean. The minimum data is for 20 percent of the regular sample collection days (based on one sample every six days).

Source: FEEMA 1995.

value of 351 μg/m^3; and in Jacarepaguá, 3 percent of the days with a maximum value of 244 μg/m^3. Although the primary 24-hour TSP standard was not exceeded, the secondary 24-hour standard (150 μg/m^3) was exceeded in Centro on 17 percent of the days with a maximum value of 173 μg/m^3; and in Maracanã, 18 percent of the days with a maximum value of 207 μg/m^3 (FEEMA and GTZ 1995).

The 1994 air monitoring effort also included the Realengo and Copacabana districts. In Realengo the primary 24-hour standard TSP standard was not exceeded on any of the days monitored; however, the secondary 24-hour TSP standard was exceeded on 18 percent of the days monitored with a maximum value of 208 μg/m^3. In Copacabana the maximum 24-hour TSP concentration was 135 μg/m^3. Ambient TSP concentrations were lower on Sundays than on any other day of the week, and higher on Saturdays than Fridays (FEEMA and GTZ 1995).

Available PM-10 data is limited to one site in Rio de Janeiro. A 1984 study by Daisy and others (1987) found that 12-hour PM-10 values in São Cristovão (Airshed III) ranged from 20 μg/m^3 to 100 μg/m^3, with an average value of 70 μg/m^3.[45] The corresponding TSP values ranged from 25 μg/m^3 to 225 μg/m^3, with an average of 100 μg/m^3. This suggests that about 70 percent of TSP are in the inhalable range (that is, less than 10 μm in size).

45. The national ambient air quality standards for PM-10 are: an annual arithmetic average of 50 μg/m^3 and a 24-hour average of 150 μg/m^3, not to be exceeded more than once a year. There are no state ambient air quality standards for PM-10.

Table 4.61 Concentrations of TSP in the Municipality of Rio de Janeiro, 1994

Station	Contributors to TSP emissions	Annual average (μg/m³)	Maximum 24-hour value (μg/m³)	Month of maximum concentration	Number of violations of 24-hour standard	Number of data points per year	Percent of violations of 24-hour standard
Airshed II							
Jacarepaguá	Regular traffic, industry	173	254	November	2	40	5
Airshed III							
Benfica	Heavy traffic, refinery	#	122	April	0	10	0
Bonsucesso	Heavy traffic, industry	190	341	November	17	63	27
Centro II	Heavy traffic	#	191	December	0	44	0
Coelho Neto	Regular traffic, industry	164	351	June	6	33	18
Inhaúma II	Light traffic, industry	178	284	July	10	40	25
Maracanã UERJ	Heavy traffic	100	207	June	0	63	0
Méier II	Regular traffic, industry	#	83	February	0	12	0
Santa Teresa	Light traffic	#	80	March	0	9	0
Other							
Copacabana	Heavy traffic	70	406	December	1	72	1
Realengo	Light traffic	97	208	September	0	32	0

Insufficient data to calculate annual geometric mean. The minimum data is for 20 percent of the regular sample collection days(based on one sample every six days).
Source: FEEMA 1995.

Ambient SO_2 data are available for 1980–84, 1989–90, and 1994. During the first period ambient SO_2 concentrations at most stations fell because of the implementation of industrial pollution control measures (Table 4.62). At many stations in Airshed III, however, ambient SO_2 concentrations were still above the standard. During July 1989-February 1990 ambient SO_2 was monitored using a mobile station in the residential-commercial neighborhood of Copacabana. Monthly SO_2 averages were found to range from 39 μg/m³ to 176 μg/m³, with an overall average (139 μg/m³) well above the annual standard of 80 μg/m³ (FEEMA 1990). During August–December 1994 ambient SO_2 concentrations were monitored at São João de Meriti and Copacabana as part of the Brazilian-German cooperation agreement. The maximum 24-hour SO_2 concentrations were 92 μg/m³ at São João de Meriti and 91 μg/m³ at Copacabana, below the Brazilian standard of 365 μg/m³. The monthly averages ranged from 33 μg/m³ to 69 μg/m³ at São João de Meriti and from 25 μg/m³ to 38 μg/m³ at Copacabana (FEEMA and GTZ 1995).

Ambient NO_2 concentrations were monitored at two locations during August–December 1994 as part of the Brazilian-German cooperation agreement. The maximum 24-hour values were 83 μg/m³ at São João de Meriti (Airshed III) and 114 μg/m³ at Copacabana. These values are lower than the WHO's 24-hour NO_2 guideline of 150 μg/m³.

Ambient CO levels were monitored in Tijuca (Airshed II) and Copacabana, the districts of Rio de Janeiro mostly affected by vehicular air pollution. During 1984–88 and 1989–90 hourly CO concentrations in Copacabana were found to be lower than the national and state 1-hour CO standard of 35 ppm (the maximum CO concentration observed was 28 ppm). The national and state 8-hour standard of 9 ppm was exceeded, however, 7.5 percent of the time during 1989–90 (FEEMA 1989; FEEMA 1990). In Tijuca the 1-hour standard for CO was exceeded on fourteen of thirty-two monitoring days during November 1988–January 1989 period. The peak value for the 1-hour CO concentration was 50 ppm (FEEMA 1995).

Air quality data on ozone is limited. The five-

Table 4.62 Annual average concentrations of SO_2 in the RJMR, 1980–84
(micrograms per cubic meter)

Station	*Potential emission sources*	*1980*	*1981*	*1982*	*1983*	*1984*
Airshed I						
Municipality of Rio de Janeiro						
Santa Cruz	Regular traffic, industry	74	80	68	50	31
Other RJMR municipality						
Itaguaí	Light traffic	—	117	56	52	25
Airshed III						
Municipality of Rio de Janeiro						
Benfica	Heavy traffic, refinery	168	149	94	111	95
Bonsucesso	Heavy traffic, industry	166	179	172	150	164
Centro	Heavy traffic	63	115	86	78	81
Irajá II	Heavy traffic	140	144	101	83	102
Ilha do Governador	Refinery, airplanes	128	129	83	76	67
Maracanã	Heavy traffic	174	151	119	113	105
Méier II	Regular traffic, industry	167	199	108	77	73
Rio Comprido	Regular traffic, industry	127	141	115	98	102
Other RJMR municipalities						
D. de Caxias-Centro	Light traffic	110	126	94	77	71
D. de Caxias-C. de Meninos	Regular traffic, industry	—	119	74	77	53
Other						
Copacabana	Heavy traffic	109	126	96	103	91

— Not available.
Source: FEEMA 1989.

day monitoring results during October 1988–January 1989 in Tijuca (Airshed II) indicate that the state and national air quality 1-hour standard of 160 $\mu g/m^3$ was exceeded on four days. The monitored ozone values ranged from 160 $\mu g/m^3$ to 397 $\mu g/m^3$ (FEEMA 1995).

During 1984–87 ambient concentrations of lead were measured at twenty-three monitoring stations in the RJMR. The highest three annual average concentrations were observed in Airshed III at the following monitoring stations: EMPA-Maracanã (0.76 $\mu g/m^3$), Maracanã (0.72 $\mu g/m^3$), and Bonsucesso (0.66 $\mu g/m^3$). About 86 percent of the reported annual averages were below 0.50 $\mu g/m^3$. The lowest annual concentrations were detected in Santa Cruz (0.08 $\mu g/m^3$), Ilha do Governador (0.08 $\mu g/m^3$), and Itaguaí (0.09 $\mu g/m^3$; FEEMA 1989). No recent ambient lead data are available, but it is likely that more extensive use of alcohol-based fuels in vehicles and the subsequent elimination of lead from gasoline in 1991 has reduced ambient concentrations of lead in the RJMR.

Sources of Pollutants

The most comprehensive air pollution inventory for the RJMR dates back to 1978 for all emission sources (FEEMA 1989). In addition, the World Bank estimated the 1994 air emissions for Airshed III. Both inventories identified industry as the main source of PM and SO_2 emissions and vehicles as the main source of CO and NO_x emissions.

In addition, inventories of the 1981 and 1983 industrial emissions were compiled for the Municipality of Rio de Janeiro and RJMR. The data indicate substantial reductions in PM and SO_2 emissions during 1978–1983 (Table 4.63). These reductions resulted from pollution control measures implemented by industry.

The results of the 1978 emissions inventory are shown in Figure 4.15. In 1978 vehicles accounted for 97 percent of CO, 73 percent of HC, 70 percent of NO_x, 9 percent of SO_2, and 2 percent of PM emissions. Industry accounted for 84 percent of SO_2 and 69 percent of PM emis-

Table 4.63 Estimated industrial emissions of PM and SO_2 in the Municipality of Rio de Janeiro and the RJMR, 1978, 1981, and 1983
(thousand tons)

	Municipality of Rio de Janeiro			*RJMR*		
Pollutant	*1978*	*1981*	*1983*	*1978*	*1981*	*1983*
PM	75	20	15	122	71	66
SO_2	58	40	35	149	117	98

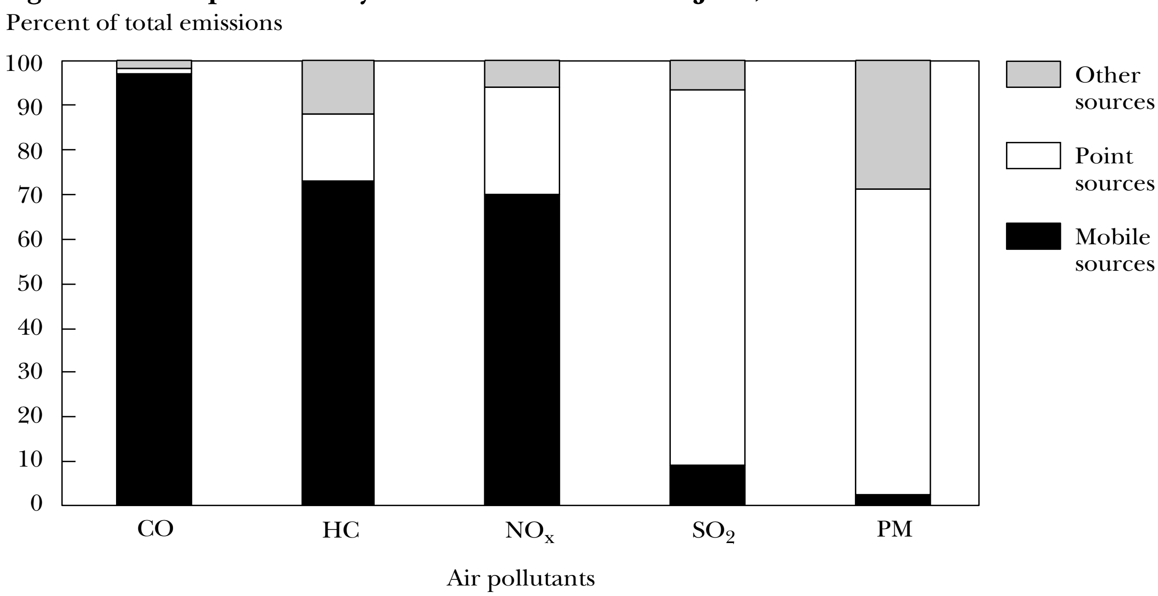
Source: FEEMA 1989.

sions. Nonmetallic mineral processing (cement and glass manufacturing and quarrying), asphalt making, and chemical industries were responsible for most PM and SO_2 emissions from industrial sources. Most SO_2 emissions from industrial sources resulted from chemical and non metallic mineral processing operations using high-sulfur diesel oil (up to 5 percent sulfur) or coal (up to 3 percent sulfur). The World Bank's estimates suggested that motor vehicles in 1994 accounted for 94 percent of CO, 85 percent of NO_x, 9 percent of PM, and 8 percent of SO_2 emissions in Airshed III. Alcohol- and gasoline-fueled vehicles emitted 74 percent of the PM from vehicular sources. Industry was responsible for 80 percent of PM, 91 percent of SO_2, 2 percent of CO, and 12 percent of NO_x emissions (World Bank 1996). No estimates were made for HC emissions.

In 1994 the number of road-based motor vehicles registered in the RJMR included 1,398,000 cars, 139,000 trucks, 16,000 buses, and 78,000 motorcycles. The number of road-based vehicles registered in the RJMR increased by 8.6 percent a year between 1976 and 1980, and 2.7 percent a year between 1980 and 1994. In 1994 vehicles registered in the Municipality of Rio de Janeiro accounted for 70 percent of those in the RJMR and 56 percent of those in the State of Rio de Janeiro. Cars made up 85 to 87 percent of the vehicle fleet in these areas (Figure 4.16).

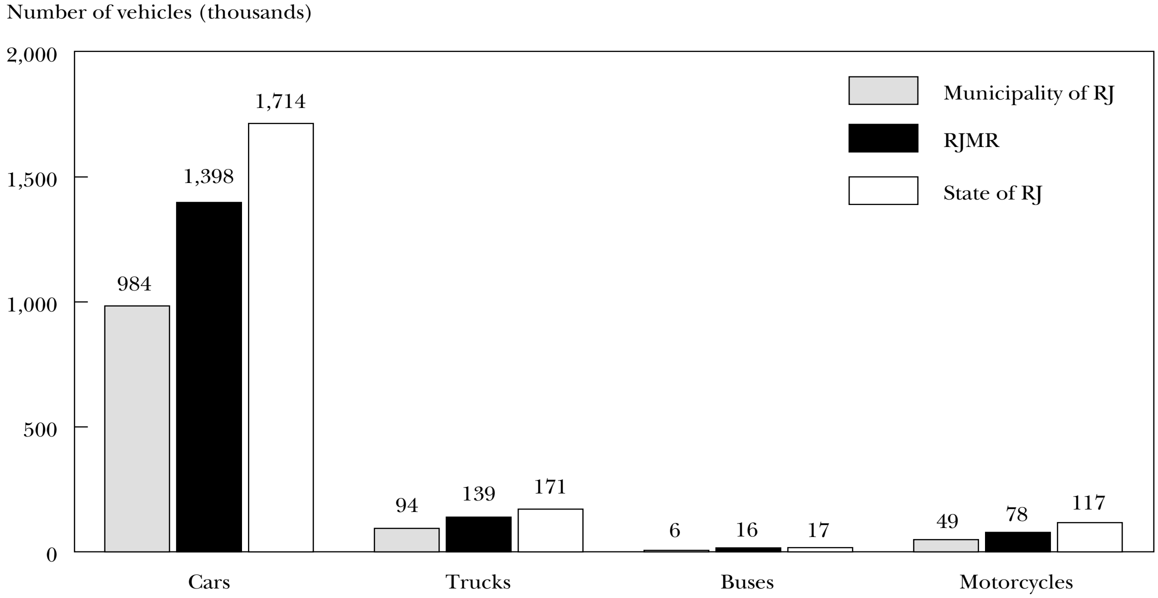
Land-based public transportation in the RJMR is provided by rail, metro, and buses. The suburban rail system (*Flumitrens*) runs for 264 kilome-

Figure 4.15 Air pollutants by emission source in the RJMR, 1978



Source: FEEMA 1989.

Figure 4.16 Types of vehicles in Rio de Janeiro, 1994



Source: PRODERJ 1995.

ters and the metro, for 23 kilometers. Flumitrens is organized in five corridors: D. Pedro II-Deodoro, Deodoro-Santa Cruz, Deodoro-Japeri, P. Pedro II-Belford Roxo, and B. Maua-Saracuruna. The metro system operates on two lines: Saens Peña-Botafogo and Estacio-Pavuna. About 60 percent of Flumitrens' tracks are electrified, and the metro is fully electrified. In addition, water-borne passenger ferry services are provided across Guanabara Bay.

A 1994 survey put the number of daily trips in Rio de Janeiro at 13.18 million, of which 79 percent are motorized (Table 4.64). Of the motorized modes, 78 percent are made by bus, 15 percent by car, and 7 percent by train, metro, and boat. Nonmotorized modes are dominated by walking, which accounts for 20 percent of total trips.

Table 4.64 Transport modes in Rio de Janeiro, 1994
(percent)

Mode	*Distribution*
Car (private and taxi)	11.50
Bus	61.02
Train	3.13
Metro	2.28
Boat	0.68
On-foot	19.68
Bicycle	1.28
Other	0.43

Source: Flumitrens 1995.

Institutional Responsibilities

Federal institutions. The federal institutions are described in the São Paulo section.

State institutions. The State Secretariat of Environment (SEMAM) was established in 1987 as part of the reorganization of the State Secretariat of Public Works and Environment. It was renamed the State Secretariat of Environment and Special Projects (SEMA) in 1991. The secretariat is responsible for environmental management in the State of Rio de Janeiro, including developing and implementing government policies on environmental control and preservation. The secretariat oversees the work of four state environmental agencies: the State Foundation for Environmental Engineering (FEEMA), State Superintendency for Rivers and Lakes (SERLA), State Forestry Institute (IEF), and Department of Mineral Resources (DRM).

