

**Coordinating Transport, Environment, and Energy  
Policies for Urban Air Quality Management:**

World Bank Perspectives

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# Contents

## **Preface**

## **Acknowledgments**

## **Abbreviations and acronyms**

## **Executive summary**

## **Environmental concerns and priorities in urban air quality management**

*The main sources of air pollution*

*Developing a strategy for mitigating air pollution*

*Vehicle emissions abatement measures and their cost-effectiveness*

Potential win-win measures

Targeted pollution abatement measures

*Cross-sectoral coordination of policies*

Using others' experiences: Risks and benefits

Vehicle technology, fuel quality, and related policies

Targeting gross emitters

Fiscal policies

Trade liberalization

*Greenhouse gas emissions*

Global trends in CO<sub>2</sub> emissions

Options for reducing GHG emissions

*Decisionmaking levels in transport-related air quality management*

## **World Bank experience with support for urban air quality management programs**

*Analytical work*

*Nonlending services*

URBAIR

Lead phaseout

Clean transport fuels

South Asia two-stroke-engine initiative

Clean air initiatives

*The urban transport portfolio*

Closed projects

The active portfolio

*Other relevant portfolios*

*Conclusions and recommendations*

## **References**

## **ANNEXES**

A Key air pollutants

B Diesel certification in California

C Closed World Bank projects in the urban transport sector

D Ongoing World Bank projects in the urban transport sector

## **FIGURES**

1 Composition of environmental damages from fuel combustion in six developing-country cities, 1993

2 Environmental cost of fuel use by sector in six developing-country cities

### 3 Levels of decisionmaking affecting transport-related urban air quality management

#### **BOXES**

- 1 Key steps in developing a pollution abatement strategy
- 2 Promoting nonmotorized transport
- 3 Private sector operation of an inspection and maintenance program in the Mexico City Metropolitan Area
- 4 Phasing out leaded gasoline: Misconceptions and facts
- 5 Fuel pricing policy in Asia and beyond: Getting the incentives right
- 6 Improving air quality in the Mexico City Metropolitan Area through a comprehensive pollution reduction program

# Preface

In many large urban centers around the world, especially in developing countries, deteriorating urban air quality is a worsening environmental problem. Poor air quality threatens human health and causes other forms of environmental damage. Vehicle emissions are often one of the main contributors to pollution, including highly damaging emissions of lead and fine particulate matter.

In the course of any effort to remedy air quality problems—even the deceptively straightforward drive to eliminate lead from gasoline—it becomes evident that programs in one sector depend on and have implications for other sectors. One-dimensional efforts to reduce air pollution by, for example, introducing strict standards or banning certain activities can be ineffective on their own, may introduce perverse incentives, or may disproportionately affect the poor. Programs to improve air quality are also bound up with such issues as trade and price liberalization, energy policies, and global climate change. Initiatives in the transport and energy sectors, such as road construction, fuel pricing reforms, and elimination of subsidies, affect, for good or ill, air pollution and therefore human health. Coordinating policies and measures in these areas is therefore essential if projects and programs are to meet their long-term objectives and contribute to sustainable development and the improvement of human welfare.

In developing countries, improving air quality is not simply a matter of importing advanced technologies or adopting Western standards. The choices about the feasibility, sequence, and timing of a range of measures have serious fiscal and economic consequences. The guiding principle for selection of strategies should be the balancing of costs, benefits, and technical and institutional feasibility.

This paper looks at the key issues of mitigating transport emissions that cut across sectors, examines the priorities for air quality management programs, and reviews experience, including that of World Bank, with air quality management efforts. It draws lessons from this assessment and offers recommendations for priorities in developing coordinated assistance strategies in the environment, urban transport, and energy sectors.

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## Abbreviations and acronyms

ACEA	Association des Constructeurs Européens d'Automobiles (European Automobile Manufacturers Association)
BAT	Best available technology
CARB	California Air Resource Board
CDM	Clean Development Mechanism
CETESB	Companhia de Tecnologia de Saneamento Ambiental (Brazil)
CIDA	Canadian International Development Agency
CNG	Compressed natural gas
CO	Carbon monoxide
CO <sub>2</sub>	Carbon dioxide
EPEFE	European Programme on Emissions, Fuels and Engine Technologies
ESMAP	Energy Sector Management Assistance Programme
EU	European Union
GDP	Gross domestic product
GEF	Global Environment Facility
GHG	Greenhouse gas
GTZ	German Agency for Technical Cooperation
ICR	Implementation completion report
IEA	International Energy Agency
I/M	Inspection and maintenance
IQ	Intelligence quotient
LAC	Latin America and the Caribbean
LIL	Learning and Innovation Loan
LPG	Liquefied petroleum gas
MCMA	Mexico City Metropolitan Area
MEIP	Metropolitan Environment Improvement Program
MON	Motor octane number
NGO	Nongovernmental organization
NIS	Newly independent states
NMT	Nonmotorized transport
N <sub>2</sub> O	Nitrous oxide
NO <sub>2</sub>	Nitrogen dioxide
NO <sub>x</sub>	Nitrogen oxides
OECD	Organisation for Economic Co-operation and Development
PCF	Prototype Carbon Fund

PM <sub>nm</sub>	Particulate matter with an aerodynamic diameter of less than <i>nm</i> microns, as in PM <sub>10</sub> and PM <sub>2.5</sub>
RON	Research octane number
SO <sub>2</sub>	Sulfur dioxide
SO <sub>3</sub>	Sulfur trioxide
SO <sub>x</sub>	Sulfur oxides
SSATPP	Sub-Saharan African Transport Policy Program
TSP	Total suspended particles
UNDP	United Nations Development Programme
UNECE	United Nations Commission for Europe
URBAIR	Urban Air Quality Management Strategy
US EPA	U.S. Environmental Protection Agency
VKT	Vehicle kilometers traveled
VOC	Volatile organic compound
WBI	World Bank Institute
WHO	World Health Organization
wt ppm	Parts per million by weight
g/km	Grams per kilometer
km/h	Kilometers per hour
µg/dl	Micrograms per deciliter
µg/m <sup>3</sup>	Micrograms per cubic meter
µm	Micron, or 10 <sup>-6</sup> meter

## Executive summary

Air pollution is one of the most serious environmental concerns in urban areas, especially in view of its adverse effects on human health. In developing countries around the world, an estimated 0.5 million–1.0 million people die prematurely each year as a result of exposure to urban air pollution, and millions of cases of respiratory illness are associated with air pollution in large cities. Among the greatest environmental health concerns are exposure to lead, which contributes to behavioral problems and learning disabilities of young children even at low levels of exposure, and exposure to fine particulates, which are known to cause serious health damage due to their penetration deep into the lungs. The economic damage from urban air pollution (including its effects on structures, crops, and vegetation and forests) is estimated to amount to US\$1 billion–US\$4 billion annually in cities in Asia and to US\$6 billion in urban areas in the newly independent states (NIS). Air pollution also contributes to the accumulation of stratospheric greenhouse gases, with implications for global climate change.

This paper discusses the growing air pollution problem in developing countries and outlines approaches to urban air quality management in the transport sector. As countries become motorized, vehicles will contribute increasingly to urban air pollution. Tackling air pollution arising from the use of vehicles in turn calls for coordinating urban transport, environment, and energy policies. Although the broader issues of long-term urban planning and measures to induce significant shifts in transport mode are important in influencing urban environmental trends, they are beyond the scope of this paper.

### Developing strategies for improving air quality

Anthropogenic air pollution originates from a variety of sources, including households; vehicles; large stationary sources; small and large industries; construction; fugitive emissions as a result of mechanical breakup, abrasion, and erosion of road surfaces, brake linings, and tires; agriculture; and forest burning. Motor emissions can contribute as much as 80–90 percent of atmospheric lead in cities where leaded gasoline is still used, and traffic is also a large contributor to fine particulate matter. Next to the elimination of lead from gasoline, which is an effective measure for reducing human exposure, the reduction of fine particulate matter is by far the highest priority. Vehicle emissions, together with stationary and natural sources, are important in the formation of ground-level ozone, which causes health damage as well as damage to vegetation and crops. Mobile and stationary combustion sources are significant contributors to ambient concentrations of a range of other pollutants.

A priori assumptions about which sources should be targeted for pollution reduction can result in choices of measures that are not cost-effective or do not have a significant impact on air quality. A systematic approach, therefore, is needed to formulate a strategy for improving urban air quality. Such an approach should:

- *Identify the main environmental concerns* on the basis of assessment of risks to human health and to environmental resources
- *Use cost-effectiveness as the primary criterion* for selecting optimal strategies across various sources and sectors
- *Harmonize policies and measures across sectors* and help implement the selected strategies.

Industrial countries have made significant progress in improving their air quality by applying a combination of environmental and sectoral regulations, incentives and fiscal measures, and advanced technologies. In many developing countries, choices about the feasibility, sequencing, and timing of similar measures have serious fiscal and economic consequences. The guiding principles for selection of strategies and regulations should be the balancing of costs and benefits and the institutional feasibility of the measures. The transfer of advanced technologies without consideration of their applicability, or the use of strictly sectoral approaches to improving air quality, may fail to produce the desired effects if not based on a comprehensive strategy. For example, advanced fuel and vehicle technologies used in industrial countries are expensive and are designed to make already clean vehicles cleaner. Importing

these standards in a situation with large numbers of highly polluting vehicles and an inadequate repair infrastructure would require a large allocation of resources and is unlikely to be cost-effective. The development community has to consider these issues in helping developing countries address their environmental issues effectively.

### **Vehicle emissions abatement measures and their cost-effectiveness**

Vehicle emissions, which occur near ground level and in densely populated areas, cause much greater human exposure to harmful pollutants in the immediate locality than do emissions from sources such as power plants that are situated at elevated levels and farther away from dense population centers. In addition, vehicle exhaust particles, being small and numerous, can be expected to have considerable health impacts. Pollution abatement in the transport sector is therefore likely to become increasingly important in urban air quality management strategies in the coming years.

#### *Potential win-win measures*

A number of measures that are typically undertaken to pursue other primary objectives are likely to generate environmental benefits as well.

- *Improved traffic flow management*—for example, coordinating traffic lights—is aimed at decreasing congestion and improving mobility but also confers environmental benefits because of the resulting lower emissions intensity of traffic. It should be noted, however, that some congestion-relieving efforts, such as road construction, can invite greater levels of motorization in the long run.
- *Traffic demand management*—for example, through the provision of public transport, promotion of nonmotorized transport, application of fuel taxes and other fiscal measures, areawide licensing, electronic road pricing in urban areas, and preferential treatment of high-occupancy vehicles—is aimed at inducing a behavioral change in the use of vehicles and has beneficial environmental impacts.
- *Some vehicle use and maintenance practices*, such as using the correct type and amount of lubricant in two-stroke engine vehicles, avoiding overfueling diesel engines, and correcting injection timing—have positive economic and environmental impacts.

#### *Targeted pollution abatement measures*

In addition to encouraging the above win-win measures, several options for targeting pollution from vehicles are widely used, but their effective application depends on a number of conditions:

- *Tightened vehicle emissions standards.* The conditions for effectively controlling emissions through standards are reliable vehicle registration, emissions standards that differentiate vehicles by type and age, means of measuring emissions levels accurately, and methods for enforcing the emissions standards. Where existing emissions and vehicle standards are inadequately enforced, it may be more productive to concentrate on enforcement than to tighten the standards.
- *Improved vehicle technology.* Three-way catalytic converters, if properly operated and maintained, can significantly reduce emissions of exhaust carbon monoxide (CO), hydrocarbons, and nitrogen oxides (NO<sub>x</sub>) from gasoline vehicles. Modern diesel engines are much cleaner than those produced in the past, but they require proper fuel quality.
- *Inspection and maintenance (I/M) programs.* I/M programs can mitigate transport pollution by strengthening the enforcement of emissions standards and can stimulate demand for vehicle repair and maintenance services, if such programs are properly operated and are corruption-free.
- *Vehicle retirement and scrappage programs.* These programs must be used with care. Income constraints make cash-for-replacement particularly difficult to design in developing countries;

owners of gross emitters with high annual vehicle kilometers traveled are often not in a position to purchase much newer vehicles.

- *Improved fuel quality.* Improvements in fuel quality can contribute to better air quality if they are closely coordinated with improvements in vehicle technology. For the World Bank's client countries, the first step in improving the quality of transport fuels is to phase out lead in gasoline. A number of developing countries have already banned leaded gasoline, and several others are planning to do so in the near future. At the same time, it is important to address other fuel parameters that may have adverse health impacts. For countries that have domestic refineries, it has to be kept in mind that refinery processes are integrated and that changing the specifications for one fuel could affect the quality of other fuels and overall refinery economics. Although there are benefits from the regional harmonization of fuel specifications, these specifications have to reflect national and local conditions.
- *Use of alternative fuels.* Alternative fuels have strong advantages and disadvantages. Vehicles using liquefied petroleum gas (LPG) and compressed natural gas (CNG) emit considerably less particulate matter than do diesel vehicles not equipped with particulate traps, and vehicles powered by electricity have no tailpipe emissions. The required investments in LPG distribution and refueling stations have not been made in most developing countries, constraining the widespread use of this fuel. CNG yields essentially no reactive organic compounds or sulfur oxide (SO<sub>x</sub>) emissions, but it is much more expensive to distribute and store than LPG. The basic requirements for the long-term viability of CNG vehicles are a natural gas distribution network that is already in place, retail fuel prices that favor CNG substantially over the fuels that CNG is intended to replace, and a favorable legislative and regulatory atmosphere. The existing diesel and natural gas pricing structure in most countries provides little incentive for switching from diesel to CNG. The major disadvantages of electric vehicles, in comparison with other alternative-fuel vehicles, are the length of time needed for recharging them, their short ranges, and their considerably higher purchase costs. The long-term viability of electric vehicles should be evaluated from the standpoint of market-based energy pricing. While pure electric vehicles may not be expected to have widespread application, hybrid electric–internal combustion engines may play a greater role in the future.

### **Cross-sectoral coordination of policies**

Policies in various sectors have close linkages and should be coordinated and harmonized to achieve optimal results. Coordination is especially important for policies that target vehicle technology and fuel quality.

#### *Vehicle technology, fuel quality, and related policies*

A number of fuel-related issues need to be considered in formulating transport, environment, and energy policies:

- Emissions levels of lead depend solely on fuel composition, and lead is extremely toxic. Its phaseout from gasoline is technically feasible and is an effective measure for reducing pollution and health impacts.
- In many developing countries the vehicle fleet is dominated by poorly maintained, often old, vehicles. As long as large numbers of these vehicles are on the road, the cost-effectiveness of tightening fuel specifications to North American or European Union (EU) standards is questionable.
- In countries where the carbonaceous component of vehicular particulate matter is still high, it may not make economic sense to target sulfur in diesel to match North American and EU fuel standards if the goal is to mitigate particulate emissions from diesel engines.

- It is not enough to regulate fuel quality. In a number of countries transport fuels are routinely adulterated by adding (lower-cost) kerosene or lead to gasoline downstream of refineries or terminals. Regular fuel quality monitoring, together with costly penalties for noncompliance, could help enforce fuel standards more effectively.
- The promotion of modern vehicle technology has to be harmonized with measures for fuel quality improvement. Modern engines often require a certain fuel quality that may not be readily available in developing countries.
- A number of conditions need to be satisfied for catalytic converters to function effectively, including wide availability of unleaded gasoline, a reasonably low level of sulfur in vehicle fuels, and an effective inspection and maintenance system, including the existence of appropriate standards. The promotion of catalytic converters provides a striking example of the interdependence of transport, energy, and environmental policies.

### *Targeting gross emitters*

The share of emissions is not uniformly distributed over the vehicle fleet. A fraction of ill-maintained, often old, vehicles is typically responsible for a disproportionate amount of pollution from the transport sector. If these “high emitters” can be repaired or permanently eliminated, a considerable reduction in pollution can be achieved at a relatively small cost. Policies targeting certain types of vehicles should take into consideration their distributional impacts on the poor.

### *Fiscal policies*

Fiscal policies include lower taxes on cleaner fuels and vehicles. A good example is a policy of pricing unleaded gasoline lower than leaded gasoline during the transition period when lead in gasoline is being phased out.

Prevailing fuel subsidies and taxation can have adverse environmental impacts. For example, gasoline is taxed to a considerable extent in many developing countries, but diesel and kerosene are either less taxed or subsidized. A large price differential between kerosene and gasoline leads to illegal addition of kerosene to gasoline, resulting in higher pollutant emissions. Similarly, a large price differential between gasoline and diesel encourages a shift from gasoline-powered to diesel vehicles—a shift that is unfavorable from the environmental point of view because of the emerging epidemiological evidence that diesel emissions are more toxic than gasoline emissions. A general policy of narrowing the price gap by taxation is not necessarily the best approach, however, because of the expected impact of such taxation on other uses of diesel—in rail transport, agriculture, and industry, for example. An alternative is to increase vehicle taxes on diesel vehicles typically used in intracity transport (that is, light-duty diesel vehicles) or to give rebates on the diesel tax to industrial and agricultural users of diesel.

Tax structures that discourage the purchase of new vehicles—for example, registration fees or excise taxes based on the market value of the vehicle—should be carefully reviewed and, if possible, revised, since they do not capture the cost of pollution. In considering fiscal measures, the socioeconomic impact of making the ownership of old vehicles more costly should be considered.

### *Trade liberalization*

The removal of barriers that hinder access to the technology available in the rest of the world would enable consumers to meet tighter emissions standards at least cost. Rules such as local content requirements often result in inefficiency. Higher import tariffs on new vehicles, rigid licensing schemes for imports, and quotas are all likely to slow the rate of vehicle renewal, with potentially adverse impacts on air pollution.

Free trade in used cars can have mixed results. Exports of gross emitters would be a classic case of environmental dumping. In the interest of environmental protection, governments may limit the age of the vehicles that can be imported, levy higher import duties, or impose other restrictions on such vehicles. The purchasing pattern of vehicle owners should be carefully balanced against the expected

environmental advantages of restricting the import of old vehicles. If, for example, consumers cannot buy relatively new vehicles, an import restriction based on age would postpone the replacement of the high emitters. Several industrial countries levy a fee to cover the final disposal of vehicles, and countries that import used vehicles could negotiate the transfer of such funds to cover disposal costs.

Liberalized trade, by enabling the use of superior fuels produced in other countries, makes it much easier to phase out gasoline lead and to implement other fuel quality improvement measures. In some regions there is a move toward harmonizing fuel specifications to ensure minimal environmental standards, foster intraregional trade, and enhance the efficiency of supply. Fuel specifications in North America, the EU, and the countries of the former Soviet Union are already harmonized for the most part, and similar measures have been proposed in Latin America.

Many refineries in developing countries are owned by the government, and some of them are not operated economically. In a number of developing countries, the net cost to society of improving fuel quality by importing superior fuels would be lower than the cost of supplying domestically manufactured fuels with less-stringent fuel specifications. Downstream petroleum sector reform through transfer of ownership from the government to the private sector, coupled with liberalization of petroleum product trade and the introduction of competition, is therefore an important condition for improving fuel quality and, ultimately, urban air quality.

## **Greenhouse gas emissions**

Most environmental externalities from transport—such as those affecting human health—impose immediate social costs and require national and local action. By contrast, emissions of greenhouse gases (GHGs), including carbon dioxide (CO<sub>2</sub>), methane, and nitrous oxide (N<sub>2</sub>O), contribute to a global externality, the impacts of which will accrue in the more distant future. Solutions to this problem require concerted international efforts.

