



Reducing Air Pollution from Urban Transport

Companion

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Foreword

Urban air pollution from road transport is a growing concern in many developing country cities. With rising incomes, motorized transport is expected to continue to increase in the coming years, further threatening air quality. Poor air quality in turn has been shown to have serious effects on public health. The World Health Organization estimated that 650,000 people died prematurely from urban air pollution in developing countries in 2000.

The need to tackle air pollution from transport is widely acknowledged. But the menu of options available is varied and can be daunting. Are there key questions that should be answered to guide policymaking? Under what conditions are the different mitigation measures likely to achieve pollution reduction? Are there critical steps to be taken or underlying conditions that must be met, without which pollution reduction is unlikely? Which mitigation measures are robust, which may be implemented successfully, and which are still in the area of pilot testing?

This report is an abridged version of the full report and is intended as a companion to it. It was prepared to provide guidelines and principles for answering the questions above and other related questions. Given the varying nature of air pollution, pollution sources, and available resources, answers and even key policy questions will differ from country to country. Hence, the report does not attempt to provide precise prescriptions applicable to all circumstances. It rather draws on lessons from international experience to propose a framework in which policy selection and implementation should occur. The three sectors most closely linked to vehicular air pollution are environment, transport, and energy. The report places a special emphasis on how to coordinate policies across the three and how to reconcile their sometimes conflicting objectives and demands in order to achieve environmental improvement.

We hope that this report will stimulate and contribute to a discussion on how best to coordinate policies across different sectors to their mutual benefit in an environmentally sustainable manner.

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Abbreviations and Acronyms

CBD	Central business district
CNG	Compressed natural gas
CO	Carbon monoxide
CO ₂	Carbon dioxide
EGR	Exhaust gas recirculation
EU	European Union
GHG	Greenhouse gas
I/M	Inspection and maintenance (systems)
LPG	Liquefied petroleum gas
MTBE	Methyl tertiary-butyl ether (an oxygenate)
NGO	Nongovernmental organization
NO	Nitric oxide
N ₂ O	Nitrous oxide (a powerful greenhouse gas)
NO ₂	Nitrogen dioxide
NO _x	Oxides of nitrogen
PM	Particulate matter
PM _{2.5}	Particulate matter of size 2.5 microns or smaller in aerodynamic diameter, also referred to as respirable particulate matter or fine particulate matter
PM ₁₀	Particulate matter of size 10 microns or smaller in aerodynamic diameter, also referred to as inhalable particulate matter
SO ₂	Sulfur dioxide
TSP	Total suspended particles
U.S. EPA	U.S. Environmental Protection Agency

Units of Measure

g	Grams
g/kWh	Grams per kilowatt-hour
km	Kilometers
km/h	Kilometers per hour
kWh	Kilowatt-hours (a unit of energy)
ppm	Parts per million. 10,000 ppm is 1 percent, 1,000 ppm is 0.1 percent, and so on.



Executive Summary

Urban transport is essential to social and economic development. In the coming decades, the demand for transport will increase rapidly in developing countries with rising income. But motorized transport also carries social and economic costs, not least of which is its adverse effect on urban air quality. The costs of air pollution include reduced visibility and damage to vegetation and buildings, but by far the greatest cost is the damage to human health where the pollutant of most concern is fine particulate matter. In a number of cities, ambient concentrations of ground-level ozone are also rising; they are alarmingly high in some cities. Although not necessarily the most important source at present, transport's contribution to these harmful pollutants is increasing, necessitating a proactive policy to limit transport emissions.

Air pollution from motorized vehicles is a concern for agencies across many different sectors and affects the role of agencies in covering social needs that include mobility, safety, and public health protection. Thus, designing strategies to reduce air pollution from mobile sources calls for actions that are compatible with the primary interests of most, if not all, of the agencies and actors involved. Where there are trade-offs to be made, they should be discussed openly through political and consultative institutions.

Policies for environmental improvement in urban transport can broadly be categorized into those that target the technology of individual vehicles and their fuels, and those that are concerned with management of the urban transport system as a whole. Both approaches are equally important for effective air quality management and require actions at national and city government levels.

Improving Transport Technology

Appropriate, well-designed, and effectively implemented standards are a fundamental requirement, molding the behavior of vehicle owners in vehicle purchase, operation, and use. Vehicle and fuel standards are usually the prerogative of central governments. Modern vehicle technologies can lower emissions significantly, but some have demanding fuel requirements. In some cases, trade-offs, such as between two pollutants or between fuel economy and reducing pollutant emission, may have to be faced. The largest absolute gains in pollution reduction have typically been achieved through the first steps in establishing new standards. For example, going from uncontrolled to controlled vehicles, such as the adoption of the European Union emission standard Euro I, results in large emission reductions. For coun-

tries that have already taken these first steps, the immediate reduction of sulfur to 500 parts per million (ppm) affects all vehicles and yields high returns.

A key policy question is how quickly to move to much lower sulfur levels. The answer is to move in concert with the introduction of advanced vehicle technologies that can take advantage of low fuel sulfur levels. The benefits of ultralow sulfur fuels accrue primarily to advanced-technology vehicles; thus, a reduction to 50 ppm or lower should be accompanied by introduction of emission control technologies that take advantage of very low fuel sulfur levels. With that in view, the development of both maintenance capability and concomitant investment in the necessary emission control technologies are two important considerations.

Vehicles fueled by gas emit much fewer fine particles than those with conventional liquid fuel technology, but certain conditions need to be met for gaseous fuel programs to be sustainable and commercially viable. They include the existence of a natural gas distribution pipeline network; availability of gas priced competitively with conventional liquid fuels; and the technical capability to maintain gaseous-fueled vehicles, often fostered through management commitment and training.

Poor vehicle maintenance is a common problem. Where governments are committed to providing adequate supervision, automation, and audits, well-designed inspection and maintenance programs operated by the private sector can be effective.

Managing the Transport System

City governments are typically able to exert the most influence on transport-related air pollution through system-oriented measures including traffic management, regulation and control of public road transport, provisions for non-motorized transport and for mass rapid transit, physical restraints, parking policies, and road pricing and land use policies.

Traffic management aims to secure uninterrupted movement at free-flow speed with existing traffic volumes. A major component of traffic management is separating different traffic modes. Mixing public transport vehicles with other vehicle categories reduces the average speed of all traffic compared with what could be achieved if traffic were segregated. Public transport priorities, in the form of dedicated lanes or totally segregated busways, are essential to counteract the problems of mixed traffic. Fundamental to the successful implementation of traffic management measures is the establishment of a traffic management unit at the local government level with the consolidated authority and ability to plan and implement suitable traffic management schemes.

Because improved traffic flow encourages more or longer trips, traffic management is likely to be effective in reducing vehicular emissions only if supported by measures to restrain the generation of new traffic. Total transport demand can be restrained by urban planning ori-

ented to public transport, by pricing policies, by parking control, and by direct restraints on traffic movement—all in the context of an integrated strategy.

Bus transport can be an instrument for air quality improvement if bus occupancy is high and emission levels are reasonably low. This requires realistic fare and finance policies and efficient operational management; these can be achieved through well-managed competition. The cities that have most satisfactorily reconciled efficient and clean operations with low budget burden are those that have introduced orderly competition for franchises. This “competition for the market” allows the authority to control the main policy-sensitive variables—such as fares, environmental performance, and service structures—while mobilizing competition to get the desired level of service and at the same time limit emission levels at the lowest possible cost.

Non-motorized transport, including walking, is entirely emission-free but is frequently ignored or discouraged by policymakers. A more positive policy stance is required, involving a comprehensive package of measures. These may include segregated infrastructure, provision for modal integration with public transport, and promotion (particularly through safety and security campaigns).

Central governments can assist local transport system policies by supporting fiscal and trade policies. Fuel taxation serves multiple objectives that necessitate a package approach to transport taxation. Gasoline taxes should be above general tax rates and diesel taxes may also need to be increased, with the possibility of rebates for non-automotive uses. Import duties based on market value may discourage imports of new “clean” vehicles. Trade policies should discourage imports of “dirty” and older vehicles.

Considerations for Policymakers

Global experience is a useful guide, not least in educating behavior, but careful adaptation to local situations is critical because the nature and sources of air pollution differ from city to city. Where it is sensible to adopt measures from other countries, policymakers still need to establish a timetable for phasing them in. Whenever possible, they should work with, and not against, the economic incentives of various actors; seek to reduce subsidies that result in environmental damage; press for reform that increases sector efficiency and reduces the cost of emission reduction; and begin with decisions that bring easy wins.

Several recommendations can be made.

- **Institutional framework.** Central governments should establish a predictable and consistent policy and regulatory framework for urban air quality management. A specific agency should be given responsibility for securing coordination in urban air quality

policy within each metropolitan authority. Establishing urban traffic management centers, and involving police in system design and training for traffic management, can be especially effective.

- **Air quality action plan.** Affected stakeholders—private sector participants, different levels of government, and civil society—should be engaged in developing an air quality action plan to the extent possible. The incentives to comply are likely to be more powerful if the stakeholders have been involved in policy formulation.
- **Fuel quality and vehicle emission standards.** Standards should be realistically set, progressively tightened over time, and stringently enforced. A targeted, well-designed, and adequately supervised emissions inspection program can foster a culture of proper vehicle maintenance. For two-stroke engines, it can be relatively low cost and effective to promote proper lubrication practices for existing vehicles and to require new two-stroke engines to meet the same emission standards as four-strokes.
- **Public transport.** Transit-oriented urban planning strategies and balanced land use should be developed to reduce trip lengths and concentrate movement on efficient public transport axial routes. Priority should be given to buses in the use of road infrastructure, and the creation of segregated busway systems should particularly be considered, in order to improve and sustain environmental standards for buses. Competition for the market can also play an effective role in efficiency improvement and creation of incentives for raising environmental performance.
- **Fiscal policies.** Taxes, import duties, and vehicle licensing can be designed to discourage purchase and continuing use of polluting vehicles and engines. In many countries, raising taxes on automotive diesel should be considered. Separate vehicle charges based on vehicle weight, axle loadings, and annual mileage may also be justified. Free on-street parking should not be provided in congested areas, and subsidies to public off-street parking should be eliminated.
- **Non-motorized transport.** Provision for safe and comfortable walking, bicycling, and other forms of non-motorized transport can benefit air quality. Careful differentiation of traffic by type of road can reduce accidents and promote non-motorized transport for short trips.

Pollution from Urban Transport: The Context

Urban transport is essential to social and economic development. It enables movement of goods to markets and provides mobility to people for economic and personal activities. But motorized transport also imposes social and economic costs, one of the most important of which is the deterioration of urban air quality. In the coming decades, the level of motorization is expected to increase rapidly with rising income in developing countries, and so will the relative importance of urban air pollution from road transport. The costs of air pollution include reduced visibility and damage to vegetation and buildings, but by far its greatest toll is on human health—an effect felt especially by the poor who live near roads or work outdoors as street vendors.

Transport as a Source of Pollution

The six pollutants categorized as classical pollutants by the World Health Organization are shown in table 1. The magnitude of damage to health from air pollution depends on four factors: the toxicity of the pollutant, the concentration to which people are exposed, the duration of exposure, and the size of the population that is exposed. In industrial countries, health-based air quality standards are established and the ambient concentrations of all the classical pollutants are regularly monitored and compared to the standards to guide government action. In the case of particulate matter (PM), environmental agencies began by measuring total suspended particles (TSP), comprising particles of all sizes. However, health studies have demonstrated that smaller particles are more damaging. For this reason, many countries have moved to measuring PM_{10} (particles smaller than 10 microns, also known as inhalable particles) and, more recently in industrial countries, to $PM_{2.5}$ (particles smaller than 2.5 microns, also known as fine particles). The standards for particulate matter and ozone in industrial countries have been increasingly tightened in recent years in response to emerging epidemiological evidence that shows harm caused by exposure to even relatively low concentrations of small particulate matter. In addition to the six classical pollutants, air toxin emissions of concern in vehicle exhaust include benzene and polyaromatic hydrocarbons, both well-known carcinogens.

As table 1 indicates, pollutants can be considered as primary or secondary. Primary pollutants are emitted directly and include lead, PM, sulfur dioxide (SO_2), oxides of nitrogen (NO_x), and carbon monoxide (CO). Secondary pollutants are formed in the atmosphere from primary pollutants; the two most common examples are ozone, and PM from NO_x and SO_2 .