FEEMA was established in 1975 to conduct

research, set standards, and train personnel on the environment. As the technical arm of the State Secretariat of Environment and Special Projects, FEEMA is responsible for developing and recommending strategies for air pollution control; preparing laws, decrees, and technical standards for the implementation of air pollution control policies; executing policies in the areas of air quality analysis, environmental permitting, enforcement, and control of emissions from industry and other sources; preparing, as requested, laws and regulations on air quality and emission standards at the national level; providing technical opinion on air pollution issues; participating in environmental training and education policy issues; conducting air quality diagnostics; participating in the national commission for the vehicular air pollution program; ensuring improvement of fuel quality; and supporting the natural gas utilization program. FEEMA consists of planning, control, and administrative departments and five regional departments. It employs about 1,000 people, 250 of whom have a university degree. Its Air Quality Division consists of twenty people: seven assigned to the air quality monitoring program and five to the enforcement of smoke emissions from diesel-fueled vehicles. Since its foundation FEEMA has served as a model agency in Brazil in the areas of environmental management, development of environmental legal framework, and technical expertise. However, over the past eight years and in particular the past four years, the agency underwent drastic decline as result of poor political support, a very limited budget, and weak strategic direction (World Bank 1996).

The State Commission of Environmental Control (CECA) was created in 1975 to coordinate, supervise, and control environmental activities in the State of Rio de Janeiro. The commission serves as the enforcement arm of the secretariat, which regulates its responsibilities, structure, and operation. The commission's principal responsibilities are to discuss and approve environmental control proposals, discuss and approve draft environmental legislation proposed by FEEMA, impose sanctions on violators of environmental legislation and collect the fines, and ensure enforcement of pollution control and environmental protection measures. The commission consists of a president appointed by the state governor for four years, a secretary, and a nine-member plenary assembly made up by representatives of state institutions and the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA).

The State Council of Environment (CONEMA) was created in 1987 to guide the Rio de Janeiro state government on environmental matters. The council, which is responsible for establishing directives guiding state policies on environmental control, consists of representatives of public organizations and civic societies, including state secretaries, state prosecutors, IBAMA, port authorities, industry federations, engineering and scientific organizations, and press and bar associations. The council is presided over by the State Secretariat of Environment and Special Projects and the State Commission of Environmental Control serves as its plenary council. It meets every two months, and more often under special circumstances.

The state and municipalities are responsible for intermunicipal and intramunicipal transport services, respectively. Metropolitan transport in the RJMR is under the jurisdiction of the State Secretariat of Transportation. The state regulates the licensing of intermunicipal bus passenger services, which are owned and operated by the private sector. The state owns and operates Flumitrens and two bus companies—CTC (which provides about 30 percent of inter municipal bus passenger services) and SERVE. Besides these two bus companies, the state also owns and operates CONERJ, which is responsible for water-borne passenger ferry services across Guanabara Bay. In addition, the state owns and operates the metro. In 1995 the assets of the metro were transferred from the Government of Brazil to the State of Rio de Janeiro. Operation of the metro network is expected to be privatized.

Local institutions. Municipalities are the most important environmental institutions at the local level. Municipalities are also responsible for managing traffic and for licensing and regulating private bus services within the municipal boundaries (including granting to concessionaires and setting up the rate structure). In addition, municipalities are responsible for planning and implementing access corridors for nonmotorized transport and traffic management within its jurisdiction. The Secretariat of Transport of the Municipality of Rio de Janeiro regulates all private bus services operating within its boundaries.

Implemented Measures

Vehicle emission standards. The national regulatory measures for light-and heavy-duty vehicles are described in the São Paulo section. These measures, which include emission standards for light- and heavy-duty vehicles, also apply to the RJMR.

Vehicle inspection programs. The national Program to Control Air Pollution from Motor Vehicles (PROCONVE) requires that state environmental protection agencies design and implement a vehicular inspection and maintenance program in their respective states. In 1996 the State Assembly of Rio de Janeiro passed a law for periodic inspection of all motor vehicles. Preparation of regulations for this law is under way.

Roadside inspections in the RJMR have been conducted only for heavy-duty vehicles. The inspections, which began in 1988, measure black smoke in exhaust emissions. Since the end of February 1989 vehicles with smoke emissions exceeding Index No. 3 on the Ringelmann scale have had to pay fines. Because no substantial reduction in the number of polluting vehicles was observed, a public campaign called "No to Black Smoke" began airing on local television stations in November 1989. As part of the campaign the public was asked to report heavy-duty vehicles emitting black smoke to FEEMA.

Roadside inspections of heavy-duty vehicles have been conducted by three different teams made up of FEEMA technicians and military police. These inspections involve stopping vehicles in circulation and testing their exhaust emissions for three minutes. During inspections bus passengers are informed about the program through distributed leaflets. Vehicles that fail the test are fined, in theory, $1,300 per violation and given a sticker that forbids them from circulating. These vehicles are required to remedy the problem after taking passengers to their destinations. Since December 1989 FEEMA has been performing the engine work required to bring vehicles into compliance with the black smoke regulation, although the original design of the program assigned this responsibility to the vehicle owner. As part of this program, in the late 1980s FEEMA sponsored five training courses on measuring black smoke from diesel-fueled vehicles in the State of Rio de Janeiro. Three of these courses were given in the Municipality of Rio de Janeiro (FEEMA 1990).

Fuel-targeted measures. Fuel policies—including type, quality, supply, and price—are determined at the national level. These policies are described in the São Paulo section and are largely applicable to the RJMR. Cars circulating in the RJMR mainly use ethanol (which contains 4 percent water) or gasohol (a blend of 22 percent anhydrous ethanol and 78 percent gasoline). Heavy-duty vehicles such as buses and trucks mostly use diesel fuel and motorcycles use gasohol.

The lead content of gasoline, which is used to formulate gasohol, was reduced from 0.25 g/liter in 1977 to 0.15 g/liter in 1979, 0.09 g/liter in 1983, and 0.06 g/liter in 1987. Use of lead in gasoline was eliminated in 1991. Thus all vehicle fuels supplied to the RJMR are lead-free.

In October 1996 the sulfur content of diesel fuel sold in the RJMR was reduced from 0.5 to 0.3 percent by weight. The sulfur content of the diesel fuel marketed for intercity transport was also reduced from 0.5–0.1 to 0.5 percent by weight. Both grades of diesel fuel are sold at the same price.

Since the early 1990s CNG has been used as an alternative vehicle fuel in Rio de Janeiro following feasibility studies conducted by the State Gas Commission. About 2,000 taxis circulating in the Municipality of Rio de Janeiro have been converted to CNG, at a cost of about $1,300 per vehicle. In addition, about 200 urban buses operating in the RJMR are CNG-fueled. Most of these buses are owned by the state company CTC. The Municipality of Rio de Janeiro promotes the use of CNG by requiring gas stations in certain areas to sell it. CNG, which is produced from natural gas obtained at the Bacia de Campos offshore field in Rio de Janeiro, sells for about 75 percent of the price of ethanol.

Transport management. Rail stations and associated components of the rail system in the RJMR are being rehabilitated as part of a World Bank-financed transport project in Rio de Janeiro. In addition, the project will construct transfer points within stations to integrate the rail system with other modes. These and other transport measures are expected to increase the use of public transport in the RJMR (World Bank 1993).

The metro has secured funds for investments that will double its ridership and increase the route length from 23 kilometers to 35 kilometers. The proposed expansion will extend the two existing lines and is being financed by the

Brazilian National Development Bank (BNDES).

The State of Rio de Janeiro recently decided to privatize both of its bus companies (CTC and SERVE). Plans are also under way to sell the assets of CONERJ and to have the ferry route operated by the private sector under a concession. This process is to be completed by 1998. In addition, the State of Rio de Janeiro is planning to involve the private sector in the operations and management of Flumitrens and the metro.

Air quality monitoring. The ambient air monitoring program was initiated in 1967 in the Municipality of Rio de Janeiro. The original program measured TSP levels at seven stations. In 1968, with the support of the Pan-American Health Organization, these stations were incorporated into a monitoring network of twenty stations to measure TSP and total sulfation. In 1975 the responsibility for operating and maintaining the network was transferred to FEEMA. In 1980 the network was expanded to the RJMR. By 1982 there were thirty-nine monitoring stations for total settleable particulates, twenty-three stations for TSP, twenty-three stations for total sulfation, thirteen stations for SO_2, and one station for CO (FEEMA 1989).

In 1975 FEEMA received an automatic ambient air monitoring station from the WHO to complement the above-mentioned network. This station, installed in Maracanã, was designed to monitor meteorological conditions and pollutants in ambient air (CO, HC, methane, ozone, SO_2, total sulfur, hydrogen sulfide, and NO_2). This network was never fully operational, however, because of a lack of spare parts and technical difficulties (FEEMA 1989).

In 1986 funds provided by the Brazilian-Japanese Technical Cooperation Project agreement paid for the installation of an automatic monitoring station in a residential neighborhood (Gavea) to measure ambient air pollution from motor vehicles. The parameters monitored by this station included ozone, CO, SO_2, TSP, NO_x, and meteorological conditions. This station was also hampered by a lack of spare parts (FEEMA 1989).

In 1987, through the Technical Cooperation Project agreement between Brazil and Germany, a mobile monitoring station was acquired and used to measure air pollution in major traffic corridors of the RJMR (Copacabana, Bonsucesso, downtown Rio de Janeiro, Tijuca, Niterói, and Méier). The parameters monitored by this station included ozone, CO, SO_2, TSP, and meteorological conditions.

Evaluation of Implemented Measures

Rio de Janeiro lacks a metropolitan air quality management entity. Establishment of such an entity—including representatives from environmental, transport, and industrial institutions—would be the first step toward formulation of an air management policy and would facilitate promulgation of specific measures for curtailing emissions of critical air pollutants.

Vehicle emission standards. The evaluation of national regulatory measures presented in the São Paulo section is also valid for the RJMR. In summary, the emission limits imposed on new light- and heavy-duty vehicles have been effective in reducing vehicular emissions. Vehicle manufacturers have complied with these limits by installing electronic fuel injection systems and catalytic converters.

Vehicle inspection programs. During 1988–90 the roadside inspection program for heavy-duty vehicles was somewhat successful in reducing smoke emissions. During the initial phase of this program (December 1988-February 1989) 65 percent of the 336 vehicles inspected failed the black smoke test. With the introduction of fines for failing vehicles at the end of February 1989, this share dropped to 53 percent of the 445 vehicles inspected between March 1989 and October 1989. Following initiation of the black smoke campaign in November 1989, this share further dropped to 43 percent of the 2,880 vehicles inspected between November 1989 and March 1990 (FEEMA 1990). The long-term results of the roadside inspection program, however, indicate that it was not a strong deterrent, since a high percentage of heavy-duty vehicle operators were still willing to risk the fine (in theory $1,300 per violation) rather than properly maintaining their vehicles. Between August 1993 and August 1994, 64 percent of the 1,324 vehicles inspected were fined, about the same rate as when the program began in 1988 (Table 4.65).

In addition, the current design of the roadside inspection program makes FEEMA responsible for inspecting and correcting the failing vehicles, but does not allow FEEMA to receive

Table 4.65 Black smoke test results of heavy-duty vehicles in the RJMR during two periods

	November 1989–March 1990			*August 1993–August 1994*		
Type of vehicle	*Inspected*	*Fined*	*% Fined*	*Inspected*	*Fined*	*% Fined*
Urban buses	2,000	685	34	362	201	56
Trucks	766	481	63	883	606	69
School buses	75	50	67	40	27	68
Tourist buses	39	20	51	39	11	28
Total	2,880	1,236	43	1,324	845	64

Source: FEEMA 1990; FEEMA 1995.

the fines collected from polluting vehicle owners.[46] As such, FEEMA's incentives are not as strong as they could be. The current proposal for municipalities to enforce the black smoke regulation and collect the fines may be a step in the right direction. Extending the roadside inspections to periodic inspections at inspection centers would further reduce emissions from vehicular sources.

Fuel-targeted measures. The evaluation of fuel types presented in the São Paulo section also holds for the RJMR. In summary, the use of ethanol and gasohol in place of gasoline has reduced CO, HC, PM, and SO_2 emissions but increased aldehyde emissions in the exhaust of light-duty vehicles that are not equipped with catalytic converters. Evaporative (HC) emissions have decreased for ethanol-fueled vehicles, but have increased for gasohol-fueled vehicles. The shift from leaded to unleaded gasoline undoubtedly has reduced lead emissions. Because of the lack of reliable ambient air quality data in the RJMR, the effects of these measures cannot be quantified.

Based on fuel quality data for 1996 the Reid vapor pressure and sulfur content of gasohol appear to be high. Lowering the vapor pressure would reduce evaporative emissions from gasohol-fueled vehicles not equipped with evaporative controls, and lowering the sulfur content would reduce CO, HC, and NO_x emissions from gasohol-fueled vehicles equipped with catalytic converters.

The addition of lighter and heavier HC fractions to meet market demand for diesel fuels increases NO_x and PM emissions from diesel-fueled vehicles. Lowering the sulfur content of the urban diesel fuel must have reduced SO_2 and sulfate emissions as well as the formation of secondary sulfates in the RJMR. The government's policy in setting the same price for both diesel grades should reduce misfueling of diesel-fueled vehicles circulating in the RJMR provided that low-sulfur diesel fuel is not in short supply.

The use of CNG as an alternative fuel has reduced CO, NMHC, and NO_x emissions from about 2,000 taxis. The main environmental benefit of converting about 200 diesel-fueled buses to CNG has been the reduction in PM, SO_2, and NO_x emissions.

Transport management. The World Bank-financed transport management project for Flumitrens is expected to shorten travel times, reduce congestion and pollutant emissions, and lower accident and fatality rates by providing safer and more comfortable rail transport. As a result this project is expected to increase daily ridership from 391,000 to about one million.

The private sector's involvement in CTC, SERVE, CONERJ, Flumitrens, and metro operations is intended to reduce large state subsidies for public transport services and improve the efficiency of these services. This should help increase public transport ridership and reduce air emissions from private cars.

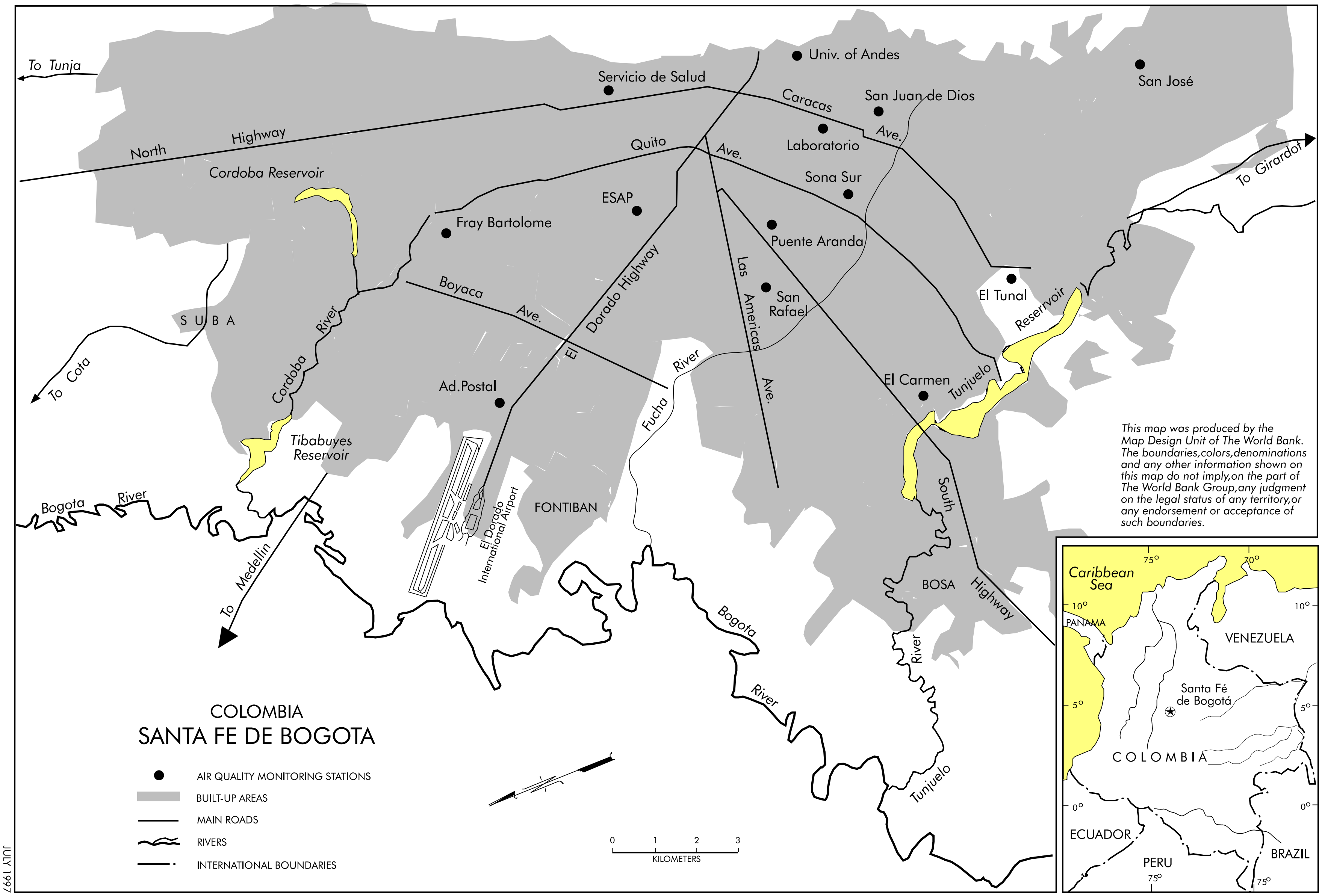
Air quality monitoring. The air monitoring stations have provided limited information on ambient pollutant concentrations in the RJMR, especially in the Municipality of Rio de Janeiro. The operation of these stations have been hampered by a lack of spare parts, technical support, and funds. Furthermore, the stations are not capable

46. Under the current system FEEMA writes the report for any infraction of environmental regulations and the State Commission of Environmental Control decides on the applicability of the fine and its amount. The fine is sent to the state treasury.

of monitoring PM-10, NO_2, ozone, or HC. These stations also lack automation.