### *Global trends in CO<sub>2</sub> emissions*

For most countries, the share of emissions arising from transport has increased in recent decades. Although the share of GHG emissions from developing countries is small compared with that of member countries of the OECD (Organisation for Economic Co-operation and Development), especially in the transport sector, there are concerns about future trends. If OECD countries begin to restrain their emissions while developing countries—whose economies are growing more rapidly than those of the OECD—do not, total emissions from the developing countries are forecast to overtake those from the OECD within a fairly short time period.

### *Options for reducing GHG emissions*

Politically, suggestions for GHG mitigation measures in developing countries are often received warily and can be perceived as a denial of these countries' basic right to economic growth and improvement of human well-being. Some measures that reduce local pollution, however, also reduce GHG emissions.

One area of overlap between local and global benefits is increased *fuel economy*. The enormous gains made in improving fuel economy in the 1970s and the first half of the 1980s have contributed to decreasing both local and global pollution in industrial countries. In developing countries fuel economy is often low because of such factors as poor vehicle maintenance, fuel adulteration, and low engine compression ratio, although small engine sizes are typically found to help offset the low fuel economy.

Another area of overlap between local and global pollution-reduction goals is *traffic management*. Traffic congestion worsens emissions of both local and global pollutants. It has been reported that increasing the average speed in city traffic from 10 kilometers per hour (km/h) to 20 km/h can cut CO<sub>2</sub> emissions by nearly 40 percent.

It is important to recognize, however, that there is not always a synergy between measures to reduce local pollution and measures to mitigate GHG emissions. Locally motivated air quality improvement

programs for urban transport in such middle-income countries as Mexico and Chile have been shown to have limited collateral benefits for reduction of GHG emissions.

The worldwide move to mitigate local pollution by progressively reformulating transport fuels through severe hydrotreating is making refinery processes increasingly energy-intensive, thus increasing GHG emissions. Diesel fuel is particularly efficient and helps reduce GHG emissions, but its emissions may be more detrimental to human health than those of other fuels.

An area that merits examination is the role of fuel pricing in encouraging better fuel economy and optimizing fuel usage. In some countries diesel is hardly taxed, making its retail price low. Such a pricing policy encourages excessive use of diesel.

## **Decisionmaking levels in transport-related air quality management**

Decisions made at different levels affect policies designed to combat transport emissions. At the global level, moves are being made to address issues such as GHG emissions that can be tackled only globally, and vehicle manufacturers are leading initiatives to harmonize fuel quality and vehicle emissions standards worldwide. At the regional level, pollutants such as sulfur dioxide (SO<sub>2</sub>) require solutions that transcend country boundaries. There are also initiatives to harmonize fuel specifications and vehicle emissions standards on a regional basis, notably in the EU. In the NIS these standards are already harmonized by virtue of the countries' history. In some regions standards are increasingly integrated on account of extensive trade. All these trends affect decisionmaking at the national level.

The national government typically sets air quality standards, fuel specifications (with geographic differentiation if the distribution infrastructure can support it), vehicle emissions standards, and definitions of what constitutes noncompliance. Air pollution problems, however, are location-specific, and it is state and municipal governments that monitor air and fuel quality, and vehicle emissions; integrate transport considerations into overall city development plans; develop traffic flow, demand management, and other strategies for dealing with traffic congestion and emissions; and, where appropriate and fiscally possible, offer financial and other incentives for vehicle renewal, nonmotorized transport, and other means of mitigating traffic emissions.

These considerations are important in determining the proper instruments and frameworks for assisting client countries in their efforts to improve their environments and strengthen their environmental policy and regulatory frameworks. The World Bank, through its policy dialogue with client governments at the national level and through sectoral programs and projects at the urban level, can be effective in forging cross-sectoral coordination of policies and supporting measures that can contribute to improved environmental conditions in developing countries.

## **World Bank experience with support for air quality management programs**

In recent years the World Bank has started to address urban air quality management and its interlinkages with the transport sector, primarily through analytical work, nonlending services, regional initiatives, and partnerships. A coherent and consistent strategy, however, does not yet exist, and examples of good practice are only starting to emerge. Coordination, within the Bank and in client countries, among the transport, environment, and energy sectors is an essential condition for air quality management but has only now begun to develop.

### *Analytical work*

In connection with its assistance to the governments of Indonesia and Chile, the World Bank developed a methodology for estimating the health impacts of key air pollutants. Analytical resources were geared toward obtaining estimates of the benefits of pollution reduction by employing models of health effects, pollutant exposure, and dispersion.

In Mexico City an analysis of pollution abatement measures in the transport sector evaluated and ranked in terms of cost-effectiveness 26 technical measures for making vehicles and fuels less polluting.

Analyses in Santiago and Mexico City showed that the measures studied could reduce local pollution by about two-thirds but that the effect on greenhouse gases was only 5 to 6 percent.

Another study estimated the social costs, including health and nonhealth damages and climate change impacts, associated with the different types of fuels and a variety of sources in six developing-country cities. The findings indicate large health effects from vehicles and small stationary sources, whereas large sources contribute the most to climate change impacts. The implication is that the overlap between measures for addressing local and global issues is likely to be limited. Diesel-powered urban vehicles and small stoves and boilers that burn coal, wood, or heavy oil impose the highest social costs per ton of fuel. The large range of environmental damages for different combinations of fuels, sources, and locations limits the efficacy of simple fuel-pricing measures. A skillful mix of policy instruments able to send highly differentiated signals to various users of fuels is required.

### *Nonlending services*

Among the Bank's major nonlending activities are the Urban Air Quality Management Strategy (URBAIR) in Asia, lead phaseout, clean transport fuel studies and programs, the South Asia two-stroke engine initiative, and regional clean air initiatives.

*URBAIR.* The objective of the URBAIR program was to assist in the design and implementation of policies, monitoring, and management aimed at restoring air quality in Asian metropolitan areas. It combined air quality analysis with economic evaluation (calculations of health damages and of the costs of mitigation measures) in four participating cities: Jakarta, Mumbai, Kathmandu, and Metro Manila. The findings and results of URBAIR are being followed up in the World Bank's Mumbai Urban Transport Project and in other programs.

*Lead phaseout.* The Bank has called for the complete *phaseout of lead* in gasoline in developing countries and has undertaken a number of activities to that end. It has supported health and feasibility studies, prepared policy papers, made public statements, and worked with bilateral and multilateral partners and nongovernmental organizations (NGOs) to raise awareness and build political commitment. The Bank has also assisted individual countries with studies and implementation and has worked to build consensus and dispel myths about lead phaseout. Elimination of gasoline lead raises complex technical and fuel quality issues that have to be addressed as part of a comprehensive, cost-effective approach to air quality management. Accordingly, lead phaseout initiatives have led to broader programs and studies that address cost-effective ways of improving transport fuel quality in specific countries or in entire regions.

*Clean transport fuels.* Vehicle fleet characteristics, fuel consumption patterns, and the downstream petroleum sector often have many similarities in a given region. By setting minimal fuel and vehicle emissions standards, which individual countries can choose to exceed to meet their own air quality objectives, a regional approach not only ensures that minimal environmental standards will be maintained but also significantly reduces illegal smuggling of lower-priced, poor-quality fuels. By facilitating intraregional trade, a regional approach also offers the potential for reducing the incremental cost of improving fuel quality and vehicle technology. The World Bank is supporting regional initiatives in Latin America and the Caribbean and in Central Asia and the Caucasus.

*Two-stroke-engine initiative.* In South Asia a World Bank study examined the options for reducing emissions from the two-stroke engines commonly used in two- and three-wheeler vehicles in the region. The findings from this initiative are being applied in several projects. Encouraging replacement of two-stroke with four-stroke engines at the time of vehicle retirement is a cost-effective mitigation measure. For existing vehicles, use of the proper quality and quantity of lubricant is a win-win action that can reduce emissions at no extra cost to the owner and that makes for better engine maintenance.

*Regional clean air initiatives.* The World Bank Institute (WBI) has undertaken Clean Air Initiatives that focus on major Latin American and Sub-Sahara African cities and is starting similar programs in East and South-East Asia and in Europe and Central Asia. The goals of the initiatives are to promote the integrated development or enhancement of clean air city action plans, with participation by all relevant stakeholders; to advance exchange of information; and to foster public participation and the active

involvement of the private sector in implementing recommendations as appropriate. The approach includes workshops, distance learning training, network support, and information and outreach activities.

### *The urban transport portfolio*

In some Bank urban transport projects, there is a fair amount of overlap between transport and environmental objectives. Examples include replacing old buses, constructing light rail systems, and improving traffic management to reduce congestion and increase road safety. Relatively few projects or components, however, have explicit air quality improvement objectives.

Some projects have financed studies to prepare action plans for addressing vehicular air pollution in urban areas. The China Liaoning Urban Transport Project supports improvements in the environmental sustainability of project investments by developing and implementing a motor vehicle emissions control strategy. Many urban transport projects seek to promote nonmotorized transport (NMT)—for example, by constructing overpasses and bicycle paths and creating pedestrian and restricted traffic zones. An NMT program within the Second Shanghai Metro Transport Project includes establishment of an exclusive 19.4-kilometer network of nonmotorized vehicle routes in and around the central business district.

Active projects in Brazil and Bangladesh allocate funds for I/M components, and projects in Argentina and Bangladesh include air quality monitoring components. Two projects in Brazil (in Belo Horizonte and Recife) emphasize the need for appropriate pricing and parking policies to deter automobile growth in city centers. In the Budapest Urban Transport Project, a proposal was made for the introduction of entry/use charges for motor vehicles in the inner city, with a dual objective of traffic restraint and generation of funds; the political aspects of such a decision are, however, sensitive.

Some projects have attempted to curb demand for polluting vehicles by, for example, banning outright certain vehicles, such as three-wheelers with two-stroke engines. Measures for traffic restriction have also been proposed.

Except for the China Guangzhou City Center Transport Project, urban transport projects typically have not attempted to address fuel quality issues such as the phaseout of lead from gasoline. One reason is that such issues are generally under the control of the energy sector at the national level, which adds to the complexity of the projects.

### *Other relevant portfolios*

Financial support for paving and rehabilitating roads—which reduces dust and the associated health effects—has typically been included in urban development projects rather than urban transport projects. Activities that improve traffic flow (repair of streets and sidewalks, installation of street signs and traffic lights, and creation of bus routes) confer health benefits. Some transport projects include components for NMT, air quality, elimination of gasoline lead, and pollution reduction.

## **Conclusions and Recommendations**

Urban air quality management is a relatively new area of focus for the Bank. This paper summarizes some of the key technical and policy issues of relevance to the Bank’s activities in the transport-environment-energy interface, describes nonlending activities, and reviews the urban transport portfolio with an emphasis on air pollution management activities in projects. The following conclusions can be drawn from this assessment:

- The Bank has supported analytical work and nonlending activities that emphasize integrated approaches to urban air quality management. Linking these activities with lending specifically targeted to improving air quality, however, remains a challenge.
- Several urban transport projects have adopted “win-win” measures that reduce both congestion and air pollution, particularly through transport management. In general, however, interventions designed to improve urban air by reducing transport emissions do not feature strongly in the

Bank's urban transport portfolio. The overall amount allocated specifically to air quality improvement objectives is typically around 1 percent of total project cost.

- Environmental measures in urban transport projects often include the introduction of air quality monitoring and vehicle inspection and maintenance. Experience suggests that the sustainability and optimal design of such monitoring systems are a major concern. In the face of widespread corruption, lack of adequate repair and service facilities, and poor cultural acceptance of regular vehicle maintenance, enforcement of existing vehicle emissions standards remains a serious challenge.
- The responsibility for many environmental regulations rests with the central government, limiting what can be achieved in the framework of urban projects. Most urban transport projects focus on local interventions such as improving traffic management, segregating nonmotorized transport routes, and strengthening local monitoring systems.
- Measures with explicit environmental objectives are not always assessed in terms of their cost-effectiveness, the presence of necessary conditions (such as fuels that match certain vehicle technologies), and linkages with policies in other sectors such as energy.

The transport sector is primarily concerned with improving people's lives and contributing to economic efficiency through better mobility and better access to transport services. The environmental implications of transport policies, as well as their social and equity implications, should therefore be an integral part of sustainable transport strategies. On the basis of the above observations, the following recommendations can be made for the Bank's urban transport and environment strategies.

- *Properly implement environmental safeguard policies.* In most cases, proper implementation of environmental safeguard policies—based on environmental assessments of projects and the execution of environmental management plans, where appropriate—are sufficient to ensure that urban transport projects do not cause undue harm to people's health and the environment.
- *Integrate environmental externalities into economic analysis of transport strategies.* The environment community has improved the analytical tools and methodologies for the economic assessment of environmental externalities, and such methodologies should be more widely used.
- *Focus on win-win measures.* Transport sector interventions should build on the synergies between reducing negative environmental impacts and reducing other negative externalities in the transport sector. Areas of such synergies include improvements in traffic and demand management, nonmotorized and public transport infrastructure, and fuel efficiency.
- *Improve the environmental outcome of projects.* Although most of the Bank's transport interventions are not primarily environmentally oriented, it may be useful to think opportunistically about what can be achieved through marginal adjustments to the projects for the benefit of the environment. The analogy is the concept of "global overlays," in which local and global pollution are considered together. How and where such a concept can be effectively utilized is an area that should be investigated.
- *Develop a proactive approach toward improving air quality.* Although win-win measures have positive environmental benefits, improving the development effectiveness of Bank assistance would require a proactive approach, especially in areas where deteriorating urban air quality causes great social damage and constrains future growth. Such an approach could include the identification of cities in which air quality is a serious problem; agreements with national and city governments to work on solutions to the problem; strategic environmental assessments to identify key sources of pollution and cost-effective sectoral interventions; and a long-term framework for Bank assistance.
- *Coordinate among sectors.* The Bank should ensure that the policies it recommends in the transport, energy, and environment areas are technically sound and internally consistent. Areas for coordination include setting fuel and vehicle emissions standards and improving fuel quality

monitoring and vehicle emissions inspection. Even the most modern engines will pollute a great deal if the gasoline with which they are fueled is adulterated with kerosene. Which fuel parameters to monitor, how often, by whom, and when are issues that the Bank is only now beginning to address.

- *Develop strategic long-term programs.* Urban air quality management involves interactions with a large number of agencies and stakeholders. In addition, a number of donors are increasingly active in this area in many of the cities in which the Bank operates. Coordination with various players requires significant resources. The Bank could lead such efforts in selected cases when governments are committed, clear targets can be set, and proper monitoring of efforts can be undertaken. Programmatic lending instruments could be utilized for such efforts.

In addition to these generic recommendations, some specific issues need to be considered:

- *Reassessment of air quality monitoring activities.* Attempts to introduce complex air quality monitoring systems have often failed in our client countries. In some cases it is recommended that only one or two pollutants be monitored, using the technology that the country has the technical capacity to operate and maintain. Air quality monitoring activities undertaken in urban transport projects should, in any case, be coordinated with the environmental authorities and with existing monitoring networks.
- *Identification of heavily polluting vehicles and design of cost-effective interventions that target them.* In most client countries, targeting gross polluters is likely to be an effective pollution reduction measure. Such interventions should consider a range of options, including incentives for regular repair and maintenance.
- *The institutional feasibility of pollution abatement measures.* While several pollution abatement measures may have promising potentials, the institutional aspects of implementing such measures in client countries have to be considered.
- *The social implications of pollution abatement measures.* Urban pollution disproportionately affects the poor, and improvements in living conditions therefore generally benefit them. Specific choices and strategies for pollution abatement, however, have direct and indirect impacts on the poor that have to be assessed.

# Environmental concerns and priorities in urban air quality management

Air pollution is one of the most serious environmental concerns in urban areas, especially in view of its adverse effects on human health. Other environmental impacts include damages to buildings and structures, agricultural crops, and vegetation and forests; reduced visibility; and increasing greenhouse gas emissions (Figure 1).

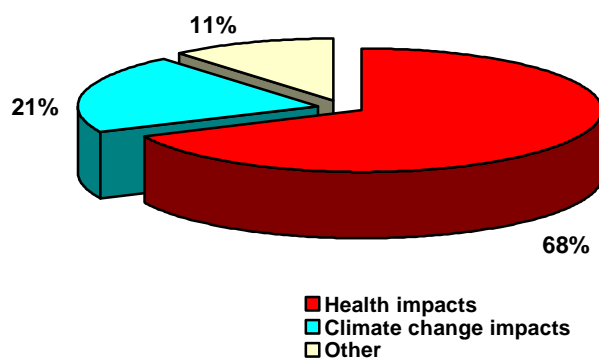
In developing countries around the world, an estimated 0.5 million–1.0 million people die prematurely each year as a result of exposure to urban air pollution. Thousands of premature deaths and millions of cases of respiratory illness are associated with air pollution in large cities. Exposure to lead contributes to behavioral problems and learning disabilities in urban children. The economic damage from air pollution is estimated to amount to US\$1 billion–US\$4 billion annually in cities in Asia and to US\$6 billion in the NIS. It represents up to 10 percent of urban income in polluted cities such as Bangkok, Kuala Lumpur, and Jakarta (World Bank 1997a; Hughes and Lovei 1999).

Comparative risk assessment and health studies in a number of cities, including Bangkok, Cairo, Mexico City, Quito, and Santiago de Chile, have indicated that the greatest damage to human health comes from exposure to *fine particulate matter* (particles smaller than 2.5 microns in aerodynamic diameter, or PM<sub>2.5</sub>) and to *lead*.<sup>1</sup> Next to elimination of lead from gasoline, reduction of fine particulate matter is by far the highest priority. Other pollutants that have impacts on human health include carbon monoxide (CO), nitrogen oxides (NO<sub>x</sub>), sulfur oxides (SO<sub>x</sub>), ozone, and airborne toxics. NO<sub>x</sub> and SO<sub>x</sub> also contribute as much as 30 percent to the formation of secondary fine particulate matter.

As the income level rises, so too do the ownership and use of motorized vehicles. Depending on topographical and meteorological conditions, ozone can then become a serious problem in large metropolitan regions with increasing gasoline consumption, as it has, for example, in Mexico City and Santiago. Ozone, a secondary pollutant, is formed by reactions of photochemically reactive organic compounds (commonly referred to as volatile organic compounds, or VOCs) with NO<sub>x</sub>.<sup>2</sup> A detailed discussion of the health impacts of various pollutants is given in Annex A.

This paper discusses the growing air pollution problem in developing countries and outlines approaches to urban air quality management in the transport sector. As countries become motorized, vehicles will contribute increasingly to urban air pollution. Tackling air pollution arising from the use of vehicles in turn calls for coordinating urban

**Figure 1. Composition of environmental damages from fuel combustion in six developing-country cities, 1993**



Note: The six cities are Bangkok (Thailand), Krakow (Poland), Manila (Philippines), Mumbai (India), Santiago (Chile), and Shanghai (China). Calculations contain large uncertainties.

Source: Lvovsky and others (2000).

<sup>1</sup> Comparative risk assessments undertaken in developing countries are summarized in Keane and Cho (2000). Lead emissions from vehicles can be classified both as fine particulate matter and as airborne toxics. Because of its extreme toxicity, however, lead has historically been placed in a category of its own in air quality guidelines. For example, the World Health Organization lists lead as one of the six “classical” air pollutants, and the U.S. Environmental Protection Agency lists it as one of six “criteria” pollutants.

<sup>2</sup> Ozone-precursor VOCs include aldehydes, olefins, and aromatics with two or more alkyl groups.

transport, environment, and energy policies. Although the broader issues of long-term urban planning and measures to induce significant shifts in transport mode are important in influencing urban environmental trends, they are beyond the scope of this paper.

### The main sources of air pollution

Anthropogenic air pollution originates from a variety of sources, including households, vehicles, large stationary sources, small and large industries, agriculture, and forest burning. Pollution from many of these sources is closely related to the production and consumption of energy, especially the combustion of fossil fuels. Along with power stations and industries, domestic use of fossil fuels—notably, heating oil, biomass, and brown coal—is a significant source of ambient particulate matter and sulfur dioxide (SO<sub>2</sub>), especially in cold-climate regions such as parts of China and Eastern Europe.