Urban air pollution has many components

Table 1: Principal Air Pollutants and Their Sources in Transport

Pollutant	Significance
Lead	Lead retards the intellectual development of children and adversely affects their behavior. At high levels, lead increases incidence of miscarriages in women, impairs renal function, and increases blood pressure. More lead is absorbed when dietary intake of calcium or iron is low, when the stomach is empty, and by children. Young and poor malnourished children are therefore particularly susceptible to lead poisoning. Lead emissions in transport are entirely from the use of leaded gasoline.
Particulate matter	The health effects of exposure to particulate matter include chronic bronchitis, asthma attacks and other forms of respiratory illness, and premature death from heart and lung disease. Diesel-fueled and two-stroke engine gasoline vehicles are two significant sources of PM emissions.
Sulfur dioxide	SO ₂ causes changes in lung function in persons with asthma and exacerbates respiratory symptoms in sensitive individuals. SO ₂ also contributes to acid rain and to the formation of small particles, called secondary particulates, through atmospheric reactions. The amount of SO ₂ emitted is directly proportional to the amount of sulfur in the fuel. Sulfur occurs naturally in crude oil and consequently is found in both gasoline and diesel fuel unless it has been removed.
Nitrogen dioxide (NO ₂)	NO ₂ causes changes in lung function in persons with asthma, contributes to acid rain and secondary particulate formation, and is a precursor of ground-level ozone. Vehicles emit nitric oxide (NO) and NO ₂ , which are jointly referred to as NO _x . NO _x is formed in high-temperature combustion, mainly from air in the combustion chamber.
Ozone	Ozone, the main chemical in photochemical smog, has been associated with lung function decrements, asthma attacks, other forms of respiratory illness, and premature death. Ozone is not emitted directly but is a secondary pollutant formed in the atmosphere through photochemical reactions of NO _x and volatile organic compounds.
Carbon monoxide	CO inhibits the capacity of blood to carry oxygen to organs and tissues. People with chronic heart disease may experience chest pain when CO levels are high. At very high levels, CO impairs vision, manual dexterity, and learning ability, and can cause death. The majority of CO emissions in transport are from gasoline-fueled vehicles.

In addition to pollutants that are directly damaging to health, transport is a growing source of greenhouse gas (GHG) emissions. Three primary GHGs from motorized vehicles are carbon dioxide (CO₂), methane (especially from vehicles fueled by natural gas), and nitrous ox-

ide (N_2O) for which vehicles with aged three-way catalytic converters are the major contributor. CO_2 makes up by far the largest proportion of GHG emissions from the transport sector. These can be reduced by cutting overall energy consumption, such as by switching to more fuel-efficient modes of transport and vehicles and to less GHG-intensive fuels.

Historically, lead and particulate emissions have been the two most damaging pollutants from urban transport. Gasoline-fueled vehicles are the only possible source of lead emissions among mobile sources; lead was added to gasoline universally until the 1970s as an octane enhancer. Since then, many countries have moved to ban lead in gasoline; in the near future transport will no longer be a source of lead emissions in most countries, including sub-Saharan Africa which is the last region of the world to switch to unleaded gasoline.

In contrast to the declining contribution of lead, particulate emissions from transport continue to be high in a large number of cities. Diesel-fueled and two-stroke engine gasoline vehicles are two important sources of particulate emissions (although contributions from four-stroke engine gasoline vehicles with no or malfunctioning catalytic converters should not be underestimated). The strongest evidence linking air pollution to health outcomes is the effect of small particles on premature mortality and morbidity. The consistent findings across a wide array of cities, including some in developing countries with diverse populations and particle characteristics, indicate that this association is robust.

Ozone concentrations tend to be on the rise in developing countries. The problem is already quite severe in some cities in Latin America, such as Mexico City, Santiago in Chile, and São Paulo in Brazil. NO_x concentrations are also on the rise in developing countries.

In many cities, motorized transport is a significant contributor to particulate air pollution. At the same time, the relative contribution of combustion—without use of emission control technology—of solid fuels such as biomass and coal as well as field-burning on agricultural land close to cities can be large in a number of developing countries. A strategy to combat air pollution will be more effective if an integrated approach addressing each distinct source is adopted, concentrating investments where the returns in terms of air quality benefits are greatest.

Where ground-level ozone is a problem, NO_x emissions from all vehicles and hydrocarbons from gasoline vehicles may be important contributors to ozone. Elevated ambient SO_2 concentrations tend to come from the combustion of coal much more than from the transport sector. Ambient CO concentrations can be high at certain “hot spots” such as traffic corridors and intersections, but CO is typically not a widespread problem in developing country cities (especially where the consumption of gasoline is relatively low compared with that of diesel).

Transport is an important contributor of some of the most harmful pollutants

Although not necessarily the largest source of air pollution now...

...its contribution is growing

Looking to the future, as incomes grow and other gross polluters either disappear naturally (domestic wood burning) or are controlled at the source (industrial pollution), the relative importance of mobile source air pollution is certain to increase in developing countries. In designing measures to improve air quality, both the current pollutants of concern and likely future trends must be taken into consideration. If, for example, ozone is within air quality limits but on the rise and the gasoline vehicle population is growing rapidly with rising household income, ozone may become a serious problem in the future unless steps are taken.

Urban air pollution is a multisector concern...

Several very different sectors are involved in policy decisions that affect the impact of urban transport on ambient air quality.

- *The urban transport sector* is primarily concerned with efficient movement of goods and increasing mobility of people, especially those from lower-income households. The sector is very fragmented both on the supply and the demand sides. Most transport actors—individual and corporate users of transport services as well as transport suppliers—are motivated by private benefit or profit.
- *The fuel sector* has the objective of supplying adequate fuels at reasonable cost. It tends to have only a handful of wholesale suppliers, but there can be many retailers, making control of fuel quality at the retail level difficult in many countries.
- *The environment sector* is concerned with mitigating the adverse health effects of air pollution from vehicles. In achieving this objective, it works with stakeholders not only in urban transport and petroleum, but also urban planning, welfare, international trade, and agencies setting fiscal policies.
- *The urban planning sector* is concerned with making the city economically efficient as well as environmentally attractive. It can affect air quality by designing cities to reduce the demand for motorized transport and improving traffic flow. Where measures raise the costs of providing cleaner transport, policymakers should guard against these costs falling disproportionately on the poor.
- *The trade and finance sectors* are more broadly concerned with transport as a facilitator of trade and as an important component of national and city budgets. International trade policy can affect the type of fuels and vehicles that are imported through regulations and tariffs, and domestic trade policy can influence the quality of fuels and vehicles manufactured domestically through competition in production.

The negative costs of air pollution are seldom paid for in financial terms by transport actors, and hence they tend to be discounted or ignored in the private decision-making process of transport users or supply agencies. The fuel sector may genuinely be unable to meet the costs of producing cleaner fuels in the short run. Urban planners may recognize the costs of air pollution but may face myriad other demands, while trade and finance sectors will rarely have urban environmental quality as their primary concern. Even the environmental agencies may have more pressing short-term environmental concerns than the air pollution effects of transport.

...but not always any sector's primary concern...

The various sector interests may sometimes be in harmony. For example, in the late 1990s, some petroleum importing countries found that unleaded gasoline was often cheaper than leaded gasoline on the international market. In response to such price trends, the government of Haiti moved to ban the use of leaded gasoline effective January 1999, thereby realizing health benefits from lead elimination without incurring additional costs.

...and sector policies are not always in harmony

Other urban air quality issues may not be so straightforward. Purchasing second-hand buses for public transport may help keep fares low, but can cause considerable pollution. Limiting vehicle age or specifying higher technology standards may reduce emissions but also increase fares, possibly restricting the mobility of those who struggle to afford higher fares.

It is therefore important to design strategies to reduce air pollution from mobile sources that call for actions that are compatible with the primary interests of most, if not all, of the agencies and actors involved, as well as in the social interest. Such actions will include better accounting and charging for environmental effects, as well as better arrangements for institutional coordination.

Policy Options

The primary environmental objective in urban transport is to reduce human exposure to harmful pollutants. This can be achieved by reducing ambient concentrations of pollutants arising from mobile sources, limiting the number of people exposed to elevated concentrations, and reducing the duration of exposure.

Air pollution from transport has many dimensions

Policies for environmental improvement in urban transport can be broadly categorized into those that target the technology of individual vehicles and their fuels—normally the prerogative of national government—and those that are concerned with management of the urban transport system as a whole—normally the responsibility of city governments. System-oriented measures include traffic management, regulation and control of public road transport,

The range of policy options is wide

provisions for mass rapid transit and non-motorized transport, physical restraints, parking policies, road pricing, and land use controls. Central government can support local system policies through taxes, import duties, and vehicle import policies.

A technology policy is fundamental and necessary...

Vehicular emission standards—and, to a considerable extent, fuel quality specifications (including consideration of alternative fuels)—must ensure that the reduction of emissions from individual vehicles be consistent with the technical and economic efficiency of those vehicles and their operation. Extensive inter-country consultation has taken place on fuel quality and vehicular emission standards. These discussions have led to considerable standardization, with the standards set by the European Union (EU) and the United States being followed by a large number of countries. The EU standards have evolved historically from Euro I (least stringent) to Euro V (most stringent); this latter is slated for adoption in the European Union at the end of this decade. The standards are being closely monitored in Central and Eastern Europe, the former Soviet Union republics, Asia, Africa, and some countries in Latin America; U.S. standards are being considered in other countries in the Americas.

...but is not sufficient by itself

The success of policies based on technical standards will obviously depend on the strictness of environmental regulations and enforcement. In that sense, transport system management is a necessary complement to a technology policy. But the importance of transport system management goes much further. Transport system management measures designed to achieve other objectives, such as reducing congestion, improving system efficiency, reducing accidents, or raising government revenue, do not usually have environmental improvement as their primary objective; however, they may have significant associated benefits or drawbacks in environmental terms depending on how they are designed. Policymakers could play an important role by managing the transport sector in such a way as to emphasize associated benefits for air quality. For example, segregated busways increase vehicle speed and yield travel time savings for passengers; they concurrently tend to reduce emissions per passenger kilometer.

While much of the policy debate in recent years has focused on how stringent fuel quality and vehicular emission standards should be and on the time frame within which to tighten standards, measures for system management are no less important. To be effective in the long term, such measures should provide incentives for individuals and firms to limit the pollution from existing vehicles and to avoid delay in adopting new and cleaner technologies and fuels. They should also equip public and private institutions with the resources and skills needed to monitor transport emissions in urban areas and take measures to reduce them. At the same time, they must foster the development of a sustainable transport system that manages total demand for motorized transport while moving goods and passengers efficiently.

Improving Transport Technology

Vehicle-level improvements are crucial for reducing aggregate emissions from urban transport. Setting and tightening standards is one of the first and most important steps in making individual vehicles cleaner. In order to fully realize and sustain the benefits of technical advances in vehicles and fuels, systemic changes are often needed in urban transport markets, maintenance practices, and even the country's trade regime. Vehicle-level and system-wide improvement measures are closely interlinked.

Environmental standards are a fundamental requirement...

At the individual vehicle level, all of the following can affect emissions: the type and quality of fuel used, vehicle technology, emission control systems, the state of vehicle repair, and vehicle tuning. These parameters can be adjusted to varying degrees and at varying costs to achieve emission reduction. Where the cost of adjustment is small or none, the logical questions are why such steps are not being taken by more vehicle owners, and how these low-cost measures can be further replicated. Where costs are significant, the question is twofold. The first is how to decide when such investments should be made; the second is how to establish an enabling environment that would accelerate the simultaneous adoption of improved fuel and vehicle technologies and vehicle operation and maintenance practices that support the new technologies.

...molding behavior in vehicle purchase, operation, and use

Fuel Quality Specifications

Most governments set standards for transport fuel quality. The emission levels of lead and SO₂ depend on the respective content of lead and sulfur in the fuel. The emissions of all other pollutants depend on fuel quality, vehicle technology, vehicle tuning, operating conditions, and vehicle speed and acceleration. As standards become more stringent, it is crucial to treat fuels and vehicles as a joint system. In addition to lead additives, parameters that may be controlled include benzene, sulfur, volatility, total aromatics, olefins, and oxygen. They all have different drawbacks and different ways in which they can be controlled:

Fuel standards should cover a range of parameters...

- *Benzene* is a carcinogen, and a fraction of benzene in gasoline is emitted unburned. Limiting benzene in gasoline is a very effective way of controlling benzene emissions, especially from vehicles not equipped with catalytic converters.
- *Sulfur* is found naturally in crude oil, and, unless it is removed during refining, gasoline and diesel will contain varying amounts of sulfur. Sulfur reduces the efficiency of cata-

lytic converters, which are by far the most effective means of reducing harmful pollutants emitted by gasoline-powered vehicles. Some state-of-the-art devices for exhaust control are extremely sulfur-intolerant, requiring the use of ultralow or “zero” sulfur fuels.

- *Vapor pressure* affects evaporative emissions. *Olefins* are strong ozone precursors, and lowering vapor pressure is one of the most cost-effective means of reducing the emissions of light olefins. Although ethanol has good anti-knock characteristics, it raises vapor pressure markedly when blended into gasoline, increasing the emissions of light olefins.
- *Aromatics* are a concern for two reasons. First, certain aromatics are strong ozone precursors. Second, aromatics as a group break down to form benzene in the engine, thus increasing benzene emissions.
- In vehicles with no oxygen sensors, the presence of *oxygen*—in the form of alcohols or ethers—can facilitate combustion, reducing hydrocarbon and CO emissions if the vehicle is running “rich” (a low air-to-fuel ratio). This is an advantage primarily in old vehicles that do not have catalytic converters and oxygen sensors. Alcohols and ethers have high octane, making manufacture of unleaded gasoline easier. These oxygenates also “dilute” other undesirable components, such as benzene, sulfur, aromatics, and olefins. Aldehydes—chemical compounds formed from alcohol combustion—are photochemically reactive and potentially contribute to ozone formation; they are also carcinogens. Contamination of groundwater with methyl tertiary-butyl ether (MTBE), an oxygenate and octane enhancer, has raised concerns in the United States and led to a ban on the addition of MTBE in gasoline in a number of states.

...but need to be associated with compatible vehicle standards...