Implementation of an air quality management program for the RJMR is essential. The emissions inventory needs to be updated to reflect the current emissions of pollutants in different airsheds of the RJMR, with priority given to areas where human exposure is greatest (such as Airshed III). The program needs to strengthen the monitoring network through automation and continuous monitoring, extend the monitoring capability to additional pollutants (such as PM-10, NO_2, ozone, and HC) and additional locations in the urban area, train monitoring personnel, model air dispersion, and disseminate air quality information to the public.

Santafé de Bogotá


IBRD 28159
COLOMBIA
SANTA FE DE BOGOTA
AIR QUALITY MONITORING STATIONS
BUILT-UP AREAS
MAIN ROADS
RIVERS
INTERNATIONAL BOUNDARIES
0 1 2 3
KILOMETERS
This map was produced by the Map Design Unit of The World Bank. The boundaries, colors, denominations and any other information shown on this map do not imply, on the part of The World Bank Group, any judgment on the legal status of any territory, or any endorsement or acceptance of such boundaries.
To Tunja
To Girardot
To Cota
To Medellin
North Highway
Caracas Ave.
Quito Ave.
Las Americas Ave.
Boyaca Ave.
El Dorado Highway
South Highway
Cordoba Reservoir
Tibabuyes Reservoir
Tunjuelo Reservoir
Cordoba River
Fucha River
Bogota River
Tunjuelo River
SUBA
FONTIBAN
BOSA
El Dorado International Airport
Univ. of Andes
Servicio de Salud
San Juan de Dios
San José
Laboratorio
Sona Sur
ESAP
Fray Bartolome
Puente Aranda
San Rafael
El Tunal
El Carmen
Ad.Postal
Caribbean Sea
PANAMA
VENEZUELA
COLOMBIA
Santa Fé de Bogotá
ECUADOR
PERU
BRAZIL
JULY 1997

Santafé de Bogotá, Colombia's capital and most populous city, comprises twenty local administrative units (*alcaldias menores*) in an area covering 311 kilometer squares. The city is part of the Capital District of Santafé de Bogotá within the Department of Cundinamarca. Although the Capital District spans an area of 1,587 square kilometers, more than 90 percent of its population lives in the city of Santafé de Bogotá. The city is a major contributor to Colombia's economy, accounting for about 25 percent of value added in manufacturing and 35 percent of domestic production of services.

Santafé de Bogotá is located on a plateau (Sabana de Bogotá) at an altitude of about 2,560 meters in the Cordillera Oriental of the Andes. Peaks as high as 3,200 meters surround the plateau, which is slightly sloped toward the eastern mountains. The climate is cool, with an average temperature of about 13°C year round, dropping as low as 0°C at night and rising to about 18°C during the day. The temperature difference between the coldest and warmest months is less than 1°C. The annual average wind speed is about 1.9 meters per second, with the lowest speeds in April, October, and December and the highest speeds in March, June and July. The dry season runs from December to March and two rainy seasons, one from April to May and another from September to November, result in annual precipitation of about 1,000 millimeters. Thermal inversions occur with a 66 percent probability during January, February, June, and between August and December (Gómez, Montejero, and Saavedra 1994).

In the past 55 years the population of the city of Santafé de Bogotá has increased by fourteen times although Colombia's population has only quadrupled. Massive urban migration resulted from a number of factors, including the country's transformation from a rural to an urban economy, regional political and guerrilla violence, and, most recently, violence from drug trafficking in rural areas. The annual growth rate of the city's population peaked in the late 1950s at 8.0 percent; by 1993 it was 2.3 percent. This decline was caused mainly by lower birth rates and a slowdown in migration due to lower economic activity. Major shifts in the city's settlement zones occurred in the southern and northern areas at the expense of the central and eastern areas. As a result, by 1985, the city's population density varied between 6,600 persons per square kilometers in the central area and 45,400 persons per square kilometers in the southern area. Between 1986 and 1990 the population decreased by 16 percent in 90 percent of the city and increased by 32 percent in the remaining area located to the east of Caracas Avenue and between 26th and 40th Streets (JICA 1992). In 1993 the city's population reached 5 million people, accounting for 19 percent of Colombia's population. Wealthier residents tend to live in neighborhoods north of the downtown area while poorer residents live to the south and northwest. Urbanization is now expanding to the outskirts of the city. Most commercial activities and service jobs are moving or being created in the northern and central uptown areas. This lack of congruency between activity centers and settlements is a major cause of the city's transport and air pollution problems (World Bank 1996).

Ambient Air Quality

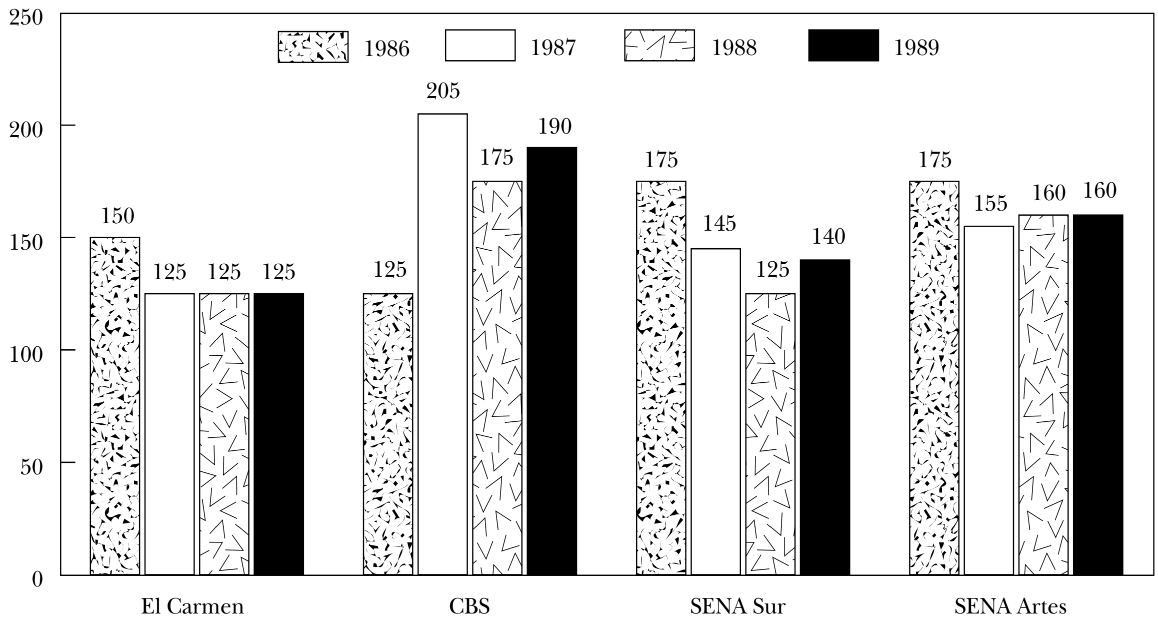
Ambient air quality data for Santafé de Bogotá are derived from monitoring by the district's Health Secretariat during 1986–89 and by a Japanese-Colombian team during November 1990–August 1991. These efforts found that PM is the main air pollutant of concern. In addition, ambient ozone, NO_2, and CO concentrations exceed air quality standards at certain locations and during certain periods.

During 1986–89 annual ambient TSP concentrations exceeded the air quality standard of 77 $\mu g/m^3$ for Santafé de Bogotá at eleven of the city's twelve monitoring stations. Only at the University of Andes station (located at the center of the city next to an unpopulated side of a mountain) was the annual ambient TSP concentration below the standard, with a value equal to 81.5 percent of the permissible limit in 1989. The highest annual concentrations were obtained in the southern part of the city, where values were 60 to 170 percent over the standard, especially in El Carmen, CBS, SENA Sur, and SENA Artes (Figure 4.17). In Adpostal (located in the northwestern part of the city) and San José (at the center) annual TSP concentrations exceeded the standard by 30 to 50 percent (Gómez, Montejero, and Saavedra 1994).

Ambient PM-10 concentrations were monitored during the November 1990–August 1991 period. PM-10 concentrations averaged 53 $\mu g/m^3$ at the Servicio de Salud station, 43 $\mu g/m^3$ at

Figure 4.17 Ambient TSP concentrations in Santafé de Bogotá, 1986–89

Micrograms per cubic meter



Source: Gómez, Montejero, and Saavedra 1994.

the Laboratorio station, 70 μg/m³ at the Puente Aranda station, 59 μg/m³ at the El Tunal station, and 62 μg/m³ at the San Juan de Dios station. The portion of PM-10 smaller than 1.1 microns varied from 26 to 46 percent at the Laboratorio station, and from 26 to 57 percent at the Puente Aranda station (JICA 1992). These results suggest a significant but nonquantifiable contribution by motor vehicles, especially those that use diesel fuel (for example, full- and medium-size buses, and trucks).

The results for 1988 are the most reliable for the ambient NO_2 monitoring conducted during 1986–88. In 1988 the highest annual average for NO_2 concentrations was 31 μg/m³ at a station in the southern part of the city. Among the other eight stations monitored, the annual average varied from 20 μg/m³ to 25 μg/m³ (Gómez, Montejero, and Saavedra 1994). These concentrations were much lower than the annual NO_2 standard of 77 μg/m³ for Santafé de Bogotá. But during November 1990–August 1991 much higher NO_2 concentrations were obtained, with violations of the annual standard at two stations (190 μg/m³ at the San Juan de Dios Hospital station, located in the southern part of the city and 114 μg/m³ at the Servicio de Salud station, located at 53rd Street and Caracas Avenue). At three other stations (Puente Aranda, Laboratorio, and El Tunal) the average NO_2 concentrations were 74 μg/m³, 52 μg/m³, and 51 μg/m³. NO_2 concentrations showed two peaks during the day, the first between 7 A.M. and 8 A.M. and the second between 6 P.M. and 10 P.M. The morning peak was lower on weekends (JICA 1992). These findings suggest that motor vehicle emissions have a strong influence on ambient NO_2 concentrations, contributing an estimated 71 to 96 percent of total NO_2 (JICA 1992).

Ambient CO concentrations were monitored at five stations during November 1990–August 1991. The highest 1-hour CO concentrations were recorded at the San Juan de Dios (30 ppm) and Servicio de Salud stations (24 ppm). At the other stations 1-hour CO concentrations varied between 10 ppm (the El Tunal station) and 16 ppm (the Laboratorio station), well below the 1-hour CO standard of 34 ppm for Santafé de Bogotá. The CO concentrations had two peaks, the first between 7 A.M. and 9 A.M. and the second between 6 P.M. and 8 P.M. These observations suggest a strong correlation between vehicle

emissions and ambient CO concentrations (JICA 1992).

During 1986–88 annual ambient SO_2 concentrations measured at nine monitoring stations ranged from 14 μg/m^3 to 35 μg/m^3, far below the annual standard of 77 μg/m^3 for Santafé de Bogotá. The highest concentration was measured in 1986 at the CBS station, located in Puente Aranda (Figure 4.18). During November 1990–August 1991 annual ambient SO_2 concentrations at five stations were also lower than the standard. The two highest concentrations were found at the San Juan de Dios (66 μg/m^3) and Puente Aranda (60 μg/m^3) stations. Motor vehicles were estimated to contribute about 53 percent to the ambient SO_2 concentrations at the San Juan de Dios station and about 19 percent at the Puente Aranda station, with the rest coming from industry. At the three other stations SO_2 concentrations ranged from 18 μg/m^3 to 26 μg/m^3. Motor vehicles contributed 11 to 39 percent of these levels (JICA 1992).

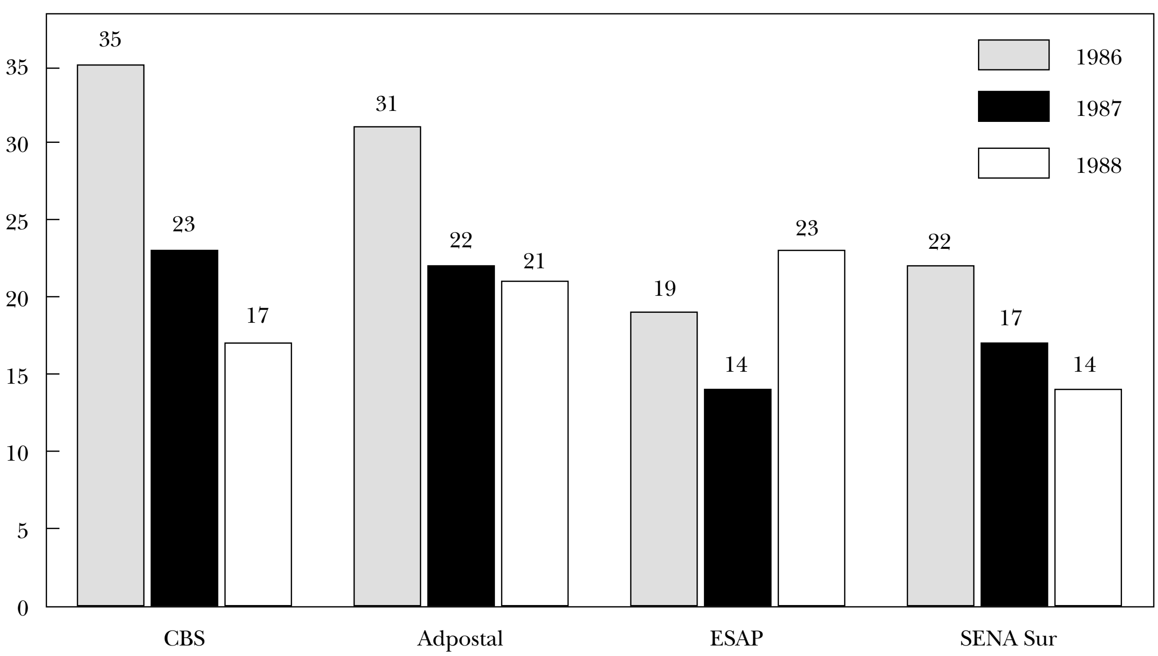
Ambient ozone concentrations were monitored at the Puente Aranda and San Juan de Dios stations during November 1990–August 1991. The maximum 1-hour ozone concentrations measured were 241 μg/m^3 at the Puente Aranda station and 224 μg/m^3 at San Juan de Dios station. Both concentrations exceeded the 1-hour ozone standard of 131μg/m^3 for Santafé de Bogotá. Ozone concentrations started to rise around 8 A.M. and peaked around 10 A.M. (JICA 1992).

Ambient HC and NMHC concentrations were monitored at the Puente Aranda and San Juan de Dios stations during November 1990–August 1991. At the Puente Aranda station the maximum HC and NMHC concentrations were 15.3 ppmC and 13.0 ppmC; at the San Juan de Dios station they were 13.3 ppmC and 11.1 ppmC. Concentrations of the two pollutants peaked at 7 A.M. at the Puente Aranda station and at 8 A.M. at the San Juan de Dios station. Methane concentrations were nearly constant during the day (JICA 1992).

Ambient lead concentrations were monitored from November 1990–July 1991, prior to the elimination of lead from gasoline. The highest monthly ambient lead concentrations were 0.31 μg/m^3 at the Laboratorio station, 0.56 μg/m^3 at the Puente Aranda station, 0.71 μg/m^3 at the El Tunal station, and 1.1 μg/m^3 at the San Juan de Dios station (JICA 1992). These concentrations

Figure 4.18 Ambient SO_2 concentrations in Santafé de Bogotá, 1986–88

Micrograms per cubic meter



Source: Gómez, Montejero, and Saavedra 1994.

Table 4.66 Estimates of emissions from fixed and mobile sources in Santafé de Bogotá, 1991

(tons per year)

Emission source	*CO*	*HC*	*NO_x*	*SO_2*	*PM*
Fixed sources	—	—	1,922	6,586	2,303
Industry	—	—	1,668	6,504	2,198
Residences	—	—	254	82	105
Road-based mobile sources	288,433	19,845	9,250	1,269	—
Cars	149,120	12,046	5,041	496	—
Buses	100,663	5,775	2,646	475	—
Trucks	38,650	2,024	1,563	298	—
Aircraft	—	—	114	29	—
Total	288,433	19,845	11,286	7,884	—

— Not available.
Source: JICA 1992.

compare with the WHO guideline of 0.5 $\mu g/m^3$ to 1.0 $\mu g/m^3$ for the annual average (there are no ambient lead standards in Colombia). With the elimination of tetraethyl lead from gasoline, ambient lead levels have almost certainly declined, although no current data are available.