Traffic is a large contributor to fine particulate emissions and often gives rise to as much as 80–90 percent of atmospheric lead in cities where leaded gasoline is still used. Lead in gasoline also contributes to fine particulate emissions.

Both natural and anthropogenic sources are important in the formation of ground-level ozone. Natural sources (such as biogenic emissions from plants and trees) and traffic emissions are important sources of atmospheric VOCs. Natural, mobile, and stationary combustion sources are significant contributors to ambient concentrations of NO<sub>x</sub>. Motor vehicles are typically responsible for the greatest part of CO emissions.

The impact of emissions on human exposure depends on the location and dispersion of pollution. Large stationary sources, often located at a distance from densely populated city centers, disperse into the higher layers of the atmosphere, while households and vehicles emit near ground level in highly populated areas. Mobile and small stationary sources thus contribute more to human exposure than their share in total emissions loads would indicate (Figure 2).

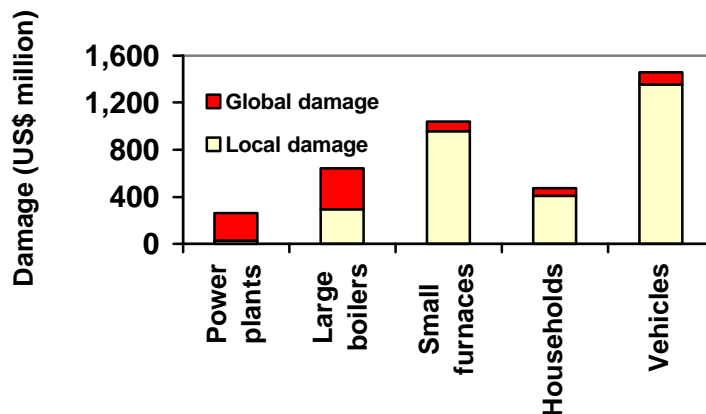
In terms of tonnage of emissions, CO typically leads all other pollutants. A common mistake is to add up amounts of all pollutants and, on finding that CO emissions from vehicles make up a sizable fraction of the total, come to such conclusions as “transport is responsible for 75 percent of air pollution.” This approach does not take into account the toxicity, health impact, or dispersion of the pollutants and may lead to incorrect inferences about priorities.

Nonexhaust particles can contribute significantly to overall particulate emissions from the transport sector. Most of the data collected so far are from highly industrialized countries (where roads are paved). It is difficult to quantify the impact of nonexhaust particles on overall ambient concentrations in developing countries because of scarcity of data. This is clearly an area to which the World Bank should pay greater attention. Another area for which only very limited data are available in developing countries is the contribution of NO<sub>x</sub> and SO<sub>x</sub> to secondary particulate formation and dry acid deposition.

### Developing a strategy for mitigating air pollution

All too often, policymakers assume a priori that certain sources should be targeted for pollution reduction, even

**Figure 2. Environmental cost of fuel use by sector in six developing-country cities**



Note: Data from 1993. The six cities are listed in Figure 1.  
Source: Lvovsky and others (2000).

when it is not clear that devoting limited resources to mitigating emissions from those sources is necessarily cost-effective or will have a significant impact on air quality. A systematic procedure needs to be followed in formulating a strategy for improving urban air quality. (Box 1).

Sectoral approaches to improving air quality, and donor assistance based on such approaches, may fail to produce the desired effects if they are not based on a comprehensive strategy. An example is the São Paulo Industrial Pollution Control Project, supported by the World Bank, which was designed to improve air quality by reducing particulate emissions from industrial sources. Although industrial particulate emissions fell substantially, the city's ambient concentrations of particulate matter did not decrease markedly because the main contributor to ambient concentrations was, in fact, vehicle emissions, not industrial sources (World Bank 1989).

Ideally, the analysis stage in constructing a strategy for mitigating air pollution should involve the following tasks:

1. *Collect air quality data.* Air quality should be monitored systematically, preferably for at least a year, to capture seasonal fluctuations. The data will show which pollutants are exceeding national and international air quality standards and guidelines.
2. *Develop an emissions inventory.* In identifying sources of emissions, it is important to consider all major sources—mobile and stationary, indoor and outdoor. In particular (although the task is difficult), an attempt should be made to obtain the best estimate of emissions from noncommercial sources such as refuse burning, which can contribute significantly to air pollution in developing countries. Also difficult to estimate is dust resuspension from road traffic, construction sites, and other areas disturbed by human activities. Obtaining a reasonable estimate of pollution from this source presents a problem even in industrial countries.
3. *Carry out dispersion modeling and source apportionment analysis.* What is of primary concern is human exposure to air pollution. The human health impact dominates the economic cost of urban air pollution. The number of people exposed, their health status, the pollutant concentration levels to which they are exposed, and the duration of exposure are the key parameters that determine the economic cost. To estimate how emissions from different sources contribute to human exposure, the first step is to model dispersion of pollutants and the resulting ambient concentrations. Emissions from tall stacks are dispersed far longer distances than those from low sources such as vehicles. Consequently, the damage costs of emissions from vehicles greatly exceed those from tall stacks for the same volume of pollutants. The results of the dispersion model should be calibrated against measured ambient concentrations. In addition, chemical and other analyses may be carried out to identify more precisely the types, characteristics, and sources of pollutants.
4. *Identify measures for improving air quality and assess their costs across sectors.* It is not enough to identify the main contributors to poor air quality; policymakers should also assess the costs of the measures available for making improvements across different sources and sectors. Because of the differences in the relative costs of mitigating emissions and in the impact of those measures on ambient air quality, a strategy that requires uniform reductions without regard for their cost effectiveness is suboptimal and costly.

Most developing countries lack the data and resources to carry out the above tasks. Meanwhile, air pollution in large cities continues to worsen, and policymakers often have to choose between alternative measures without having the necessary information about them. Under these circumstances, there is often a temptation to import cutting-edge Western standards and technologies without assessing their costs, their benefits, and the feasibility of operating and maintaining them—but this is seldom the answer.

**Box 1. Key steps in developing a pollution abatement strategy**

1. *Identify the main environmental concerns* on the basis of assessment of risks to human health and environmental resources.
2. *Use cost-effectiveness as the primary criterion* for selecting optimal strategies across various sources and sectors.
3. *Build mechanisms for cross-sectoral coordination* to implement the selected strategies.

This dilemma underscores the importance of a cross-sectoral, multiprong approach. The World Bank, as it assists its client countries through policy dialogue, programs, and investments, can help address complex environment challenges such as urban air quality management. This support can be most effective if the Bank helps client countries embark on the above steps in a way commensurate with their internal capacity, builds on lessons from cities that have gone through these steps, and integrates recommended measures—policy changes and cost-effective interventions—into its policy dialogue and its sectoral programs and projects.

### **Vehicle emissions abatement measures and their cost-effectiveness**

As noted above, vehicle emissions, which occur near ground level, cause much greater human exposure to harmful pollutants within a few tens of meters than do emissions from sources at elevated levels, such as power plants, for which the impact would not be localized. Furthermore, most particulate emissions from vehicles fall into the fine particulate range, now widely regarded as the size fraction most damaging to human health (in contrast to coarse particles). Pollution abatement in the transport sector, therefore, is likely to be a key part of urban air quality management strategies in a growing number of cities.

Tackling air pollution from the transport sector is not necessarily a high priority for every targeted pollution reduction program. The principal sources of the emissions that contribute to ambient concentrations must first be identified. In the short run, it could be more cost-effective to concentrate on reducing pollution from such sources as household use of coal and biomass (fuelwood, crop residues, dung, and so on) for heating, cooking, and other purposes.

This is not to say that nothing should be done to mitigate emissions from the transport sector without a thorough assessment of all sources. There are several “no-regrets” steps, such as the phaseout of lead in gasoline and the correction of the quantity and quality of lubricant used in two-stroke engines, that should be pursued without waiting for an in-depth investigation. Other potential win-win measures that can have important positive environmental benefits are described below. Aggressive targeted emissions abatement measures, such as adoption of strict Western emissions standards (for example, European Union emission standards for 2000–2005), however, should not be recommended in developing countries without a better understanding of the local situation.

Where transport has been determined to be a main source of urban air pollution problems, additional targeted measures should be identified and implemented. In general, measures to mitigate the negative effects of pollution might focus on separating pollution sources and receptors, reducing polluting activities, reducing the pollution characteristics of these activities, and using filtering devices to control emissions. Not all of these alternatives are available for all pollutants and all sources. Changing the location of the pollution source may be an effective strategy for pollutants such as particulate matter that have especially damaging health effects in the vicinity of the pollution source. Urban planning, zoning, and other land use regulations can influence urban air quality through microlevel decisions. These measures, however, are not necessarily effective for persistent pollutants such as heavy metals or for those with significant regional impacts such as sulfur dioxide and ozone. Neither do they address the global impacts of emissions of greenhouse gases such as carbon dioxide. In addition, transboundary impacts are increasingly recognized even for pollutants—such as fine particulate matter—that were previously considered to be a local problem.

#### *Using others' experiences: Risks and benefits*

Because the optimal strategy and the best choice of abatement measures are location-specific, merely “importing” regulations from other countries may not be the best solution. This is not to say that every city has to design mitigation measures from scratch; much can be learned from experience elsewhere. Furthermore, some measures, such as the phaseout of lead in gasoline, are, in essence, universally applicable to all major cities. It is nevertheless important to understand the reasons for the adoption of various measures in different parts of the world and to distinguish which are likely to be effective in a specific situation and which are unlikely to be suitable. The guiding principle for the selection of

strategies should be the balancing of costs and benefits. This means concentrating on vehicles driven in densely populated areas, particularly in cities with unfavorable meteorological conditions (for example, a low mixing layer).

It is important to distinguish between strategies that use cost-effectiveness as the principal criterion and those that promote the best available technology (BAT). Examples of the latter include adoption of the most advanced fuel and vehicle technologies from North America, the European Union (EU), and Japan. These are very expensive measures designed to make vehicles that are already relatively clean (in comparison with those found in developing countries) even cleaner. Current standards and technologies in industrial countries effectively amount to mandating the manufacture of new vehicles with extremely low emissions—so low that exhaust measurements are actually becoming difficult—and the use of fuels to match state-of-the-art vehicle technology. Importing these standards would require a large allocation of resources for this purpose and is unlikely to prove cost-effective, given the conditions in developing countries: large numbers of highly polluting in-use vehicles and a culture that does not attach importance to vehicle maintenance. The economic cost to society of such measures should be carefully examined, in view of the many competing and compelling claims on the limited resources available—such as provision of access to clean water, adequate health care, universal primary education, and so on.

In some instances governments have adopted technology-specific policies to reduce vehicle emissions. Examples include mandatory catalytic converters in new vehicles and a ban on the use of two-stroke-engine vehicles. A rationale for following technology-specific rather than emissions-based policies might be the difficulty of monitoring the latter. The cost-effectiveness of technology-specific policies needs to be carefully considered, as do the socioeconomic impacts of, for example, banning certain vehicles or prohibiting traffic in certain areas.

#### *Potential win-win measures*

A number of measures that are typically undertaken to pursue other primary objectives are likely to generate environmental benefits as well. The long-run sustainability and real-world interactions of these measures have to be kept in mind; some promising initiatives have backfired. There are also measures in the area of vehicle operation and maintenance that save costs for drivers and reduce emissions.

*Improved traffic management.* Traffic management yields significant economic benefits because it decreases congestion and improves mobility. Traffic congestion reduces average speed and increases emissions (except for NO<sub>x</sub>). An analysis of traffic speed in Bangkok and Kuala Lumpur suggested that the effect on emissions of increasing vehicle speed from 12–15 kilometers per hour (km/h) to 30 km/h would be equivalent to installing three-way catalytic converters in 50 percent of the cars in these cities. Improved traffic management thus confers environmental benefits because of the lower emissions intensity of traffic. Traffic-management measures such as coordination of traffic lights are generally beneficial.

Experience suggests, however, that efforts to reduce congestion in the short run can invite greater motorization in the long run, leading to further congestion. A 1994 report commissioned by the U.K. government concluded that increasing the capacity of the road network eased congestion only temporarily because it generated additional traffic, undermining the original objective. A recent study by the U.S. Environmental Protection Agency (US EPA) suggested that up to half of the annual U.S. traffic growth of 2.7 percent could be a result of construction of added road capacity.

A measure imposed in Mexico City in 1989 was meant to reduce traffic volume but had the unintended effect of adding high emitters to the vehicle fleet. Under the Hoy no Circula scheme, vehicles had to stay off the road one day a week, depending on the last digit of the license plate number. During the first months of implementation, traffic volume decreased dramatically. Many households, however, soon purchased an additional vehicle—typically, old and polluting—to get another license plate number so that household members could drive every day without restrictions.

A much more successful version of this scheme is Bogotá's Pica y placa system. The exclusion in this case is for two days a week, but it applies only to peak-hour use of vehicles. Another reason that Pica y

placa has reportedly avoided the shortcomings of the Mexico City plan is that it was part of a more thoroughgoing strategy to change the proportions of transport modes used (“modal split”). Other aspects of the program included a “car-free day” experiment and a major investment in Transmilenio, a high performance, segregated busway system.

*Traffic demand management.* Because vehicle ownership is primarily income-elastic, vehicle usage and traffic volume increase as economies develop. The desire for more space is also income-elastic, resulting in urban sprawl. There is a question as to whether and to what extent the growth rate of traffic volume can be controlled in the longer run through demand management (for example, provision of public transport, fiscal measures, areawide licensing, pricing instruments such as electronic road pricing in urban areas, and preferential treatment of high-occupancy vehicles). Available studies indicate that in industrial countries the long-run, own-price elasticity of gasoline consumption may be significant enough to make fuel taxation a potential policy instrument for reducing vehicle usage and kilometers traveled. A World Bank study concluded that judicious use of a tax on gasoline could save the citizens of Mexico City US\$110 million a year more than would an otherwise well-designed control program with no gasoline tax (Eskeland and Devarajan 1996).<sup>3</sup>

In developing countries the mode of choice for accessible public transport, given budgetary constraints, is buses. Dedicated bus lanes are seriously considered for this reason. Curitiba is often cited as an example of the reduction in transport fuel usage that can be achieved through an extensive network of bus routes. The questions are, can use of buses alone have a significant impact on motorization, and how large would the benefits have to be to justify the scale of investment required for a measurable impact? It may be that in formulating public transport strategies, consideration of mobility and access will determine the outcome and environmental benefits will play only a minor role.

Another area that the World Bank is exploring as a means of curtailing motorization is elimination of impediments to nonmotorized transport (Box 2). Measures of this kind include building more sidewalks and bicycle lanes, making streets more pedestrian friendly, and making bicycles more affordable by reducing import tariffs. An added motive for looking into this set of measures is that nonmotorized transport is the form of transport often used by the poor.

*Proper vehicle operation and maintenance.* Certain practices are costly to vehicle drivers and increase harmful emissions. An example is the addition of excess lubricant of the wrong type to gasoline for two-stroke engine vehicles. A common practice is to add two or three times the amount of lubricant recommended by the vehicle manufacturer—often in the mistaken

#### **Box 2. Promoting nonmotorized transport**

Nonmotorized transport (NMT) is used in developing countries predominantly by those who cannot afford motorized transport, rather than as a matter of choice. The use of NMT is more widespread in densely populated areas, where the distances traveled tend to be short. A policy question is to what extent government intervention—such as introducing stringent parking restrictions and constructing safe bicycle routes—can prevent NMT users from switching to motorized transport, or can at least delay the switch, particularly given the public perception of NMT as transport for the poor.

In many developing countries bicycles are owned by middle-income households rather than by the poorest segment of society. There is often a strong gender bias in the use of bicycles, with most users across a sample of countries being men. In cities in developing countries the typical bicycle user is an employed man between 25 and 35 years of age. Many bicycle users prefer bicycles to public transport for reasons of speed, convenience, and cost.

As an example of positive policy intervention, in the two cities where the World Bank supported NMT infrastructure investments—Lima, Peru, and Leon, Nicaragua—the modal share of NMT is reported to have increased (I-ce 2000).

<sup>3</sup> The study by Eskeland and Devarajan found a fairly high estimate for the price elasticity of gasoline. Many other country studies have found a rather lower value, which, if accurate, would imply lower savings in Mexico. The Eskeland-Devarajan study did not test for stationarity or cointegration of the time series, the presence of which can lead to substantial bias in parameter estimates where there are trends in all data series, nor was it based on an error-correction mechanism, which is the standard approach for dealing with such problems. Further studies are needed to confirm the magnitude of the price elasticities and hence of the savings implicit in the policy recommended.

belief that this will increase fuel economy—while using substandard quality lubricant that does not mix well with gasoline and does not provide sufficient protection against engine seizure. In reality, this practice accelerates the fouling of the engine and increases particulate emissions. By reducing the amount of lubricant added and switching to proper lubricant manufactured for use in vehicles, drivers can simultaneously save money, reduce emissions, and help maintain the vehicle better (Kojima, Brandon, and Shah 2000). Another practice is overfueling diesel engine vehicles, often because of a misapprehension that this will increase power. In practice, overfueling may not yield any greater power output, but it does result in lower fuel economy and much greater smoke emissions. Yet another example is allowing the injection timing of diesel engines to slip, resulting in overly retarded timing. The consequences are lower fuel economy, the mixing of gasoline with lubricant (resulting in lubricant acidification and, eventually, engine wear), and increased smoke emissions. By properly adjusting the injection timing, all of these problems can be reduced.

### *Targeted pollution abatement measures*

*Tightening vehicle emission standards.* Most countries that have large cities with serious air pollution problems have vehicle emissions standards, although these standards may be outdated or unsuited to local conditions. Important preconditions for effective emissions control through standards are emissions standards that differentiate vehicles by type and age, means of measuring emissions levels accurately, and methods for enforcing the emissions standards.

One prerequisite for mounting an emissions control program is a reliable vehicle registration record. Many developing countries are known to issue the same registration number to two or more vehicles, and all too often there are no records of vehicle registration by vehicle age. Attrition of vehicles is often not recorded in the vehicle registries. Addressing such deficiencies in the database should be given high priority.

Vehicle emissions standards are rarely enforced in developing countries. Whether to tighten vehicle emissions and fuel standards should be weighed against the alternative of ensuring that existing standards, however lax, are enforced. Old and poorly maintained vehicles that are not in compliance are generally responsible for the greatest part of vehicle emissions. It may not be cost-effective to devote increased resources to reducing emissions from new vehicles (which are, in any event, much cleaner than old ones) without addressing the problem of gross polluters.

If the emissions standards are so strict that a significant fraction of the existing vehicles is bound to fail the emissions tests, widespread corruption and evasion are likely to ensue. The enforcement of emissions standards will be more effective if the standards are set so that only a small fraction of vehicles is estimated to be in noncompliance; standards can then be gradually tightened.

*Improving vehicle technology.* Largely in response to stricter vehicle emissions requirements, considerable progress had been made in improving the vehicle hardware for reducing emissions. For gasoline vehicles, efficiently operated three-way catalytic converters can reduce exhaust CO and hydrocarbon emissions by as much as 95 percent and NO<sub>x</sub> by over 75 percent. For these pollutants, catalytic converters are by far the most effective means of reducing gasoline-vehicle exhaust emissions. Modern diesel engines, too, are much cleaner than those produced in the past.