Recent tightening of fuel quality specifications in industrial countries has been driven primarily to enable the use of advanced exhaust control systems to meet extremely tight exhaust emission standards. Used in vehicles without these control systems, the benefits of tighter economy-wide fuel quality standards would be markedly less and the relative costs of accompanying air quality benefits higher. In all cases, it is essential to introduce changes in vehicle and fuel standards in parallel and realistically.

...and supported by appropriate operational behavior

Although not directly related to fuel quality, the special case of two-stroke gasoline engines, typically used for two and three-wheeled vehicles in developing countries, should be mentioned. For two-strokes, a lubricant is added directly to gasoline, and loss of unburned lubricant to the exhaust gas stream is responsible for much of the particulate emissions. The situation is exacerbated when a cheaper but inferior-quality lubricant—so-called straight mineral oil, intended for use only in slow-moving stationary engines—is used instead of proper 2T oil. Particulate emissions increase further when excess lubricant is added in the mistaken belief that the extra lubricant would increase fuel economy or engine power or both. Adding

the correct quantity of lubricant with appropriate quality is a low-cost means of significantly reducing particulate emissions from two-stroke engine gasoline vehicles. If drivers are routinely adding excess straight mineral oil, switching to proper 2T oil may not cost them any more money if they simultaneously cut back the quantity to that recommended by vehicle manufacturers.

The characteristics of diesel fuel that are most relevant to air quality are density, sulfur, polyaromatic hydrocarbons, and cetane. Fuel properties—for example, density, aromatics, and cetane—are often intercorrelated and tend to move together. It is important to decouple fuel properties that increase or decrease together before attributing the effect of each fuel parameter on emissions. The impact of increasing cetane number on particulate emissions is engine-specific; in the majority of cases, cetane has little influence. Total aromatics generally have no impact on particulate emissions. Decreasing density as well as polyaromatic hydrocarbons reduces particulate emissions in older technology, high-emitting vehicles, but has little or no impact on modern, lower-emitting engines (Lee and others 1998).

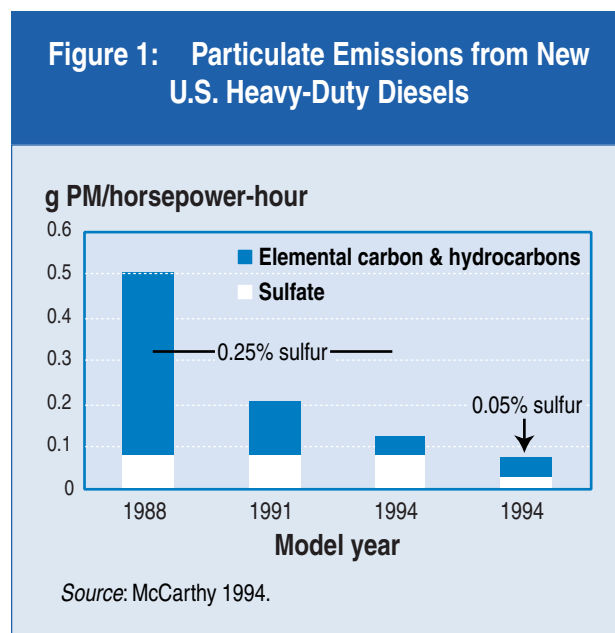
Diesel fuel typically contains more sulfur than gasoline. Sulfur is emitted as sulfate-based particles; in addition, SO_2 produced during combustion and emitted in the exhaust gas contributes to secondary particulate emissions through transformation in the air to sulfates. Total particulate emissions are not directly proportional to the sulfur content of diesel. Particles emitted consist mainly of elemental carbon, hydrocarbons, and sulfates. The relative proportion of these components can vary substantially depending on the engine technology, vehicle tuning, state of vehicle repair, and operating conditions.

Figure 1 shows the contribution of sulfur to total particulate emissions from new heavy-duty diesel vehicles in the United States. The data represent PM emissions of new diesel engines that are properly tuned and operated, so that differences among the data points reflect differences in the vehicle technology and fuel quality. The data do not include secondary particulate formation in the atmosphere from sulfur emitted as SO_2 .

Diesel characteristics affect particulate emission levels

Sulfur reduction diminishes particulate emissions directly...

Figure 1: Particulate Emissions from New U.S. Heavy-Duty Diesels



The reductions in PM emissions shown in the first three columns were achieved without improvements in fuel quality. The figure shows that vehicle manufacturers first improved engine technology which also reduced carbonaceous particulate emissions. By the 1994 model year, the majority of PM emissions were sulfate-based, so it would not have been possible to lower PM emissions significantly further without reducing the sulfur content of diesel fuel. At that point, the U.S. Environmental Protection Agency (U.S. EPA) lowered the maximum sulfur level permitted in diesel fuel from 0.25 percent, or 2,500 parts per million (ppm), to 0.05 percent (500 ppm).

**...and indirectly
by reducing its
own deactivating
effect on exhaust
control
technologies**

Sulfur reduction has another advantage. A number of exhaust control devices are deactivated by sulfur. For example, the hydrocarbon component of particulate emissions from diesel vehicles can be reduced by means of oxidation catalysts (which reduce the emissions of hydrocarbons and CO but not NO_x). Effective operation of such catalysts requires fuel sulfur to be no more than 500 ppm and preferably lower, because the effectiveness of a catalyst increases with decreasing sulfur. Another reason for limiting sulfur is that an oxidation catalyst oxidizes sulfur and contributes to sulfate-based particulate emissions to varying degrees, depending on the catalyst activity, so that higher sulfur could even increase, rather than decrease, particulate emissions.

**Reduction of
sulfur to 500 ppm
yields high
returns**

Lower sulfur levels reduce acidification rates and engine corrosion, potentially offering significant cost savings by increasing maintenance intervals and reducing maintenance costs. The largest benefits in this regard occur by reducing sulfur levels from thousands of ppm to 500 ppm. Acid formation is already low at 500 ppm, and prolonged engine life due to less corrosion is not expected when comparing 500 ppm and 10–50 ppm sulfur, though these levels are desirable for other reasons discussed below.

Several developing countries, including Mexico, the Philippines, and Thailand, have already moved to a maximum of 500 or 350 ppm sulfur in diesel. Others, such as Brazil, Chile, and India, have limited sulfur in large cities to 500 ppm or below while the rest of the country is supplied with higher-sulfur diesel, typically 1,500–2,500 ppm. Chile, for example, lowered the limit on sulfur in diesel to 500 ppm from 3,000 ppm in seven regions (out of 12 in the country) and to 50 ppm in the Metropolitan Region (which includes Santiago) beginning January 2005; this enables fleets to adopt the Euro IV emission standards in Santiago. All these countries are now looking at the cost effectiveness of limiting sulfur in diesel fuel to 10–50 ppm. In contrast, many developing countries are still using diesel fuel with a high sulfur content—in some cases, as high as 7,000–10,000 ppm (or 0.7–1.0 percent). In these cases, the impact on particulate emissions of lowering sulfur to 500 ppm can be considerable, especially if particulate pollution is characterized by a high proportion of sulfates.

For those countries with very high levels of sulfur in diesel, a minimalist approach to meeting Euro I or U.S. EPA's 1991 emission standards would require lowering sulfur in diesel fuel to 2,000 and 2,500 ppm, respectively. In some cases, this may be achievable at not much additional cost. Even where levels of sulfur in diesel fuels are very high, a strategy should be identified and implemented to reduce sulfur to 500 ppm or lower. In situations where reduction to 500 ppm is very difficult in the near term (for example, where reduction to 500 ppm entails refinery closure), immediate steps should be taken to lower sulfur to 2,000–3,000 ppm (including the import of cleaner blending components where appropriate).

The European Union and North America are planning, respectively, to move entirely to 10 (also called “sulfur-free”) and 15 ppm sulfur limits in diesel during the latter half of this decade. The purpose is to exploit new advanced technologies, which have extremely low tolerance for sulfur, for the reduction of exhaust emission from diesel vehicles. Such technologies include particulate filters (traps), NO_x adsorbers, and selective catalytic reduction (for NO_x control). These devices can make diesel vehicles as clean as natural-gas-powered vehicles. Ultralow sulfur diesel combined with particulate filters and other advanced exhaust control devices is collectively called “clean diesel,” in contrast to conventional diesel. A corollary of requiring diesel sulfur to be reduced to ultralow levels should be the simultaneous requirement that new diesel vehicles meet extremely stringent particulate emission standards through the use of particulate filters for PM control.

Reducing sulfur to 10–15 ppm requires expensive hydrodesulfurization processes, but investment costs are expected to fall with the increasing scale of application and experience. The incremental cost of producing ultralow sulfur fuels is generally the lowest in large-scale refineries. Where large refineries are being built or upgraded, countries should seriously consider investing in the necessary facilities to produce ultralow sulfur fuels, provided that there will be a market for these higher-cost ultralow sulfur fuels. Importing countries can take advantage of ultralow sulfur fuels as they become more available. For other non-importing developing countries, the cost effectiveness of mandating ultralow sulfur fuels should be compared with other strategies for improving air quality.

Alternative Fuels

Alternative fuels include gaseous fuels such as compressed natural gas (CNG) and liquefied petroleum gas (LPG), biofuels, and electricity. Without tax concessions, they are typically more expensive to use as automotive fuels than conventional gasoline and diesel. Justifications for their use include diversification of energy sources, environmental improvement, life-cycle reductions in GHG emissions, and—for biofuels—aid to domestic agriculture.

Returns on ultralow sulfur fuels accrue primarily to advanced-technology vehicles

A range of alternative fuels merit consideration

Gaseous fuels emit much fewer particles than conventional liquid fuel technology...

Gaseous fuels have a marked advantage over conventional diesel with respect to PM emissions. However, they have little environmental advantage compared to gasoline when used in vehicles with modern engines equipped with three-way catalytic converters. A switch to gaseous fuels can be achieved either by converting existing vehicles running on liquid fuels or purchasing new vehicles manufactured to use gaseous fuels. Vehicles can be made to run on both liquid and gaseous fuels or only on a gaseous fuel. Vehicles designed to run only on a gaseous fuel are preferable in terms of reducing emissions: engines converted or manufactured to operate on a single fuel (CNG or LPG) can be optimized for that fuel for best performance and least emissions. If they have to be designed to operate on both a liquid and gaseous fuel, their performance and emissions would be suboptimal with regard to one or both of the fuels.

...though conversion of existing vehicles may have some adverse side effects

Converting an existing vehicle is cheaper than purchasing a new dedicated gaseous fuel vehicle. In the case of vehicles previously fueled by gasoline, conversion to CNG typically results in a power loss of about 10 percent, which is not popular with consumers. Because CNG, LPG, and gasoline—but not diesel—use the same ignition technology, conversion of gasoline vehicles to a gaseous fuel is much easier than conversion of diesel vehicles. Experience with conversion of in-use heavy-duty diesel vehicles to CNG has been problematic. Poor conversions can increase, rather than decrease, emissions of pollutants other than PM. In cities where ambient ozone concentrations are high, increased emissions of NO_x , an ozone precursor, resulting from conversion from diesel to CNG can exacerbate the ozone problem. Poor conversion can also lead to safety hazards, as demonstrated by bus fires in some cities. Authorities should therefore develop and enforce strict regulations to control the quality of conversion. There is a particular danger that many small operators will enter the conversion business with little or no quality control. Programs to promote fuel switching to gas need to be implemented with a high degree of technical competence to avoid environmental and safety problems.

Purpose-built gas-powered vehicles may be more expensive

Because vehicles designed for gaseous fuels cost more than vehicles powered by conventional liquid fuels, they will be attractive to consumers only if the higher incremental cost of vehicle acquisition can be offset through lower maintenance and operational expenses. This is typically not the case when switching from diesel to CNG. Maintenance costs are often higher, so fuel costs would need to be very much lower to offset the higher vehicle acquisition and maintenance costs. Because diesel is not taxed much in many, if not most, developing countries, the price difference between diesel and CNG is often too small to make switching from diesel fuel to CNG financially attractive for vehicle operators. The usual trend is that fuel switching is predominantly from gasoline to CNG (or LPG), and seldom from diesel unless mandated. To achieve reductions in particulate emissions by switching to gaseous fu-

els, relative tax levels need to be set to encourage the substitution for diesel and not merely for gasoline.

Typical preconditions for successful implementation of CNG vehicle programs include the following:

- A natural gas distribution pipeline for other uses of natural gas is in place.
- Established and adequate safety and performance standards are monitored and enforced.
- A realistic plan to match supply and demand during the initial phase is in place. Adequate refueling infrastructure for the CNG vehicles is in operation, and a sufficient number of CNG vehicles, given the number of refueling stations, is in existence or is soon to be established. However, dedicated CNG fleets, such as a downtown bus fleet with private refueling facilities, can be successful without an extensive refueling infrastructure network.
- Managers of CNG fleets have made a commitment to provide technical support to deal with CNG-specific maintenance and operational issues not generally encountered with diesel vehicles.

CNG programs require certain conditions to be sustainable

Two commonly used biofuels are bioethanol from sugarcane or maize and biodiesel from plant seed oil. Ethanol has historically been used to accelerate the phase-out of leaded gasoline, most notably in Brazil. Today, most developing countries are lead free or will become so soon, thus limiting the potential environmental benefits of replacing lead additives with ethanol. As for particulate matter, gasoline-powered vehicles contribute much less to elevated concentrations of PM than diesel, thus limiting the contribution that replacing gasoline with ethanol can make to lowering particulate air pollution.

Biofuels have environmental advantages...

