Reduced fuel consumption per unit of movement can have direct benefits for reducing the emissions of harmful local pollutants such as fine particulates, and can also bring reductions in greenhouse gas (GHG) emissions. The main exceptions to this occur when measures to improve fuel economy are made at the expense of increased emissions of local pollutants (see discussion of “lean burn” in chapter 3, Vehicle Technology) or by shifting from gasoline to diesel.

There are several ways in which fuel consumption can be reduced. One way is to increase the inherent fuel economy of individual vehicles. Another is to encourage vehicle operation that minimizes fuel consumption. A well-known approach is to smooth out traffic speed so that for the same distance traveled, much less fuel is used. Shifting the mode of transport, such as from motorized to nonmotorized transport or from private cars to public transport, can also reduce fuel consumption. Promoting or protecting nonmotorized transport should generally result in significantly reduced fuel consumption and should be supported for equity reasons in any case.

### Improving Fuel Efficiency through Vehicle Technology

Vehicle technology options for improving fuel economy include increasing engine efficiency, decreasing vehicle weight, improving aerodynamics, and lowering rolling friction for tires. Fuel efficiency increases with increasing engine compression ratios. It also increases at a higher air-to-fuel ratio (lean burn), with precise injection timing, and anything else that increases the completeness of fuel combustion.

Switching from mechanical to electronic fuel injection is one of the most important steps developing countries can take to improve fuel economy.

Everything else remaining the same, lowering the vehicle weight (and hence decreasing the vehicle size) and power increases fuel economy. The principal reason fuel economy in the mainstream vehicle fleet in some industrial countries has not improved over the past two decades is that technological advances in energy efficiency have been overwhelmed by the trend towards increased power and speed of vehicles and the simultaneous shift to larger and heavier vehicles. In many developing countries, vehicle size and power are much smaller than in industrial countries, so that there is not much scope to reduce them further. Overall reductions in fuel consumption and emissions are possible in industrial countries and in developing countries in the future if motorists can be persuaded, and encouraged through fiscal policies, to accept reduced engine power and smaller vehicle size. Small vehicles must also be crashworthy, to ensure that there is not a serious trade-off between safety and fuel economy. Standards for new vehicles must be continuously reviewed and revised to take advantage of the technological potential to improve fuel economy and reduce air pollution.

A shift from gasoline to diesel for fuel economy reasons can have potentially negative environmental effects. Diesel is an inherently more efficient fuel than gasoline, and worldwide, future demand growth for motor fuels is anticipated to favor diesel, while demand growth for gasoline is expected to stagnate. Unfortunately, conventional diesel engines produce much more particulate emissions in mass than do...
gasoline engines. This can be overcome by the use of advanced control technologies and ultralow sulfur fuel. At the present time, PM control technologies are still emerging for light-duty diesel vehicles, and with heavy-duty vehicles, a number of preconditions must be met for the control devices to be effective (see Frequently Asked Question 5 on pages 44 and 45). Careful consideration should be given to the likely impact on particulate emissions when deciding whether to encourage a shift from gasoline to conventional diesel for fuel economy reasons.

Some governments have imposed fuel economy standards or negotiated them with the auto industry. The best-known case is the development of the corporate average fuel economy (CAFE) standards in the United States. Unfortunately, the CAFE standards have changed little since their inception in the 1970s, with improvements in technology permitting increased vehicle power rather than progressively reducing total fuel consumption and emission levels. Low fuel taxes have contributed to this trend. The lack of progress in U.S. fuel economy has been exacerbated by legislation that sets lower fuel economy and emission standards for light trucks—such as pick-up trucks, passenger vans, and sport utility vehicles (SUVs)—and by a large tax exemption on these vehicles for small businesses. As a result, the average fuel economy of all new vehicles in the United States peaked in the mid-1980s, and has declined since. The increasing fraction of light trucks in the total new vehicle sales, now exceeding 50 percent, has been the main cause. For light trucks with low fuel economy, there is no comparable “gas guzzler tax,” a graduated tax on new passenger cars based on fuel economy. Some of the largest SUVs are in fact classified as heavy-duty trucks. There have been cases where vehicle manufacturers increased weight ratings of some popular pick-up models to avoid fuel economy standards, or redesigned them to avoid being classified as light trucks (Wells 2003). It is important to minimize opportunities for vehicle manufacturers to exploit loopholes or act in an opportunistic manner in an attempt to circumvent fuel economy and emission standards.

In the EU, where fuel taxation is generally much higher, vehicle manufacturers entered voluntary agreements with the European Commission to reduce average CO₂ emissions from new passenger cars to 140 g/km by 2008 and to 120 g/km by 2012. The Commission confirmed at the end of 2002 that European manufacturers were on course to meet their target. However, by the end of 2003, available data indicated that European automotive manufacturers are unlikely to meet 2012 goals for CO₂ emission reductions. Monitoring figures showed that emissions increased from 164 g/km in 2001 to 165 g/km in 2002. As in the United States, this is primarily because of the trend towards larger and heavier vehicles with an emphasis on performance in terms of acceleration and top speed rather than fuel economy. The “performance race” of recent years lies at the heart of the problem. Manufacturers cited growing consumer demand for SUVs and higher vehicle weights associated with tighter safety standards as two primary reasons for this trend (Automotive Environment Analyst 2003a).