The United States, the EU, and Japan have the most stringent vehicle emissions standards and fuel specifications. These countries are pursuing the best available technology for further reducing emissions from new vehicles. The control measures include a combination of dramatic reduction of sulfur in gasoline and diesel (to extend the useful life of the catalyst and to enable new technologies for improving fuel economy and reducing NO<sub>x</sub> and particulate emissions); new measures for control of tailpipe emissions (for example, particulate traps with regeneration for diesel engines); emerging vehicle technologies such as direct injection gasoline engines; and the use of alternative fuels for vehicles with very low or zero emissions (as mandated in California). The rest of the world will probably adopt similar standards and technologies eventually, but for developing countries the immediate issue is how to phase in appropriate measures cost-effectively.

*Inspection and maintenance (I/M) programs.* Vehicle emissions standards and technologies are not effective without proper maintenance. Poorly maintained vehicles are high emitters and are responsible for a disproportionate fraction of total vehicle emissions. A well-run, corruption-free I/M program should, in principle, be able to mitigate transport pollution by strengthening the enforcement of emissions standards. An I/M program cannot be successful unless gross emitters are identified accurately and unless vehicles that fail are repaired promptly. The latter condition, in turn, depends on wide availability of adequately trained and equipped repair mechanics. Yet in many developing countries this service infrastructure is lacking, partly because, when emissions standards and other standards for in-use vehicles are not enforced, there is only a small market for repair mechanics.

The usual reason for not properly maintaining vehicles is cost. Certain maintenance practices, however, would actually yield cost savings. An example is use of the correct kind and amount of lubricant in the two-stroke engines common in Asia. At a minimum, wide public education campaigns should be undertaken to promote these cost-effective practices.

An I/M system based on centralized, high-volume, inspection-only centers, as in Mexico City, is considered more effective than a decentralized system with a large number of private garages participating. Computerizing emissions measurements as much as possible to minimize tampering is another useful measure. The private sector can be an important partner in operating I/M programs (Box 3). A traditional I/M program may be supplemented by a scheme using remote-sensing devices (which can measure more than 4,000 cars per hour on a continuous basis) to identify gross emitters for more intensive testing.

When emissions standards are enforced to a reasonable extent under I/M programs, the cost of owning old vehicles effectively increases, promoting vehicle renewal. Empirical evidence from Spain suggests that changes in the I/M program may have had a considerable effect on trends in first-time vehicle registration (European Conference of Ministers of Transport 1999).

*Vehicle retirement and scrappage programs.* Several vehicle retirement programs, targeting mostly passenger vehicles, have been conducted in North America and Europe (including Eastern Europe). For the success of such a program, it is important to be able to identify gross emitters with high annual vehicle kilometers traveled (VKT) and a reasonable remaining life. High emitters are not necessarily old vehicles, although in the absence of detailed data, vehicle age is often used as a selection criterion.

If the number of vehicles retired is very small or negative in comparison with the number that would have been retired without the program (as was the case in Spain in 1995), the resources spent on implementing the program represent a deadweight loss for the economy. If the number of high emitters is a small percentage of the total vehicle fleet, the program can target a limited number of these vehicles, thereby avoiding major market perturbations, keeping the overall cost of the program low, and making it possible to design a cost-effective scheme.

Offering financial incentives to remove older vehicles from the market entails a number of difficulties. The government's entry into the market shifts the demand curve for old vehicles, possibly raising their prices. A vehicle is typically retired when the cost of repairing it exceeds the market value of the vehicle after repairs are made. If prices of old vehicles rise, some owners may decide to keep and repair their old vehicles instead of scrapping them. Generally, prices are higher in urban centers than outside, giving owners of old vehicles outside the city an incentive to bring their vehicles to urban centers and sell them.

There are important distinctions between cash-for-scrappage (where there are no requirements for replacement vehicles) and cash-for-replacement. According to an analysis prepared for the European Conference of Ministers of Transport (1999), cash-for-scrappage may yield a reasonable benefit-cost ratio, depending on program design, whereas the cash-for-replacement schemes implemented to date are said to be much less cost-effective. Income constraints make cash-for-replacement particularly difficult to design in developing countries. Owners of gross emitters with high annual VKT are often those who are not in a position to purchase much newer vehicles. By requiring that the replacement vehicles be new or relatively new, the scheme fails to attract the vehicles that ought to be selected for the program on the

### **Box 3. Private sector operation of an inspection and maintenance program in the Mexico City Metropolitan Area**

Mandatory testing for vehicle emissions in the Mexico City Metropolitan Area (MCMA) was first introduced in 1988. The emissions standards, which initially applied to hydrocarbons and carbon monoxide, were tightened progressively in 1994 and 1996, with further changes introduced in 1999. In 2000 limits for nitric oxide were established.

The emissions testing program in the MCMA has evolved through several phases since its inception. Initially, tests were carried out in government test-only centers and in privately owned test-and-repair garages. By 1992 all vehicles circulating in the MCMA had to display a certificate showing that they had passed the annual emissions test or be liable to a fine imposed by traffic police.

The use of test-and-repair garages in the absence of a strong enforcement program made it possible and profitable for many garages to issue false pass certificates. Estimates suggested that as many as 50 percent of vehicles obtained passes incorrectly. This led to the closing of all test-and-repair centers and the establishment of privately owned and operated “verificenters” (multilane, test-only centers) with much improved protocols for discouraging testers from issuing false pass certificates. Thus, the private sector in Mexico was able to provide testing centers competitively, but the government had to regulate the sector in order to prevent profit-seeking activities, such as issuance of false passes, that were counter to the public interest.

The experience in Mexico City shows that for a testing program to be effective, several conditions have to be met:

- A legal framework has to be established that allows sanctions to be applied for failure to carry out the testing protocols correctly. The testing stations must be subject to monitoring by independent bodies, and in cases of noncompliance, sanctions must be applied.
- The certificate for passing the test has to be easy to monitor, and there should be sufficient monitors (for example, traffic police) to ensure a high probability of catching vehicles that do not display such a certificate.
- The fine for not displaying or not having a legal emissions test certificate must be high enough to act as an incentive to pass the test.
- The testing technology has to be able to prevent the use of temporary “tuning,” which enables a vehicle to pass the test but cannot be sustained for regular driving. In the absence of such a technology, motorists and garages become adept at circumventing the purpose of the testing procedure—to identify high-polluting vehicles.
- All testing centers must be subject to equally rigorous implementation of protocols and inspection of their procedures; otherwise, owners of the highest-polluting vehicles easily identify the “softest” centers for passing the test.
- The optimal number of centers, relative to the volume of traffic to be tested, has to be licensed. If there are too many small centers, the rigor of the tests tends to be watered down as each garage tries to increase market share.

*Source:* Bacon and Kojima (2000)

basis of cost-effectiveness. Delhi (India), however, has conducted a successful vehicle replacement program for auto rickshaws combined with a mandatory phaseout of older vehicles.

Experience with vehicle retirement schemes that target heavy-duty vehicles is limited. These schemes merit further examination. In many developing countries, particularly those in which particulate emissions are the most serious air pollution concern, commercial vehicles (buses, trucks, and taxis) contribute the most to urban air pollution. Here, the vehicle purchasers are not households but, for the most part, enterprises and business owners. Hungary introduced a retirement scheme for heavy-duty vehicles by offering US\$3,600 (in 1997 dollars) for replacement of an old bus with a new one that complied with the most recent emissions standards or for replacing its engine. Similar incentives were given for old trucks. In the early 1990s Chile used an effective scrappage policy combined with tax incentives to remove the most-polluting diesel buses from the urban transport fleet.

*Fuel quality improvement.* All countries have some kind of fuel standards. Some countries, such as the United States, offer a great deal of flexibility by allowing the option of fuel certification on the basis of vehicle emissions rather than fuel composition. In addition, fuel specifications in the United States are regionally differentiated. The combination of these two factors has given a tremendous cost advantage to the U.S. refining sector, which has the freedom to seek the least-cost solution for meeting specific vehicle emissions standards while adjusting the refinery product slate according to market demand. Most other countries stipulate the composition of each fuel.

For the World Bank's client countries, the first step in improving the quality of transport fuels is to phase out lead in gasoline. Lead has historically been added to gasoline as an octane enhancer. Because of its toxicity, there is a growing worldwide move to ban its use in gasoline (Box 4). More than three-quarters of the gasoline sold in the world today is unleaded. A number of developing countries, including Bangladesh, Brazil, Honduras, Hungary, India, the Slovak Republic, and Thailand, have already eliminated lead in gasoline, and several other countries are planning to ban leaded gasoline in the near future.

In the absence of other significant sources of lead, eliminating lead in gasoline can reduce ambient concentrations of lead to less than 0.2 micrograms per cubic meter ( $\mu\text{g}/\text{m}^3$ ) and the level of lead in blood to less than 5 micrograms per deciliter ( $\mu\text{g}/\text{dl}$ ). Many health organizations consider 10  $\mu\text{g}/\text{dl}$  to be the threshold above which action is called for.

Cars without catalytic converters can run on either leaded or unleaded gasoline, but cars equipped with catalysts must use unleaded gasoline because lead deactivates catalysts permanently. The availability of unleaded gasoline throughout a country is a prerequisite for the introduction of catalytic converters.

Leaded gasoline is not the only source of human exposure to lead, and other sources should be tackled in parallel. Furthermore, many of the gasoline-blending components that are used to increase octane after elimination of lead have adverse health effects of their own. Excessive presence of benzene, olefins, and total aromatics in unleaded gasoline are a matter of concern. It is necessary to ensure that overall emissions of harmful pollutants are kept under control at least cost to society. By controlling gasoline volatility and adjusting refinery operations and processing units, all these blending components can be managed at a reasonable cost in the drive for lead phaseout (Kojima and Mayorga-Alba 1998).

Fuel quality requirements are location-specific. Factors to consider include climate conditions, pollutants present in elevated ambient concentrations, vehicle fleet characteristics, the state of domestic refineries (if any), and other sources of emissions. Although lessons from other countries should always be examined and taken into account, each situation should be studied separately. Fuel specifications should not be simply imported from other countries without first considering local conditions. Countries

#### **Box 4. Phasing out leaded gasoline: Misconceptions and facts**

Although unleaded gasoline was first introduced in the United States and Japan to protect catalytic converters, countries around the world have accelerated the phaseout of leaded gasoline in response to emerging medical evidence of the impacts of lead on human health and especially on the intellectual development of young children, even at low levels of exposure. In countries with refineries, the first step toward phasing out lead is typically the reduction of gasoline lead concentration (Faiz, Weaver, and Walsh 1996). This alone can help bring about a considerable decrease in the level of lead in the general public.

Despite significant progress worldwide in eliminating lead in gasoline—by the end of 2000 over 45 developing and industrial countries had banned its use—there are persistent misconceptions about unleaded gasoline (Lovei 1998, 1999). One is that only cars equipped with catalytic converters can use it; in reality, all gasoline-fueled cars can. Another is that many, if not most, old vehicles running on leaded gasoline will suffer from valve seat recession and, ultimately, engine failure if switched to unleaded gasoline. Lead does act as a lubricant, and laboratory tests have demonstrated that without it, soft engine exhaust valve seats in old vehicles can suffer from valve seat recession if driven under severe conditions (that is, heavy loads and high speeds). In practice, however, valve seat recession has seldom been found to be a problem in most countries that have eliminated lead. In Latin America and the Caribbean, where lead phaseout has progressed rapidly in recent years, none of the countries have observed any marked increase in valve seat problems. Thailand introduced a lubricating additive to protect old engines from potential recession but stopped its use after it was demonstrated that the vehicles did not need it.

In the early days of lead elimination, the phaseout process in some cases lasted for decades, as was the case in the United States. More recently, several countries, including the Slovak Republic and Thailand, have completed lead removal in four to five years. Countries that rely to a significant extent on gasoline imports can switch to unleaded gasoline even faster. Bangladesh, El Salvador, and Georgia eliminated gasoline lead in less than a year.

Such a swift transition to unleaded gasoline has a number of advantages. Little investment in the distribution infrastructure is needed because a dual distribution system does not have to be set up to segregate leaded and unleaded gasoline. Minimizing the transition period during which both leaded gasoline and unleaded gasoline are marketed also minimizes the chances of cross-contamination and of misfueling catalyst-equipped cars with leaded gasoline.

that have domestic refineries merit special attention because refinery processes are integrated and changing the specifications of one fuel could affect the quality of other fuels and overall refinery economics.

*Use of alternative fuels.* Vehicles that use gaseous fuels such as liquefied petroleum gas (LPG) and compressed natural gas (CNG) emit considerably less particulate matter than diesel vehicles not equipped with particulate traps, and hence the substitution of these fuels for diesel would bring about significant public health benefits. Vehicles powered by electricity have zero tailpipe emissions. The use of these alternative fuels, all of which are being piloted in a number of developing countries, is described in more detail in this section. Other alternative fuel options include alcohols and biofuels, but they are not economic under most circumstances and usually require large subsidies (Faiz, Weaver, and Walsh 1996).

**LIQUEFIED PETROLEUM GAS.** LPG is a mixture of light hydrocarbons, mainly propane/propene and butanes/butenes. LPG is easier to distribute and store than CNG; it requires pressures ranging from 4 to 13 bar, compared with 200 bar for CNG. Among LPG's good environmental features are its limited amount of highly reactive hydrocarbons and its low sulfur content, in comparison with gasoline or diesel. It does, however, contain olefins, which are photochemically reactive.

Although not as high in octane as natural gas, LPG has excellent antiknock characteristics. Propane has an antiknock index (the average of the research and motor octane numbers) of 104, allowing dedicated propane vehicles to take advantage of engines with slightly higher compression ratios than can be used with gasoline.

The main potential problems in introducing LPG to the transport sector have to do with sources of supply and the distribution system. Several countries already import significant amounts of LPG. India, Pakistan, and Sri Lanka, for example, import about a third or more of their LPG demand, making it difficult for LPG to become competitive on a cost basis. On the distribution side, LPG is stored under pressure both inside the vehicle and in the refueling tanks. Special refueling equipment is needed to transfer the pressurized liquid from storage tanks to the vehicle and to ensure that no LPG escapes during refueling. The required investments in LPG distribution and refueling stations have not been made in most developing countries, constraining widespread use of LPG.

**COMPRESSED NATURAL GAS.** CNG yields essentially no VOC or SO<sub>x</sub> emissions. Methane, which constitutes the bulk of CNG, has an antiknock index of over 120. Dedicated CNG vehicles can therefore take advantage of the high octane number of the fuel and operate at a high compression ratio. CNG is safe in the sense that, because natural gas (unlike LPG) is lighter than air, if the gas escapes, it will not lie along the ground or enter sewerage systems.

In practice, the composition of pipeline natural gas varies depending on the source and processing of the gas, as well as the time of year. As a result, not only does the fuel octane number vary, but the heating value can vary by as much as 25 percent, affecting vehicle performance. Moreover, when used as a fuel in vehicles, the heavier hydrocarbons in natural gas can condense, and the condensation and revaporization lead to fuel enrichment variations that affect both emissions and engine performance.

A vehicle capable of running on either CNG or gasoline suffers a power loss of about 10–15 percent when running on CNG. In addition, the extra weight of carrying two fuel systems detracts from the efficiency of dual-fueled vehicles. With its compression requirement of 200 bar, CNG is expensive to distribute and store. Depending on the fueling system, refueling can take a long time, and this in turn may serve as a disincentive for switching to CNG.

The basic requirements for the long-term viability of CNG vehicles are an existing distribution system for natural gas, fuel prices that are not distorted by subsidies, and a favorable legislative and regulatory atmosphere. Support for the elimination of distortionary subsidies is a key element in the World Bank's assistance to client countries in the energy sector, and it should also make the use of cleaner fuels more competitive. Fleet operations driven by economic rather than emissions concerns tend to be most successful and sustainable in the long run. A failed example that illustrates this point comes from New Zealand. Starting in the early 1980s, an aggressive government and industry program provided financial incentives, including subsidies, that led to the conversion of 110,000 vehicles to natural gas by

1986. When the government withdrew its support, however, the market essentially died, and only about 10,000 natural gas vehicles remain today—a decline of 100,000 from the peak. Clearly, the program design was not sustainable. According to the International Association for Natural Gas Vehicles, “governments that believe that all they need is a two- to three-year kick-start are wasting their time and money” (Cumming 1997).

For there to be an economic incentive to convert to gas, the prices for CNG at retail outlets need to lie in the range of 50 to 65 percent of the fuel being replaced. It is difficult to institute and maintain an effective CNG program without the support of a consistent pricing policy, and, given fluctuating oil prices, such a policy may not be easy to maintain. The loss of tax revenues on fuels that are replaced by untaxed natural gas is a disincentive for government support for CNG.

Historically, CNG has been substituted for gasoline because gasoline is taxed heavily in many parts of the world, making it easier to maintain the price differential between gasoline and CNG that is needed for the latter to be economical. For example, the retail price of premium gasoline in Argentina, the largest CNG vehicle market in the world, is as much as US\$1.00 per liter. From the point of view of urban air pollution, however, it would make more sense to replace diesel, rather than gasoline, with CNG in order to reduce particulate emissions. In most parts of the world, and particularly in developing countries, diesel is scarcely taxed, increasing the difficulty of making the operation of CNG vehicles economical. In the extreme, diesel begins to compete with CNG, capturing the market from CNG. In Argentina today, as much as 50 percent of all new taxis is said to be powered by diesel, directly competing with CNG.

Poor conversion of existing vehicles to CNG can actually increase vehicle emissions. In Chile, where tests for converting to CNG have been carried out with taxi fleets, the conversions failed because of a poor choice of aftermarket gasoline-to-CNG conversions; the option of a fully factory-built CNG car would have been more satisfactory. It is very important, when retrofitting existing vehicles, that conversion be carried out properly, ensuring customer satisfaction as well as achieving the expected emissions reductions.

The existing diesel and natural gas pricing structure worldwide provides little incentive for switching from diesel to CNG. Furthermore, there is a growing view in the United States and Europe that “clean” (particulate trap-equipped) diesel buses are more cost-effective than CNG buses for reducing harmful emissions. While clean diesel may be many years away in developing countries, these trends in industrial countries do affect the future of the auto industry and vehicle technology worldwide.

Finally, if natural gas pipelines are not already in place, the incremental cost of setting up a distribution and refueling infrastructure would be too high to make CNG vehicles economic. As an extreme example, selecting CNG buses for the purpose of reducing particulate emissions in a city that does not yet have a natural gas pipeline would be costly and not economically viable.

**ELECTRIC.** The battery of an electric vehicle is central to its fuel system and its success. Lead-acid batteries are currently used in electric vehicles, and there is no consensus as to what type of battery may be best for the future. Because it takes 6 to 10 hours to recharge batteries of ordinary electric vehicles, recharging would generally be done at night. Lead-acid batteries emit hydrogen as they recharge, so indoor recharging facilities must be well ventilated.

The main disadvantages of electric vehicles, in comparison with other alternative-fuel vehicles, are the length of time needed for recharging them, their short ranges, and their even higher purchase costs than other alternative-fuel vehicles. The economics of electric vehicles depends, among other things, on the price of electricity. The power sector in many developing countries is currently undergoing reform and restructuring. The long-term viability of electric vehicles should be evaluated from the standpoint of market-based energy pricing. Given the current state of the technology, electric vehicles would not be expected to have widespread application, but with carefully considered government intervention, they could play a useful, although limited, role in extremely polluted traffic corridors. It is also worth mentioning that significant efforts are now being directed to hybrid electric–internal combustion engines rather than pure electric-engine vehicles.

## Cross-sectoral coordination of policies

There are very close linkages between policies undertaken in various sectors, and these policies should be coordinated and harmonized to achieve optimal results. As is stressed in the next section, coordination is especially important for policies targeting vehicle technology and fuel quality. Also discussed are the economic, socioeconomic, and environmental interactions that have to be considered in efforts to eliminate gross emitters from the vehicle fleet and in liberalization of trade in fuels and vehicles.