Biodiesel tends to reduce CO, hydrocarbon, and PM emissions and increase NO_x emissions relative to petroleum diesel. An extensive study by the U.S. EPA concluded that a blend of 20 percent biodiesel derived from soybeans and 80 percent petroleum diesel reduces PM emissions by 10 percent compared to pure petroleum diesel (U.S. EPA 2002).

Brazil is the world's lowest-cost producer of bioethanol and its industry is mature, having been established in 1975. Brazil has a number of factors in its favor for ethanol production: large land mass, good climatic and soil conditions favorable to sugarcane production, availability of adequate infrastructure, and the presence of a functioning capital market. Even so, the government of Brazil provides implicit subsidies to the ethanol industry. For example, hydrous ethanol—used in flex-fuel vehicles—is exempt from the fuel excise tax, amounting to some US\$0.19 per liter in early 2004. Every bioethanol program in the world has been, and continues to be, subsidized to the same order of magnitude or more.

...but generally remain expensive

Biodiesel is considerably more expensive to manufacture than bioethanol, and is unlikely to be a cost-effective means of improving urban air quality or reducing GHG emissions for the foreseeable future. Germany, the world leader in biodiesel production and consumption, provides a subsidy of US\$0.57 per liter for biodiesel, made largely from rapeseed oil. The United States began providing a subsidy of US\$0.26 per liter for biodiesel made from crops, principally soybeans, in January 2005. The income that can be derived from the global carbon market is likely to be on the order of US\$0.01–0.02 per liter of biofuel in the near future, which is significantly below the support that has historically been needed to cover the incremental cost of biofuel manufacture.

Electric trams and trolleybuses are best for high-volume activities; private automobiles may do best as hybrids

Electric vehicles are the least polluting at the point of operation. In battery configurations, they also have the advantage of allowing the recovery of some energy during braking. For public transport vehicles, direct collection of current by trams or trolleybuses is well established, with the limitations being the inflexibility of routes and the typically higher overall expense compared with diesel propulsion. Electric trains or trolleybuses are therefore most cost effective for fixed-route public transport operations on high-volume routes. For private automobiles, the development of cost-effective hybrids appears to be the most promising way of mobilizing the emission reduction advantages of electric propulsion.

Vehicle Technology and Emission Standards

Modern technologies can suppress emissions significantly

Enormous advances have been made in vehicle technology in the last three decades. Proven technologies for gasoline vehicles include three-way catalytic converters, positive crankcase ventilation (recycling back exhaust gases that escape past the piston rings into the crankcase), canisters for controlling evaporative emissions, electronic ignition, computerized ignition, and fuel injection. Three-way catalytic converters are the most effective means of reducing CO, hydrocarbon, and NO_x emissions from gasoline-fueled vehicles. More generally, three-way catalytic converters can be used when the air-to-fuel ratio is tuned “stoichiometric”: when there is just enough air to burn all the fuel. They cannot be used when the air-to-fuel ratio is “lean,” that is, when there is excess air. Because all diesel vehicles run lean, three-way catalysts cannot be used and NO_x control becomes more complicated. Diesel vehicles can use oxidation catalysts, which do not reduce NO_x but control CO and hydrocarbon emissions and which can function in lean operation. Proven technologies for diesel vehicles include direct injection, various forms of turbocharging, high-pressure injection, electronic controls, oxidation catalysts, and exhaust gas recirculation (EGR—a technology for reducing NO_x). Diesel particulate filters have been deployed in a large number of vehicles, and, in a few years, all new diesel vehicles in North America and the European Union will likely be equipped with them.

Some technologies for emission control have specific fuel requirements. Historically, the first such case was the requirement that no car equipped with a catalytic converter could be fueled with leaded gasoline, because lead acts as a permanent poison for the catalyst. Catalysts contain metals that are also easily deactivated by sulfur: the lower the fuel sulfur content, the more active the catalyst and the longer its life. Unlike lead, the poisoning effects of sulfur are reversible to a large degree for conventional catalysts. Historically, a rule of thumb for traditional catalytic converters has been a limit on fuel sulfur of 500 ppm; today, more advanced applications of catalysts are extremely sensitive to even trace sulfur, requiring that fuel sulfur be lowered to 50 ppm and preferably to 10–15 ppm.

Some have specific fuel requirements...

Other technological advances can be implemented without changing fuel quality. If such technologies carry associated environmental and financial benefits, they should be pursued as a first priority. An example is electronic fuel injection, which is one of the most important steps up the vehicle technology ladder. It also increases fuel economy markedly and reduces emissions, especially in higher-speed operations. As such, it is an obvious starting point for emissions improvements in all engines. Although electronic fuel control requires more sophisticated maintenance, fuel cost savings may quickly pay back the investment in training maintenance technicians. Electronic fuel injection is also a prerequisite for adoption of more advanced exhaust control devices, such as diesel particulate filters.

...while others can be effective with existing fuel quality

Manufacturers are constantly faced with trade-offs in developing new technologies. A classic example is between emission reductions and fuel economy. Another is between PM and NO_x control for diesel vehicles—for example, EGR reduces NO_x but increases PM, and not using EGR would mean resorting to much more sophisticated NO_x control measures. CNG vehicle manufacturers have debated between lean-burn technology and stoichiometric formulation. The former provides superior fuel economy but increases methane emissions and requires sophisticated emission control; the latter has a fuel economy penalty relative to lean burn but allows the use of simpler exhaust control technology.

Some important trade-offs may have to be faced in developing new technologies

Worldwide, emission standards for new vehicles have been tightened progressively since they were first introduced. Nearly all countries now set some type of emission standards for new vehicles. The most widely discussed are the Euro standards, referred to by number. Euro I was adopted in the European Union between 1992 and 1994, Euro II between 1996 and 1997, and Euro III in 2000. Euro IV standards are being promulgated in 2005–06, and Euro V will become effective from 2008. Fuel quality specifications have been changed to enable these emission standards. Many developing countries follow Euro standards with some time lag. In the United States, emission standards were first set in 1970 for gasoline vehicles;

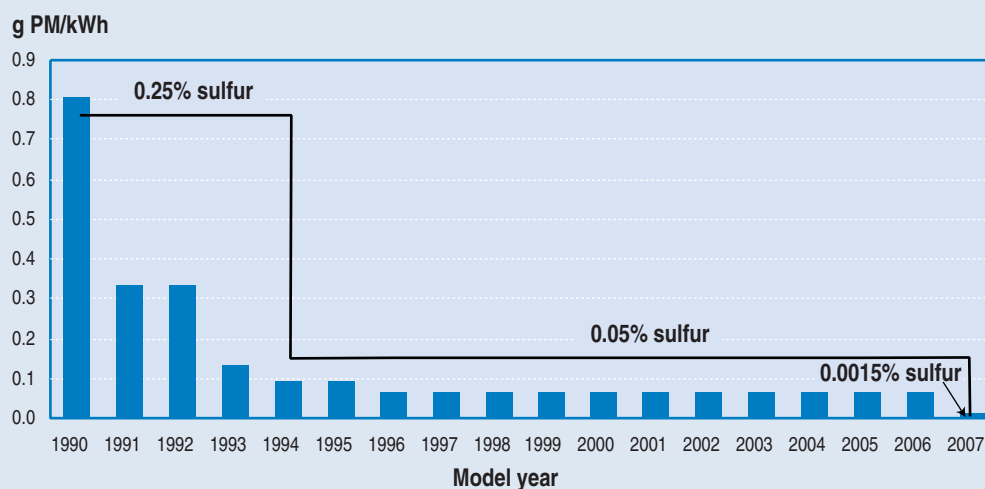
Emission standards can force the pace of technological development

standards for heavy-duty diesel engines (such as buses and trucks) were not introduced until 1989.

In comparing emission standards, it is important to note that U.S. and EU driving cycles—drive patterns that are used to measure emissions in vehicle certification procedures—are different. Transient driving cycles, where the vehicle speed is continuously changed during the test cycle, are more demanding than steady-state driving cycles where vehicles are driven at constant speeds. This is because emissions are higher during acceleration. Thus, meeting the same numerical emission standard using a transient driving cycle would require a cleaner vehicle than at a steady speed. Because the U.S. EPA has been specifying transient driving cycles for all vehicle categories for quite some time, U.S. standards have, until recently, been more stringent at comparable numerical emission limits. The European Union introduced transient driving cycles for heavy-duty vehicles for the first time for Euro III. In the United States, buses have historically been held to higher standards than trucks.

Figure 2 shows the evolution of PM emission standards for urban buses in the United States. Also shown in the figure is the diesel fuel sulfur requirement to enable compliance with the emission standard. In absolute mass, the largest reduction in PM emissions occurred between 1990 and 1991. The reduction was close to 0.5 grams (g) of PM per kilowatt-hour (kWh). The reduction between 1992 and 1993 was the second largest in absolute mass. Between 1990 and 1993, the aggregate reduction amounted to more than 0.65 g/kWh. Subsequent reductions are large in percentage terms but not in absolute mass. In many developing

Figure 2: U.S. Particulate Emission Standards for Urban Buses



Source: U.S. EPA 1997 and 2000.

countries, heavy-duty diesel vehicles are emitting at levels comparable to 1990 model year buses shown in the figure or higher. Considerable environmental benefits can be achieved by lowering emissions from these high levels to those equivalent to 1993 or 1994 model year; this is possible at a diesel fuel sulfur content of 0.05 percent (500 ppm), a limit that a number of developing countries have already adopted or set a timetable to move toward.

Enforcement of Standards

Establishing fuel and vehicle emission standards is an important first step, but such standards need to be effectively enforced to realize environmental benefits. The ease of fuel quality control depends on the number of sellers involved: the more sellers, the more fragmented the market, the more difficult to control quality. It is thus relatively easy to enforce fuel quality at the refinery gate because of the small number of refineries. Even enforcing the quality of imported fuels is not too difficult if there are only a handful of importers, which would be the case if fuels are imported by ship. However, where fuels are imported by land using numerous trucks, quality control becomes more difficult. If fuels are smuggled in, there is no control on fuel quality at the point of entry into the country whatever the mode of transport.

In most countries, fuel quality is most susceptible to being altered during distribution to retail outlets or at retail outlets, primarily through adulteration. Fuel adulteration occurs because there are financial gains arising from differential taxes or prices. From an environmental viewpoint, adulteration with heavier fuels is the most damaging. It increases deposits in engine cylinders and fouls injectors. For vehicles equipped with catalysts, premature catalyst deactivation can also occur. This means adulteration of gasoline with kerosene or diesel, and of diesel with lubricants or crude oil, is especially damaging. Contrary to popular perception, the addition of kerosene to diesel—which is a common malpractice in many countries where the price of kerosene is markedly below that of diesel—does not increase smoke emissions.

Identifying and checking fuel adulteration presents a difficult challenge in the face of enormous incentives to adulterate in some countries. An important step in tackling fuel adulteration is to reduce the incentives to engage in it. Government policies on fuel quality enforcement are likely to be most effective if they combine the reduction of incentives to adulterate with measures to detect and punish criminal adulteration. A number of analytical techniques are available to detect adulteration and require good sampling techniques and access to a sophisticated petroleum analytical laboratory. Because significant financial benefits are reaped by those engaged in fuel adulteration, anyone investigating it must have the direct protection of local law enforcement agencies when taking field samples. Given historical problems

Enforcement of standards is critical

Control of adulteration is a serious problem...

...which can be addressed through attention to institutional arrangements

with fuel adulteration in many developing countries, strong political will by sufficiently high levels of government needs to be generated before appropriate regulatory and enforcement steps can be taken.

The manner in which retail fuels are distributed has an important bearing on fuel adulteration. Having numerous small, independent fuel transporters or retailers can create an environment conducive to adulteration. An effective market-based approach is practiced in many industrial countries where oil companies are involved in retail sales and assume responsibility throughout the supply chain to guarantee fuel quality in order to protect their public image and market share. The guaranteeing of fuel quality by fuel suppliers has been introduced in some developing countries, such as the “Pure for Sure” program in India.

Poor vehicle maintenance is a significant problem...

Setting high emission standards will not achieve the desired emission reductions if vehicles are not well maintained. Particulate emissions can increase substantially where engines are underpowered or poorly maintained or adjusted. Black diesel smoke results from overfueling (the injection of diesel into the combustion chamber in too high a ratio of fuel to air), dirty injectors, and injection nozzle tip wear. Overfueling is a common phenomenon worldwide. It increases power output, although at the expense of fuel economy. Underpowered engines (which is what happens when a vehicle is overloaded, carrying much more weight than the maximum specified by the vehicle manufacturer) exacerbate the tendency to overfuel. Dirty injectors are common because injector maintenance is expensive in terms of both repair costs and losses stemming from downtime. Reducing fuel injection rates to match the fuel-air ratio with the manufacturer’s specifications and maintaining fuel injectors are relatively low-cost measures for emission reductions compared to adoption of more advanced vehicle technologies.

...requiring well-designed inspection and maintenance programs

To control emissions through proper vehicle maintenance for vehicles in use, a number of governments have introduced inspection and maintenance (I/M) programs. The underlying principle of I/M programs is to identify vehicles that are not in compliance with emission standards and to get them repaired or replaced. The challenge of establishing an effective inspection program should not be underestimated. All too often, I/M programs are little more than mechanisms to collect fines, often in the form of “informal” fines paid with little relationship to vehicles’ actual emission levels. There are, however, valuable lessons from a handful of successful cases in developing country cities, most notably Mexico City.