Sources of Pollutants

Air quality in Santafé de Bogotá is affected by pollutants emitted from mobile as well as fixed sources. The 1991 pollutant emissions from the city were estimated as part of an air pollution study sponsored by the Japan International Cooperation Agency. The study estimated that mobile sources accounted for 16 percent of SO_2 emissions and 82 percent of NO_x emissions (Table 4.66). Industry was identified as the main source of PM emissions, although road-based mobile sources, especially diesel-fueled vehicles, also emit PM (but were not covered by the study).

In 1991 the main types of fuels used by industry included crude oil (102 million liters), light oil (45 million liters), and coal (142,000 tons). In addition, unspecified amounts of fuel oil, coke, wood, natural gas, and propane were combusted. Four industries—food, beverages, textiles, and ceramic, stone, and clay products (especially brick and cement manufacturing)—accounted for 80 percent of SO_2 emissions, 84 percent of NO_x emissions, and 86 percent of PM emissions from fixed sources The principal industrial zones are located in the southern and central areas (such as Puente Aranda) of the city. Residences use electricity, kerosene, and propane for energy.

Gasoline and diesel fuel are the main types of motor vehicle fuels used in Santafé de Bogotá, with a 1991 consumption of 635 million and 56 million liters, respectively. In addition, some trucks use LPG. Cars, jeeps, light-duty trucks, and microbuses (vans) are fueled with gasoline. Full- and medium-size buses and other trucks use gasoline and diesel fuel.[47] In 1990 about 82 percent of buses and 77 percent of trucks used gasoline; the rest used diesel fuel. A survey of 160 vehicles operating in the city found that gasoline-fueled vehicles emitted higher concentrations of CO and HC than diesel-fueled vehicles, diesel-fueled vehicles emitted higher concentrations of NO_x than gasoline-fueled vehicles, and older vehicles emitted higher HC concentrations than newer ones (JICA 1992).

In 1991, 342,902 vehicles were registered in the city of Santafé de Bogotá (Table 4.67). Of these, 64.5 percent were cars, 14.2 percent were light-duty trucks, 10.7 percent were jeeps, 5.9 percent public transport vehicles (3.5 percent full-size buses, 2.0 percent medium-size buses, 0.4 percent vans), and 4.7 percent were trucks. In addition, about 230,000 vehicles registered in outside areas were believed to be circulating

47. The average riding capacity of a full-size bus is seventy people, and that of a medium-size bus is thirty. In 1991 the average medium-size bus carried fifty-one people (JICA 1992).

Table 4.67 Age of vehicle fleet in Santafé de Bogotá, 1991
(percent)

		Share of vehicles older than			
Vehicle type	*Number*	*3 years*	*7 years*	*12 years*	*19 years*
Cars	220,962	75	56	39	21
Jeeps	36,806	87	78	41	26
Light-duty trucks	48,683	85	67	48	36
Microbuses (vans)	1,525	97	97	86	79
Medium-size buses	6,955	99	85	47	15
Full-size buses	11,889	86	80	65	43
Trucks	16,082	91	83	70	55
Total	342,902	79	63	43	26

Source: JICA 1992; Ecopetrol 1992.

in the city (JICA 1992). Since 1991, when the government relaxed import restrictions and vehicle prices began to fall, the city's vehicle fleet has grown by about 10 percent a year. In 1996, 559,000 vehicles were registered in the city, of which 83.3 percent were private cars. Among public transport vehicles, there were 11,600 full-size buses and 10,300 medium-size buses, vans, taxis, light-duty trucks, and jeeps (Uribe 1996). Unlicensed jeeps and light-duty trucks provide transport services to low-income residents in hilly areas of the city that are not serviced by regular public transport vehicles. They are also used when driving conditions on rainy days do not permit regular bus service to the low-income neighborhoods located at the city's periphery, where about 500,000 people live (World Bank 1996).

The vehicle fleet in Santafé de Bogotá is old (see Table 4.67). In 1991, 43 percent of the fleet was older than 12 years and 26 percent was older than 19 years. Some 39 percent of cars were older than 12 years and 21 percent were older than 19 years. On the average, 60 percent of the road-based public transport vehicles (full- and medium-size buses and vans) were older than 12 years and 36 percent were older than 19 years (JICA 1992; Ecopetrol 1992). Currently, about 50 percent of the public transport fleet is estimated to be older than 20 years (World Bank 1996).

Transport in the city depends on road-based motor vehicles. The surface rail system is limited to tourism, and there is no metro system. Of the total trips in 1990, 88.9 percent were by road-based motor vehicles, 9.1 percent were by pedestrians, 0.4 percent were by bicycles, and 1.6 percent were by other modes. Medium-size buses accounted for 54.0 percent of the trips, followed by full-size buses (20.6 percent), private cars (7.4 percent), special buses (mainly school buses, 3.6 percent), microbuses (1.9 percent), and taxis (1.4 percent). The average city resident takes between 1.4 and 1.6 trips a day. The average vehicle speed is 16.5 kilometers/hour (JICA 1992), although in some parts of the city center operating speeds are below 10 kilometers/hour (World Bank 1996).

In 1991 about 14,000 full- and medium-size buses were operated for public transport by the city authority and thirty-nine private companies on 450 routes, most of which were 20 kilometers to 30 kilometers long and 268 of which ran through the city center. The average number of passengers per day on these buses was 2.5 million, with an average daily ride frequency of 6.3 million (JICA 1992). In 1996 about sixty-three private companies operated public transport services on 671 routes, with about 90 percent of the trips concentrated in fourteen main corridors. The public sector does not provide any transport services.

The main road network consists of the trunks running parallel and perpendicular to the hilly regions and three loop roads, with Caracas Avenue being the most important. The trunk road network comprises fifty-three parallel and eighty-one perpendicular roads. There are also service roads. Combined with a 10 percent annual increase of the vehicle fleet, a growing population, and increasing commercial activity, the road network's limited capacity will further strain the existing system, resulting in more congestion and increased air pollutant emissions.

Institutional Responsibilities

National institutions. Colombia has some of most comprehensive environmental legislation in Latin America. The Renewable Natural Resources and Environmental Protection Code, adopted in 1974, established the country's basic environmental legal framework. The Institute of Renewable Natural Resources and the Environment was responsible for implementing and enforcing the code. The Institute focused its efforts on natural resources, however, often to the exclusion of urban environmental issues. Moreover, other national and regional agencies carried out related activities, often resulting in unclear lines of authority and overlaps and gaps in responsibility.

The 1991 Constitution recognizes that Colombian citizens have a right to a healthy environment and identifies environmental protection among the state's main objectives for maintaining the general welfare and improving the quality of life. Law 99 of 1993 established a National Environmental System within the Ministry of the Environment, replacing the Institute of Renewable Natural Resources and the Environment. The ministry's responsibilities—which encompass areas that were previously scattered among the ministries of agriculture, health, mining, and energy—give it policy, regulatory, and enforcement authority on environmental matters, including pollution prevention and control and environmental licensing. It is also responsible for the National Environmental Fund and five scientific institutions, including the Hydrology, Meteorology, and Environmental Studies Institute established by Decree 1600 of 1994. In carrying out its mandate, the ministry must work closely with the National Planning Department, the ministries of economic development, health and education, and other government agencies as needed. The Ministry of the Environment is preparing regulations, standards, and procedures to institutionalize the National Environmental System and to implement the provisions of Law 99.

The transport system has gone through a number of institutional and policy changes over the past few decades. The current framework was developed in 1993, when reforms decentralized the system. Until 1987 urban transport was the responsibility of the Ministry of Public Works and Transportation, which through its National Transportation Institute licensed and supervised urban bus and taxi services and established their fares. Decrees 80 of 1987 and 1066 of 1988 transferred these responsibilities to local governments and redefined the National Transportation Institute's role in urban transport as a normative entity. In 1993 the institute was disbanded by Decree 2171 and its responsibilities were transferred to the Ministry of Transportation. The Ministry of Transportation is responsible for intermunicipal routes within Santafé de Bogotá.

Regional and local institutions. The National Environmental System adopted in 1993 decentralized environmental management in Colombia and increased regional and local responsibilities for policy implementation and enforcement. Thirty-four regional autonomous agencies, working under the general guidance of the Ministry of the Environment, are responsible for environmental management functions at the regional level. These functions include implementing national policies, plans, and programs; issuing environmental licenses; setting regional environmental standards; monitoring and enforcing environmental standards; and collecting environmental fees and taxes. Although the Department of Cundinamarca has its own regional autonomous agency, Santafé de Bogotá, as a major urban center containing more than one million inhabitants, was given a special status by Law 99 to assume the same functions as the regional autonomous agencies (the other Colombian urban centers with the same status are Medellín, Cali, and Barranquilla). Under the 1991 Constitution the Capital District of Santafé de Bogotá also has administrative autonomy, and Decree 1421 of 1993 enhanced its administrative, organizational, and fiscal abilities. Thus the district is able to manage, finance and implement programs and projects within its jurisdiction.

Until 1993 different entities were responsible for environmental management in the Capital District of Santafé de Bogotá, including the district's Secretariat of Health for air pollution control, the Secretariat of Transit and Transportation for emissions from mobile sources, and the Regional Autonomous Agency of Cundinamarca for the use of natural resources and industrial discharges. Planning and coordination of environmental management efforts were the responsibility of the district's Environmental Agency, which was established in 1990. Law 99 assigned the agency additional responsibilities, including environmental permitting, concessioning, and licensing; control of air and wastewater

discharges; and solid and hazardous waste management. In addition, the agency was given the task of preparing and regulating land use plans and developing environmental protection norms for the district. In 1994, the Environmental Agency was restructured to reflect these new responsibilities, making it the district's principal environmental policy and enforcement institution.

In November 1995 the agency's responsibilities were restructured again by Decree 673. Its current functions include formulating the district's environmental policies; directing, coordinating, and controlling environmental management in the district to conform with the National Environmental System's policies and guidelines; coordinating and guiding the implementation of the district's environmental management plan; designing, implementing, and maintaining the Environmental System for the district; carrying out targeted actions to preserve the environment; issuing norms and standards to control and preserve the district's ecological heritage; and managing, administering and controlling the use of natural resources. Accordingly, the Environmental Agency now includes planning, environmental quality, development, and legal departments and has a staff of 142 people, 75 percent of whom are professionals. The World Bank-financed Urban Environmental Management Project will help strengthen the agency's institutional and technical capabilities.

The district has comprehensive responsibilities for transport, from road construction to traffic police and bus routes. This concentration of authority within one local entity offers an opportunity for integrated management of the transport system. This opportunity has not been used effectively, however, because of inadequate coordination among the district's various agencies and poorly defined policymaking authority (World Bank 1996).

Three district agencies are responsible for transport. The Urban Development Institute builds new roads, the Public Works Secretariat maintains public facilities, including roads and parks, and the Secretariat of Transit and Transportation is responsible for vehicular emissions, traffic law enforcement, traffic safety and signs, driver and vehicle licensing, and supervision of public transport. Other entities with sector responsibilities include the local telephone company, which maintains the traffic signal system, and the District Planning Department, which defines medium- and long-term investment plans (World Bank 1996).

Implemented Measures

Vehicle emission standards. Emission standards for gasoline- and diesel-fueled vehicles were established in 1996 by the Ministries of the Environment and Transportation. Limits for CO and HC from gasoline-fueled vehicles are set separately for altitudes up to 1,500 meters and altitudes higher than 1,500 meters (Table 4.68). For diesel-fueled vehicles smoke emissions are limited by specific opacity measurement values (Table 4.69). These standards became effective on January 1, 1997.

The ministries also established emission standards for light-, medium-, and heavy-duty gasoline- and diesel-fueled vehicles imported to Colombia. Starting with 1997 model-years, CO,

Table 4.68 Exhaust emission standards for new and in-use gasoline-fueled vehicles in Colombia

	CO (percent by volume)		*HC (parts per million)*	
Model -year	*0–1,500 meters*	*1,501–3,000 meters*	*0–1,500 meters*	*1,501–3,000 meters*
2001 and newer	1.0	1.0	200	200
1998–2000	2.5	2.5	300	300
1996–1997	3.0	3.5	400	450
1991–1995	3.5	4.5	650	750
1981–1990	4.5	5.5	750	900
1975–1980	5.5	6.5	900	1,000
1974 and older	6.5	7.5	1,000	1,200

Note: At idle and low speed (a maximum of 900 rpm). Santafé de Bogotá is at an altitude of about 2,560 meters.
Source: Resolution 5 of the Ministries of the Environment and Transportation dated January 9, 1996.

Table 4.69 Exhaust smoke opacity standards for new and in-use diesel-fueled vehicles in Colombia
(percent)

Model -year	*Light-duty vehicles*[a]	*Medium-duty vehicles*[b]	*Heavy-duty vehicles*[c]
2001 and newer	40	40	40
1996–2000	50	50	50
1991–1995	55	55	55
1986–1990	60	60	60
1981–1985	65	65	65
1980 and older	70	70	70

Note: At free acceleration.
a. Light-duty vehicles are those designed to carry no more than twelve passengers or to have no more than 2,800 kilograms in gross vehicle weight when carrying freight.
b. Medium-duty vehicles are those designed to carry more than twelve passengers or to have 2,801 kilograms to 3,860 kilograms in gross vehicle weight when carrying freight.
c. Heavy-duty vehicles are those designed to carry more than nineteen passengers or to have more than 3,860 kilograms in gross vehicle weight when carrying freight.
Source: Resolution 5 of the Ministries of the Environment and Transportation dated January 9, 1996.

HC, and NO_x emissions in the exhaust are limited for vehicles imported from all countries except Ecuador and Venezuela (Table 4.70). Evaporative emissions are limited to 6 grams/test for gasoline-fueled vehicles tested using the SHED method or an equivalent method approved by the Ministry of the Environment. To reduce evaporative emissions from the crankcase, gasoline tank, and carburetor (if used) of gasoline-fueled vehicles, the resolution requires installation of a control system that includes a ventilation valve and an activated carbon canister. Ecuador and Venezuela were given a one-year exemption from these requirements because they are signatories of the Industrial Complement of the Automotive Sector Agreement of the Andean Pact with Colombia. Starting with model year 1998 vehicles, emission standards for light-, medium-, and heavy-duty gasoline- and diesel-fueled vehicles manufactured or assembled in Colombia are the same as those for imported vehicles. Locally-manufactured or imported vehicles are subject to a warranty requirement for 20,000 kilometers.

In 1995 the Ministry of the Environment's Decree 948 established requirements to control air pollution from fixed and mobile sources. The decree requires diesel-fueled public service and freight vehicles with two or more axles to install turbochargers or equivalent control technology starting with model year 1997 vehicles. The decree also requires that freight vehicles be covered to control PM emissions. In 1995 the Ministry of the Environment's Decree 2107 required freight vehicles heavier than 3,000 kilograms and public transport vehicles carrying more than nineteen passengers to install vertical exhaust pipes at a minimum height of 3 meters from the ground or 15 centimeters above the roof of the vehicle.

Vehicle inspection programs. Decree Law 1344 of the National Transit Code of 1970 required that in-use vehicles have an annual mechanical, safety, and environmental inspection. Until 1993 annual inspections were performed at private and government-operated inspection centers under the purview of departmental and municipal transport authorities. Since then the district's Environmental Agency has shared this responsibility with transport authorities in Santafé de

Table 4.70 Exhaust emission standards for gasoline-and diesel-fueled vehicles imported, assembled, or manufactured in Colombia

Vehicle category	*Unit*	*CO*	*HC*	*NO_x*	*HC + NO_x*
Light-duty vehicles	g/km	2.1	0.25	0.62	
Medium-duty vehicles	g/km	11.2	1.05	1.43	
Heavy-duty vehicles	g/bhp-h	25.0			10

Note: A blank space indicates that no standard was established. Test procedures are FTP-75 for light- and medium-duty vehicles (test performed at sea level) and USA-3 for heavy-duty vehicles.
Source: Resolution 5 of the Ministries of the Environment and Transportation dated January 9, 1996.

Bogotá. Inspections focus on mechanical and safety aspects because very few government-operated inspection centers are equipped to measure pollutants in vehicular emissions. In 1995 the Ministry of the Environment's Decree 2150 changed inspection requirements to include only public and freight transport and mixed-use vehicles for annual inspections. In 1996 Resolution 5 established inspection requirements for public service, government, and private vehicles, to go into effect in 1997. Owners of vehicles passing the inspection must be provided with inspection results. Vehicles that fail the inspection must be repaired within a 15 calendar day period. Inspection centers can be established, owned, and operated by the private sector provided they are certified by the district's Environmental Agency. The agency is responsible for verifying the adequacy of the inspection equipment from time to time. The operations of the inspection centers, including the setting of tariffs for inspection services, are the responsibility of departmental and municipal transit authorities.