### *Vehicle technology, fuel quality, and related policies*

The promotion of catalytic converters provides a striking example of the complex interactions among transport, energy, and environmental policies. A number of conditions need to be satisfied if catalytic converters are to function effectively:

- Wide availability of unleaded gasoline and, preferably, complete phaseout of leaded gasoline to eliminate the chances of misfueling
- Differentiated taxation to discourage misfueling<sup>4</sup>
- A reasonably low level of sulfur in gasoline, preferably less than 500 parts per million by weight (wt ppm)
- Specification of emissions performance levels and the length of time during which the catalyst system must meet those levels
- Effective inspection and maintenance to ensure that converters are operating properly.

Unless these conditions are met, the additional cost associated with the installation of converters may not be justified by the benefits. Even where effective use of catalytic converters is considered feasible, governments should consider specifying emissions levels for new vehicles rather than mandating catalytic converters per se. Retrofitting in-use vehicles with catalytic converters is typically not considered cost-effective.

Unfortunately, examples of uncoordinated policies are not difficult to find. In one country the government proposed mandatory installation of oxidation catalysts in heavy-duty diesel vehicles without taking measures to lower the sulfur level in diesel sold on the market—0.7 weight percent, or 7,000 wt ppm. At such a high sulfur level, the life of the catalyst is shortened, and the oxidation catalyst merely oxidizes sulfur completely to sulfur trioxide (SO<sub>3</sub>). SO<sub>3</sub>, in turn, eventually forms sulfate particulate matter and so significantly *increases* particulate emissions. In another country the government mandated catalytic converters in passenger cars without specifying precisely the emissions levels to be met—an omission that could defeat the purpose of the new requirement. In other cases, catalytic converters have been mandated even though there was no reliable system for providing unleaded gasoline.

A number of fuel-related issues need to be considered in formulating environment, transport, and energy policies:

1. For such pollutants as lead and SO<sub>x</sub>, emissions levels depend solely on fuel composition. If high ambient concentrations of these pollutants originating from transport are a public health concern, eliminating lead in gasoline and reducing sulfur in transport fuels will be effective. In fact, high ambient concentrations of SO<sub>x</sub> per se from vehicles are seldom a problem.<sup>5</sup> Lead, by contrast, is extremely toxic, and the amount of lead emitted from vehicles varies linearly with the amount of

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<sup>4</sup> Many countries have made effective use of differentiated taxation—taxing leaded gasoline more than unleaded gasoline—to encourage the use of unleaded gasoline and prevent the use of leaded gasoline in cars equipped with catalytic converters. In the absence of such a fiscal policy, control programs need to be in place to prevent permanent deactivation of catalytic converters on a large scale as a result of misfueling. The effectiveness of differentiated taxation depends on the extent to which fuel quality standards—in this case, for leaded versus unleaded gasoline—are enforced.

<sup>5</sup> The main motive for reducing sulfur in diesel is usually to reduce the secondary formation of sulfate-based fine particulate matter (see point 3).

lead in gasoline. Phaseout of lead from gasoline is therefore usually a sensible mitigation measure.

2. In many developing countries the vehicle fleet is dominated by poorly maintained, often old, vehicles. As long as large numbers of these vehicles are on the road, the cost-effectiveness of tightening fuel specifications to North American or EU standards is questionable. In the United States the Auto/Oil Air Quality Improvement Research Program (a US\$40 million program jointly undertaken by the auto and oil industries in 1989–95) found that high-emitting, poorly maintained vehicles represented only about 20 percent of the vehicle stock but contributed about 80 percent of total vehicle emissions. Improving fuel quality decreased emissions somewhat, but not nearly as much as changing vehicle technology (for example, by identifying and repairing old vehicles). Similarly, the European Programme on Emissions, Fuels and Engine Technologies (EPEFE) found that the spread in emissions levels related to vehicle technologies was wider than the variations attributable to fuels.
3. Sulfur in diesel was lowered to 0.05 weight percent (500 wt ppm) in 1993 in the United States and in 1996 in Europe to meet new standards for particulate emissions. This move came after a number of vehicle technology measures had substantially lowered the carbonaceous contribution to particulate emissions. In countries where the carbonaceous component of vehicular particulate matter is still high, it may not make economic sense to target sulfur in diesel to match North American and EU fuel standards if the goal is to mitigate particulate emissions from diesel engines.
4. In extreme cases, proposed emissions standards are incompatible with the transport fuels actually available on the market. For example, Euro 2 emissions standards can be imposed only if corresponding fuel specifications (such as the amount of sulfur in diesel) are met. Insistence on purchasing Euro 2-compliant buses when the sulfur level in diesel is 5,000 wt ppm is not technically coherent.
5. Vehicles using different fuel formulations can meet the same emissions standards. It is important to understand which fuels are costly to manufacture and which are not. Annex B contains an example illustrating how use of an inappropriate standard can lead to excessively stringent specifications for fuels and impair flexibility in fuel formulation.
6. It is not enough to regulate fuel quality; in some countries transport fuels are routinely adulterated. Examples of fuel adulteration that increases vehicle emissions include the addition of (lower-cost) kerosene, naphtha, or petrochemicals such as toluene to gasoline and the addition of lead and other heavy metal additives to gasoline downstream of refineries or terminals, as in Central Asia and the Caucasus. Regular fuel quality monitoring, together with costly penalties for noncompliance, could help enforce fuel standards more effectively.

### *Targeting gross emitters*

The share of emissions is not uniformly distributed over the vehicle fleet. A fraction of ill-maintained, often old, vehicles is typically responsible for a disproportionately high amount of pollution from the transport sector. If these “high emitters” (generally, commercial vehicles and public transport vehicles, including, in some places, two- and three-wheeler taxis with two-stroke engines) can be repaired or permanently eliminated, a considerable reduction in pollution can be achieved at a relatively small cost.

The implementation of such a scheme, however, is far from simple. To be cost-effective, any program targeting high emitters should identify polluting vehicles with high annual VKT operating in densely populated areas. Old vehicles in very poor condition may be candidates for retirement. Those that are highly polluting but are better maintained may be considered for repair or for retrofitting with more recent vehicle technology.

Policies targeting certain types of vehicles should take into consideration their distributional impacts on the poor.

## *Fiscal policies*

Fiscal policies include lower taxes on cleaner fuels and vehicles. Limited attempts have been made to retire old vehicles through cash-for-scrappage or cash-for-replacement. A pilot program implemented in 1996 in British Columbia, Canada, provides an example of modal-shift promotion. Owners of vehicles of model year 1983 or older were offered a choice of incentives for scrapping their vehicles: cash, or a one-year free transit pass on the local public transport network, worth about 1,000 Canadian dollars. Fifty-two percent of the owners participating in the program chose the second option.

Gasoline is taxed at fairly high rates in many developing countries, but diesel and kerosene are much less taxed (Box 5). A large price differential between kerosene and gasoline leads to illegal addition of kerosene to gasoline, resulting in higher pollutant emissions; a large price differential between gasoline and diesel encourages a shift to diesel from gasoline-powered vehicles. Examples include the introduction

### **Box 5. Fuel pricing policy in Asia and beyond: Getting the incentives right**

Around the world, the retail price of diesel is typically lower than that of gasoline, as a result of differential taxation. The trend is particularly pronounced in South Asia. In Bangladesh, for example, the retail price of gasoline was almost double the price of diesel in 1999. The price differential, together with the low profit margin fixed by the government for the sale of gasoline, has led to the adulteration of gasoline with kerosene and, as an unintended consequence, to higher emissions from vehicles. In Sri Lanka, where the price of diesel was less than a third of that of gasoline at the time, the ratio between diesel and gasoline consumed reached 7 to 1 in 1999, which is very high by international comparison. Similar trends have been observed in India and Pakistan. As a corrective action, the governments of Sri Lanka and India have recently increased the price of diesel sharply on several occasions.

There is a sound economic argument for lower taxes on diesel: diesel is used in freight transport, agriculture, and industry and, as such, is an intermediate good. It can be shown that if a specific set of conditions is met—that is, if all final goods are taxed and pure profits have been taxed away or, equivalently, there is perfect competition and constant returns to scale—the optimal rate of tax on diesel as an intermediate good is in fact zero (Newbery 1988). Since these conditions do not apply in most developing countries, a non-zero rate of tax on diesel is a way of indirectly taxing final consumption of those goods that use diesel as an input and are not directly taxed. Applying a low tax rate to diesel, however, has significant environmental as well as fiscal impacts in Asia. Large tax differences or, in many cases, subsidies (for example in Indonesia) in favor of diesel have led to switching from gasoline to diesel, diminishing the government's principal fuel tax base (gasoline) and promoting the excessive use of diesel. Diesel vehicles emit far more fine particulate matter than gasoline vehicles, and in developing countries, where vehicles are typically poorly maintained, they are an important source of serious health damages attributable to particulate emissions.

There are several considerations when seeking to influence the environmental impacts of diesel use:

- *How diesel is used in the transport sector.* From the point of view of public health, what is important is the amount of diesel used in urban transport. If the bulk of diesel is used for intercity transport (for example, long-distance trucking and railways), the environmental impact is not as much of a concern as increased use of diesel for transport within cities would be.
- *Economic incentives for switching to diesel.* There are several ways of reducing the economic incentives for using diesel: (a) decreasing the retail price differential between gasoline and diesel (and possibly giving rebates to industrial and agricultural users of diesel); (b) making it more expensive to own a diesel vehicle for purposes that, in the absence of a large price differential, could just as well be served by a gasoline vehicle—for example, by taxing light-duty diesel vehicles more heavily than similar gasoline-powered vehicles; or (c) using a combination of these two approaches. The first option affects the market for diesel fuel, including that used in long-distance transport. The second option targets light diesel vehicles more directly (with the exact effect of the tax depending on the design of the fiscal measures employed) but is more difficult to implement. In both cases, an evaluation should be carried out of the likely macroeconomic consequences.
- *Different diesel technologies.* The emissions from diesel-powered vehicles differ by orders of magnitude depending on the technology employed and, to a lesser extent, the quality of diesel used. In the extreme, state-of-the-art diesel vehicles that use ultra-low-sulfur diesel fuel and continuously regenerating traps can be almost as clean as vehicles that use compressed natural gas. Such advanced technologies are unlikely to offer cost-effective solutions in developing countries any time soon, but their existence underlines the point—an important one to keep in mind in formulating incentive policies—that not all diesel vehicles are alike.

of diesel-powered three-wheelers in South Asia and the large proportion of diesel passenger vehicles in Europe. Conversion to diesel may not be favorable from the environmental point of view; there is emerging epidemiological evidence that diesel emissions are more toxic than gasoline emissions.

Although a large price differential between gasoline and diesel tends to encourage conversion to diesel vehicles, it does not necessarily follow that the solution is to narrow the price gap to capture the environmental externality of diesel emissions. If the bulk of diesel fuel is consumed outside large cities (by railroads and interurban transport), it may make more sense to increase vehicle taxes on diesel-engine vehicles typically used in intracity transport—that is, light-duty diesel vehicles—so that the choice of diesel versus gasoline vehicles will be financially neutral for vehicle owners. An option successfully adopted in Chile is to increase the tax on diesel to make the price of automotive diesel comparable to that of gasoline but to give rebates to industrial and agricultural users of diesel. Another option is to tax automotive diesel more and use a dye to distinguish automotive diesel from diesel for other uses.<sup>6</sup>

Fiscal incentives to support the use of cleaner fuels have been successfully applied. Differentiation of excise taxes on leaded and unleaded gasoline in favor of the latter is one example. Another is the differentiation of taxes on diesel on the basis of sulfur content, as is done in Europe, so that low-sulfur diesel can be used in urban buses equipped with state-of-the-art emissions control technologies such as continuously regenerating traps.

Tax structures that discourage the purchase of new vehicles—for example, registration fees or excise taxes based on the market value of the vehicle—should be carefully reviewed and, if possible, revised, since they do not capture the cost of pollution. Possible measures to alter the incentives include lowering or eliminating import tariffs on new vehicles, abolishing the practice of charging vehicle registration fees proportionally to the book value of the vehicle (which makes it more expensive to own new vehicles than old ones), and minimizing the tax on the purchase of new vehicles. In considering any of these measures, the socioeconomic impact of making it more costly to own old vehicles and the environmental benefits of reducing vehicle emissions need to be weighed.

### *Trade liberalization*

*Trade in vehicles.* Liberalization of vehicle trade is an important reform, particularly in countries that have automobile manufacturing facilities. The removal of barriers that hinder access to the technology available in the rest of the world would enable consumers in these countries to meet tighter emissions standards at least cost. Rules such as local content requirements (for example, requiring that a certain proportion of the vehicle weight or content must be produced domestically) are based on the infant-industry argument. They often result in inefficiency—and in production of heavier vehicles, if the percentage is based on weight. Higher import tariffs on new vehicles, rigid licensing schemes for imports, and quotas are all likely to slow the rate of vehicle renewal, with potentially adverse impacts on air pollution.

Free trade in used cars raises the question of “environmental dumping.” Among the largest recipient markets for used cars are Cyprus, Jamaica, Peru, Sri Lanka, and Russia. Japan remains the largest single identifiable source of used-car exports. The forces driving the export of used cars by industrial countries will become stronger as emissions standards become more stringent and regulations affecting end-of-life vehicle are implemented, as in the EU (Neiwenhuis and Wells 1999). This may have mixed results. Where the vehicles exported are relatively new, the environmental impact may not be so serious and may in fact be positive. (Many relatively new Japanese cars have been exported because of the vehicle tax

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<sup>6</sup> As long as price incentives persist, the success of measures to prevent diversion and adulteration may be limited. For example, Thailand saw significant adulteration of gasoline and, to a lesser extent, diesel with kerosene in the early 1980s, when kerosene was heavily subsidized. To prevent adulteration, the government tried a number of methods, which met with varying success: dyeing kerosene blue, limiting the sale of kerosene to 20-liter containers, and mounting intensified police crackdowns on adulteration. Kerosene consumption fell, but it was not until interfuel prices were adjusted, between 1986 and 1991, that the practice of widespread adulteration with kerosene ceased. (The police could be bribed, and the dye could be removed from kerosene.)

structure, which used to impose large expenses on owners when vehicles turned three years old.) Exports of gross emitters would be a classic case of environmental dumping.

In the interest of environmental protection, the government may limit the age of the vehicles that may be imported. For example, Hungary set the age limit at 10 years in 1991 and progressively reduced it to 8, 6, and finally, in 1997, 4 years. Chile and India ban imports of used vehicles altogether. The purchasing pattern of vehicle owners, however, should be carefully balanced against the expected environmental advantage of restricting the import of old vehicles. If, for example, commercial operators of vehicles are in no position to buy relatively new vehicles, an import restriction based on age would constrain the supply and increase the price of replacement vehicles, postponing the replacement of the high emitters.

*Trade in transport fuels.* Transport fuels are international commodities. Having an open border and being able to take advantage of superior fuels produced in other countries make it much easier to phase out gasoline lead and to implement other fuel quality improvement measures. In some parts of the world there is a move toward harmonizing fuel specifications and vehicle emissions standards to ensure minimal environmental standards, foster intraregional trade, and enhance the efficiency of supply. Fuel specifications in North America, the EU, and the countries of the former Soviet Union are already harmonized for the most part. Similar measures have been proposed in Latin America.

There is a tradeoff between harmonizing fuel specifications and vehicle emissions standards, and setting site-specific standards. If two neighboring countries have very different air pollution problems (as in, for example, India and Sri Lanka), harmonizing fuel and vehicle emissions standards would not be sensible. Even within a country, provided that the distribution system can handle segregation of different fuels, cleaner (and costlier) transport fuels should ideally be used in large cities, and the use of fuels with less-stringent specifications should be confined to areas outside urban centers. Leakage and other enforcement problems, as well as the logistics of delivering fuels of different qualities to different depots, make it difficult, however, to implement such regional differentiation cost-effectively.

Countries that import the bulk of their transport fuels typically find it easier to harmonize with neighboring countries than do countries that have domestic refineries. Trade considerations (between Canada and the United States, within Central America, and within the EU) are a strong driving force for harmonizing fuel and vehicle emissions standards. Harmonizing standards with North America or the EU with no time lag, on the other hand, is unlikely to be cost-effective for developing countries.

Where the downstream petroleum sector is regulated as regards pricing, ownership, and petroleum product trade, the government necessarily becomes involved in changes in fuel quality. Many refineries in developing countries are owned by the government, and some of them are not operated economically at present. In the absence of price and trade reforms, revamping refineries to improve fuel mix and quality is likely to render them even less commercially viable. Under these circumstances, the government may resist requiring changes in fuel quality, or if it requires changes, it is likely to do so while maintaining import protection through restrictions or high tariffs. In a number of developing countries, the net cost to society of improving fuel quality by importing superior fuels would be lower than the cost of supplying domestically manufactured fuels with less-stringent fuel specifications. In one country, where the downstream petroleum sector is controlled by the government to a significant extent, 100 percent of the gasoline sold on the market is leaded even today, although there are abundant supplies of unleaded gasoline in the region. Downstream petroleum sector reform and privatization, coupled with liberalization of petroleum product trade and the introduction of competition, are therefore important conditions for improving fuel quality and, ultimately, urban air quality.

## **Greenhouse gas emissions**

Most environmental externalities from transport—such as those affecting human health—impose immediate social costs and require national and local action. By contrast, emissions of greenhouse gases (GHGs), including carbon dioxide (CO<sub>2</sub>), methane, and nitrous oxide (N<sub>2</sub>O), contribute to a global

externality, the impacts of which will accrue in the more distant future.<sup>8</sup> Solutions to this problem require concerted international efforts. Policies and measures aimed at reducing or restraining GHG emissions contain elements of political and economic uncertainty or offer few rewards from a national perspective, as the December 1997 negotiations in Kyoto and, more recently, the November 2000 Conference of the Parties at the Hague revealed.

GHG emissions from travel and freight, which are dominated by CO<sub>2</sub>, have increased in most industrial countries faster than population and, in many cases, as rapidly as gross domestic product (GDP). Indeed, in virtually all regions of the world, CO<sub>2</sub> emissions from transport are rising in relation to total emissions. Policymakers around the world are attempting to understand and address this phenomenon.

#### *Global trends in CO<sub>2</sub> emissions*

Member countries of the Organisation for Economic Co-operation and Development (OECD) account for by far the greatest part of world CO<sub>2</sub> emissions from energy use, but non-OECD countries, particularly in Asia and the Middle East, are responsible for most of the growth. Between 1971 and 1994, the share of world carbon emissions attributable to Asia grew from about 10 to 23 percent, while the share attributable to OECD countries declined from 64 to 52 percent. For most countries, the share of emissions arising from transport has increased.

According to data from the International Energy Agency (IEA), per capita CO<sub>2</sub> emissions from the transport sector grew strongly from 1971 to 1995, pausing, in all but a few countries, only briefly after each of the two oil shocks of the 1970s. This trend, which is in contrast to that for emissions from stationary sources, is in part a reflection of the constancy of emissions per unit of energy for transport. If OECD countries begin to restrain their emissions while developing countries—whose economies are growing more rapidly than those of the OECD—do not, total emissions from the developing countries are forecast to overtake those from the OECD within a fairly short time period.

#### *Options for reducing GHG emissions*

Politically, suggestions for GHG mitigation measures in developing countries are often received warily and can be perceived as a denial of these countries' basic right to economic growth and improvement of well-being. The keys to changing this perception are (a) to link GHG mitigation to emission-reducing policies whose goals are of far greater immediate relevance than GHG mitigation, and (b) to facilitate financial assistance from industrial countries to reward developing countries for the global benefits of accelerating the introduction of such local measures. Several measures that reduce local pollution also reduce GHG emissions.