Experience in Mexico demonstrates that an inspection system is more likely to be successful when a small number of firms operate centralized, high-volume, test-only inspection centers. An accurate, computerized, and up-to-date vehicle registration system is an essential requirement for an inspection system. It is advisable to set emission standards for in-use ve-

hicles that are achievable, with some effort, by a majority of vehicles, but that effectively eliminate the worst polluters. It is better to set lenient standards that are strictly enforced and that are tightened over time than to set stringent standards that result in a socially unacceptable failure rate. Government must be committed to invest the resources, staff, and effort in auditing and supervising the program, and the program must be seen by the public to be fair and transparent.



A vehicle emissions inspection system using centralized, high-volume, test-only centers operated by private sector firms, as shown here in Mexico City, can be effective.

Other lessons include the following:

- It is important to have maximum automation of test procedures and results to minimize chances of human tampering.
- Test protocols, designed to be difficult to cheat on or bypass, should enable reproducible, accurate, and meaningful results to be obtained across different test centers.
- Numerous control measures should be adopted including audits of calibration and test procedures and real-time transfer to a central database of test results that in turn are automatically audited.
- A legal framework should be established to apply penalties to test centers found in violation of test protocols or engaging in fraudulent practices.

Imposing penalties, including revocation of the license to operate, is generally easier if the inspection centers are in the hands of the private sector rather than the government.

An inspection program cannot monitor engine tuning or operating conditions. For example, if it becomes known that overfueling increases smoke emissions and hence chances of failing the test, then owners of vehicles with underpowered engines will lower the fuel injection rate just for the test, only to adjust it back after the test. In one city during a trial inspection program, some drivers of two-stroke engine gasoline three-wheelers, upon learning that the lubricant in gasoline is responsible for smoke emissions, reported to the test center with no lubricant added to the gasoline. This greatly increased the possibility of damage to the engine but virtually ensured that their vehicles would pass the smoke test.

Vehicle Retirement Schemes

Where vehicles' pollution levels grossly exceed emission standards and remedial measures are very expensive, it may be sensible to introduce measures to remove them from operation. In some cases, incentives have been offered; in others, withdrawal has been mandated, typically in the form of age limits. Rigorously enforced emission standards could also achieve this for the worst offenders, possibly at the cost of hardship to the poorest old-vehicle owners. The guiding principle is to concentrate on high-usage, high-emission urban vehicles that would be kept operating for too long in the absence of a retirement scheme.

Financial incentives can help remove polluting vehicles

Three main types of incentives have been used to try to improve the average quality of vehicle fleets: (1) incentives to scrap without replacement (*cash for scrappage*); (2) incentives to replace with new, or less polluting, vehicles (*cash for replacement*); and (3) other fiscal and administrative devices that, although not offering direct financial incentives to scrap, operate through their impact on the scrapping decision (*indirect scrappage incentives*).

Experience shows that such incentives are not easy to design or implement. It is important to ensure that the vehicles actually be scrapped and not sold elsewhere—or else they may be sold in outlying rural areas, only to migrate back to cities. Identifying gross polluters that are not cost effective to repair is extremely difficult, and vehicle age is therefore often used as a proxy for high emissions in retirement schemes. One reasonable approach in countries that have been progressively tightening emission standards is to select age limits on the basis of when the emission standards for new vehicles were made more stringent. In this way, age limit decisions are based on the dominant forms of vehicle technology employed.

Age-based schemes should not discourage good vehicle maintenance

Mandatory retirement based on vehicle age unnecessarily penalizes those vehicle owners who have taken good care of their vehicles. Age-based retirement schemes are especially problematic if a given vehicle category has a large number of owners with different maintenance behaviors and driving patterns. Imposing a relatively low age limit—beyond which vehicles are not allowed to operate in the city or are even scrapped altogether—may actually discourage the practice of regular vehicle maintenance. If, on the other hand, the level of vehicle maintenance, as well as accumulated kilometers, is fairly uniform across a given vehicle category—for example, if all large buses belong to one public sector bus company—then vehicle age is probably a good indicator of vehicle emission levels. Even then, if the vehicles have been run down and poorly maintained because the fleet operator is cash strapped as a result of mismanagement, fare controls, or undue restrictions placed on its operation by government regulations, these problems need to be addressed in parallel.

The effect of any incentive scheme, whether it is to scrap or to replace, depends crucially on the vehicle market structure. Owners' response to financial incentives affects the entire vehicle market, and not just those who participate directly in scrappage or replacement schemes.

In cash-for-scrappage schemes, the size of the incentive is an important variable. The larger the bonus, the more vehicles are likely to be scrapped. However, if the oldest and most polluting vehicles are the first to respond, there will be diminishing returns from an environmental perspective as the scrappage bonus increases. Cash-for-scrappage schemes can be effective for private cars, but typically only if carried out on a relatively small scale and if the vehicles to be scrapped are carefully selected.

Cash-for-replacement schemes for scrapped vehicles often insist that a new vehicle be bought, since new vehicles embody cleaner technology—and the cleaner technology is likely to be longer lasting. However, attempts to force replacement by a new vehicle tend to be attractive to those who are replacing relatively young vehicles, such as high-income households and users of cars for business. Experience in Denmark, France, and Italy shows that only 10 percent of annual replacements involve replacing a car more than 10 years old by a new one. A scheme in Hungary that targeted old, highly polluting, two-stroke engine models and required replacement by a new model failed to attract many participants. Normally, a very large inducement is required to bring about the direct replacement of a significant number of very old vehicles with new ones.

Cash-for-replacement schemes may attract a higher take-up rate if replacement by second-hand vehicles also qualifies. But this has environmental benefits only if the emissions of the replacement vehicles are tested and shown to be significantly lower than those of the vehicles being scrapped. In Greece, the bonus was paid only if the replacement vehicle had a catalytic converter. Cash-for-replacement schemes can miss the worst polluters or, if the worst polluters are replaced by only slightly less-polluting vehicles, can yield marginal emission reduction benefits.

Despite these caveats, cash-for-replacement schemes can be successful if they target operators who normally keep their vehicles for long periods, ultimately replacing old vehicles with new, cleaner, and more efficient ones. Large fleet operators of buses and trucks may be especially good candidates for this reason. Scrappage-with-replacement schemes are thus most appropriate for large commercial fleets of heavy public transport and freight vehicles.

Cash for scrappage incentives can be effective for private cars

Cash for replacement schemes are more effective for commercial vehicle fleets...

...and all schemes need a supporting fiscal and regulatory environment

A number of other measures can supplement or support scrappage programs. The introduction and strict enforcement of environmental standards through an I/M program encourages owners to keep their vehicles in good condition and replace vehicles when it becomes increasingly expensive to meet the standards. Tax incentives can help. For example, the German and Hungarian governments give tax advantages for the purchase of lower-pollution vehicles. A variation is a reduction in import duties for cleaner vehicles and engines. Public transport franchising policies can be very important, particularly where buses are a significant part of the problem. Both in Santiago, Chile, and in Bogotá, Colombia, environmental objectives have been incorporated in municipal public transport policies. Both schemes recognized the need to maintain affordable public transport service. Environmentally oriented vehicle replacement requirements were incorporated in a broader scheme that ensured the continued financial viability of the operating agencies. The Bogotá case illustrates that forced scrappage of public transport vehicles can be effective in the context of well-regulated franchise systems.

Managing the Transport System

The contribution of transport to air pollution can be viewed broadly as the product of emissions per unit distance traveled and the total distance traveled. To lower these two factors and thereby reduce the adverse effect of urban transport on the environment, transport managers have a menu of options, such as limiting the number of vehicles on the road, optimizing traffic flow, improving the efficiency of transport operators and citywide transport systems, restricting traffic in heavily concentrated pedestrian areas, and reducing total demand for transport. Table 2 describes different measures that have been used and their potential effects on air pollution. Some measures fall directly under transport policy. Others do not: land use is in the domain of urban planning, fiscal issues are handled by the ministry of finance, and vehicle import policy typically falls under the ministry of trade or its equivalent. The remainder of this chapter discusses these options and their specific links to air quality.

There are many transport system management options

The driving pattern has a significant influence on emissions. Both fuel consumption and pollutant emissions are many times higher per unit distance during acceleration than during cruise. Engines are most polluting when they are cold, making short trips disproportionately polluting for PM, CO, and hydrocarbon emissions. The optimum steady speed from an emissions perspective is usually in excess of 60 kilometers per hour (km/h) and is rarely achieved in congested urban traffic. PM emissions from conventional diesel vehicles can rise exponentially below 20–30 km/h. These observations suggest that congestion worsens air pollution.

The driving pattern affects emissions markedly

Traffic speed and its variability are also affected by the extent to which different types of traffic are mixed and how traffic is managed. For example, mixing buses and other vehicle categories reduces the speed of both. Traffic mix is especially problematic when motorized and non-motorized traffic share road space. In Dhaka, Bangladesh, the presence of a large number of cycle rickshaws has historically made the operation of bus transport very difficult. Unnecessary stops and starts can be caused by uncoordinated traffic signals, contributing to higher fuel consumption and emissions.

Traffic Management

Traffic management aims to improve traffic speed with existing traffic volume. If traffic management can reduce the variability of traffic speed and locate major traffic flows—particularly congested flows—away from environmentally sensitive spots, it has the potential to improve air quality. It should be designed to ensure that improvements in the flow of motorized traffic not be achieved at the expense of safety and access of non-motorized traffic and pedestrians. The most common traffic management instruments are traffic signal control

Good traffic management is essential

Table 2: System-wide Improvement Measures and Their Effects

Measure	Link to air pollution
Traffic management	Traffic management can smooth out speeds of existing traffic volumes and reduce emissions. CO, hydrocarbon, and PM emission levels tend to fall, and NO _x emissions rise, with increasing vehicle speed. Stop-and-start driving, typical of congested traffic, increases total emissions of PM for the same distance traveled.
Regulation and control of public bus transport	Large buses with high occupancy can displace a number of small vehicles, potentially reducing both congestion and aggregate emissions. However, if buses are grossly polluting, and especially if they are under-occupied, then the impact on emissions or congestion or both could even be negative. Regulation and control of public bus transport can help make it clean, efficient, attractive, and affordable.
Mass rapid transit	Electric rail transport is very clean at the point of use, but expensive. More affordable alternative mass rapid transit—segregated busway systems, for example—can often yield substantial environmental benefits at much reduced cost.
Non-motorized transport	Provision for safe and comfortable walking and other forms of non-motorized transit can reduce the amount of short motorized trips, which are disproportionately polluting. Segregation of motorized and non-motorized traffic is important for environmental, safety, and efficiency reasons.
Physical restraint	Physical restraints on vehicle use may take the form of limiting use of vehicles on specific days or in specific areas. An effective policy, with a concomitant reduction in pollution, is likely to combine car restraint and public transport improvement.
Parking policies	Policies that combine limitations on the amount or location of parking space with high charges for long-term parking have been widely and successfully used in European countries, particularly to discourage commuting trips by cars. Strong regulation to limit on-street parking to locations where it has no effect on traffic flow is likely to reduce both congestion and the demand for motorized transport.

systems. Linking uncoordinated signals to create “green waves” can reduce both travel times and emissions by about 10 percent. Other devices include one-way street systems.

A major component of traffic management is separating different traffic modes. Mixing public transport vehicles, whether buses or auto-rickshaws, with other vehicle categories reduces the average speed of all traffic compared with what could be achieved if traffic were segregated. A bus journey in mixed traffic usually takes at least twice as long as an equiva-

Table 2: (continued)

Measure	Link to air pollution
Road pricing	Underpricing the use of transport infrastructure will tend to increase the number and length of automobile trips. Direct pricing of road use has a high potential in developing countries for generating local revenue and reducing congestion and air pollution. Options include direct pricing of road use such as tolls and congestion pricing. Examples of cities with congestion pricing include Singapore and, more recently, London.
Land use	Population density and city structure affect demand for transport. A low-density population with high dispersion of residential areas and places of employment would not only increase demand for transport but also make provision of accessible public transport services uneconomic. To control aggregate transport emissions, it would be helpful to develop a policy that increases, or at least maintains, the population density and favors the concentration of employment and retail activity in a central business district.
Fuel taxation	Fuel tax provides incentives for reducing the amount of motorized transport and encouraging the use of fuel-efficient vehicles. A large difference in gasoline and diesel taxes in favor of diesel could lead to inefficient consumption of diesel and even “dieselization” of light-duty vehicles that might otherwise run on gasoline. Fuel price subsidies also slow the adoption of more stringent fuel quality standards.
Vehicle taxation	Because fuel taxation does not differentiate between fuels used in urban transport and fuels used elsewhere (such as diesel in agriculture or long-distance rail transport), differentiation of vehicle taxes may be a sensible complement to fuel taxation to encourage cleaner technologies and as a way of implementing the “polluter pays” principle.
Vehicle import policy	Absence of restrictions on vehicle age or technology could encourage imports of old, unsafe, polluting vehicles. Import tariffs based on market value make new vehicle imports more expensive and could slow down vehicle renewal if the tariff rates are high.

lent car journey, making private cars very attractive. Auto-rickshaws offer point-to-point service at a relatively low cost (compared to four-wheel taxis), but add to congestion. Public transport priorities, in the form of dedicated lanes or totally segregated busways, are essential to counteract the problems of mixed traffic. Priority bus lanes are the simplest measures, but they are very difficult to enforce effectively. When buses in bus lanes are operated in the same direction as the main traffic flow, they are susceptible to invasion by other traffic. Operation against the direction of flow is more self-enforcing but can increase pedestrian acci-



Total segregation of bus lanes from the rest of the traffic, such as what was done for TransMilenio in Bogotá, markedly reduces both emissions and travel time.

dents. Totally segregated busways using central lanes, along with protected pedestrian crossings at stations, overcome the problems of accidents and of access to roadside premises associated with bus lanes. With good traffic management, segregated bus systems can produce both efficiency gains and environmental benefits without significantly increasing car delays. Segregated busways in Curitiba, Brazil, and in Bogotá, Colombia, are two of the most successful examples.