Fuel-targeted measures. The state petroleum company Ecopetrol has exclusive rights to refine and import motor vehicle fuels in Colombia. Ecopetrol has improved the quality of gasoline by eliminating lead (in January 1991), reducing vapor pressure (in November 1991), and increasing the octane number (in March 1994 for the northern coastal area and in January 1996 for the rest of the country). The production of unleaded gasoline is achieved by optimizing the catalytic cracking process without resorting to catalytic reforming or addition of oxygenates. Typical quality of regular and extra gasoline grades consumed in Colombia in 1996 are presented in Table 4.71.[48]

Elimination of lead was achieved gradually. First, in the early 1980s Ecopetrol reduced tetraethyl lead content from 3 milliliters to 0.15 milliliters per gallon of gasoline.[49] However, import of leaded gasoline continued until January 1991. Since then only unleaded gasoline has been marketed in Colombia. The incremental cost of importing unleaded gasoline was about \$2/barrel. Along with the elimination of lead from gasoline, Ecopetrol conducted a public awareness campaign on the benefits of engine tuneup and filter change, disseminated manuals to mechanics and vehicle owners on engine tuneups, provided advice to fuel distributors on storage tank cleanup and installation of filters in fuel discharge lines, and trained mechanics on engine tuneup (Ecopetrol 1996).

Table 4.71 Typical quality of gasoline consumed in Colombia, 1996

Fuel parameter	*Regular*	*Extra*
Reid vapor pressure (psi)	8.5	8.5
Research octane number	86	94
Aromatics (percent by volume)	24	28
Benzene (percent by volume)	0.8	0.9
Olefins (percent by volume)	17.5	23
Sulfur (percent by weight)	0.06	0.06

Source: Ecopetrol 1996.

In 1995 the Ministry of the Environment prohibited production, import, and distribution of gasoline containing tetraethyl lead for road-based motor vehicles.[50] That same year, the ministry established quality standards for gasoline and diesel fuel supplied by Ecopetrol or imported to Colombia (Tables 4.72 and 4.73). The resolution required use of dispersants, detergents, and chemical additives that control deposits in the engines in all Colombian gasoline grades. It also defined a registry requirement for gasoline suppliers, distributors, and retailers and made the authorities responsible for verifying gasoline quality and imposing sanctions, if necessary. The Tibú and Orito refineries were given two years to make the necessary modifications and produce fuels with the required specifications.

In 1995 about 2 billion liters of gasoline was sold in Santafé de Bogotá.[51] At the end of 1995 the City Council approved a measure to impose a 13 percent tax on local gasoline prices (to be implemented in 1996) and to use these revenues

48. In 1996, 91.5 percent of gasoline consumed in Colombia (130,000 barrels a day) was regular unleaded and 8.5 percent was extra unleaded. Of the amount consumed, 23 percent was imported (Ecopetrol 1996).

49. This corresponds to a reduction of gasoline's lead content from 0.84 g/liter to 0.04 g/liter.

50. Ministry of the Environment's Decree 948 of 1995.

51. This corresponds to about 27 percent of gasoline consumed in Colombia.

Table 4.72 Gasoline quality standards in Colombia

Parameters	Unit	Effective date: January 1, 1996	January 1, 2001	January 1, 2006
Minimum octane				
Regular gasoline	(RON + MON)/2[a]	81	81	81
	RON	86	86	86
Super gasoline	(RON + MON)/2	86	86	86
	RON	94	94	94
Reid vapor pressure	psia (max.)	8.5	8.1	8.1
Sulfur	percent by weight (max.)	0.10	0.05	0.03
Oxygen	percent by weight (min.)		2.0	2.0
Aromatics	percent by volume (max.)	28.0	25.0	25.0
Benzene	percent by volume (max.)	1.1	1.0	1.0

Note: A blank space indicates that no standard was established.
a. RON is research octane number; MON is motor octane number.
Source: Resolution 898 of the Ministry of the Environment, August 23, 1995.

for road maintenance. In May 1996 the average retail prices of regular and super unleaded gasoline grades in Santafé de Bogotá were $0.26/liter and $0.34/liter, respectively.

A program to use LPG in public transport vehicles (such as full- and medium-size buses and taxis) is being initiated by the district's Environmental Agency. This effort is being coordinated with Ecopetrol.

Transport management. All public transport services in Santafé de Bogotá are privately operated. These companies do not receive any government subsidies. The local government awards licenses to companies that issue route rights to bus owners. There are sixty-three such companies, which are groupings of several thousand affiliates who are owners or owner-drivers. For a monthly fee the companies organize route assignments to roughly equalize the profitability of their affiliated members. In theory the licensing system controls entry, routes, frequencies, and fares. In practice there is little enforcement of license terms and companies have no difficulty in creating a new route or withdrawing from an existing service (World Bank 1996).

In 1990 bus fares were restructured and raised in real terms to encourage fleet renewal and improve service. As the fleet is renewed, air pollutant emissions should fall. Although the fare system has been somewhat simplified since then, it is still complicated and difficult to enforce. In general, fares are higher for services using newer buses, night operations, and for peripheral routes (World Bank 1996).

The old vehicle fleet in Santafé de Bogotá is partly the result of a rigid financial system that made long-term credit unavailable to small bus enterprises. In addition, trade restrictions have contributed to the aging vehicle fleet. These policies were reversed in 1990, when the government dismantled most import barriers on vehicles and parts and took steps to allow for the development of a more competitive finan-

Table 4.73 Diesel fuel quality standards in Colombia

Parameter	Unit	Effective date: January 1, 1996	January 1, 1998	January 1, 2002
Sulfur	percent by weight (max.)	0.4	0.1	0.05
Aromatics	percent by volume (max.)	20	20	20
Cetane index	index (min.)	45	45	45

Source: Resolution 898 of the Ministry of the Environment, August 23, 1995.

cial sector (World Bank 1996). In addition, Transportation Law 105 of 1993 limited the maximum age of public transport, freight, and mixed-use vehicles as follows: by July 1995 all vehicles with 1968 and older model-years must be retired, by 1996 all vehicles with 1970 and older model-years must be retired, by 1997 all vehicles with 1974 and older model-years must be retired, by July 1999 all vehicles with 1978 and older model-years must be retired, and by 2002 all vehicles with 1982 and older model-years must be retired. In subsequent years all vehicles with a service life of twenty years must be retired. Decree 2105 of 1995 reiterated these requirements and prohibited any measure to extend the life of these vehicles.

One of the main transport management measures implemented in Santafé de Bogotá is the use of a busway on Caracas Avenue, the city's busiest traffic corridor. This corridor connects the low-income suburbs to the south of the city center with the busy business and shopping district in the center and to the north. The busway was constructed in two phases. The first phase, undertaken during 1989–90 for an 8-kilometer section in the southern part of Caracas Avenue, cost $4 million. The second phase involved construction of a second 8-kilometer segment north of the central area during 1991–92 at a cost of $10 million. Until the first busway was opened in June 1990, car and bus flows were mixed and used two-directional three-lane ways separated by a large central divider. Space for the two new lanes was obtained by removing the central divider and by reducing the width of the lanes to 2.9 meters for cars and 3.25 meters for buses. The busway consists of two lanes in each direction for the exclusive use of buses; the remaining two lanes in each direction are for general traffic flow. Bus and car lanes are separated by concrete blocks, allowing for fast removal of buses in case of mechanical failures or accidents. The bus lanes are located in the center of the road. Bus stops are located every 450 meters for passengers to board and exit from buses. To accommodate the large number of buses and routes, each stop is 200 meters long. Each bus route is assigned to a specific section of the stops, with color coding for passenger orientation. Crossing, signals, bus shelters, and protection fences were built for pedestrians, and the timing of traffic signals was improved. Left tuns are prohibited from car lanes, but not at most junctions from the bus lanes. In addition, bus routes were reassigned to achieve a smoother load profile and eliminate bottlenecks (World Bank 1996).

A new project financed by the World Bank is under way to extend the Caracas Avenue busway to 80th Street and implement complementary traffic management measures on 68th Street and some transverse streets. The project will also plant trees along these streets, and will pave and upgrade surfaces of about 30 kilometers of roads to improve public transport access to low-income areas (World Bank 1996).

To relieve traffic congestion in Santafé de Bogotá, some restrictions have been implemented to limit circulation of trucks weighing more than 4,500 kilograms. No heavy-duty trucks can circulate from 7 A.M. to 9 A.M. and from 6 P.M. to 8 P.M. in the city center, and from 7 A.M. to 8 A.M. and from 6 P.M. to 7 P.M. in the surrounding districts (JICA 1992).

Recreational cycling is popular in Santafé de Bogotá. Major avenues are converted to bicycle paths on weekends. This practice is being expanded in other sections of the city, especially in the south. Bicycling is much less common on weekdays, however, because without segregated bikeways cycling in traffic is very dangerous. To promote nonmotorized modes of transport, the city is constructing new bicycle paths available for use at all times.

Air quality monitoring. Ambient air quality monitoring in Santafé de Bogotá was initiated in November 1967. This network, called the Panaire Network was installed by the Ministry of Health with assistance from the Pan-American Health Organization. Pollutants monitored by this network included TSP, settling particles, and SO_2.

During 1983–89 twelve monitoring stations were operated by the district's Health Secretariat in the following points of the city: two in the north (Adpostal and Fray Bartolomé), two in the Puente Aranda (Cyanamid and CBS), two in the residential and institutional zone of CAN (ESAP and IIT), two downtown (Capitol and University of Andes), and four in the south (San José, SENA Sur, El Carmen, and San Rafael). TSP was monitored at all stations, and SO_2 and NO_2 at nine.

In November 1990 the Japanese International Cooperation Agency funded the installation of five air monitoring stations following a study of the air pollution problem in Santafé de Bogotá. These stations were located at the eastern zone

on 53rd Street and Caracas Avenue (Servisalud), the central zone on 22nd Street, Puente Aranda, the south-central zone at the San Juan de Dios Hospital, and southern zone in the El Tunal neighborhood. Pollutants monitored by these stations included PM-10, SO_2, NO_2, and CO. Ozone was also monitored at two of the stations (Puente Aranda and San Juan de Dios).

The air monitoring stations installed under the Japanese cooperation program have not been in operation since 1993 because of a lack of spare parts. A project has been prepared to install a new automatic network that consists of nine monitoring and four meteorological stations and an automatic data transmission system. Pollutants to be monitored include TSP, PM-10, CO, HC, SO_2, NO_2, and ozone. The network is expected to cost $1.5 million to install and $0.4 million a year to operate.

Evaluation of Implemented Measures

Vehicle emission standards. Air pollutant emissions from vehicular sources in Colombia have long been aggravated by a lack of pollution control measures. Vehicles manufactured in Colombia are not equipped with catalytic converters or gasoline tank emission controls. Emissions from these vehicles are comparable to those 1975–79 models manufactured in the United States, which had modified engine and carburetor designs to control pollution. The age of Santafé de Bogotá's vehicle fleet contributes to the air pollution problem: a large number of vehicles are more than 20 years old and poorly maintained.

The newly adopted emission standards for vehicles are expected to reduce emissions of CO, HC, NO_x, PM-10, and SO_2. These new standards are based on the USEPA's 1983 emission standards for new vehicles and 1975 emission standards for in-use vehicles.

The requirement to install turbochargers on heavy-duty diesel-fueled vehicles will reduce the NO_x and PM emissions and improve the fuel economy of these vehicles. The requirement to install vertical pipes on heavy-duty vehicles will not reduce emissions but will lessen street-level concentrations of pollutants (especially CO and PM-10) through dispersion.

Vehicle inspection programs. Decree 2150 of 1995 limits inspection of vehicles to public transport, freight, and mixed-use vehicles. The perodic inspection and maintenance program that will be initiated in 1997 will encourage public, freight, and mixed-use vehicle operators to better maintain their vehicles and thus should curtail air pollutant emissions (CO, HC, and PM-10). Engine adjustments resulting from the program are expected to lower CO emissions by 45 percent and HC emissions by 55 percent (Ecopetrol 1992), or 62,700 tons a year for CO and 7,800 tons a year for HC. Better combustion of CO will also improve fuel efficiency. This program is also expected to retire the most polluting public transport and freight vehicles.

The exclusion of private vehicles from the inspection program is a setback to the 1970 requirement that all types of vehicles submit to inspection and maintenance programs. If private cars were subject to scheduled inspection, CO emissions would be reduced by 67,100 tons a year and HC emissions by 6,600 tons a year based on Ecopetrol's emission reduction estimates of 45 percent for CO and 55 percent for HC per inspected vehicle (Ecopetrol 1992).

Fuel-targeted measures. The gasoline and diesel fuel quality standards set in Resolution 898 target fuel quality improvements as a way to reduce pollutant emissions from mobile sources. With the exception of sulfur in gasoline and diesel fuel these requirements are generally similar to those used in industrial countries. The requirements for a minimum oxygen content will reduce CO and HC emissions in the exhaust (given Santafé de Bogotá's high altitude), those for vapor pressure will reduce evaporative (HC) emissions (which are precursors for ozone formation), those for aromatic HC will reduce NO_x, benzene, and reactive HC emissions in the exhaust, and those for benzene will reduce emissions of this carcinogenic compound in the exhaust. To meet the gasoline sulfur and oxygen content requirements for 2001 and subsequent years, Ecopetrol needs to make refinery modifications that would include new desulfurization and oxygenation units.

Resolution 898 limits the maximum content of sulfur in gasoline to 0.1 percent for 1996, 0.05 percent for 2001, and 0.03 percent for 2006. For newer vehicles equipped with oxidation catalysts these concentrations are too high, and could reduce the efficiency of the catalyst. Tests performed by General Motors on pre-1981 model catalytic converter-equipped U.S. vehicles found

that reducing sulfur in gasoline from 0.09 percent to 0.01 percent lowered HC emissions by 16 percent, CO emissions by 13 percent, and NO_x emissions by 14 percent. Other tests performed on newer vehicles found that reducing sulfur from 0.045 percent to 0.005 percent reduced HC emissions by 18 percent, NMHC emissions by 17 percent, CO emissions by 19 percent, and NO_x emissions by 8 percent (Faiz, Weaver, and Walsh 1996).

The olefinic content of gasoline in Colombia (17.5 percent by volume for regular unleaded gasoline and 23 percent by volume for extra unleaded gasoline) is not regulated and is higher than in some other countries. For example, the olefinic content of gasoline in Mexico varied between 8.3 and 12.3 percent by volume in 1995, and in the United States it was 10.8 percent by volume in 1990. Reduction of olefinic compounds in gasoline would reduce emissions of highly reactive HC emissions that contribute to ozone formation.

The new requirement for the sulfur content in diesel fuel (Resolution 898 of 1995) is comparable to that in Brazil. However, the targeted level for 2006 is equal to the sulfur content of the diesel fuel currently available in Mexico.

The City Council's decision on the fuel tax and the use of tax revenues for road maintenance has two benefits. First, the 13 percent local tax on retail gasoline should reduce somewhat the traffic flow in Santafé de Bogotá. Second, the revenues from this tax, which will be used for road maintenance, will improve traffic conditions and vehicle speeds.

Use of LPG as a motor vehicle fuel is expected to bring environmental benefits to Colombia's urban centers, including Santafé de Bogotá. Switching light-duty gasoline-fueled 1984 model-year vehicles to LPG lowers HC emissions by 63 percent, NO_x emissions by 84 percent, and CO emissions by 95 percent (JICA 1992). In addition, the switch will lower the need for gasoline imports. In the cities of Santafé de Bogotá, Medellín, Cali and Bucaramanga, LPG could potentially be used as a fuel in about 84,000 vehicles (such as full- and medium-size buses, vans, and taxis) and substitute for about 25,000 barrels a day of gasoline consumption (Ecopetrol 1992). The LPG program is projected to reduce gasoline imports for 1998 by 15 percent. The maximum impact will be achieved in 2000 and 2001, when gasoline imports will be reduced by about 38 percent (Vargas 1995). Switching to LPG will require opening ten mechanical shops in 1998 and twenty in 2000, and sixty-five service stations in 1998 to supply an average of 272,000 liters of LPG a month (ACOGAS 1995).

Transport management. Lack of systematic urban planning and a rational bus routing system are at the root of Santafé de Bogotá's traffic congestion problem. Over the years the city has expanded into lands of agricultural and ecological value as well as into high-risk areas subject to landslides and floods.

Congestion occurs for about five hours a day. Conversion of some streets to one-way traffic during peak hours has improved flows, but conditions are once again becoming severely congested. Because off-street parking is scarce, curb parking, which interferes with traffic on busy streets, is common. Traffic law enforcement is inconsistent. Pedestrians are provided with minimal facilities. Public transport is hindered by congestion, with speeds below 10 kilometers an hour on some corridors and a large number of buses that block traffic because of their stop-on-demand driving patterns. Even though the traffic signals in Santafé de Bogotá are technologically advanced, their timing is not synchronized, contributing to congestion and vehicular air pollution (World Bank 1996).