One area of overlap between local and global benefits is increased *fuel economy*.<sup>9</sup> The enormous gains made in improving fuel economy in the 1970s and the first half of the 1980s have contributed to decreasing both local and global pollution in industrial countries. In these countries, current and future options for improving fuel economy include reduction of vehicle weight, direct fuel injection, lean-burn technology, measures to increase the share of diesel (which may, however, adversely affect local pollution), optimized engine transmission systems, and hybrid vehicles. The European Automobile Manufacturers Association (ACEA) and the European Commission reached an agreement in the late 1990s whereby by 2008 average CO<sub>2</sub> emissions from new cars will be reduced by one-quarter compared with current levels, to 140 grams per kilometer (g/km). The agreement also required some ACEA members to make available by 2000 cars emitting no more than 120 g/km. Some analysts argue that moves toward

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<sup>8</sup> Recent measurement results have shown that N<sub>2</sub>O emissions from three-way catalysts are substantially higher after 15,000 km–25,000 km than emissions from new catalysts. Tests on comparable models show that aged catalysts emit roughly from one-third more to almost five times the rate of new catalysts.

<sup>9</sup> For example, the removal of decorative “crowns” from heavy-duty trucks in Pakistan is estimated to increase fuel economy by as much as 20 percent.

gasoline direct-injection and diesel common-rail technology could help significantly in compensating for growth in vehicle numbers in industrial countries.

In developing countries, average engine size tends to be smaller, so there may not be much scope for further reducing vehicle size. Fuel economy, however, is often low because of such factors as poor vehicle maintenance and fuel adulteration. Use of gasoline with an octane number lower than that recommended by vehicle manufacturers—because lower-octane gasoline (for example 80 research octane number, RON) is available and is cheaper, or because of adulteration of gasoline with kerosene—decreases fuel economy, leads to knocking (and, ultimately, to engine damage), and makes for higher emissions. Data collected in India in November–December 1999 during a series of inspection and maintenance “clinics” for two-wheelers indicated that minor vehicle repairs improved fuel economy by an average of 17 percent (in 210 motorcycles randomly selected from those reporting to dealers for scheduled servicing) and reduced CO emissions by 44 percent (Iyer 2000).

The scope for improving fuel economy is particularly large in countries where gasoline octane remains low. In the NIS, many vehicles run on gasoline with a motor octane number (MON) of 76 or even 72. Increasing the octane and the engine compression ratio would result in fuel savings—and reductions in GHG emissions—in the long run.

Another area of overlap between local and global pollution-reduction goals is *traffic management*. Traffic congestion worsens emissions of both local and global pollutants. It has been reported that increasing the average speed in city traffic from 10 km/h to 20 km/h can cut CO<sub>2</sub> emissions by nearly 40 percent.

It is important to recognize, however, that there is not always a synergy between measures to reduce local pollution and measures to mitigate GHG emissions. The evaluation of mitigation measures for local pollution focuses on vehicle emissions, whereas in addressing GHG emissions, the entire fuel cycle, from well to tailpipe, needs to be analyzed. Strategies for improving local air quality in middle- and high-income countries have focused on vehicle and fuel quality improvement, to reduce tailpipe emissions of harmful pollutants, much more than on reducing demand for fuel. As is described in the section on World Bank analytical work, below, locally motivated air quality improvement programs for urban transport in such middle-income countries as Mexico and Chile have been shown to have limited collateral benefits for reduction of GHG emissions (Eskeland and Xie 1998).

Diesel is a particularly efficient fuel, and hence favorable from the point of view of reducing GHG emissions. However, recent scientific findings suggest that diesel emissions are more damaging to human health than emissions from other fuels. The suitability of diesel for reducing emissions is therefore in question.

The worldwide trend toward mitigating local pollution by progressively reformulating transport fuels through severe hydrotreating is making refinery processes increasingly energy-intensive, thus increasing GHG emissions. This is particularly true of the recent moves in North America and the EU to limit sulfur in gasoline and diesel to 10–50 wt ppm or even lower.

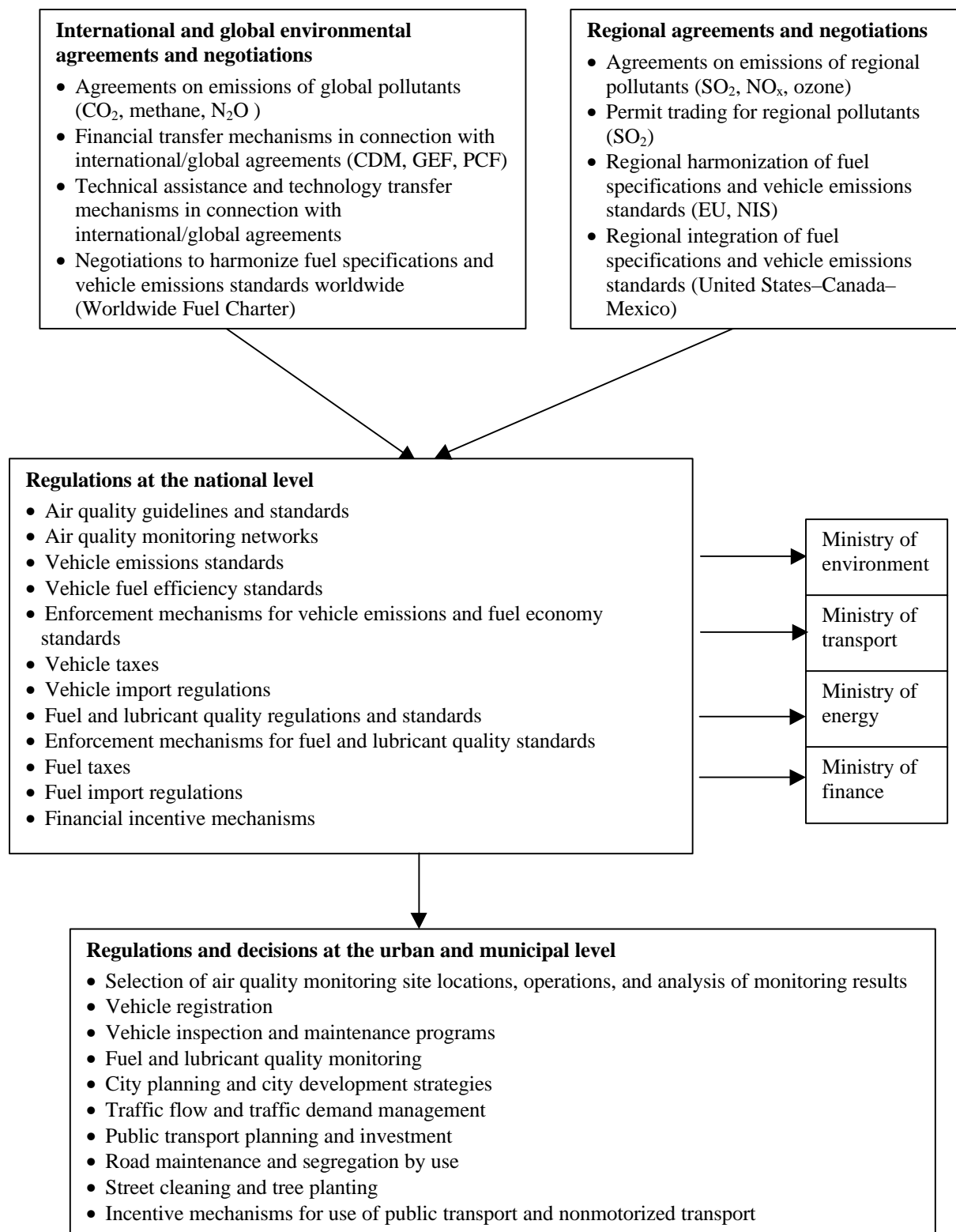
An area that merits examination is the role of fuel pricing in encouraging better fuel economy and optimizing fuel usage. Auto manufacturers in industrial countries responded to the oil crisis of the 1970s by adopting measures to increase fuel economy. In the United States, however, retail gasoline prices remain relatively low compared with those in the EU countries and Japan, and the average fuel economy of new vehicles has declined so much in recent years that it is now on a par with the figures for 1980. The gains in the intervening period have been offset by the increased popularity of sport utility vehicles. A similar pattern may exist in those developing countries where diesel is hardly taxed, making its retail price low. Such a pricing policy not only encourages excessive use of diesel but also makes market penetration by cleaner fuels (alternative fuels) difficult.

### **Decisionmaking levels in transport-related air quality management**

Decisions made at different levels affect policies designed to combat transport emissions (see Figure 3). At the global level, there are moves to address issues that can be tackled only globally (GHG emissions) as well as initiatives, led by vehicle manufacturers, to harmonize fuel quality and vehicle

emissions standards worldwide. On the regional level, there are pollutants such as SO<sub>2</sub> that require regional solutions. There are also initiatives to harmonize fuel specifications and vehicle emissions standards on a regional basis, notably in the EU. In the NIS, these standards are already harmonized by virtue of the countries' history. In some regions, standards are increasingly integrated on account of extensive trade. Canada, Mexico, and the United States are in this category, although with a considerable time lag in Mexico. All these trends affect decisionmaking at the national level.

**Figure 3. Levels of decisionmaking affecting transport-related urban air quality management**



*Note:* CO<sub>2</sub>, carbon dioxide; N<sub>2</sub>O, nitrous oxide; NO<sub>x</sub>, nitrogen oxides; SO<sub>2</sub>, sulfur dioxide; CDM, Clean Development Mechanism; EU, European Union; GEF, Global Environment Facility; PCF, Prototype Carbon Fund.

The national government typically sets air quality standards, fuel specifications (with geographic differentiation if the distribution infrastructure can support it), vehicle emissions standards, and definitions of what constitutes noncompliance. Air pollution problems are location-specific, and once these standards are set, particularly if there is geographic differentiation, it is state and municipal governments that act to implement them. Governments at these levels monitor air quality, fuel and lubricant quality, and vehicle emissions; integrate transport considerations into overall city development plans; develop traffic flow, demand management, and other strategies for mitigating traffic congestion and emissions; and, where appropriate and fiscally possible, offer financial and other incentives to facilitate vehicle renewal, nonmotorized transport, and other means of mitigating traffic emissions.

These considerations are important in determining the proper instruments and frameworks for assisting client countries in their efforts to improve their environments and strengthen their environmental policy and regulatory frameworks. The World Bank, through its policy dialogue with client governments at the national level and through sectoral programs and projects at the urban level, can be effective in forging cross-sectoral coordination of policies and supporting a combination of measures that can contribute to improved environmental conditions in developing countries.

# World Bank experience with support for urban air quality management programs

In recent years the World Bank has started to address urban air quality management and the interlinkages with the transport sector, primarily through analytical work, nonlending services, regional initiatives, and partnerships. A coherent and consistent strategy, however, does not yet exist, and examples of good practice are only starting to emerge. Coordination, within the Bank and in client countries, among the transport, environment, and energy sectors is an essential condition for air quality management but has only now begun to develop.

The following sections review the Bank's analytical work, its nonlending services, its urban transport portfolio, and other relevant portfolios. The Bank has been active in conducting analytical work, providing technical assistance, and disseminating information and experience concerning the various aspects of urban air quality management. Among its major activities are analytical work on the assessment of the health impacts of air pollution and the identification of cost-effective approaches across sectors; the Urban Air Quality Management Strategy (URBAIR) in Asia; lead phaseout initiatives; clean transport fuel studies and initiatives; the South Asia two-stroke engine initiative; and regional clean air initiatives.

## Analytical work

In connection with its assistance to the governments of Indonesia and Chile, the World Bank developed a methodology for estimating the health impacts of key air pollutants—particulate matter, SO<sub>2</sub>, NO<sub>x</sub>, and lead—on the basis of meta-analyses of dose-response functions established in epidemiological studies carried out primarily in industrial countries. Ostro and others (1996, 1999) laid the groundwork for using transferred dose-response functions for health effects. In a study in Santiago, a subset of the dose-response functions was estimated locally, lending empirical support to the working assumption that dose-response functions can be applied to transfers from other cities with similar conditions (Eskeland 1997; World Bank 1994).

The study in Jakarta examined the impact of ambient concentrations of pollutants on health and suggested that significant benefits could result from reducing exposure to both outdoor and indoor air pollutants. The greatest estimated benefits came from reducing particulate matter concentrations, but those from reducing exposure to lead and NO<sub>2</sub> were also significant (Ostro 1994).

Analytical resources were geared toward obtaining estimates of the benefits of pollution reductions by employing models of health effects, pollutant exposure, and dispersion. In Santiago the cost-effectiveness of a range of pollution abatement interventions was assessed and ranked to assist policymakers in setting priorities. The Santiago study (Eskeland 1997) analyzed emissions standards for buses, cars, and trucks. It broke new ground by completing a multipollutant cost-benefit analysis of emission controls, including cost control alternatives, dispersion and exposure modeling, dose-response estimation for health effects, and valuation of these health effects.

In Mexico City a similar cost-effectiveness assessment (Eskeland 1992) focused on pollution abatement measures in the transport sector. The analysis evaluated and ranked in terms of cost-effectiveness a wide range of technical measures (26, in all) for making vehicles and fuels less polluting. These measures included vehicle retrofitting, emissions standards and vehicle inspection programs, fuel improvements, and alternative fuels. The study assigned different weights to the pollutants considered in calculating cost-effectiveness but did not estimate the benefits of reductions in urban pollution.

These analyses showed that the Mexico City program could reduce 64 percent of the locally weighted air pollutant emissions from motor vehicles and that the measures identified in Santiago reduced 65 percent of local pollution. In an attempt to determine how urban air pollution control programs could be modified to take into consideration global climate change concerns, Eskeland and Xie (1998) reexamined locally motivated programs for control of pollution from transport in Mexico City and Santiago. The

Mexico City program had a very small effect on the global environment, decreasing GHG emissions only 6.5 percent. A similar rather limited synergy was found in Santiago, where the identified measures lowered GHG emissions only 5.3 percent.

Lvovsky and others (2000) estimated the social costs, including health and nonhealth damages and climate change impacts, associated with different types of fuels and a variety of sources in six developing countries. The major qualitative findings of the exercise indicated that:

- The environmental costs of fuel use in large developing-country cities can be so high that marginal damage costs may exceed both producer and retail prices for some fuel uses.
- In highly polluted urban areas, local health effects dominate the damage costs from fuel use, with global climate change impacts being much smaller.
- Vehicles and small stoves and boilers are responsible for most of the health and overall damages from fuel use, while large sources contribute the most to climate change impacts. This implies that the overlap between measures for addressing local and global issues is likely to be limited.
- The sectoral differentiation in fuel use is at least as significant for the environmental costs of fuel combustion as the differences in types of fossil fuel used.
- Marginal damage costs per ton of “local” pollutants vary greatly across sources and locations. They are much higher for small (low-stack or low-level) sources because of dispersion and exposure patterns.
- Diesel-powered urban vehicles and small stoves and boilers that burn coal, wood, or fuel oil impose the highest social costs per ton of fuel. The greatest disparities between local and global damage costs are also found for these fuel uses.
- The large range of environmental damages for different combinations of fuels, sources, and locations limits the efficacy of simple fuel-pricing measures and necessitates a skillful mix of policy instruments able to send highly differentiated signals to various users of fuels.

The methodology established by this study provides a useful tool for assessing key environmental externalities of fuel use. Combined with an estimate of cost-effective interventions, the methodology can guide policymakers in choosing urban air quality management interventions. In Katowice, Poland, for example, it was estimated that an “optimal” pollution control strategy (consisting of the most efficient combination of measures for reducing the total social damage caused by PM<sub>10</sub>, SO<sub>2</sub>, NO<sub>x</sub>, and CO<sub>2</sub>) had benefits equal to or greater than any strategy that focused on only one or two of these pollutants. This analysis helped the Bank in designing the Poland Environmental Management Project.

## **Nonlending services**

### *URBAIR*

URBAIR was undertaken during 1992–95 under the auspices of the Metropolitan Environment Improvement Program (MEIP), financed by the United Nations Development Programme (UNDP) and executed by the World Bank. The objective of the study was to assist in the design and implementation of policies, monitoring, and management aimed at restoring air quality in Asian metropolitan areas. URBAIR combined air quality analysis (air quality data assessment, emissions inventories, and dispersion modeling) with economic evaluation (calculations of health damages and of the costs of mitigation measures). In each of the four participating cities—Jakarta, Mumbai, Kathmandu, and Metro Manila—locally staffed teams on air quality, economic and health analysis, and policy met frequently to discuss and analyze information.

Government and industry representatives, local researchers, representatives of nongovernmental organizations (NGOs), and international and local experts met at workshops and working group meetings in each city. Collectively, they reviewed air quality data and the results of modeling and economic calculations with the aim of designing action plans that took into account the economic costs and benefits

of air pollution abatement measures. The analyses that formed the basis for the selection of the action plans included a good balance of technical and economic evaluations.

The findings and the results of the URBAIR process are being followed up in the World Bank's Mumbai Urban Transport Project under preparation. In Manila the Asian Development Bank used the URBAIR Action Plan in an air quality management project. The government of China has also used the URBAIR approach in its urban transport projects.

### *Lead phaseout*

A number of risk assessment and environmental health studies have indicated that lead is a serious environmental health problem in urban areas in the developing world. Recognizing that phasing out lead from gasoline is a cost-effective and technically feasible way of addressing the problem, the Bank has called for the complete phaseout of lead in gasoline in developing countries and has undertaken a number of activities to that end. It has supported several health and feasibility studies, prepared policy papers, made public statements, and worked with bilateral and multilateral partners and NGOs to raise awareness and build political commitment.

The Bank has initiated and participated in several regional lead phaseout initiatives, including the Regional Program for Elimination of Lead in Gasoline in Latin America and the Caribbean, funded by the joint UNDP/World Bank Energy Sector Management Assistance Programme (ESMAP) (World Bank 1997b); the preparation of a pan-European strategy to phase out leaded gasoline under the leadership of the United Nations Economic Commission for Europe (UNECE) and the government of Denmark; the National Commitment Building Program to Phase Out Lead from Gasoline in Azerbaijan, Kazakhstan and Uzbekistan, funded by the Danish Environmental Protection Agency; and the ESMAP-funded Elimination of Lead in Gasoline in the Middle East and North Africa program.

The Bank has also assisted individual countries with introducing appropriate policies, conducting feasibility studies, and implementing policies. These countries include Bangladesh, Bulgaria, China, the Dominican Republic, El Salvador, Haiti, Indonesia, Jamaica, Malaysia, Romania, Thailand, and more recently, Pakistan, Sri Lanka, and Vietnam (the last three have programs in progress). In Pakistan, where the gasoline supply is entirely leaded, the ESMAP-funded Pakistan Clean Fuels Program examined the cost of phasing out lead, the policy barriers to the introduction of clean fuels, and the role of interfuel pricing in discouraging overuse of automotive diesel.

In all these activities the Bank has played the catalytic role of bringing together a wide range of stakeholders and interested international participants, including representatives from the transport, environment, and energy sectors and from industry, academia, and NGOs. The Bank has helped build consensus, transfer experience from other countries and regions, dispel myths about lead phaseout, and point out the need for an integrated approach so that fuel parameters other than lead are considered when refineries are upgraded to handle lead elimination. To ensure that refinery modernization schemes (which may be required for phasing out lead) are optimally designed, the programs have stressed the importance of addressing comprehensive fuel quality issues as part of lead phaseout plans.

A common misperception that continues to be encountered, although there is no technical basis for it, is that vehicles have to be retrofitted with catalytic converters before lead in gasoline can be phased out. A more plausible (from the technical point of view) but much exaggerated concern is that a significant fraction of the vehicle fleet will experience valve seat recession. As noted in Box 4, above, the Bank has been able to refer governments to experience in other countries with similar vehicle fleet characteristics that have already eliminated lead in gasoline and that have found valve seat recession to be extremely rare. This evidence has proved valuable in persuading governments to ban lead in gasoline as soon as possible.