Traffic management requires careful institutional coordination

Although affordable by most countries, traffic management is not a guaranteed, one-shot cure for traffic congestion or air pollution. To be effective, traffic management measures need planning, implementation, and enforcement, as well as continuous political and institutional support. It is essential to create traffic management units at local government levels with the authority to plan and implement traffic management schemes. Police should be involved at this level also, to enforce new traffic regulations. But traffic management may fail to reduce air pollution if improved traffic flow encourages individuals to make more or longer motorized trips. Traffic management therefore is effective in reducing emissions only when combined with measures to reduce the generation of new traffic.

Public Transport

Bus transport can be an instrument for air quality improvement...

Public buses have a significant potential to reduce overall traffic emissions by reducing emissions per passenger. A well-organized, segregated busway system using large, clean buses, such as TransMilenio in Bogotá, can be an effective tool for sustaining environmental standards because it attracts passengers from both private cars and more polluting smaller buses. However, if buses run with too few passengers—which is rare in low-income countries but has happened in middle-income cities such as Santiago—then public bus transport could exacerbate congestion and increase aggregate emissions. Buses may also be heavily polluting if the bus operator cannot or will not reduce emissions through appropriate operation and maintenance practices.

The two criteria—that bus occupancy be high and emission levels be reasonably low—require both that bus companies offer services that are sufficiently attractive and financially viable, and that fares be affordable to users. High-quality service can be offered using very clean buses at a cost, but if that means raising fares, informal operators may enter the market using smaller, often very old and polluting, vehicles. If fares are capped but more stringent standards are imposed on traditional formal sector buses, operators may not be able to comply with the standards. Cash-strapped bus companies will have trouble maintaining buses properly and not be in a position to worry about emissions or passenger comfort. During the last decade, conventional bus systems have failed completely in many countries in Africa, Central Asia, and elsewhere as a result of governments' attempts to enforce simultaneously socially desirable fares and high-service quality without an adequate financial basis.

...but requires realistic fare and finance policies...

The key to avoiding the decay of traditional bus services and adverse effects on air quality is to improve the efficiency of the bus transport system at two levels: system-wide and at the level of bus companies. There should also be incentives for the supply of attractive and clean (that is, low emission) bus service. However, the combination of public ownership and statutory monopoly in most public sector bus companies provides little drive to improve performance. Against this background, commercialization and competition can provide incentives to improve efficiency.

...and efficient operational management...

Competition in bus transport is seen in some quarters as the enemy of environmental quality. It has been associated with excessive supply (as in Santiago until the early 1990s); the use of old, polluting vehicles (as in Lima, Peru, today); or dangerous operating practices (as in Delhi, India). Unregulated competition "in the market" can be dangerous, inefficient, and environmentally damaging.

But this is not inevitable. Institutional and regulatory reform to create orderly competition for franchises has improved performance and maintained public transport share in many countries. This "competition for the market" allows the authority to control the main policy-sensitive variables, such as fares and service structures, while mobilizing competition to get the desired level of service at the lowest possible cost. This type of franchising has shown reductions of between 20 and 40 percent in cost per bus kilometer and is now the preferred form of competition in large cities. The replacement of competition "in the market" by competition "for the market" in the central area of Santiago allowed the authorities to get the economic benefits of competition without environmental damage. This was accomplished by requiring that all buses in the fleet meet certain pollutant emission standards as a condition for holding any franchise and by using exhaust emission levels below the maximum as one of the criteria on which competitively tendered franchises are awarded.

...which can be achieved through well-managed competition

For competitive tendering to be effective, a franchising authority must be technically and administratively able to design and award franchises with sensible environmental conditions and to monitor performance—including vehicle emissions—effectively. There is now a wealth of experience in doing this, in both industrial and developing countries. Furthermore, effective competition is dependent on the commercialization or full privatization of the incumbent parastatal operator; this is because private operators will be at a disadvantage if they have to compete with an agency that can rely on deficit finance from its owner to ensure that it retain its position in the market. The cities that have most satisfactorily reconciled efficient and clean operations with a low budget burden are those that have developed effective competition, as in the example of Santiago in box 1.

Non-motorized Transport

Non-motorized transport is clean transport...

Short journeys, which typically account for a majority of trips in developing country cities, are disproportionately polluting. They are most suitable for walking and cycling, referred to collectively as non-motorized transport. Bicycles can account for as much as 50 percent of to-

Box 1: From Competition “in the Market” to Competition “for the Market”: Experience of the Bus Sector in Santiago, Chile

Between 1979 and 1983, both entry to the bus market and fares were deregulated in Santiago. The public sector operator was driven out of the market, and total capacity more than doubled. But by 1985, regular bus fares had tripled, and the average age of buses had increased from 7 to 12 years.

Competition concentrated on routes to the center of the city, which became congested and polluted by buses with too few passengers. Initial attempts to address these problems included banning 20 percent of the bus fleet from operation on each day of the week and banning buses more than 22 years old. But these measures gave little relief.

In the early 1990s, the government introduced a system of competitive tendering for franchises to operate buses on routes entering the city center, limiting the capacity. The fare offered was one main criterion in selecting franchisees; another was the environmental characteristics of the vehicles offered. Congestion, air pollution, and fares all fell dramatically. By the mid-1990s, improved service—an important benefit of competition—had been retained, while the drawbacks associated with competition had largely been eradicated. In the 10-year period between 1992 and 2002, the number of buses fell from 14,000 to 7,500, and the average age of buses from 15 years to 5 years.

Reform measures continue to be taken in Santiago. Those currently under way include rationalization of bus supply, especially during off-peak hours; requiring a minimum of Euro III technology for new buses; increasing use of segregated busways; and use of higher-capacity vehicles. These and other measures are anticipated to reduce particulate emissions by as much as 75 percent and NO_x emissions by 40 percent.

tal movements in some low-income countries in Africa and in many Asian cities. Unfortunately, in many developing country cities, walking or using other non-motorized forms of transport is so inconvenient and dangerous that even very short motorized trips are common.

Despite its advantages, the bicycle either tends to be neglected or is actively discriminated against. This is partly because the bicycle is considered by many governments in developing countries to be associated with poverty, and hence to be a mode that should disappear as incomes increase. In China, bicycles are increasingly viewed by government as a barrier to modern road transport and are consequently being banned from main roadways in many cities. Often this is being done without a consequent provision of alternative space for bicycles, or without adequate consideration for mobility decisions of displaced bicyclists. In Vietnam, bicycles are quickly being replaced by motorcycles as incomes rise in the major cities, giving high levels (and expectations) of individual mobility in those cities. There is a danger that the motorcycle is the first step in the direction of reliance on the private automobile, which would not be sustainable given the density of the central cities.

An environmentally friendly policy response, now being adopted in a number of industrial countries, is to view the bicycle as a suitable mode for shorter trips and to plan proactively to make it attractive. Eliminating impediments to non-motorized transport by providing adequate sidewalks and bicycle lanes and ensuring the safety of pedestrians and cyclists can discourage short motorized trips. This can reduce pollution and has the added advantage of reducing the number of deaths and injuries markedly—every year more than 1 million die in road accidents worldwide, over four-fifths in developing countries, and as many as 50 million are injured (*The Economist* 2004).

In practice, some of the earlier initiatives to re-establish the bicycle through provision of sections of bicycle track, as in Lima in the mid-1990s, have had limited success. This is because there are many necessary components to a successful bicycle program, including segregated infrastructure, provision for modal integration with public transport, promotion (particularly through safety and security campaigns), and other incentives. These elements should combine to enable a cyclist to undertake complete trips by bicycle without having to compete on the road with cars and other vehicles. Included in this comprehensive package of measures should be safe access for the cyclist to the same destinations as cars and buses. Long experience in the Netherlands and the increased bicycle use more recently achieved in Bogotá exemplify viable policies for making the bicycle attractive and sustainable as incomes rise.

...but is frequently ignored or discouraged

A more positive policy stance is required...

...involving a comprehensive package of measures

Transport Demand Management

Demand can be restrained...

Trip lengths can be shortened, nonessential trips discouraged, and private car use restrained through a range of pricing and administrative regulation measures.

...by public transport-oriented urban planning...

Demand for movement is derived from the demand to undertake activities at different locations. This demand can in principle be reduced by planning land use in ways that minimize travel requirements—and particularly private car movements—for a given level of activity. For a given urban population, the length and number of daily trips are closely correlated with the average population density in built-up areas and the spatial distribution of trip destination and origin.

Population density affects motorized trips for two reasons. First, for a given population, the higher the density and the shorter the distance between two points in general, the greater the number of people who can walk to work or shopping areas. Second, the higher the density, the easier it is to provide frequent and easily accessible public transport services, thereby reducing demand for private motorized transport.

It is easier to operate an efficient public transport system when the destination of the majority of trips is concentrated within the central business district (CBD) area. In cities where most jobs and retail shops are concentrated in the CBD (called “monocentric”), the share of trips using public transport tends to be higher than those where the CBD contains only a small fraction of the total number of jobs and retail shops. Even if a city moves toward the “right” structure, air quality may not improve—or may even worsen—if traffic is poorly managed in the CBD. High densities and monocentric city planning require appropriate public transport investment and rely more on efficient management and traffic law enforcement than lower-density and dispersed city forms. In South Asia, where urban densities have increased, the number of two- and three-wheelers has increased appreciably, in part because of their maneuverability in congested traffic. Given the large number of operators involved, these vehicles are difficult to control for emissions as well as for traffic management.

Urban planning can also play a useful role in controlling re-suspended road dust, which can account for a significant portion of suspended particulate matter. This problem can often be addressed by simple urban designs and landscaping that can be implemented at a small incremental cost in many road projects. Whenever possible, road projects should include provision for paving all sections of the road including sidewalks and, where paving is not practical, landscaping with trees that require no watering.

...by pricing policies...

Demand for movement is a function not only of the location of activities but also of the costs of movement. Any form of subsidy for transport, whether public or private, will tend to in-

crease trip length by broadening the range of locations at which it is affordable to satisfy particular demands. Tendencies towards increased road use can be corrected by the introduction of road congestion pricing or some proxy, such as high fuel taxation or parking charges; such measures may be essential to create appropriate long-term incentives influencing decisions on the location of activities and the distribution of trips. Direct pricing can include charges for entering or traveling within a designated part of the city experiencing congestion (typically the CBD), for use of selected road links, or for parking.

Where externalities of road traffic—both in the form of congestion and environmental impact—are substantial, the cost of road space to the road user is likely to be considerably below its marginal social cost. While physical restraint measures have hitherto proven more acceptable than direct charges for road use in both industrial and developing countries, their effectiveness appears to have been exhausted even in industrial countries. Several cities have introduced or proposed congestion charging systems. For example, congestion charging introduced in February 2003 in London appears to have been successful in shifting motorists to public transport and reducing journey times. Direct pricing of road use has a high potential in developing countries both for generating local revenue and for reducing congestion and air pollution.

Parking policies affect both the effective supply of road space and the demand for it. In many developing countries, vehicles are parked on both the highways and the walkways, reducing road space, inconveniencing non-motorized transport, congesting traffic, and increasing air pollution. Strong regulation limiting on-street parking to locations where it has no effect on traffic flow is likely to be the appropriate response.

...by parking controls...

Unfortunately, in order to reduce on-street parking, many cities and countries require all new developments to create enough off-street parking space to cater to all vehicles wishing to access the development. The logic underlying this is that as long as the costs of parking space are recovered through property rents, parking users can be said to be paying for the space allocated to parking. That can be a badly mistaken approach. Vehicles entering a city use both road space and parking space. The provision of off-street parking space may thus actually attract new traffic, thereby offsetting the gains from removing parked cars from the streets.

If road space is provided below cost, then parking—a jointly demanded good—should be charged more than its full costs in order to avoid excessive vehicle use of roads. For that reason, many industrial country cities use parking pricing and availability as a demand-restraint measure. The amount of parking in any area is then limited to the maximum level considered necessary to support an “optimal” amount of road use. Pricing and regulation of parking supply are used to implement this strategy, which also implies specification of maximum (rather than minimum) parking provisions for new developments. Parking strategies

for developing country cities should similarly be part of a comprehensive transport plan and, particularly in central areas of cities, should not necessarily aim at accommodating all possible vehicle parking demands.

...and by direct restraints on traffic movement...

Direct restraints on vehicle use have been used worldwide. The most popular measures, especially in developing countries, are schemes that limit use of vehicles on specific days according to their registration plate number. Such schemes have been introduced in Athens, Bogotá, Lagos, Manila, Mexico City, Santiago, São Paulo, and Seoul, both to reduce congestion and to improve the environment. They have achieved public acceptance as a demonstration of commitment by government to reduce congestion and air pollution, and have proved less difficult to enforce than might have been expected. In the short term, they have achieved their objectives (Bogotá reports a 20 percent increase in average travel speeds). If well designed to discourage peak use and coupled with public transport improvements, as in Bogotá, administrative restraint mechanisms can thus at the very least give a “breathing space” to develop more effective traffic restraint policies.