In addition, road maintenance has lagged well behind requirements. Street drainage works are poorly maintained, and flooding on rainy days creates traffic gridlock. The local government's program for road maintenance (a pothole patching program) has had limited success because of uneven supervision and poor execution standards. A number major rehabilitation works for structurally damaged road sections have been around. The City Council's decision to use the revenues from gasoline taxes for road maintenance is expected to overcome these problems.

The 1990 government reforms have somewhat improved the underlying conditions for the development of public transport services. But these reforms have also lowered the costs of vehicle ownership, increasing the number of vehicles in circulation, congestion, and air pollution.

Exhaust gas measurements have revealed that older vehicles, which lack efficient engine design and pollution control systems, emit higher levels of air pollutants than newer vehicles (JICA 1992). Based on this finding, Transportation Law 105 of 1993 was justified. Implementation of this law will significantly reduce the number of pol-

luting vehicles between 1996 and 2001 and improve air quality in Santafé de Bogotá. Some 8,700 full- and medium-size buses and vans are expected to be retired from traffic by 1997, an additional 3,300 by mid-1999, and an additional 2,700 vehicles by 2002. Even if these vehicles are replaced by newer models, pollutant emissions will be reduced considerably. Replacing a 20-year-old vehicle with a similar one less than 5 years old would cut HC emissions by half and CO emissions by 38 percent (Ecopetrol 1992). As newer vehicles equipped with improved pollution control technologies (such as catalytic converters) are introduced these reductions will become more significant. Financial incentives provided to the owners of old vehicles will encourage the vehicle retirement program.

With the establishment of the exclusive busways on Caracas Avenue, the number of passengers moved in each direction increased from 19,000 to 30,000 during peak hours, more than on most of the world's busways and light railways. The average bus speed increased from about 12 kilometers an hour to more than 20 kilometers an hour during peak hours. The average speed of general traffic on Caracas Avenue increased from 13 kilometers an hour 24 kilometers an hour (World Bank 1996). The busway operation is estimated to be have lowered overall emissions by 30 percent. On the northern segment of the busway, the annual reduction in emissions was calculated to be 3,300 tons for HC, 26,000 tons for CO, and 200 tons for NO_x (World Bank 1991).

Still, the performance of the Caracas Avenue busway has deteriorated in recent years. The main problems include the shutdown of traffic lights during some periods as part of the national energy savings measures implemented between March 1992 and April 1993, the lack of maintenance and enforcement by the unit responsible for enforcing vehicle and pedestrian traffic on the busway (because of underfunding and inadequate staffing), and in the northern segment the absence of area-wide traffic management measures. The Bogotá Urban Transport Project, financed by the World Bank, aims to improve traffic on Caracas Avenue. Specific measures will include reorganizing bus routes to reduce the bus volume on the northern segment of Caracas Avenue from 573 buses an hour to 450 buses an hour; diverting medium-size buses to parallel routes on which bus stops will be organized; managing traffic on Caracas Avenue and other roads through such measures as prohibition of left turns from Caracas Avenue, optimization of traffic signals, introduction of new traffic signals, on-street parking controls, pedestrian crossings, and footpaths; and constructing small-scale bus terminals to allow buses to stop off the main routes (World Bank 1996).

With the extension of the Caracas Avenue busway to a new busway on 80th Street as well as traffic management measures on 68th Street, congestion will be relieved and vehicular emissions on these roads will be reduced by an estimated 12 percent. The paving or resurfacing of roads will reduce PM emissions on a road length of about 30 kilometers (World Bank 1996).

Air quality monitoring. Air quality data are not comprehensive in terms of pollutant parameters and spatial distribution. In addition, although emission rates are changing over time, no updated air quality data have been generated since 1993 because of the lack of spare parts for the monitoring instruments. Installation of an automatic air quality monitoring network and development and maintenance of an updated emissions inventory are needed for better air quality management in Santafé de Bogotá. The district's Environment Agency has initiated a bidding process to buy new air monitoring equipment.

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5

CONCLUSIONS

Air pollution typically is most severe in congested urban areas, especially where motor vehicle emissions are relatively uncontrolled and topographical or atmospheric conditions are unfavorable for dispersion of air pollutants. Latin America and the Caribbean is the most urbanized region in the developing world and suffers severe air pollution problems in many of its major cities, including several cities located at high altitudes or surrounded by mountains that trap pollutant emissions. Public health is seriously affected in many large urban areas, and although some improvements have been made, additional air pollution control measures must be adopted soon to prevent worsening air quality caused by growing motor vehicle fleets.

In 1994, 73.5 percent of the region's 472 million people is estimated to live in urban areas, forty-three of which had populations exceeding 1 million people. Four of these cities—São Paulo, Mexico City, Buenos Aires, and Rio de Janeiro—ranked second, fourth, eighth, and tenth among the world's most populated urban centers. In addition, thirty cities had populations between 500,000 and 1 million. By 2010, forty-two urban areas are expected to have populations exceeding 1 million.

Ambient air concentrations of many pollutants in seven urban centers (Mexico City, Santiago, São Paulo, Belo Horizonte, Buenos Aires, and Rio de Janeiro, and Santafé de Bogotá) exceed the national or U.S. standards and WHO guidelines (Table 5.1). The most critical pollutants are ozone, PM, and CO. In Mexico City, Santiago, and Sao Paulo maximum 1-hour ozone concentrations exceed the WHO guideline by three to five times, and maximum 1-hour concentrations of NO_2 (an ozone precursor) are about two times higher than the guideline. In some of these urban areas the maximum 24-hour average PM-10 concentrations are two times higher than the U.S. standard and the maximum 24-hour average TSP concentrations are four to five times higher than the WHO guideline. Maximum 1-hour and 8-hour CO concentrations in traffic-congested downtown areas are as much as 2.6 times higher than the WHO guideline.

The frequency of excessive air pollution is also high, putting human health at great risk. For example, the 1-hour national standard for ozone is exceeded on about 300 days of the year in Mexico City and 155 days (404 times) in Santiago. In São Paulo the 1-hour national standard for ozone is exceeded 30 times a year and the 1-hour national standard for NO_2 is exceeded on 58 percent of the days.[1] Ambient concentrations of PM-10 exceed the 24-hour national standard 13 percent of the days in Mexico City and 17 to 20 percent of the days in São Paulo and Santiago. The 24-hour ambient TSP concentrations are above the national standards 64 percent of the days in Mexico City, 50 percent of the days in Santiago, and 20 percent of the days in São Paulo.[2] This high frequency of short-term pollution episodes helps drive annual average concentrations of air pollutants above the national standards and WHO guidelines. For example, in Mexico City, Santiago, and São Paulo annual average TSP concentrations are two to

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1. The 1-hour national standard for ozone standard is 220 $\mu g/m^3$ for Mexico, and 160 $\mu g/m^3$ for Brazil and Chile.

2. The 24-hour national standard for TSP is 260 $\mu g/m^3$ for Mexico and Chile, and 240 $\mu g/m^3$ for Brazil.

Table 5.1 Maximum ambient pollutant concentrations in selected Latin American urban centers

Pollutant	*Mexico City*	*Santiago*	*São Paulo*	*Belo Horizonte*	*Buenos Aires*	*Rio de Janeiro*	*Santafé de Bogotá*	*WHO guideline*
TSP (μg/m^3)								
24-hour	727 (1995)	621 (1995)	685 (1995)	604 (1992)	335[a] (1994)	634 (1994)		150–230
Annual	375 (1995)	266 (1995)	131 (1995)	107 (1992)	146 (1994)	190 (1994)	205 (86/89)	60–90
PM-10 (μg/m^3)								
24-hour	252 (1995)	302 (1995)	184 (1995)	276 (1996)				150[b]
Annual	87 (1995)	109 (1995)	105 (1995)				70 (1991)	50[b]
CO (mg/m^3)								
1-hour	31 (1995)	41 (1995)			78 (1996)	44 (88/89)	27 (1991)	30
8-hour	19 (1995)	26 (1995)	22 (1995)		15 (1995)			10
NO_2 (μg/m^3)								
1-hour	835 (1995)	724 (1995)	1,097 (1993)		447[c] (1994)			400
Annual	87 (1995)	98 (1995)	99 (1993)		157[c] (1994)		190 (1991)	100[b]
SO_2 (μg/m^3)								
24-hour	224 (1995)	161 (1995)	179 (1995)	130 (1996)	31 (1994)	92 (1994)		100–150
Annual	62 (1995)	37 (1995)	46 (1995)		9 (1994)	139 (1990)	72 (1994)	40–60
O_3 (μg/m^3)								
1-hour	698 (1995)	448 (1995)	763 (1995)			397 (1988)	241 (1991)	150–200

Note: Numbers in parentheses indicate years that pollutants were measured.
a. 1-hour concentration.
b. The U.S. standard. The WHO guideline is not established.
c. NO_x concentrations.
Source: CMPCCA 1994 and DDF 1996 for Mexico City; SESMA 1996a and SESMA 1996b for Santiago; CETESB 1994 for São Paulo; FEAM 1992 and Fundação Christiano Ottini 1992 for Belo Horizonte; DVA 1995 and FAS21 1995 for Buenos Aires; FEEMA 1995 and FEEMA and GTZ 1995 for Rio de Janeiro; Gómez, Montejero, and Saavedra 1994 and JICA 1992 for Santafé de Bogotá; and WHO/UNEP 1992 for WHO guidelines.

six times higher than the WHO guideline, and annual average PM-10 concentrations are two times greater than the WHO guideline (Table 5.1). In Santiago the annual average concentration of PM-2.5, which is more damaging to human health than PM-10, exceeds the proposed USEPA standards by nearly four times.[3]

In many urban centers lead in gasoline is the main source of airborne lead pollution. However, lead in ambient air is no longer a concern in Belo Horizonte, Buenos Aires, Rio de Janeiro, São Paulo, and Santafé de Bogotá because lead has been eliminated from gasoline in Argentina, Brazil, and Colombia. In Mexico City and Santiago ambient lead concentrations have decreased substantially as a result of the introduction of unleaded gasoline and reduction in the lead content of leaded gasoline. For example, between 1990 and 1994 ambient lead concentrations decreased by 80 percent in Mexico City.

Adverse health effects of air pollution in Latin American and Caribbean urban centers have been documented, although epidemiological studies are scarce. For example, in Mexico City a positive correlation has been identified between the level, duration, and frequency of air pollution episodes and the incidence of symptoms such as eye irritation, shortness of breath, sore throat, coughing, and hoarseness. Santiago, with its high levels of air pollution, also has higher rates of coughing and hoarseness among children, asthma and pneumonia among the general population, and air pollution-related mortality than in other parts of Chile. In Mexico City and São Paulo a positive correlation between lead concentrations in ambient air and blood has been documented.

Adverse meteorological and topographical conditions play an important role in the high pollution levels observed in many Latin American urban centers. For example, elevated ambi-

3. USEPA's proposed standards for PM-2.5 are 25 μg/m^3 for a 24-hour average and 15 μg/m^3 for an annual average. PM-2.5 constitutes about 50 percent of PM-10 in Santiago.

ent air temperatures in Brazil and Mexico cause higher evaporative emissions of motor vehicle fuels, and solar radiation enhances formation of ozone as a secondary pollutant. At higher altitudes, where air is less dense, CO and HC emissions increase significantly from older vehicles not equipped with catalytic converters. Urban centers located at higher altitude in the Andean range—such La Paz and Quito—remain particularly vulnerable to severe air pollution episodes though confirming air quality data are not available. Some cities such as Mexico City, Santiago, São Paulo, and Rio de Janeiro, are beset with thermal inversions that trap pollutants. The hills and mountains that surround some urban centers also prevent dispersion of air pollutants. For example, even though PM-10 emissions are much lower in Santiago than in São Paulo, the annual average ambient PM-10 concentration is about the same in both urban areas because of the mountains surrounding Santiago. The "street canyon" effect caused by tall buildings in downtown areas of cities like Buenos Aires also results in high concentrations of pollutants (such as CO).

Road-based motor vehicles are the main emission source of air pollution in many urban centers. For example, in Mexico City, São Paulo, and Santiago motor vehicles contribute more than 93 percent of CO emissions, 70 to 97 percent of NO_x emissions, and 54 to 90 percent of HC emissions. Light-duty vehicles contribute most CO and HC emissions, but both light- and heavy-duty vehicles are major contributors to NO_x emissions. HC and NO_x emitted by motor vehicles are the main contributors of ozone formed in urban areas. However, the share of airborne PM contributed by motor vehicles is quite variable. For example, in Mexico City and Santiago most PM-10 is caused by natural dust while motor vehicle emissions account for less than 12 percent of total PM-10. By contrast, in São Paulo motor vehicles contribute 40 percent of airborne PM-10, not counting their contribution to secondary particle formation. Heavy-duty vehicles have the largest share of PM emissions from vehicular sources. Other important PM emission sources may include industry and road dust. Heavy-duty diesel-fueled vehicles and industrial sources are among the main contributors to SO_2 emissions in the region's urban centers. However, because pollutants emitted from tall stacks are often dispersed before reaching ground level, their contribution to ambient concentrations are reduced. By contrast, pollutants from motor vehicles are emitted at ground level and therefore pose a greater risk to public health. Although, 24-hour SO_2 concentrations higher than the WHO guideline have been observed in industrial sections of Mexico City, Santiago, and São Paulo, annual average SO_2 concentrations have been generally within the guideline.

The overwhelming concentration of motor vehicles in urban centers is an important factor contributing to the urban air pollution problem. For example, the Santiago metropolitan area contains 58 percent of the motor vehicle fleet in Chile, the Buenos Aires metropolitan area 51 percent of the fleet in Argentina, and the Santafé de Bogotá metropolitan area 28 percent of the fleet in Colombia. The three largest metropolitan areas in Brazil (São Paulo, Rio de Janeiro, and Belo Horizonte) collectively have 45 percent of the national motor vehicle fleet (31, 10, and 4 percent, respectively).[4]

Not only are there more vehicles in urban areas, but the number of vehicles per capita is also much higher than corresponding national averages. For example, in the São Paulo metropolitan area the motorization level is about three times higher than the national level, in the Santafé de Bogotá metropolitan area it is about two times higher, and in the metropolitan areas of Belo Horizonte, Buenos Aires, Mexico City, Rio de Janeiro, and Santiago it is between 30 and 70 percent higher. Motorization levels are even greater in the urban core sections of metropolitan areas. For example, in Buenos Aires the motorization level in the Federal Capital is about 50 percent higher than in the broader metropolitan area.

The region's vehicle fleet has grown steadily, but it remains an aging fleet because vehicle retirement is not significant. For example, the average vehicle age is thirteen years old in Costa Rica, twenty years in Venezuela, and twenty-three years in Paraguay. Vehicles more than ten years old make up 50 percent of the fleet in Argentina, 60 percent in Ecuador, and 64 percent in El Salvador. In Lima about 75 percent of vehicles are more than ten years old, and in Santafé de Bogotá about half of public transport vehicles are more than twenty years old. In Mexico City

4. Light-duty vehicles (mostly private cars) generally account for more than 90 percent of road-based urban fleets in Latin America and the Caribbean.

about 42 percent of the vehicle fleet is more than 10 years old and 68 percent is not equipped with catalytic converters. In São Paulo vehicles not equipped with catalytic converters constitute about 80 percent of the fleet. These old and in general poorly maintained vehicles are responsible for the largest share of motor vehicle emissions in urban centers.

Measures to curtail pollutant emissions from fixed and mobile sources have been implemented in some urban centers (such as Mexico City, São Paulo, and Santiago), where air pollution problems became a serious threat to human health. These measures have been somewhat successful in reducing ambient concentrations of some air pollutants (such as SO_2 and lead) and stabilizing the levels of other pollutants (such as ozone). However, ambient concentrations of many air pollutants in these urban areas are still high and continue to pose a threat to human health. The extent of the air pollution problem in many Latin American urban centers is not yet quantified because air quality monitoring is either insufficient or nonexistent.

Since 1992 motor vehicle fleets in some Latin American urban centers have grown as much as 10 percent a year. Annual registrations for vehicles have been about 100,000 in the Buenos Aires Metropolitan Area and 400,000 in the São Paulo Metropolitan Region. As a result of economic growth and trade liberalization policies, vehicle sales in the region are expected to reach 4.5 million in 2000, three times more than in 1990. Most of these vehicles, especially cars, will enter urban fleets. Although the newly registered vehicles with pollution controls will make only a small contribution to overall emissions, they will worsen congestion and thereby increase the emissions contributed by older more polluting vehicles. Existing large urban centers, and those that are growing quickly and have unfavorable topographical or climatic conditions, are most likely to be adversely affected. Unless adequate air pollution control measures are adopted soon, worsening of air quality in these urban centers is likely to affect not only vulnerable population groups, but the general population as well.

Planning Tools for Air Quality Management

Efforts to formulate an urban air quality management strategy require information on ambient air quality and pollutant emissions data, models to predict dispersion of these pollutants, and epidemiological studies that ascertain the health effects of different ambient pollutant concentrations.