### *Clean transport fuels*

Lead phaseout cannot be implemented in isolation; it raises complex technical and fuel quality issues that have to be addressed as part of a comprehensive, cost-effective approach to air quality management.

Accordingly, lead phaseout initiatives have led to broader programs and studies that address cost-effective ways of improving transport fuel quality in specific countries or in entire regions.

Vehicle fleet characteristics, fuel consumption patterns, and the downstream petroleum sector often have many similarities in a given region. Regional programs make it possible to explore these common elements as part of the development of an integrated air quality management program. By setting minimal fuel and vehicle emissions standards, which individual countries can choose to exceed to meet their own air quality objectives, a regional approach not only ensures that minimal environmental standards will be maintained but also significantly reduces illegal smuggling of lower-priced, poor-quality fuels. By facilitating intraregional trade, a regional approach also offers potential for reducing the incremental cost of improving fuel quality and vehicle technology.

As part of the Regional Program on the Elimination of Lead in Gasoline in Latin America and the Caribbean, the Latin America and the Caribbean (LAC) Fuel Quality Improvement Program funded by ESMAP developed—with the active participation of the key stakeholders in the region—gasoline, diesel, and LPG specifications that can be adopted by the entire region for the purpose of facilitating intraregional trade and ensuring minimal environmental protection (World Bank 1998).

The regional study on Cleaner Transportation Fuels for Better Air Quality in Central Asia and the Caucasus built on the National Commitment Building Program to Phase Out Lead from Gasoline in Azerbaijan, Kazakhstan, and Uzbekistan. It was funded by ESMAP and the Canadian International Development Agency (CIDA) and was a joint effort by the Energy and Environment Departments of the World Bank's Europe and Central Asia Region and the Environment and Oil, Gas and Chemicals departments of the World Bank. The program examined the eight countries in the region: Armenia, Azerbaijan, Georgia, Kazakhstan, the Kyrgyz Republic, Tajikistan, Turkmenistan, and Uzbekistan. Consisting of three principal components—air quality monitoring, vehicle fleet characterization, and downstream petroleum sector analysis—the study assessed the current status of air quality and air quality monitoring systems; current and future vehicle fleet characteristics and their fuel requirements; the current status of vehicle emissions inspection programs; the implications of changing demand and fuel quality for the refining sector; and changes in petroleum sector policy such as pricing, fiscal measures, and liberalization of product trade to facilitate the introduction of cleaner fuels (Kojima and others 2000).

The study found that the most significant challenges to urban air quality management in the transport sector and to the refining sector in the region are the rapid rise in diesel consumption in the coming decade, as heavy-duty vehicles switch from gasoline to diesel, and the increased use of high-octane gasoline as gasoline vehicles with low-compression-ratio engines are replaced by modern engine vehicles requiring high octane. The air quality monitoring system, standardized throughout the former Soviet Union, is not capable of generating data that can be compared with international air quality standards and guidelines. The key recommendations of the study were discussed and unanimously endorsed by government representatives and other stakeholders in the region at the final regional workshop in October 2000.

The Sri Lanka Clean Air/Fuels Program has an urban air quality management component that will examine vehicle maintenance, the role of fiscal policy, fuel quality, and other matters related to transport emissions in Colombo. The ESMAP-funded Mexico Energy-Environment Review and Turkey Energy-Environment Review both address transport emissions and, in particular, the quality of transport fuels.

#### *South Asia two-stroke-engine initiative*

Two- and three-wheelers with two-stroke engines are a significant source of fine particulate emissions in Asia. In South Asia two-stroke-engine vehicles are extremely popular because of their low cost and make up about 60 percent of the total vehicle fleet. The high particulate emissions levels of these vehicles are primarily attributable to the use of incorrect quantities and quality of lubricant and to poor vehicle maintenance. The initiative examined different measures for reducing emissions from two-stroke engines, including the role of lubricant dosage and quality, fuel quality, fuel type, vehicle technology, emissions standards, and fiscal and policy options. Noting the scarcity of data on particulate emissions from two-stroke engines, the initiative also mounted an experimental program to measure mass particulate

emissions as a function of vehicle age, vehicle maintenance, lubricant quality, lubricant quantity, and fuel quality. The findings of this initiative are being applied to the Bangladesh Air Quality Management Learning and Innovation Loan (LIL), the Sri Lanka Clean Air and Fuels Program, the ESMAP-funded Dhaka Baby Taxi Auto-Clinics and Bangkok Motorcycle Clinics, and the Bangkok Motorcycle Upgrade Project.

For new vehicles, promoting a switch from two-stroke to four-stroke engines is one of the most cost-effective mitigation options. The price differences between the two engine types are small, and two- and three-wheelers with four-stroke engines have higher fuel economy and significantly lower particulate emissions than do their two-stroke counterparts, especially if emissions deterioration with increasing vehicle age is taken into account. For in-use vehicles, by far the most cost-effective mitigation option is the use of the correct quantity and quality of lubricant. Although vehicle manufacturers recommend only 2 percent lubricant for two-wheelers and 3 percent for three-wheelers, some drivers of three-wheeler taxis add as much as 8 to 12 percent lubricant. Furthermore, all too often the lubricant they add to gasoline is not intended for use in two-stroke engines; in the case of Bangladesh, the most commonly used lubricant is straight mineral oil, designed for use in slow-moving stationary engines. The impact of using 10 percent lubricant is dramatic. In a demonstration for auto mechanics conducted under the Dhaka Baby Taxi Auto-Clinic Program, a taxi running on gasoline containing 10 percent lubricant of the wrong type smoked so badly that the mechanics had to walk away from the vehicle, while smoke from a taxi running on the proper 3 percent lubricant for two-stroke engines was hardly visible. This represents a rare “win-win” situation; drivers need pay no more for using the correct amount of two-stroke-engine lubricant, smoke emissions are lower, and vehicle maintenance is improved.

#### *Clean air initiatives*

The World Bank Institute (WBI) is actively involved in disseminating information and strengthening local capacity in the Bank’s client countries to develop and execute an integrated urban air quality management plan. Among the most prominent activities undertaken by the WBI are clean air initiatives in different regions of the world. The Clean Air Initiatives in Latin America and the Caribbean and in Sub-Saharan Africa were launched in 1998, and similar initiatives in East and South-East Asia, and in Europe and Central Asia are being initiated. The Clean Air Initiative approach provides systematic and comprehensive learning opportunities to various sectors of civil society through such modalities as city-specific workshops, distance learning training, network support, and information and outreach activities.

In Sub-Saharan Africa the initiative has focused primarily on transport-related air pollution. The partner cities include Abidjan (Côte d’Ivoire), Cotonou (Benin), Dakar (Senegal), Douala (Cameroon), Harare (Zimbabwe), Lagos (Nigeria), Nairobi (Kenya) and Ouagadougou (Burkina Faso). This is a regional program jointly initiated and managed by the Urban Mobility Component of the Sub-Saharan African Transport Policy Program (SSATPP) and the WBI. The initiative is built on the concept of partnership among development agencies, African authorities, research organizations, environmental institutions, and consultants

The initiative in Latin America and the Caribbean has focused on five major cities—Buenos Aires, Lima-Callao, Mexico City, Rio de Janeiro, and Santiago de Chile—with a view to developing city action plans and distance learning. The private sector partners include DaimlerChrysler, Renault, Shell, and Volvo. The bilateral and multilateral agencies participating in the initiative include the German Agency for Technical Cooperation (GTZ), the Netherlands Ministry of Foreign Affairs, the Inter-American Development Bank, the Pan American Health Organization, and the UNDP. The initiative covers issues of environment, urban transport, health, energy, industrial pollution, and global emissions as they relate to air quality in the subject cities. Its three goals are to promote the integrated development or enhancement of clean-air city action plans, with participation by all relevant stakeholders; to advance exchange of information; and to foster public participation and the active involvement of the private sector in implementing innovations in the use of low emission/low carbon technologies.

## The urban transport portfolio

On account of heavy costs to human health, urban air quality is a serious environmental problem that affects the economic development of many countries. The preceding discussion has shown that one of the contributors to deteriorating urban air quality is transport-related. It would therefore be informative to review the Bank's urban transport portfolio to see whether the Bank is proactively addressing this growing problem, over and above the approach of "do-no-harm" (whereby the environmental implications of projects are considered through integrating environmental aspects into economic analysis, preparing proper environmental assessments, and introducing measures to mitigate negative environmental impacts).

This section presents a brief overview of air pollution management in urban transport projects—past and ongoing. In some cases there is a fair amount of overlap between transport and environmental objectives. For example, activities such as purchasing new buses to replace old fleets, replacing some bus service with a rail system, and improving traffic management to reduce congestion and increase road safety are all likely to contribute to improving air quality in the short term. When only those components with explicit pollution control objectives are classified as air quality components, for ease of disaggregating the total project budget, less than 1 percent of the total ongoing portfolios listed in Annex D can be said to directly target air pollution abatement. For the closed projects listed in Annex C, the share increases to 27 percent because of the inclusion of the Mexico Transport Air Quality Management Project. If that project is omitted, the share falls to less than 0.5 percent. These numbers should not be overinterpreted, however, on account of the very narrow definition employed for classifying "air quality components" in the projects reviewed, for the reason given above. The overall impact on urban air quality of many of these projects is expected to be considerably higher than these percentages would indicate.

### *Closed projects*

During 1980–99, 19 urban transport projects were closed (see Annex C). Of these, only one, the Mexico City Transport Air Quality Management Project, was designed to reduce air pollution from the transport sector. It was the first Bank project to focus exclusively on supporting a comprehensive program to reduce air pollution in an urban area (Box 6).

Two other projects had an explicit environmental component: Chile Urban Streets and Transport, and Sri Lanka Colombo Urban Transport. Among the objectives of the Chilean project were to promote integration of the urban transport elements and to reduce congestion and air pollution. About 7 percent of the total cost was set aside for identifying and evaluating traffic management actions to reduce congestion and air pollution. This investment included two separate studies: identification and evaluation of traffic management actions that would effectively reduce congestion and air pollution in Santiago, and a feasibility analysis for a bikeway in the Greater Santiago Area (although

#### **Box 6. Improving air quality in the Mexico City Metropolitan Area through a comprehensive pollution reduction program**

The Mexico City Metropolitan Area (MCMA), the most populated urban area in Latin America, has a very serious air pollution problem. The city occupies an area of about 1,200 square kilometers and lies at an average altitude of 2,200 meters. Following the World Bank's first urban transport project there in 1989, the Bank decided to support a project with a comprehensive program to reduce air pollution in the MCMA. The project included measures to (a) reduce emissions of key pollutants from transport sources; (b) develop a policy framework to support both transport and air quality management objectives, including vehicle emissions standards, an improved I/M program, and regulations to phase out lead from gasoline; (c) improve the scientific basis underpinning the development and management of the air quality program; and (d) strengthen institutional capabilities to plan and implement air quality programs effectively over the long term.

During the implementation period of the project, vehicle emissions standards were revised, and the I/M system was modified, making it a centralized system consisting of high-volume, test-only centers. A gasoline vapor recovery program, part of the ozone control effort, was begun.

Mexico eliminated lead in gasoline in 1997. There are now 32 automatic air quality monitoring stations in Mexico City, supplemented by 19 manual monitoring stations. The Metropolitan Environmental Commission implemented over 100 measures for air quality improvement during the project period.

bikeways were not built under this project).

The Colombo Urban Transport Project in Sri Lanka procured air quality testing equipment. Automated, continuous air quality monitoring is currently being carried out.

### *The active portfolio*

Twenty-two urban transport projects were under supervision in fiscal 2000 (see Annex D). Nine projects have set aside some resources for specific air pollution mitigation measures. The amount for mitigation measures ranges from 0.3 percent (to review the ongoing I/M program in the Brazil Rio Mass Transit Project for vehicle emissions and noise and to propose corrective measures) to 8.5 percent (for constructing a vehicle emissions and noise laboratory and developing capacity for air quality modeling in the Brazil São Paulo Integrated Urban Transport Project). The air quality–related activities range from air quality monitoring (in, for example, Buenos Aires Urban Transport) to the design of I/M programs for vehicle emissions (the Belo Horizonte and Recife Metropolitan Transport Decentralization projects).

The active portfolio of projects initiated between 1992 and 1999 shows no observable trend in the amount allocated to investment in the air quality mitigation measures. Some recent projects, such as Brazil Salvador Urban Transport (1999), Vietnam Urban Transport Improvement (1998), and Turkmenistan Urban Transport (1997), have not allocated funds explicitly for air pollution purposes. Some of these projects, however, mention the positive urban air quality impact the project will have by improving traffic and vehicles through, for example, improving bus routes, replacing the existing bus fleet, retrofitting the current fleet with alternative-fuel engines, and implementing traffic management measures.

*Fuel.* The World Bank has taken several initiatives in fuel quality improvement, typically led by the environment and energy sectors and only rarely influencing urban transport projects. Urban transport projects may provide an opportunity to start a dialogue to support this goal. None of the active urban transport projects, except for the China Guangzhou City Center Transport Project, have attempted to address fuel quality issues such as the phaseout of lead from gasoline.

*Vehicle emissions standards.* Some projects have financed studies to prepare action plans for addressing vehicular air pollution in urban areas. The China Liaoning Urban Transport Project supports improvements in the environmental sustainability of project investments by developing and implementing a motor vehicle emissions control strategy, which is to include the establishment of an I/M system and a vehicle emissions research center.

*I/M.* The Brazil Rio Mass Transit Project has set aside US\$0.6 million for a study to design the I/M program in Rio de Janeiro. Two other projects in Brazil—Belo Horizonte Metropolitan Transport Decentralization and Recife Metropolitan Transport Decentralization—have I/M components under the environmental and safety component. The objective is to support the review of an I/M program for vehicle emissions and noise. Each project has allocated 0.2 percent of the total project cost for the I/M component.

The Bangladesh Dhaka Urban Transport Project, which has as one of its objectives the reduction of vehicular emissions, has allocated US\$1.0 million to assist in the vehicle I/M program by setting up a vehicle emissions laboratory. The project will use the results of annual roadside emissions checks on at least 3,000 auto rickshaws (three-wheelers) and 500 buses and trucks, starting in 2001, as performance indicators.

The Brazil São Paulo Integrated Urban Transport Project supports the construction of a vehicle emissions and noise laboratory, along with hardware and software, and the development of capacity for air quality modeling at CETESB (Companhia de Tecnologia de Saneamento Ambiental—the Environment Sanitation Agency). The expected result of this effort will be a fully operational emissions and noise laboratory and a functional I/M program in the city by 2001.

*Air quality monitoring.* Air quality monitoring is important for obtaining information on the spatial and temporal distribution of air pollution in urban areas. The Buenos Aires Urban Transport Project

includes a US\$4.1 million component for implementing an air quality monitoring system consisting of 13 fixed sites in the city of Buenos Aires. This system will be expanded into the surrounding areas of Greater Buenos Aires under the Argentina Pollution Management Project.

The Dhaka Urban Transport Project has set aside US\$1.0 million for assisting in air quality monitoring, which is being implemented in the Bangladesh Air Quality Management LIL.

The sustainability and optimal design of such monitoring systems is a major concern. A number of developing countries find that when (or even before) donor funds are phased out, they cannot purchase calibration gases, maintain equipment, or keep technical personnel who are capable of analyzing the data. For example, in one city, after the World Bank purchased air quality monitoring equipment, the counterpart agency was not able to maintain the equipment, and the number of monitoring stations had to be reduced to one. At that point the counterpart agency selected a heavily polluted traffic corridor as the location for the station rather than a site more representative of the exposure of the general public. This points up the importance of close coordination among different sectors—in this case transport, environment, and health.

*Pricing.* Two projects in Brazil—Belo Horizonte Metropolitan Transport Decentralization and Recife Metropolitan Transport Decentralization—emphasize the need to use appropriate pricing and parking policies to deter automobile growth in city centers. The argument is that any investment in public transport such as a light rail system is questionable unless the growth of automobile traffic is reduced and that such investment must therefore be accompanied by policies to create disincentives for the use of automobiles in the central business district. Similar recommendations have been made for the Budapest Urban Transport Project, where the proposal was to recommend the introduction of entry/use charges for motor vehicles in the inner city with a dual objective of traffic restraint and generation of funds. The city administration, however, has been instructed to reexamine the pricing issue before implementing the charges because of the sensitive nature of the political decision to be made in this process.

*Demand management.* Some projects have attempted to curb demand for polluting vehicles, through measures that can include an outright ban on such vehicles. For example, one of the agreements reached during the negotiation of the Dhaka Urban Transport Project was that the registration of additional two-stroke-engine three-wheelers would be discontinued.

Measures for traffic restriction have been proposed in other projects as well. Under the Budapest Urban Transport Project, for example, the municipality was committed to an active traffic restraint approach for the inner city and an environmentally oriented traffic-calming approach for noncentral zones.

*Nonmotorized transport.* A common theme in many of the urban transport projects reviewed is the promotion of nonmotorized transport. In the Dhaka Urban Transport Project, physical investments are being made to provide facilities for NMT. The indicators used to monitor implementation are the improvement of the NMT network, construction of secondary road links at three locations for NMT, construction of overpasses for NMT movement in three locations, and parking facilities for NMT on secondary roads. Similar efforts to promote NMT have been adopted in the Budapest Urban Transport Project. The strategy is to create a network of environmentally friendly zones across the entire urban area: people-only streets and zones, restricted traffic zones, and bicycle paths. The target under the project is to construct about 44 kilometers of bicycle paths in and around the city center. A similar NMT program in the Second Shanghai Metro Transport Project includes establishment of an exclusive 19.4-kilometer network of nonmotorized vehicle routes in and around the central business district.

## **Other relevant portfolios**

Dust is a serious health problem in most cities in developing countries. The paving of unimproved urban roads has helped alleviate this problem to a certain extent. Financial support for paving roads has typically been included in urban development projects rather than urban transport projects. A review of the 15 implementation completion reports (ICRs) for urban development projects file between 1990 and 1999 revealed that 5 of them included components to improve urban streets by paving unpaved roads and,

in some cases, by rehabilitating old, crumbling, dusty roads in urban centers. Most of the environmental benefits, however, are attributed to better traffic flow as a result of the repair of streets and sidewalks, the installation of street signs and traffic lights, and, in some cases, creation of bus routes.

Several other non-urban transport projects with urban air pollution components have been identified:

- The first phase of the Peru Transport Rehabilitation Project contained a major component for a pilot NMT program in Lima. Activities included the construction of bicycle ways, provision of low-cost credit for the purchase of bicycles, provision of low-cost bicycles, and education and public relation campaigns. The pilot, however, was not replicated in the second phase.
- Mexico Air Quality II (under consideration) would be a follow-up operation to the Mexico City Transport Air Quality Management Project. The objective is to help establish a consistent and integrated transport/air quality policy framework in the Mexico City Metropolitan Area.
- One objective of the Highway Sector Project in Croatia is to decrease road vehicle emissions by reducing lead in gasoline and eventually eliminating it. The project aims to make unleaded gasoline widely available at a price equal to or less than that of leaded gasoline.
- The primary objective of the Thailand Clean Fuels and Environmental Improvement Project is to support the reduction of air pollutants attributable to petroleum fuels in Thailand.
- One of the main objectives of the Argentina Pollution Management Project is air quality and noise management—setting up a network of air quality and noise monitoring stations and a motor vehicle emissions laboratory and certification center, developing an air quality management plan for Greater Buenos Aires, and strengthening the existing vehicle I/M program. Of a total project cost of \$36.0 million, almost half (\$15.1 million) has been set aside for this purpose.
- The Bangladesh Air Quality Management LIL is devoted entirely to urban air quality management. It has two principal components, of which the first is designed to reduce vehicle emissions by revising emissions standards and enforcement and establishing pilot programs for cleaner technologies, and the second deals with air quality monitoring and evaluation. The project focuses on Dhaka first and will then replicate some of the activities in other cities.