There are, however, obvious risks with this kind of policy. As observed in Mexico City, it may encourage an increase in the number of vehicles owned and induce more trips by permitted vehicles than would otherwise have been made. In particular, for the sake of having an additional license plate, it may encourage drivers to retain in operation old, high-polluting vehicles that would otherwise have been scrapped. Against this concern, Bogotá’s experience suggests that careful design of the system—for example, limiting the restriction to the peak time and making the proportion of nonuse days sufficiently large that it is difficult to evade by owning a single extra vehicle—may minimize the possibility of counterproductive behavior.

...all in the context of an integrated strategy

One aspect of restraint is particularly important. It is politically difficult to restrict the movement of private vehicles unless there is a viable alternative. Both theory and practical experience indicate that, at least with respect to trips to central areas, a sustainable policy is likely to include a combination of car restraint and improvement in public transport.

Fiscal Policies

Direct charges on emission outputs are not yet feasible...

Environmental externalities should be corrected for by taxing polluting goods, not by subsidizing non-polluting alternatives. The economic ideal for air pollution control would thus be a system of direct taxation on emission outputs. Unfortunately, for vehicles in use, the continuous measurement of emission levels and application of variable taxation levels are technically possible, but practically a long way off.

It is therefore necessary to devise the best proxy tax or taxes. Because many pollutants are emitted in rough proportion to the amount of fuel burned, fuel taxation is an obvious candidate. High taxation on transport fuels will encourage a reduction in trip numbers and trip lengths and will favor public over private transport modes. A high tax on fuel will also encourage the use of more fuel-efficient vehicles. But the level of congestion is an important factor in determining fuel consumption, and the fuel tax is not very efficient as a congestion charge.

...but taxation on inputs can be used as a proxy

In most countries, fuel taxation is the prerogative of central government, and taxes on hydrocarbons can account for as much as one-fifth of all central government tax revenue. These taxes are usually considered to be a reliable revenue source because fuel has a low price elasticity of demand and taxes can be collected cheaply. But they are usually expected to fulfill at least four functions:

Fuel taxation serves multiple objectives...

- **Revenue function.** They are primarily aimed at raising revenue for general (non-transport) expenditure purposes.
- **Road user charge function.** Taxes on transport fuels are often the primary means by which vehicles can be charged for using roads, and some part of fuel tax revenue is often earmarked for financing road provision and maintenance.
- **Redistributive function.** As part of central government policy, their redistributive characteristics can also be of great importance.
- **Environmental function.** In the absence of direct charges for air pollution, they may be expected to be a surrogate environmental charge.

It is clearly not possible to achieve so many objectives simultaneously and efficiently through a single tax. In the design of fuel taxes, compromises thus have to be made between the effects on government revenue generation, income distribution, the efficient use of roads, and air pollution. Although fuel taxes can strongly affect fuel consumption patterns, they have other significant welfare effects. For example, if taxes are raised high in the hope of performing all the functions above, such a move would affect the poor who will have to pay more not just for transport, but also for other basic goods, because of the impact of higher energy prices on the economy. This points to the need to address externalities from air pollution not through the single instrument of fuel taxes but through a combination of instruments. More precisely targeted alternatives to fuel taxes should be considered wherever possible. For example, differentiated taxes on vehicles should be considered as complements. Differentiation of annual license duties among vehicle categories is common. Where that is the case, it is sen-

...which necessitates a package approach to transport taxation

sible to consider the possibility of using differentiation of vehicle license duties to encourage cleaner technologies. Emission standards should also be part of that package.

Gasoline taxes should be above general tax rates

Absent any other direct charges for road use, pump prices of transport fuel should cover the fuel resource cost, the costs of road use (both road damage and occupation of road space), and some portion of the environmental costs associated with the fuel. There is thus a strong case for setting the gasoline tax above the general tax rate on commodities. Car ownership is concentrated in the upper-income groups in developing countries, and systems for direct taxation are weak; this makes a high tax rate on gasoline a very progressive tax. Relatively high taxes on gasoline can be economically efficient and attractive in terms of income distribution.

Diesel taxes may also need to be increased...

Tax policies for petroleum fuels should carefully consider, and minimize, possibilities for socially undesirable interfuel substitution. In the past, dieselization of light-duty vehicles has adversely affected urban air quality. While the most advanced diesel vehicle technology is very clean, dieselization in developing countries is likely to continue to have adverse effects on air quality in the near term. Minimizing socially undesirable fuel substitution is not the only objective in determining the differentiation between gasoline and diesel tax rates. In principle, users ought to pay the long-run marginal costs of road use. Many developing countries have poor-quality road systems because maintenance is underfunded. A fuel tax may be the most obvious and acceptable proxy for direct charging, especially when the revenues are transferred directly to a user-managed road fund. As wear and tear is caused primarily by diesel-fueled heavy vehicles, a tax on diesel might be an appropriate proxy for direct road maintenance charges. (The same argument applies to the tax levied on natural gas used by buses.) A diesel tax, however, does not accurately reflect the road deterioration caused by different vehicle categories and provides inefficient signals on vehicle size and weight. Even within the automotive diesel fleet, a tax on diesel should be supplemented by some charge on vehicle axle loadings, preferably levied on the basis of distance traveled.

Furthermore, from the point of view of air quality, diesel vehicles are typically more damaging than gasoline vehicles. This is especially true when comparing gasoline vehicles equipped with three-way catalytic converters, an increasingly common phenomenon as developing countries move to 100 percent unleaded gasoline. Heavy-duty vehicles worldwide run on diesel, but light-duty vehicles can run on either gasoline or diesel. For vehicles of comparable size, diesel vehicles are more expensive to purchase, but if diesel taxes are markedly lower, fuel cost savings can compensate for the higher purchase price of diesel vehicles. Diesel is especially suitable for vehicles used for high annual mileage. Nevertheless, diesel fuel should be properly taxed in order to reflect the marginal social damage caused by in-

creasing air pollution. This is likely to mean that, in nearly all developing countries, the tax on diesel would need to be raised to capture marginal social damage per liter of fuel.

One concern about increasing diesel taxes is the impact on the economy, and on the poor in particular. The share of expenditure on all fuels as a percentage of total household expenditure consists of direct consumption of fuels and indirect consumption through purchases of goods and services that have fuels as inputs. Direct consumption tends to be concentrated at the top of the income distribution for both gasoline and diesel. However, the indirect effect is more important for lower-income groups for diesel, because it is an important input to many goods and services purchased by the poor. Studies that have examined the impact of raising the diesel tax on household expenditures in developing countries have shown a modest regressive effect—that is, the total expenditures of poor households rise more in percentage terms than those of the rich when the price of diesel is increased, although these effects are small. Because of the significant impact of higher taxation on non-automotive uses of diesel—in rail transport, agriculture, and industry, for example—it may be sensible to give rebates on the higher diesel tax to industrial and agricultural diesel users.

...with rebates to non-automotive uses if necessary

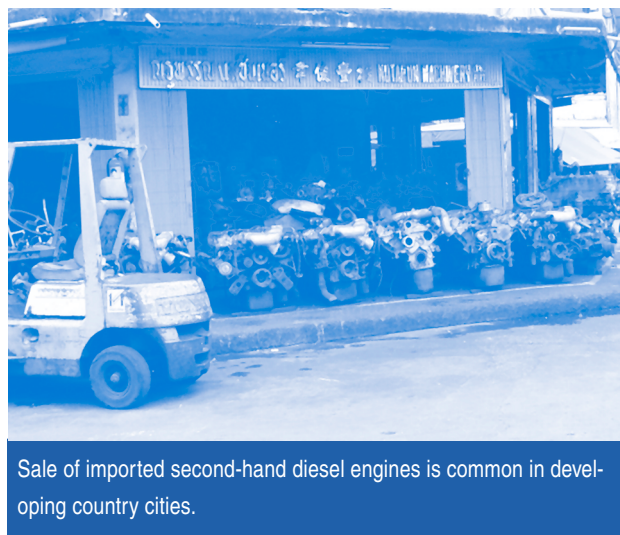
Import policies for vehicles can affect vehicle fleet characteristics. Import duties on vehicles are standard in developing countries. Usually, the level of such duties is motivated either by revenue maximization or protection of local manufacturers. In either case, the result is that duties typically are based on the market values of vehicles so that those on new vehicles are greater than those on old, and duties on sophisticated vehicles greater than those on simpler technology. This discourages imports of cleaner vehicles. The impact on air quality should be borne in mind when determining the structure of duties on vehicle imports.

Import duties based on market value may discourage import of “clean” vehicles...

Any measures that protect a domestic auto industry, such as quantitative restrictions on imports, are likely to delay the introduction to the domestic market of cleaner vehicles utilizing more advanced technology. In the absence of any restrictions and import duties that do not depend on vehicle age or technology, imports of second-hand vehicles and engines, especially for commercially operated vehicles (such as delivery vans, buses, and trucks), become common. Where import duties are markedly higher for fully assembled vehicles than parts that will be locally assembled subsequently, second-hand engines (all too often of unknown quality) and chassis tend to be imported for local assembly. Establishing and enforcing meaningful emission standards for imported second-hand vehicles or vehicles locally assembled from imported second-hand engines would be extremely difficult, especially for diesel-fueled vehicles, and is not done in developing countries.

...and trade policies may encourage replacement by “dirty” vehicles

Differentiated age restrictions can worsen rather than improve air quality depending on how they are structured. In Sri Lanka, diesel vehicles carry higher import duties than gasoline ve-



Sale of imported second-hand diesel engines is common in developing country cities.

hicles, but the age limit has historically been three for cars and five for dual-purpose vans, so there has been a steady shift from gasoline cars to diesel vans because five-year-old diesel vans are cheaper than three-year-old gasoline cars even after taking higher import duties into account.

Physical measures on imported vehicles should not place more restrictions on new vehicles than old. In some countries, importing second-hand engines and chassis

and putting new bodies on them is one way of bypassing emission standards for new vehicles. While maintaining control of type approval on new vehicle imports, efforts must also be concentrated on controlling imports of old vehicles or rehabilitated components.

Considerations for Policymakers

Urban air pollution, especially from elevated concentrations of fine particulate matter, has been highlighted as a serious public health concern for a number of years in developing countries. Transport is a significant and often growing contributor, and as such requires immediate attention. There is now a wealth of global experience to guide policymakers. The challenge is to distill useful lessons from other situations and adapt them to meet the specific local needs.

Identifying Priorities

In most cases, mitigation measures have immediate and noticeable financial implications for transport service suppliers or users or both. Where possible, cost-effectiveness analysis (and sometimes cost-benefit analysis) can be used in determining priorities. Locally available data should be exploited as much as possible in ranking priorities. Because data tend to be limited in developing countries, it is useful to facilitate research institutions and universities in generating data by providing them with funds and promoting collaboration.

Where large financial outlays are needed—for setting up segregated bus lanes, improving fuel quality, or upgrading vehicle fleets—one of the most important roles of the government is to create an enabling environment to accelerate adoption of these measures. Establishing a clear and transparent legal and fiscal framework is a first step. Phasing out protection or subsidies for the auto industry and in the downstream petroleum sector is essential for moving to cleaner technologies cost effectively. If the fuel and vehicle manufacturing sectors are inefficient, it is very difficult to tighten fuel quality or vehicle emission standards.

In countries with inefficiently operated domestic refineries or vehicle manufacturers, a further consequence of their protection is that consumers are denied access to cleaner fuels and vehicles that are available internationally—and that are often cheaper than their dirtier, domestically produced counterparts. A competitive market that does not give preferential treatment to some suppliers (often government-owned) reduces opportunities for corruption and provides a sound basis for attracting new investment. An effective and well-regulated competitive market imposes relentless pressure on participants to improve efficiency and to share cost reductions with customers. The government's primary role is as a regulator: to create and maintain a level playing field by ensuring that rules are fair and equally enforced on

Priorities must be carefully identified

Government must establish the proper enabling conditions...

...by creating an efficient and non-discriminatory regulatory framework...

all participants, and to provide reasonable consumer protection. Stability of regulations is equally important. If standards are announced only to be changed time and again, or effective dates are postponed at short notice, investor confidence is eroded and it becomes difficult to implement more stringent standards.

...recognizing the importance of quality...

While regulatory authority is in the hands of the government, it is more difficult for the government to influence what may be called the business environment. If shops receiving goods are not too demanding about the time of delivery and are concerned primarily about the delivery cost, then overloading trucks becomes attractive and preventive vehicle maintenance may be viewed as a luxury. If public transport fares are capped at uneconomically low levels without any compensating subsidy, then there will be inadequate resources for regular—let alone preventive—vehicle maintenance. Under these circumstances, the condition of vehicles deteriorates, and they are repaired only when broken, with the cheapest spare parts that will “fix” them sufficiently to start operating again.