Air quality monitoring. Ambient air quality standards are a prerequisite for sound air quality management. Primary ambient air quality standards specify pollutant concentration limits above which adverse health effects may occur. Compliance with these standards needs to be monitored by measuring the spatial and temporal distribution of pollutant concentrations. The monitoring data should be used to inform the public about air quality, to trigger measures that both reduce emissions and lessen public exposure, and to help policymakers formulate air pollution control measures or evaluate measures that have already been implemented.

There are no ambient air quality standards in Guyana, Paraguay, Peru, Suriname, Uruguay, or any of the Central American and Caribbean countries.[5] Although standards have been established in all other countries in the region, in many cases they are inadequate or ignore pollutants that pose serious health concerns. For example, only Bolivia, Brazil, Chile, and Mexico have standards for PM-10. Countries that only have TSP standards should adopt PM-10 standards instead, and all countries soon may need to adopt PM-2.5 standards to regulate the most damaging portion of airborne PM. In Argentina NO_2 standards should be established to replace the existing NO_x standards, and SO_2 standards need to be revised. In addition, air quality indices that trigger preventive measures should be established in countries where ambient concentrations are (or are suspected to be) above national standards or WHO guidelines. Argentina, Brazil, Chile, and Mexico already have such indexes, though in Argentina the indices need to be revised.

Air quality monitoring networks need to be established in urban areas where air pollution is an actual or potential problem. These networks should have adequate spatial coverage, be fully automated, and provide real-time air quality data to the public. Such networks can be supplemented with semiautomated air monitoring stations. In Latin America and the Caribbean such

5. Standards are being prepared in Guatemala, Paraguay, Peru, and Uruguay.

systems have been established only in Mexico City and São Paulo. Santiago also uses automated and semiautomated air monitoring stations, but its network has a small spatial coverage and does not disseminate real-time air quality data to the public through billboards. This network, however, is unique in Latin America for its PM-2.5 monitoring capability.

Although fixed stations may adequately measure exposure of the general population to air pollutants, they often underestimate the exposure of population subgroups that are in close proximity to from motor vehicle emissions (traffic police, street vendors, pedestrians, and people who live alongside congested streets). For example, in Buenos Aires ambient CO concentrations recorded at road intersections have been found to be higher than those from fixed monitoring stations. Because lifestyles in Latin American and Caribbean countries are more conducive to outdoor urban activities than in most industrial countries, air monitoring by fixed stations should be supplemented by short-term special studies to determine pollutant concentrations at high exposure areas.

Commitment to providing adequate financing and trained personnel is essential for the success of air quality monitoring programs. Experiences in some Latin American urban centers are especially illustrative in this respect. For example, in Belo Horizonte, Rio de Janeiro, and Santafé de Bogotá monitoring stations installed with foreign assistance fell into disrepair because spare parts, technical expertise, and financial resources were lacking. Air quality monitoring efforts are limited in Belo Horizonte, Rio de Janeiro, and Buenos Aires, and are nonexistent in Santafé de Bogotá because of insufficient commitment of resources. In many urban centers existing stations need to be upgraded or new ones installed to monitor additional pollutants or areas suspected of having poor ambient air quality. Moreover, the air quality management capability of many local or regional institutions needs to be strengthened and, in some cases, monitoring could be concessioned to the private sector.

In urban areas with ozone pollution air monitoring data can be used to generate plots that relate HC and NO_x concentrations to ozone concentrations. This would help identify which of these precursors to control in order to most effectively reduce ozone pollution. Such plots have been developed for Mexico City and need to be replicated for other Latin American and Caribbean urban centers such as São Paulo and Santiago.

Emissions inventories and dispersion models. Emissions inventories are a useful planning tool for estimating sources and quantities of pollutants emitted into the atmosphere. These inventories should include, at a minimum, all major emission sources in an urban area. The inventories must be kept current to evaluate the impacts of changes in emission source characteristics (such as growth of the vehicle fleet) and the effectiveness of air pollution control strategies on ambient air quality.

Many urban centers beset by air pollution need to develop emissions inventories or update previously existing ones. The most comprehensive emissions inventory compiled in Latin America and the Caribbean is for Mexico City. The emissions inventory for São Paulo includes detailed information about mobile sources, but is out of date for industrial sources. In some other urban centers—such as Belo Horizonte, Rio de Janeiro, Santafé de Bogotá, and Santiago—emissions inventories were developed as part of specific environmental projects but have not been updated for use as a continuing planning tool. No systematic effort has been made to develop emissions inventories in Buenos Aires.

MOBILE5a is one model commonly used to estimate emissions from mobile sources. Because this model was developed for U.S. vehicles, it requires adjustments to match local conditions such as characteristics of the motor vehicle fleets, fuels, driving patterns, and ambient climatic conditions. Dynamometer testing on typical vehicles can be used to validate emission factors derived from modeling.

Air dispersion modeling is required to relate emissions data to ambient pollutant concentrations. Air dispersion modeling efforts have been conducted in some Latin American urban centers, including Mexico City, Santiago, São Paulo, and Santafé de Bogotá, and need to be initiated in many others. Urban areas with ozone problems should use a model that incorporates the photoreactivity of NO_x and HC emissions when estimating ambient ozone, NO_x, and HC levels. Validation and fine-tuning of such models with actual monitoring data will also be necessary.

Epidemiological studies. Many air pollutants emitted by motor vehicles adversely affect people's

respiratory and cardiovascular systems, in some cases causing sickness and, possibly, premature death. The impacts are especially severe on children, the elderly, and people with a history of respiratory or heart disease. In addition, lead poses a significant hazard because it affects the neurological systems of children, especially those less than three years old. A few studies have documented the adverse health effects of air pollution in some of the region's urban centers. However, most epidemiological data relating the dose-response functions of air pollutants has been based on research conducted in industrial countries, especially in the United States. These functions, which are used for estimating the benefits of alternative air pollution control measures, still need to be developed for many Latin American and Caribbean urban centers. In the meantime, some estimates of dose-response functions can be made using data from industrial countries although differences between the baseline conditions of the original and extrapolated populations may have a significant impact on the dose-response relationships. Care should be also exercised in extrapolating the original data beyond the range for which it was developed.

Air Pollution Control Measures

Air quality management strategies for urban centers typically include command-and-control measures and market-based incentives targeted at vehicles, fuels, and transportation management. Selection of specific measures should be based on a careful evaluation of emissions and ambient air quality data, air dispersion models, and the estimated costs and of the benefits of adopting different measures.

Vehicle-targeted measures. The most appropriate vehicle-targeted measures for Latin American and Caribbean countries include vehicle emission standards, emission restrictions on imported vehicles, vehicle inspection programs, and vehicle retrofit, replacement, or scrappage programs. These measures can be complemented with differential vehicle registration fees and taxes.

Emission standards for new and in-use vehicles are a commonly used policy measure. In Latin America and the Caribbean vehicle emission standards usually are set by national transportation or environment agencies, though enforcement of vehicle standard for in-use vehicles is conducted or supervised by regional or local institutions.

Emission standards and related measures for new vehicles. Establishment of stringent emission standards for new vehicles in Latin American and Caribbean countries is necessary to minimize the adverse air quality impacts from rapidly increasing new vehicle sales. Emission standards for new vehicles should be set by vehicle class (light-duty, medium-duty, heavy-duty) and engine type (spark-ignition engines designed to burn such fuels as gasoline, gasohol, ethanol, CNG, LPG, and LNG; and diesel engines designed to burn diesel fuel). The regulated pollutants for exhaust emissions should include CO, NO_x, and HC. In addition, there should be limits on evaporative emissions from vehicles fueled with gasoline or alternative fuels; PM emissions from diesel-fueled vehicles; and aldehyde emissions from vehicles fueled with ethanol or ethanol-blend fuels.

In devising emission standards for vehicles, the government must select standards that are achievable by the target date. In countries that manufacture vehicles, standards affect the design and production of new vehicles.[6] For this reason vehicle manufacturers must be consulted to ensure that the required pollution control technologies are available and can be incorporated into new vehicle models by the target date. In addition, the costs of these technologies should not create a major burden on consumers. Coordination with government institutions responsible for energy planning and fuel supply issues is essential to ensure that motor vehicle fuel specifications are compatible with proposed emission standards. Government authorities must consult petroleum refiners to help determine the time, technology, and cost required to modify refineries to produce the desired fuels. The government must also lead public awareness and education programs.

Most Latin American countries that have developed vehicle manufacturing industries (Argentina, Brazil, Chile, Colombia, and Mexico) have established emission standards for new vehicles and have tightened the standards gradually to bring them more in line with U.S. emission

6. Vehicle manufacturing countries in Latin America the include Mexico, Brazil, Argentina, Venezuela, Colombia, Chile, and Uruguay. In 1993, Mexico, Brazil, and Argentina accounted for 93 percent of motor vehicles manufactured in Latin America.

standards. For example, to comply with tightened emission standards, the Mexican automotive industry manufactured 1994 model-year vehicles that emit 93 percent less CO, 90 percent less HC, and 73 percent less NO_x than 1975 model-year vehicles. Three-way catalytic converters have played an important role in meeting stricter HC, CO, and NO_x emission standards for new vehicles and facilitating conversion to unleaded gasoline. Beginning with 1994 model-year cars, Mexico has required new vehicles to meet the same emissions standards as 1981 model-year cars in the United States. Brazil applied those standards beginning with 1997 model-year cars. The U.S. standards for 1987–93 model-year cars have been applied to new cars in Chile beginning with the 1992 model-year, and in Argentina beginning with the 1997 model-year.

Emission standards for new vehicles should be accompanied by certification, assembly line testing, recall, and warranty requirements. In Latin America and the Caribbean certification testing of new vehicles for emissions is conducted only in Brazil and will be initiated in Chile in 1997. Certification testing facilities need to be constructed in other Latin American countries as well, especially those that have vehicle manufacturing industries. This measure should also include development of testing procedures and personnel training. International trade agreements are expected to contribute to the regional harmonization of certification testing procedures as well as emission standards for new vehicles.

Emission restrictions on imported vehicles. Emission restrictions should be imposed on imported vehicles as a measure to limit emissions of air pollutants. Such restrictions are already imposed in Bolivia, Costa Rica, Ecuador, and El Salvador. Restriction can be associated with the model-year or age of the vehicle, use of a certain emission control technology (such as three-way catalytic converters), or compliance with certain vehicle emission standards. Because certification testing facilities are not available in most importing countries, official certification test results from the vehicle's country of origin should be required.

Emission standards and inspection programs for in-use vehicles. Emission standards limit allowable pollutant discharges from in-use vehicles and are enforced through inspection programs. Such measures offer considerable potential for reducing air pollution in Latin America and the Caribbean because the vehicle fleets are old, poorly maintained, and have a large proportion of highly polluting vehicles.

Emission standards for in-use vehicles have been set in Argentina, Bolivia, Brazil, Chile, Colombia, and Costa Rica, and need to be established in other countries. Standards should be based on the reductions achievable through proper vehicle maintenance taken into consideration the types and age distribution of the fleet. Test requirements should simulate actual driving conditions. As a minimum, the regulated pollutants should include CO and HC from the exhaust of vehicles with spark-ignition engines (using fuels such as gasoline, gasohol, and ethanol) and smoke from the exhaust of diesel-fueled vehicles.

Establishing emission standards for in-use vehicles is not sufficient to ensure compliance and therefore should be complemented by periodic inspection and maintenance programs and roadside inspections. These inspections are especially useful for pressuring vehicle owners to bring their vehicles into compliance and forcing gross polluters that are unable to meet the standards through maintenance and repair to remove their vehicles from circulation. For example, the inspection and maintenance program for light-duty vehicles in São Paulo is estimated to reduce emissions of CO by 11 percent, PM-10 by 20 percent, and HC by 19 percent. The program for light-duty vehicles in Santafé de Bogotá is estimated to reduce emissions by 55 percent for CO and 45 percent for HC. Emission tests on diesel-fueled buses with rebuilt engines in Santiago show that CO and PM emissions can be reduced by half if a bus that receives no maintenance is maintained according to manufacturers' specifications. Inspection and maintenance programs also help identify vehicles that have been tampered with, such as those lacking their originally installed catalytic converters. U.S. experience has shown that such vehicles can emit up to twenty times more pollutants than unmodified properly maintained vehicles, and a small number of them can have a significant negative impact on the environment.

The design of periodic inspection and maintenance programs should take into consideration factors such as convenience to vehicle owners, accuracy of inspection results using either automated or manual instruments, potential for fraud, the public sector's ability to control private inspection operations, and cost. Mexico

City's experience is useful for comparing centralized versus decentralized inspection stations, and government versus private operation of the stations. After evaluating the results of various schemes, in January 1996 Mexican authorities chose to have fully automated central inspection stations run by concessionaires. This type of system, which also was selected in São Paulo and in both the city and province of Buenos Aires, should be considered for other Latin American and Caribbean urban areas.

Fully automated central inspection stations are also best suited to identifying the exact source of the problem in vehicles equipped with on-board diagnostics. On-board diagnostics, which have already been installed in new cars manufactured in the United States, are expected to be available soon in Latin America and the Caribbean. On-board diagnostics also enable the vehicle operator to recognize problems between inspections and to take necessary corrective measures.

Periodic inspection schedules should give first priority to older vehicles lacking pollution control technology, especially high use vehicles that contribute the most air pollution. The program in Santafé de Bogotá covers inspection of public, mixed-use, and freight vehicles but needs to be expanded to include private cars because they are the largest source of NO_x, CO, and HC emissions by motor vehicles and a major contributor to the city's ambient ozone problem.

Periodic inspection of vehicle emissions should be complemented by random testing on the road or at terminals (roadside inspections). This approach is especially feasible for heavy-duty diesel-fueled vehicles because the most excessive polluters can often be identified visually (through excessive black smoke emissions in the exhaust) and pulled over for inspection. Roadside inspections of diesel-fueled vehicles has been conducted in Belo Horizonte, Buenos Aires, Mexico City, Rio de Janeiro, São Paulo, and Santiago. Rio de Janeiro and Santiago have also conducted public awareness campaigns to involve the public in reporting polluting vehicles. Remote sensing technology that measures concentrations of CO and HC in vehicle exhaust shows promise in identifying gross polluters without stopping the vehicles. The vehicle owners could then be contacted to have their vehicles inspected.

Vehicle retrofit, replacement or scrappage programs. Retrofit programs are aimed at bringing in-use vehicles manufactured without emissions controls in the compliance with emission standards, while replacement or scrappage programs seek to retire the old, highly polluting vehicles that are not suitable candidates for retrofitting. These programs are most effective in urban centers where a small percentage of vehicles are responsible for a large percentage of air pollution and where institutions have the necessary resources to purchase old vehicles or to provide financial incentives (such as tax relief) to individuals who are willing to retrofit or trade in their old vehicles for new ones. Such programs have been carried out in Mexico City, Quito, and Santiago. These programs should be directed at the oldest and most polluting high-use vehicles (such as buses) and should include measures to prohibit importation of such vehicles from outside the program area.

Differential vehicle registration fees and taxing schemes. Differential vehicle registration fees and taxing schemes can be designed to favor less polluting vehicles. Although such measures have not been implemented in Latin America and the Caribbean, they are used in other countries. For example, in Singapore car owners who replace their cars within ten years with new cars are exempt from registration fees. Some European countries have used tax credits for vehicles equipped with catalytic converters, and higher taxes for cars with emissions above specific standards.

Fuel-targeted measures. Implementing standards to improve the quality of gasoline and diesel fuel, promoting alternative fuels, and imposing carefully designed fuel taxes are among the most effective measures to reduce vehicular air pollution.

Gasoline quality standards. Gasoline standards should be designed to meet the fuel quality requirements of new model-year vehicles equipped with catalytic converters and to reduce pollutant emissions from older model-year vehicles that lack proper controls. These standards should include limits on volatility and on the content of lead, benzene, other aromatic hydrocarbons, sulfur, and oxygen (or oxygenates). Establishment of stringent gasoline standards has major implications for petroleum refiners and vehicle manufacturers. To meet new fuel standards, petroleum refiners must modify the operating conditions of existing refinery units or construct new units. Refinery investments usually take two to five years and are expensive, although in free market systems these costs would

be passed on to consumers. Vehicle manufacturers must modify their vehicle designs and assembly lines to produce vehicles capable of using these fuels.