## Conclusions and Recommendations

Urban air quality management is a relatively new area of focus for the Bank. This paper has summarized some of the key technical and policy issues of relevance to the Bank's activities in the transport-environment-energy interface; summarized nonlending activities; and reviewed the urban transport portfolio, with an emphasis on air pollution management activities in projects. The following conclusions can be drawn from this assessment:

- The Bank has supported analytical work and nonlending activities that emphasize integrated approaches to urban air quality management. Linking these activities with lending specifically targeted to improving air quality, however, remains a challenge.
- Several urban transport projects have adopted “win-win” measures that reduce both congestion and air pollution, particularly through transport management. In general, however, interventions designed to improve urban air by reducing transport emissions do not feature strongly in the Bank's urban transport portfolio. The overall amount allocated specifically to air quality improvement objectives is typically around 1 percent of total project cost.
- Environmental measures in urban transport projects often include the introduction of air quality monitoring and vehicle inspection and maintenance. Experience suggests that the sustainability and optimal design of such monitoring systems are a major concern. In the face of widespread corruption, lack of adequate repair and service facilities, and poor cultural acceptance of regular vehicle maintenance, enforcement of existing vehicle emissions standards remains a serious challenge.

- The responsibility for many environmental regulations rests with the central government, limiting what can be achieved in the framework of urban projects. Most urban transport projects focus on local interventions such as improving traffic management, segregating nonmotorized transport routes, and strengthening local monitoring systems.
- Measures with explicit environmental objectives are not always assessed in terms of their cost-effectiveness, the presence of necessary conditions (such as fuels that match certain vehicle technologies), and linkages with policies in other sectors such as energy.

Because the transport sector is primarily concerned with improving people's lives and contributing to economic efficiency through better mobility and better access to transport services, the environmental implications of transport policies, as well as their social and equity implications, should be an integral part of sustainable transport strategies. On the basis of the above observations, the following recommendations can be made for the Bank's urban transport and environment strategies.

- *Properly implement environmental safeguard policies.* In most cases, proper implementation of environmental safeguard policies—on the basis of environmental assessments of projects and the execution of environmental management plans, where appropriate—is sufficient to ensure that urban transport projects do not cause undue harm to people's health and the environment.
- *Integrate environmental externalities into economic analysis of transport strategies.* The environment community has improved the analytical tools and methodologies for the economic assessment of environmental externalities, and such methodologies should be more widely used.
- *Focus on win-win measures.* Transport sector interventions should build on the synergies between reducing negative environmental impacts and reducing other negative externalities in the transport sector. Areas of such synergies include improvements in traffic and demand management, nonmotorized and public transport infrastructure, and fuel efficiency.
- *Improve the environmental outcome of projects.* Although most of the Bank's transport interventions are not primarily environmentally oriented, it may be useful to think opportunistically about what can be achieved through marginal adjustments to the projects for the benefit of the environment. The analogy is the concept of "global overlays," in which local and global pollution are considered together. How and where such a concept can be effectively utilized is an area that should be investigated.
- *Develop a proactive approach to improving air quality.* Although win-win measures have positive environmental benefits, improving the development effectiveness of Bank assistance would require a proactive approach, especially in areas where deteriorating urban air quality causes great social damage and constrains future growth. Such an approach could include the identification of cities in which air quality is a serious problem; agreements with national and city governments to work on solutions to the problem; strategic environmental assessments to identify key sources of pollution and cost-effective sectoral interventions; and a long-term framework for Bank assistance.
- *Coordinate among sectors.* The Bank should ensure that the policies it recommends in the transport, energy, and environment areas are technically sound and internally consistent. Areas for coordination include setting fuel and vehicle emissions standards and improving fuel quality monitoring and vehicle emissions inspection. Even the most modern engines will pollute a great deal if the gasoline with which they are fueled is adulterated with kerosene. Which fuel parameters to monitor, how often, by whom, and when are issues that the Bank is only now beginning to address.
- *Develop strategic long-term programs.* Urban air quality management involves interactions with a large number of agencies and stakeholders. In addition, a number of donors are increasingly active in this area in many of the cities in which the Bank operates. Coordination with various players requires significant resources. The Bank could lead such efforts in selected cases when

governments are committed, clear targets can be set, and proper monitoring of efforts can be undertaken. Programmatic lending instruments could be utilized for such efforts.

Some specific issues need to be considered:

- *Reassessment of air quality monitoring activities.* Attempts to introduce complex air quality monitoring systems have often failed in our client countries. In some cases it is recommended that only one or two pollutants be monitored, using the technology that the country has the technical capacity to operate and maintain. Air quality monitoring activities undertaken in urban transport projects should, in any case, be coordinated with the environmental authorities and with existing monitoring networks.
- *Identification of heavily polluting vehicles and design of cost-effective interventions that target them.* In most client countries, targeting gross polluters is likely to be an effective pollution reduction measure. Such interventions should consider a range of options, including incentives for regular repair and maintenance.
- *The institutional feasibility of pollution abatement measures.* While several pollution abatement measures may have promising potentials, the institutional aspects of implementing such measures in client countries have to be considered.
- *The social implications of pollution abatement measures.* Urban pollution disproportionately affects the poor, and improvements in living conditions therefore generally benefit them. Specific choices and strategies for pollution abatement, however, have direct and indirect impacts on the poor that have to be assessed.

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## Annex A. Key air pollutants

### *Lead*

In cities where leaded gasoline is still used, airborne lead poses a serious threat to human health. The largest body of observational studies on the health effects of lead documents its impact on children's intellectual development, typically measured in terms of intelligence quotient (IQ), and on behavioral problems. There has been much public health interest in this issue because of mounting evidence that continual exposure of children to even low levels of lead could have a negative impact on their intelligence. The World Bank has repeatedly called for the elimination of lead in gasoline in recent years and has been actively engaged in programs worldwide for phasing out leaded gasoline.

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

Although the effect of lead on children's IQ is probably the most significant impact of using leaded gasoline, there are other health effects. There is qualitative evidence that lead may adversely affect the reproductive process in men and women (as manifested, for example, in increased incidence of miscarriages), although below blood lead levels of 30 µg/dl the results are conflicting. Impairment of renal function has been correlated with blood lead levels above 35 µg/dl. The effect of lead on the cardiovascular system has been studied extensively. There appears to be a weak but positive association between lead in blood and blood pressure (WHO 1995).

### *Fine particulate matter*

In low-income countries the vehicle emissions problem tends to be dominated by emissions from old and poorly maintained heavy-duty vehicles that contribute to high ambient concentrations of fine particulate matter. Although diesel vehicles are associated with both fine particulate matter and NO<sub>x</sub> emissions, it is fine particulate matter that is of concern at this stage of development. In Asia the particulate problem is exacerbated by the widespread use of two-stroke-engine gasoline vehicles that use excessive amounts of poor-quality lubricant, which for these engines is blended directly into gasoline.

In terms of health impact, PM<sub>10</sub> and PM<sub>2.5</sub> are much more serious than total suspended particles (TSP), which include particles of all sizes. Coarse, wind-blown particles, for example, are believed not to have a significant effect on health. Recent studies indicate that the number of particles to which the individual is exposed could be more important than their mass. Particles from vehicles fall predominantly into the submicron range, and their small average size means that they are able to penetrate deep into the respiratory tract, especially into the alveolar regions of the lung. Animal studies indicate a potentially important role of ultrafine particles less than 0.05 microns (µm) in diameter. These particles are cleared only very slowly from the lung, and they can penetrate the pulmonary interstitium, inducing inflammatory responses.

A series of extensive studies, mainly in the United States, has demonstrated small changes in a wide range of health indicators—mortality, hospital admissions, emergency room visits, time off school or work, respiratory symptoms, exacerbation of asthma, and changes in lung function—that show clear associations with ambient particulate concentrations. Of the various health indicators, the measurement of mortality has been particularly well studied. Although the composition of PM<sub>10</sub> can vary widely from area to area and over time, the size of the estimated effects, especially those on mortality, does not vary greatly with location (Holgate and others 1999). The actual adverse impact of fine particulate matter on public health may be considerably greater in developing countries than existing data indicate; most studies have been carried out on urban populations in industrial countries who receive high-quality medical care and who do not spend as much time outdoors as some segments of the population in developing countries do.

There is a growing consensus that diesel exhaust poses a cancer risk.<sup>10</sup> This suggests that diesel particulate emissions are especially harmful to public health—a matter for concern, since the consumption of diesel far exceeds that of gasoline in many developing countries.

All combustion and metallurgical processes and many other industrial operations lead to the emission of particles into the atmosphere. Particles emitted directly from a source are termed *primary*; particles that are formed within the atmosphere, mainly from the chemical oxidation of atmospheric gases, are termed *secondary*. The largest contributor to fine particulate formation is incomplete combustion of fossil fuels and biomass. Poor fuel quality, inefficient combustion processes, and poor vehicle and equipment maintenance all contribute to particulate emissions. Transport contributes significantly to fine particulate emissions. In the United Kingdom road traffic sources are responsible for only 25 percent of PM<sub>10</sub> but for 60 percent of PM<sub>0.1</sub> (particles smaller than 0.1 μm). Gasoline engines also contribute a rather high share of the smaller particles. If health concerns become more focused on the smaller particles, further pressure to reduce vehicle emissions from gasoline engines, as well as diesels, can be expected.

Nonexhaust particles can contribute significantly to overall particulate emissions from the transport sector. The factors affecting the total level of nonexhaust particulate emissions include:

- Tires and their interaction with different road surfaces
- Wear of brake linings on vehicles
- The operating characteristics of vehicles, such as their speed, acceleration, and loading
- Type of road (paved versus unpaved)
- Ambient weather conditions (for example, temperature, rain, and wind).

The US EPA gives emission factors of 0.001 and 0.008 gram of PM<sub>10</sub> per kilometer traveled from tire wear and wear of brake linings on cars, respectively. A recent emissions inventory study in the United Kingdom indicated that tire wear and brake linings contributed 1 percent and 7.5 percent, respectively, of total primary PM<sub>10</sub> emissions from vehicles. The Swedish National Chemicals Inspectorate estimates that tire wear releases approximately 40,000 tons of polycyclic aromatics as PM<sub>10</sub> across Europe each year, amounting to one-fifth of current exhaust particulate emissions from gasoline and diesel vehicles. The health impact of these nonexhaust particles is expected to be serious because they are typically very small, with an average aerodynamic diameter of just 1 μm for bitumen particles. Tires use a blend of natural rubber (latex and dry sheet) and synthetic rubber. There is, reportedly, growing evidence of a relationship between the incidence of asthma and the concentrations of natural latex protein particles in the atmosphere resulting from the abrasion of tires and roads.

Since the early days of paved highway construction, rubber has been added to modify asphalt. Its release into the atmosphere following abrasion by vehicle tires increases the concentration of rubber particles in the atmosphere. Unpaved roads create a different problem, the significant resuspension of road dust.

It is difficult to quantify the impact of nonexhaust particles on overall ambient concentrations. In particular, emissions factors for dust resuspension by traffic on roads are virtually absent. The US EPA's a formula for calculating emissions from this source is based on old measurements made near exceptionally dusty roads. While these may be more typical of road conditions in developing countries, more data need to be collected. This is clearly an area to which the World Bank should pay increasing attention.

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<sup>10</sup> The advisory board to the U.S. National Toxicology Program has recommended that diesel exhaust particles be listed as "reasonably anticipated to be a human carcinogen." The California Air Resource Board (CARB) has officially recognized that some elements of emissions from diesel engines are carcinogens. Japanese scientists claim that they have found 3-nitrobenzanthrone to be one of the most carcinogenic substances ever discovered; emissions of 3-nitrobenzanthrone increase markedly when a diesel engine is operating under high load.

### *Carbon monoxide*

Carbon monoxide (CO), a colorless, odorless gas, is a product of incomplete combustion of fossil fuels. In most cities gasoline-fueled vehicles account for the bulk of CO emissions. CO inhibits the capacity of blood to carry oxygen to organs and tissues. People with chronic heart disease may experience chest pains when CO levels are high. At very high levels (far in excess of the ambient CO levels typical of those from vehicle emissions), CO impairs vision, manual dexterity, and learning ability and can cause death. The level of CO emissions can be reduced by incorporating oxygenates into gasoline for old vehicles and by using oxidation catalysts to oxidize CO to carbon dioxide. Although CO levels may exceed the guidelines recommended by the World Health Organization (WHO) in some cities, the extent of exceedance is typically not nearly as much as that for fine particulate matter, especially in countries where the consumption of gasoline is relatively low compared with that of diesel.

### *Oxides of sulfur and nitrogen*

Sulfur oxides (SO<sub>x</sub>) are products of the combustion of sulfur-containing fossil fuels. SO<sub>x</sub> contributes to acid rain, which is a regional air pollution problem, and to the formation of secondary particulate matter. The amount of sulfur emitted is directly proportional to the amount of sulfur in the fuel and is reduced by treating the fuel itself (for example, by hydrotreating diesel and gasoline). Sulfur dioxide (SO<sub>2</sub>) causes changes in lung function in asthmatics and exacerbates respiratory symptoms in sensitive individuals. Where significantly elevated levels of ambient SO<sub>2</sub> are found, the SO<sub>2</sub> is much more likely to come from the combustion of coal than from the transport sector. In countries where coal is rarely used, the available data suggest that ambient SO<sub>2</sub> concentrations tend to be low. For example, in Pakistan, where the limit on sulfur in diesel is among the highest in the world and where diesel consumption is several times the consumption of gasoline, measured airborne SO<sub>2</sub> levels are low. (Monitoring procedures, however, need to be checked for quality control.)

Nitrogen oxides (NO<sub>x</sub>) are formed during combustion as nitrogen in the air reacts at high temperatures with oxygen. The amount of NO<sub>x</sub> formed can be reduced by controlling the peak combustion temperature (for example, by recirculating exhaust gas in vehicles), by reducing the amount of oxygen available during combustion, or by converting NO<sub>x</sub> to nitrogen and oxygen-containing inorganic compounds after its formation (for example, by installing three-way catalytic converters for gasoline engines). Nitrogen dioxide (NO<sub>2</sub>) causes changes in lung function in asthmatics. NO<sub>x</sub> contributes to acid rain and secondary particulate formation and is a precursor of ground-level ozone. Both diesel- and gasoline-fueled vehicles contribute to NO<sub>x</sub> emissions. In developing countries ambient NO<sub>2</sub> concentrations are often below the WHO guidelines but are on the increase.

### *Ozone*

Ozone is responsible for photochemical smog and has been associated with transient effects on the human respiratory system. Of the documented health effects, the most significant is decreased pulmonary function in individuals taking light to heavy exercise. Photochemically reactive VOCs and NO<sub>x</sub> are two main precursors of ozone, and gasoline-fueled vehicles are a significant source of VOCs. Ozone abatement is complicated by nonlinear interactions among ozone precursors. In developing countries ambient ozone levels are often below the WHO guidelines but are rising.

### *Airborne toxics*

Toxic emissions from vehicles include benzene, polycyclic aromatics, 1,3-butadiene (a potent carcinogen), and aldehydes. The WHO lists acetaldehyde, benzene, diesel exhaust, and polycyclic aromatics as carcinogens and provides guidelines for ambient concentrations. The WHO also provides guidelines for formaldehyde and several aromatics (toluene, xylenes, and ethylbenzene).

## Annex B. Diesel certification in California

The importance of understanding how different fuel compositions can meet the same vehicle emissions standards can be seen in a California program that targeted NO<sub>x</sub> emissions and diesel fuel composition. California issued specifications for diesel fuel that set a maximum permissible level of 500 wt ppm for sulfur and 10 percent for aromatics. In addition, the state offered an alternative method for certifying a diesel fuel; the NO<sub>x</sub> reduction produced by the fuel was to be the same as for a California reference fuel run in a Detroit Diesel Series 60 engine. The California reference fuel controlled many more parameters than the specification, as shown in Table B-1. Also shown in the table are four alternate diesel fuel formulations that are equivalent to the California reference in NO<sub>x</sub> reduction. The four alternate diesel formulations are much less costly to produce (because they require less severe hydrotreating) than the California reference.

**Table B-1. Diesel formulations certified by the California Air Resource Board**

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

a. With cetane-improvement additives

In 1997 the environment ministry in one country proposed diesel specifications that were essentially identical with the composition of the California reference fuel. Had the proposal been accepted as new diesel specifications, the cost to the country of meeting the specific vehicle emissions standards would have been much greater than necessary, and in the event of a shortage of diesel, it might not have been possible to import diesel with the required composition. Some policymakers in developing countries appear to have the mistaken notion that, ultimately, they should be targeting 10 percent aromatics in diesel.

## Annex C. Closed World Bank projects in the urban transport sector

<i>Country</i>	<i>Project</i>	<i>Cost (US\$ millions)</i>
Brazil	São Paulo Metro Transport Decentralization (1992)	281.0
Brazil	Urban Transport Rail II (1980)	312.8
Brazil	Third Urban Transport (1981)	257.0
Brazil	Fourth Urban Transport (1987)	468.2
Chile	Urban Streets and Transport (1989)	150.0
China	Liaoning Urban Infrastructure (1991)	126.2
India	Calcutta Urban Transport (1980)	121.7
Indonesia	Regional Cities Urban Transport (1987)	88.1
Indonesia	Jabotabek Urban Development (1988)	223.9
Ghana	Urban Transport (1993)	87.0
Jamaica	Kingston Urban Transport (1984)	29.7
Jordan	Amman Transport and Municipal Development (1983)	65.6
Kazakhstan	Urban Transport (1994)	42.4
Korea	Seoul Urban Transportation (1985)	204.6
Korea	Taegu Urban Transport (1988)	145.7
Mexico	First Urban Transport (1987)	294.9
Mexico	Transport Air Quality Management (1993)	1,086.7
Sri Lanka	Colombo Urban Transport (1993)	25.3
Tunisia	Second Urban Transport (1984)	82.46

## Annex D. Ongoing World Bank projects in the urban transport sector

<i>Country</i>	<i>Project</i>	<i>Cost (US\$ millions)</i>
Argentina	Buenos Aires Urban Transport (1997)	400.0
Bangladesh	Dhaka Urban Transport (1998)	234.2
Brazil	São Paulo Integrated Urban Transport (1998)	95.1
Brazil	Rio Transport Decentralization (1993)	272.0
Brazil	Rio Mass Transit (1997)	373.0
Brazil	Belo Horizonte Metropolitan Transport Decentralization (1995)	197.3
Brazil	Recife Metropolitan Transport Decentralization (1995)	203.8
Brazil	Salvador Urban Transport (1999)	308.0
China	Second Shanghai Metro Transport (1993)	657.1
China	Guangzhou City Center Transport (1998)	550.0
China	Liaoning Urban Transport (1999)	384.0
Colombia	Bogota Urban Transport (1996)	141.0
Egypt	Greater Cairo Urban Development (1988)	91.0
Hungary	Budapest Urban Transport (1995)	67.1
Kenya	Urban Transport Infrastructure (1996)	155.0
Korea	Pusan Urban Transport Management (1995)	365.4
Mexico	Medium-Size Cities (1993)	471.1
Russia	Urban Transport (1995)	304.0
Senegal	Urban Transport Reform (TA) (1997)	8.7
Turkmenistan	Urban Transport (1997)	38.3
Venezuela	Urban Transport (1993)	149.3
Vietnam	Urban Transport Improvement (1998)	47.2

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