...and providing adequate incentives

In many developing countries, the underlying conditions needed to promote improved maintenance, including effective enforcement of emission standards, do not yet exist. Government can use its fiscal and regulatory powers to ensure that individuals and firms see financial advantage in acting in more environmentally friendly ways. Several instruments need to be used simultaneously to this end. “Dirty” fuels and vehicles should be taxed more heavily than clean ones. Incentives can be given to purchase clean vehicles. Examples include exemption from annual emissions inspection for new vehicles and reduced road user charges or vehicle taxes for vehicles meeting emission standards ahead of schedule. Gradually enforcing and tightening emission standards will give vehicle operators and owners the incentive to pass emission tests and avoid penalties. Equally important, enforcement of standards will create demand for vehicle service and repair facilities with good diagnostic equipment and qualified technicians; these are in short supply in most developing countries. Raising public awareness is important to show that regular and preventive maintenance can be a cost-effective approach due to reduced downtime, and to encourage the public to demand higher-quality service and withdrawal of gross polluters from circulation. Consulting the key stakeholders who might be adversely affected is critical to all these measures.

Developing Institutional Coordination

Many agencies influence air pollution from transport...

Steps to tackle mobile sources of urban air pollution affect, and are affected by, a wide range of sectors and institutions. Transport, petroleum, environment, finance, and urban planning are among the sectors involved. A number of groups are engaged to varying degrees in policy formulation and implementation. They include the auto and oil industry; goods deliv-

ery and passenger service firms; vehicle repair and service industries; manufacturers of emissions measurement equipment; environmental nongovernmental organizations (NGOs); firms with their own fleets; private vehicle owners; municipal, state, and national governments; and regional trade organizations.

Air quality policy needs a high level of integration with, and within, the policy of agencies for which air quality may not be the central issue of concern. Integrated action within and among actors in different sectors is vital to optimal policy formulation. In some cases, the problem is simply a matter of lack of coordination; in others, there may be clear conflicts of interest between different ministries or agencies. At the national level, for example, the environment ministry may want a low tax on CNG, but the finance ministry may not want transport fuels to carry a low tax—especially if a low tax on CNG means large-scale switching from high-tax gasoline to CNG. It is important to encourage close collaboration among the national ministries of environment, transport, finance, and energy on air pollution strategy.

Central government has a variety of functions critical to the establishment and implementation of an air quality improvement strategy at the city level. First, central government is usually the only agency commissioned to set policy and standards for fuel and vehicles. Municipal governments may be able to impose tighter standards in some cases, but they cannot “relax” the standards set by central government—even if relaxation would mean much more effective enforcement in practice. Central government usually has the ultimate power in fiscal matters. There may also be a range of direct expenditures that, because of their public good characteristics, are likely to be undertaken only if centrally financed. These may include expenditure on environmental research, central laboratory facilities, and environmental education and information programs. Central government should accept the responsibility for encouraging clean air by having a policy on public expenditure related to its promotion.

Once standards are set, particularly if there is geographic differentiation with tighter standards for more polluted cities, state and municipal governments must act to implement them. Governments at these levels monitor air quality, emission and discharge levels, and fuel and lubricant quality; integrate air quality 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 cleaner technology and fuels, retirement of old equipment and vehicles, and other means of mitigating air pollution. Devolution of responsibilities may require the granting of some powers to local authorities to levy surcharges as part of local environmental policy or to be able to retain as local trading income the revenues of local road

...so institutional coordination is essential

Central government must lead by setting overall policies and standards...

...and municipal authorities must foster an integrated approach to urban air pollution management

pricing schemes. Where responsibility for urban transport is decentralized, appropriate fiscal arrangements should be made to facilitate local ability to meet those responsibilities.

Inter-jurisdictional collaboration should be promoted...

Fragmented responsibility between government hierarchies may also cause problems. If different cities with comparable air pollution and population exposure allocate varying amounts of funds for air quality monitoring and mitigation measures, then some large cities that have chosen not to allocate much funding for air quality monitoring could end up not collecting even basic data on ambient air quality. In the absence of such fundamental and critical data, it would be difficult for central government to set environmental standards. Standardizing equipment specifications and data collection procedures across major cities in the country, and ensuring that essential data be collected in very large cities, is critical to policy formulation at both the national and municipal levels.

...and arrangements established for conflict resolution

Problems arising from different objectives in different ministries and departments must be addressed. At the national level, such conflicts may be well aired and find their resolution in high-level cabinet decisions. At the municipal level, the police, city planning, transport, and other agencies are frequently less well coordinated. For example, the police may wish to give priority to cars at junctions to keep traffic moving, while the transport department may wish to give priority to buses to attract passengers to public transport. This type of conflict is accentuated where the police report directly to a central ministry rather than through the local authority structure. The paucity of adequate technical advice and the lack of effective political representation of some sector interests in mayoral decisions may also result in suboptimal resolution of such conflicts. One solution may be to establish a department or agency with comprehensive responsibility for setting a transport and land use plan, with air quality as one of its objectives, to which contributory technical functions (traffic management, public transport policy, road investment) must conform.

The division of responsibility between state and municipalities for the provision of bus services has inhibited coordination of services in large conurbations in some countries, of which Brazil is the most striking. Similarly, competition between independent municipal jurisdictions in continuous conurbations has often resulted in policies that may be to the short-term advantage of the individual jurisdiction but make all worse off when pursued by all. There are several institutional ways of confronting this. In a number of industrial and developing countries, there are single-purpose, conurbation-wide agencies for urban transport planning and management that have priority in strategic decisions over the separate jurisdictions. Others use formal consultation and collaboration arrangements. It is important to make the environmental effects of urban transport one of the responsibilities of urban transport and land use institutions even if another institution is responsible for air quality protection.

It is important to involve and consult the many private agents who make decisions on transport and who must have an incentive to comply with environmental policy. Incentives are likely to be more powerful if the agents themselves have been involved in policy formulation. Pressure from a vocal civil society can be harnessed to promote cost-effective mitigation measures when the needed sector reform and other measures are politically difficult, or where “the need for more study” is used to justify inaction. NGOs have played a critical role in influencing or driving the environmental agenda through, for instance, public pressure on the oil industry to phase out leaded gasoline and to assume more responsibility for the quality of the fuels sold at their franchised retail outlets, and on police to stop and fine heavily smoking commercial vehicles. Increasing consumer awareness about fraud in vehicle and fuel markets can motivate citizens to “vote with their feet,” taking business to those providing higher-quality service and products.

Wide consultation on policy measures can be highly productive

Setting an Air Quality Agenda for Action

Given the multiplicity of issues involved and the potential conflicts among agencies in addressing those issues, governments must have—and should make public—an explicit agenda for reducing air pollution from mobile sources against which actions can be checked.

Pulling together all the different considerations and issues is a daunting task, not least because conditions vary so substantially from one city or country to another. But some general principles for policy formulation can be stated:

An agenda should be based on some defining principles...

- Recognize the primary objectives of different sectors and promote sector objectives that will help achieve the environmental objective.
- Work with, not against, the economic incentives of various actors to the extent possible.
- Begin with those decisions that bring large benefits at the expense of compromising the interests of a small number of affected stakeholders rather than with decisions that go against the interests of substantial proportions of stakeholders.
- Press for sector reform that increases sector efficiency, benefits society at large by providing goods and services at lower cost, and at the same time reduces emissions.
- Raise awareness about business “best practice” that may also bring about environmental benefits to society.
- Seek to reduce, and eventually eliminate, subsidies that result in environmental damage.
- Set standards considered reasonable, in terms of costs and effort required, by the majority of society while making steady progress toward air quality improvement.

- Enforce the new policy uniformly and fairly to ensure a level playing field for all affected stakeholders.

**...from which
cost-effective and
robust policy can
be derived**

Following these principles, it is possible to identify a range of mitigation measures that have been found to be relatively easy or cheap to carry out, and that simultaneously address environmental and transport sector objectives. Many of these actions are robust in the sense that they are almost certain to be needed in order to have any reasonable chance of reducing the contribution of urban transport to air pollution.

**Cleaner fuels
need to be
phased in**

Many countries will not be able to afford or enforce the immediate application of the most stringent fuel quality standards to which they must ultimately aspire. But it is important for them to commit to a sequence of improvements that should include the following:

- Immediately eliminate lead from gasoline while ensuring that benzene and total aromatics do not rise to unacceptable levels.
- If these steps have not yet been taken, immediately identify and, as soon as possible, implement a strategy to reduce sulfur in both gasoline and diesel to at most 500 ppm as a first step toward lower levels.
- Examine the cost effectiveness of moving to fuel sulfur limits of 50 ppm or lower, taking into account maintenance capabilities and the concomitant investments in the necessary emission control technologies to exploit lower sulfur fuels.
- Where the resource and infrastructure conditions for natural gas are favorable and those for clean diesel technology are much less so, consider shifting high-mileage public transport fleets from diesel to CNG.
- Take steps to prevent fuel adulteration and the smuggling of low-quality fuels from neighboring countries, and consider holding fuel marketers legally responsible for the quality of fuels sold.

**Vehicle standards
should also be
progressively
tightened...**

The following measures are likely to be beneficial in most circumstances:

- Vigorously enforce emission standards for in-use vehicles that are considered achievable in fleets with good maintenance.
- Progressively tighten vehicle emission standards for new vehicles while ensuring consistency with fuel quality specifications.
- Set emission standards that would effectively require the installation and continued maintenance of catalytic converters on all new gasoline-powered vehicles (provided that lead in gasoline has been eliminated).

- Require that all new two-stroke motorcycles meet the same emission standards as four-stroke.
- Examine the cost effectiveness of carefully designed and evaluated targeted incentive schemes for scrappage or replacement of high-mileage gross polluters.

The government can also take steps to improve the general level of vehicle maintenance. These steps might include the following:

- Undertake education campaigns, such as on maintenance and lubrication of two-stroke engines.
- Develop a targeted, efficient, and effective vehicle inspection program through use of centralized, test-only, private sector centers using modern instrumentation, maximum automation, and “blind test” procedures; these centers would be subject to independent monitoring.



Campaigns to educate the public about proper vehicle maintenance and use of lubricant for two-stroke engines, such as one organized by motorcycle manufacturers in Bangkok shown here, promote cost-effective mitigation measures.

...and measures should be taken to develop a vehicle maintenance culture

Many of the technological measures require central government action. But city administrations can also take action to reduce air pollution. The following measures are likely to be beneficial in most circumstances:

- Implement bus priority or segregation systems to improve bus performance and attract a higher share of total urban movements to public transport.
- Implement fiscal or administrative devices to restrain private-car traffic in congested areas, particularly at peak times.
- Analyze the protocols for traffic signal system settings and implement and enforce coordinated settings giving reduced air quality emissions.
- Provide adequate pedestrian and bicycle facilities to discourage short-distance motorized trips and improve safety.
- Institute air quality audit of all new major infrastructure schemes.

City governments may adapt traffic management and planning to mitigate air pollution...

There are also indirect measures that could yield air quality benefits, but whose effect on air quality is less certain. They include developing transit-oriented urban planning strategies and balanced land use to reduce trip lengths and to concentrate movement on efficient axial routes of public transport, and the introduction of regulated competition for the urban bus market.

...particularly if supported by appropriate fiscal measures

These efforts need to be supported by a range of appropriate fiscal policies that may include the following:

- Setting efficient taxes on transport fuels
- Introducing tax, import duty, and vehicle licensing disincentives for polluting vehicles and engines
- Introducing direct charges for the use of urban road space
- Eliminating free on-street parking and subsidies to public parking where they affect traffic flow.

Institutional arrangements are the basis for sound policy

Whether at the national or city government level, institutional changes are usually necessary as the basis for effective policy formulation and implementation to reduce urban air pollution from transport. Such changes include the following:

- Assign responsibility for an effective air quality monitoring regime and invest in its implementation; invest in studies to apportion the sources of pollution contributing to elevated ambient concentrations, especially of PM, in large cities.
- Establish and enforce a clear, transparent, and stable legislative and fiscal framework for the auto and oil industry, thus creating fair and effective competition and a level playing field and allowing for the supply of clean fuels and vehicles at least cost.
- Make attention to air quality a statutory obligation of all the agencies involved with urban transport and vehicle and energy supplies.
- Develop and implement legal sanctions on fuel adulteration.
- Establish urban traffic management centers, involving police in traffic management system design and training.



References

The Economist. 2004. "Road Traffic Deaths." April 17–23: 102.

Gwilliam, Ken, Masami Kojima, and Todd Johnson. 2004. *Reducing Air Pollution from Urban Transport*. Washington, DC: World Bank. www.cleanairnet.org/cai/1403/article-56396.html.

Lee, Rob, Joanna Pedley, and Christine Hobbs. 1998. "Fuel Quality Impact on Heavy Duty Diesel Emissions: A Literature Review." SAE Technical Paper Series 982649. Warrendale, Pennsylvania: SAE.

McCarthy, Christopher I. 1994. "Update on the Effect of Government Regulations on Diesel Fuels." Presentation made at the 1994 NPRA (National Petrochemicals and Refiners Association) National Fuels and Lubricants Meeting, Houston, Texas, November 3–4.

U.S. EPA (U.S. Environmental Protection Agency). 1997. "Emission Standards Reference Guide for Heavy-Duty and Nonroad Engines." EPA420-F-97-014, September. www.epa.gov/otaq/cert/hd-cert/stds-eng.pdf.

———. 2000. "Final Emission Standards for 2004 and Later Model Year Highway Heavy-Duty Vehicles and Engines." EPA420-F-00-026, July. www.epa.gov/otaq/regs/hd-hwy/2000frm/f00026.pdf.

———. 2002. "A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions, Draft Technical Report." EPA420-P02-001, October. www.epa.gov/otaq/models/analysis/biodsl/p02001.pdf.