Lead is the gasoline quality parameter that should be given highest priority in urban centers where leaded gasoline is still used. Reduction or elimination of lead in gasoline reduces ambient lead levels and associated health impacts. In addition, unleaded gasoline is required for vehicles equipped with catalytic converters, which are entering the region's fleets in large quantities. Lead has been eliminated from gasoline in Antigua and Barbuda, Argentina, Belize, Bermuda, Bolivia, Brazil, Colombia, Costa Rica, El Salvador, Guatemala, Honduras, and Nicaragua. Venezuela uses only leaded gasoline even though it produces unleaded gasoline for export. All other countries use both leaded and unleaded gasoline. By 2000 the percentage of unleaded gasoline in Latin America and the Caribbean is projected to increase to 83 percent from the current 68 percent, and the amount of lead addition is projected to decrease to 6,250 tons from the current 10,400 tons. It is important that the lead reduction and elimination programs be given priority in these countries, especially in Venezuela and Peru which jointly contribute 38 percent of the region's lead pollution from gasoline. These programs should ensure that the reformulated gasoline does not result in emissions of other pollutants (such as carcinogenic or ozone-forming chemicals) that have serious health or environmental consequences, particularly in urban areas where a sizable portion of the fleet consists of vehicles with no catalytic converters. Unleaded gasoline production programs should also include measures to reduce sulfur content. Sulfur in gasoline not only causes sulfur compound emissions, but more importantly reduces the efficiency of catalytic converters, resulting in higher emissions of CO and ozone precursors (HC and NO_x).

Volatile components of gasoline have toxic properties and contribute to ozone and smog formation. Stringent vapor pressure limits should be established to curtail evaporation of the most volatile portion of gasoline, especially in urban areas with hot climates and high ambient ozone concentrations, and where vehicles lack evaporative controls. More stringent vapor pressure limits can be established for populated urban areas than for the rest of the country (this has been done in Mexico) and for summer months in areas with seasonal temperature variations (this has been done in Santiago).

The benzene and aromatics content of gasoline should be restricted because of their toxicity and contribution to higher CO and HC in exhaust emissions. Currently only, Argentina, Chile, Colombia, Mexico, and Trinidad and Tobago limit benzene content in gasoline, and only Mexico limits aromatics content.

Oxygenates in gasoline reduce exhaust emissions of CO and HC by enhancing clean combustion, but may increase NO_x emissions. Gasoline quality standards in Argentina, Brazil, and Mexico specify requirements for oxygenate content. Other countries without specific standards have also used oxygenates to increase the octane number of gasoline. The predominant types of oxygenates used are ethanol in Brazil and MTBE in some other countries of the region. Use of oxygenated gasoline should be considered for traffic-congested urban centers with high ambient CO concentrations. It should also be considered for urban areas that are both located at high altitudes and where significant fraction of vehicles are equipped with carburetors or continuous fuel injection systems (such as Quito and La Paz). Development of an oxygenated gasoline program requires careful evaluation of the impacts on vehicle emissions and ambient air quality. This analysis needs to include NO_x and reactive HC emissions, especially in urban centers where ambient ozone concentrations are high.

Diesel fuel quality standards. Diesel fuel standards have been established in Argentina, Brazil, Chile, Colombia, and Mexico, but still need to be set in many other countries. These standards should include limits for sulfur, cetane number, aromatics, and density.

Reducing the sulfur content of diesel fuel is important for urban centers that have high ambient SO_2 and PM concentrations caused by emissions from diesel-fueled vehicles. A lower sulfur content can be required for diesel fuel in these urban areas than for the rest of the country, and can be promoted through tax incentives. The lowest sulfur diesel fuel in Latin America and the Caribbean (0.05 percent) is produced for use in the Mexico City Metropolitan Area.

The cetane number, aromatics content, and density of diesel fuel are interrelated and should be controlled because they are associated with higher CO, HC, and PM emissions in the exhaust of diesel-fueled vehicles. Benzene and PAH are toxic and carcinogenic.

Brazil's addition of lighter and heavier petroleum fractions to meet the high demand for diesel fuel has negative emissions impacts. Addition of the lighter fraction increases NO_x emissions, and addition of the heavier fraction increases PM emissions. Although rapidly growing sales of gasohol-fueled vehicles are expected to correct somewhat the imbalance in demand for diesel fuel and gasoline, specific measures to improve the quality of diesel fuel should be taken to reduce PM-10 and NO_x emissions.

Alternative fuels. Alternative fuels such as CNG and LPG can reduce CO and NMHC emissions from vehicles with spark-ignition engines, and PM and sulfur emissions from diesel-fueled vehicles. Alternative fuel programs should be accompanied by a differential taxation policy that reflects the health impacts and environmental damage associated with different motor vehicle fuels. Alternative fuel programs should also take into consideration changes in the infrastructure for vehicle fueling and in the approval process for fuel-conversion kits. Where the price of alternative fuels compares favorably with gasoline and diesel fuel, conversion to alternative fuels should be considered especially for high-use (mass transport or commercial) vehicles in polluted urban areas. In countries where such price differentials have been created, vehicle conversion costs have been recovered within a few years.

The region's largest producers of natural gas are Mexico, Venezuela, Argentina, Trinidad and Tobago, Brazil, Colombia, and Bolivia. But the most extensive CNG use in the transport sector has been in Argentina. About 80 to 90 percent of gasoline-fueled taxis and other high-use vehicles with spark-ignition engines (some commercial vehicles and private cars with long commutes) in the Buenos Aires Metropolitan Area have been converted to CNG. In Venezuela vehicle conversions to CNG have been increasing rapidly. In the São Paulo and Rio de Janeiro Metropolitan Regions the use of CNG is limited to some taxis and buses. Extensive use of CNG in high-use vehicles (especially in urban buses) should be considered in Santiago, São Paulo, and Rio de Janeiro following construction of the Argentina-Chile and Bolivia-Brazil gas pipelines. More extensive use of CNG should also be considered in urban areas (such as Mexico City and La Paz) of other countries that produce natural gas.

LPG is used extensively as a motor vehicle fuel in Venezuela and Suriname. Greater use of LPG in gasoline-fueled vehicles should be considered for Mexico City, Santafé de Bogotá, La Paz, and other polluted urban areas in countries that exploit and process natural gas or petroleum.

Brazil has the world's largest alternative fuel program. It is based on the use of ethanol (which contains 4 percent water) and gasohol (which contains 22 percent anhydrous ethanol and 78 percent gasoline) in motor vehicles with spark-ignition engines. This program, which was initiated in 1975 to respond to the country's energy needs and support the sugar industry, has led to the development of an alcohol-based auto manufacturing industry, rapid elimination of lead from gasoline, and an imbalance in the production ratio of gasoline to diesel fuel with a resulting decline in diesel fuel quality and an increase in PM and NO_x emissions from diesel-fueled vehicles. The use of ethanol instead of gasoline has reduced CO, PM, HC, lead, and SO_2 emissions, but increased aldehyde (especially acetaldehyde) emissions. To a lesser extent, gasohol also reduces CO, PM, HC, sulfur, and lead emissions in the exhaust when used in place of gasoline, but results in increased evaporative (HC) emissions in vehicles without emission controls. In São Paulo use of these alternative fuels has reduced ambient SO_2 and lead levels, and somewhat stabilized PM-10, NO_2, and ozone concentrations despite a rapid increase in the vehicle fleet. However, the national program to support the widespread use of alcohol-based fuels has also created a financial burden on the Brazilian economy. Such a large-scale alcohol-based fuel program is not recommended for other Latin American countries. Where use of an oxygenate is desired for specific urban areas, ether-based oxygenates (such as MTBE) are recommended over alcohol-based oxygenates because of their lower vapor pressure, especially in areas with hot climates and where ambient ozone concentrations are high and the motor vehicle fleet lacks evaporative controls.

A side benefit of the alcohol-based fuel program in Brazil was the development of another alternative fuel, which was used in spark-ignition vehicles during the alcohol crisis of the early 1990s. This fuel—called MEG—consists of 33 percent methanol, 60 percent ethanol, and 7 percent gasoline, and has properties similar to ethanol.

Fuel taxes. Fuel taxes should be used differentially among various fuels or fuel grades to promote the consumption of cleaner fuels. Such taxes should incorporate the costs associated with

adverse effects on human health and the environment. In particular, fuel taxes should be used to ensure that the retail price for unleaded gasoline is not higher than for leaded gasoline. Fuel taxes have considerably reduced the price gap between leaded and unleaded gasoline in some countries such as Ecuador and Mexico, and eliminated it in others such as Barbados and Chile. However, in Peru, Uruguay, and some other countries the leaded grade has a lower tax and retail price than the unleaded grade, encouraging increased consumption of dirty fuels and misfueling of catalytic converter-equipped vehicles which renders the converters ineffective. In some countries, including Brazil, differential fuel taxes have eliminated the price gap between low- and high-sulfur diesel fuel grades.

Differential taxation policies should also be used between conventional and alternative fuels. For example in Argentina where CNG is exempt from taxes, conversion to CNG in the transport sector has been pursued to a great extent by high-use gasoline-fueled vehicles (taxis and commercial vehicles). Because the price differential between diesel-fuel and CNG was insignificant until late 1996, conversion of diesel-fueled vehicles to CNG did not occur. However, the new taxing policy has widened the price gap between diesel fuel and CNG, which is expected to increase such conversions. In Mexico, the recent fuel taxation policy created an incentive for the conversion of gasoline-fueled vehicles to CNG, but is still insufficient to promote conversion of diesel-fueled vehicles to CNG.

Fuel taxes can also be used to discourage fuel consumption, thereby reducing pollutant emissions, improving air quality, and lessening adverse health effects. This would be particularly effective in a country like Venezuela, which has substantially lower gasoline price s than other countries in the region.[7] A gasoline tax that brought the Venezuelan price more in line with the rest of the region would promote use of more fuel-efficient vehicles and discourage unnecessary driving, especially of the inefficient and highly polluting vehicles.

Transport management measures. Proper transport and traffic management measures are essential for urban air pollution abatement efforts in Latin America and the Caribbean because the rapid growth of urban vehicle fleets, especially private cars, results in congestion which might completely overshadow the potential improvements from vehicle- or fuel-targeted measures. Transport and traffic measures include driving bans, traffic flow control measures, promotion of public and nonmotorized transport, and land use planning and control.

Driving bans. Seasonal driving bans that prohibit part of the vehicle fleet from circulating on given days based on license plate numbers have not been highly effective for curtailing air pollution in Latin American urban centers. Experiences from Mexico City and Santiago have shown that households circumvented the ban by purchasing old polluting cars from outside the metropolitan area to use on days that their primary vehicles were banned, postponing car trips to other days of the week rather than forgoing them, or obtaining multiple sets of license plates for a single vehicle. Imposing a temporary but nearly comprehensive driving ban based on the projected severity of air pollution on a specific day appears to be a more effective approach. Mexico City uses such a ban on high pollution days, but exempts low-emitting vehicles. In Santiago a comprehensive ban is imposed on the downtown area when pollution exceeds specific limits, and is expanded to cover the entire metropolitan area when even more severe pollution episodes occur.

Driving bans in highly congested business districts of urban centers, applied to a portion or entirety of the motor vehicle fleet, should be considered to relieve congestion and reduce human exposure to air pollutants from motor vehicles (such as CO) in the immediate area. This measure, however, is ineffective in improving air quality over an entire metropolitan area. In Santiago restricting taxis without passengers from entering a forty-block area of the city center during the day, coupled with parking bans, has reduced traffic flow in the restricted area by 30 percent and lowered emission of pollutants as well. Such measures should not be relaxed by issuing special permits to certain vehicle types if they would block the flow of traffic.

Prohibition of circulation based on vehicle age is an effective measure to reduce air pollution in Latin America and the Caribbean because old

7. In January 1996 the gasoline tax and retail price were \$0.016 a liter and \$0.106 a liter in Venezuela. By contrast, in Uruguay the gasoline tax and retail price were \$0.431 a liter and \$0.790 a liter (Alconsult International Ltd. 1996).

vehicles produce a disapprotionately large share of pollutant emissions. Circulation bans were implemented in Mexico City for vans older than eight years and taxis older than six years. Circulation bans were imposed on urban buses more than ten years old in Buenos Aires, more than eighteen years old in Santiago, and more than twenty years old in Santafé de Bogotá. Banning trucks from daytime circulation in congested areas, especially in business districts, is also an effective measure to reduce human exposure to emissions.

Traffic flow control measures. Traffic management measures should be implemented to smooth traffic flow, improve road safety, and reduce pollutant emissions. Some traffic management measures include installation of signals at intersections, prohibition of conflicting turns, designation of one-way streets, and segregation of motorized and nonmotorized traffic. Traffic flow in heavily congested streets can also be improved through on-street parking restrictions. Depending on the flow pattern at specific locations, these restrictions can be implemented either at peak hours, throughout the entire weekday or at all times. Such measures require installation of signs and a firm enforcement effort. In addition, on-street parking restrictions can be complemented by the provision of off-street parking facilities. Heavy taxes on parking in congested areas should be used to encourage use of public transportation rather than private cars.

Improvements in road infrastructure should be pursued in combination with tight control of traffic flows. Otherwise, better driving conditions could attract more vehicles, leading to renewed congestion with no reduction in pollutant emissions. One way to control the flow of vehicles is by charging motorists a fee for the use of a road or entry to an urban area in the hopes of encouraging use of public transport, high-occupancy vehicles (HOV), alternate routes, or driving at off-peak hours. Although examples are available from different parts of the world, in Latin America and the Caribbean road pricing to control urban congestion has been used only in Buenos Aires, and area licensing has not been implemented in any urban area. These measures should be seriously considered, especially for large metropolitan areas which are already congested. Another way to reduce the number of vehicles on the road is to allow only HOV on certain dedicated roads or lanes. This measure—which promotes ride sharing, but requires special dedicated infrastructure and enforcement—may not be effective for societies that are unaccustomed to commuting directly between home and office every morning and evening.

Promotion of public transport. Measures should be taken to encourage use of public transport services rather than private cars. Public transport ridership can be increased by improving the quality of services, lowering fares, and simplifying fare structures. By adopting prepaid ticket systems, elevated bus platforms, travel time for buses can be shortened and traffic priority measures such as special bus lanes, improved routes, or signal preemption. Cities that use traffic priority measures for buses include Buenos Aires, Curitiba, Lima, Porto Alegre, Santafé de Bogotá, and Santiago.

Simplification of fare structures (for example, flat or zone-based fares) and integrated fares between different modes of transport may increase the perceived value of public transport and boost ridership. Lower fares also encourage public transport ridership, but they should not be so low that they prevent full recovery of investment and operating costs, or do not allow for maintenance and improvement in transport infrastructure and services. The efficiency of public transport systems can be greatly increased by providing these services through the private sector. However, the public sector still plays an important role in regulating the private sector's operation of the transport system, licensing public transport routes and vehicles, improving and extending the road network, regulating and managing traffic, and setting environmental and safety standards.

Promotion of nonmotorized transport. Nonmotorized transport (walking, bicycling) should be promoted through construction of sidewalks, improvement in safety of the walking environment, closure of certain streets to motor vehicle traffic, construction of bikeways, promotion of the domestic bicycle industry, reduction of import taxes on bicycles and other measures. Curitiba's success in promoting non motorized transport should be used as a model for other Latin American and Caribbean urban centers.

Land use planning and controls. The objective of land use planning should be to create a desirable environment for the future instead of merely to solve short-term traffic problems. Curitiba's program to reduce traffic density and vehicular air pollution should be studied for possible application to other Latin American

urban areas. In many areas where urban sprawl and low population density promote the use of private cars rather than public transport, environmentally sound land use policies should be developed and plans should be devised to create mixed-use multinucleated urban areas that encourage walking for short trips and use of mass transit for long trips.

Formulation and Implemention of Urban Air Quality Management Strategy

Formulation and implementation of a comprehensive and effective urban air quality management strategy require a coordinated effort among national, regional, and local institutions representing the various jurisdictions in urban areas. National institutions are most likely to be involved in urban areas that include capital cities. At a minimum, institutions responsible for environment, transport and traffic, fuel quality and supply, industry, and health issues should participate. The participation of the scientific and business communities, labor unions, and NGOs is also important. Moreover, a participation plan should be developed to ensure that the public's views are identified and incorporated into the decisionmaking process.

Many urban areas, including Buenos Aires, Santafé de Bogotá, Rio de Janeiro, and Belo Horizonte, have serious air pollution problems yet lack integrated air pollution management strategies. These areas should benefit from the experiences of Mexico City and Santiago. The strategy put together for Mexico City for 1995-2000 is a particularly useful blueprint for other urban areas to follow in designing their own management strategies (DDF 1996).

Formulation and implementation of pollution control measures generally have been hampered by unclear or overlapping institutional responsibilities; inadequate equipment, technical expertise, and human and financial resources; weak financial management; lack of political will; and limited public support or participation. Among the human resource problems are an excessive number of poorly paid and unmotivated staff, and budget rigidities limiting access to nonstaff resources. Lifetime employment and declining budgets also restrict new hiring. These institutions must strengthen their human and financial resources and their management systems if they are to implement and enforce an effective air quality management strategy.

Although some measures, such as eliminating lead from gasoline, are widely recommended, ultimately it is impossible to prescribe a detailed set of measures that should be applied regionwide. Each urban area, with its specific pollution problems and unique combination of environmental, physical, social, and economic factors, would be best served by its own mix of pollution control strategies. Measures to improve transport management may involve common principles and dynamics, but must be tailored to each situation. Even fuel standards, which should be in place in all countries, may vary depending on local conditions. The important point is that the tools and knowledge are available to make substantial gains at reasonable cost in most cities, and concern for the environment, human health, and quality of life provide a compelling case for making vehicular pollution control a high priority.

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