Among developing countries, the People’s Republic of China is planning to phase in minimum fuel economy standards on new cars beginning in July 2005. The proposed standards are reportedly much more stringent than those in the United States (Automotive Environment Analyst 2003b).

Lastly, it is important to bear in mind that travel demand has a tendency to increase as a result of a technical improvement in energy efficiency, and this is known as the rebound effect. As with traffic management discussed below, it is important to offset this tendency for increased travel resulting from improved fuel economy by the simultaneous introduction of demand management instruments.

**Increasing Fuel Efficiency through Vehicle Operation**

Poor vehicle maintenance and certain operational practices—such as overly retarded injection timing, not correctly inflating tires, or driving behavior characterized by sudden acceleration and deceleration—
lower fuel economy. Retarded injection timing increases fuel consumption under all circumstances. Low tire pressure increases vehicle rolling resistance causing higher engine power levels and increased fuel consumption by 5–10 percent, raising in parallel the emissions of NOx and possibly particulate matter. Some studies have reported fuel consumption differences of as much as 15 percent. Driver behavior also affects fuel economy: minimizing unnecessary braking, observing the speed limit, and avoiding excessively rapid acceleration can improve fuel economy by a few percent over normal driving behavior. It is possible to increase fuel economy by another few percent via optimal vehicle maintenance. Poorly maintained roads make it difficult for drivers to maintain a steady speed and lower fuel economy markedly. Further, if roads are in very bad condition, there may be an incentive for larger four-wheel drive vehicles or SUVs, even in situations where a small car might otherwise do. Overloading, a common practice in many developing countries, accelerates damage to roads. *Proper vehicle and road maintenance as well as proper vehicle operation can improve fuel economy significantly.*

In countries where transportation fuels are cheap, as in Turkmenistan or Venezuela, a recent report by the U.S. Congressional Budget Office on instruments for improved fuel economy may be informative. Examining three different approaches to decreasing fuel consumption by 10 percent, the report indicated that the cheapest and most effective path would be a substantial increase in the fuel tax. Simply raising the CAFE standard would be the most costly to consumers, adding an average US$153 to the cost of a new vehicle. Raising gasoline taxes would not only cost less than the other two approaches considered (both of which involved raising CAFE standards), but it would start reducing consumption immediately, and the market effect would gradually drive the transition to more fuel-efficient vehicles (Automotive Environment Analyst 2004). *Raising fuel prices to reflect the real cost to the economy is an important consideration in stimulating fuel economy as well as in reducing non-essential trips, especially in developing countries.*

**Encouraging Nonmotorized Transport**

Traffic mix is an important determinant of emission levels for two reasons. First, because most emissions from motorized vehicles are highest at cold start of the engine, short trips are disproportionately polluting. These are the trips that are most suitable for nonmotorized transport (NMT). Unfortunately, in many developing country cities, walking or using other nonmotorized forms of transport is so inconvenient and dangerous that even very short motorized trips are common. Eliminating impediments to NMT by providing adequate sidewalks and bicycle lanes and ensuring the safety of pedestrians and cyclists can deter the use of the most polluting motorized vehicles for short trips. An equally important, or an even more important, consideration is that segregated lanes for bicyclists and pedestrians can enhance public safety and help to reduce 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). *Provision for safe and comfortable walking and other forms of nonmotorized transport should be an integral part of an urban air quality strategy.*

Second, traffic mix has a substantial impact on variability of traffic speed. This is a serious problem where motorized and nonmotorized traffic share road space. Measures to segregate these types of traffic on main thoroughfares are thus as important for environmental as for safety and efficiency reasons. For example, in Dhaka, the presence of a large number of cycle rickshaws has historically made the operation of bus transport very difficult. In contrast, in residential areas it may be better to use traffic-calming measures to harmonize speeds of different traffic categories at a safe level. Traffic calming also has the indirect effect of deterring traffic from using residential roads as a short cut. *Careful differentiation of traffic segregation policies by type of road can reduce environmental impacts and accidents while increasing average speed for all traffic.*

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2See the various reports of the U.K. Standing Advisory Committee for Trunk Road Assessment.
Bicycles can account for as much as 50 percent of total movements in some low-income countries in Africa and in many Asian cities. Despite this, the bicycle tends either to be neglected or is actively discriminated against. This is partly because the bicycle is considered by government to be associated with poverty, and hence to be a mode that will disappear as incomes increase. In China, bicycles are viewed by government as a barrier to modern road transport and are consequently being banned from roadways in many cities. Often this is being done without a consequent provision of alternative space for bicycles, or without adequate consideration to mobility decisions of displaced bicyclists. In Vietnam, it is striking how quickly bicycles are being replaced by (predominantly four-stroke) motorcycles as incomes rise in the major cities, and consequently how high is the level 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.

The appropriate policy response, now being adopted in a number of industrial countries, is to view the bicycle as an environmentally friendly mode for shorter trips and to plan positively to make it attractive. Some of the earlier initiatives to re-establish the bicycle through provision of sections of bicycle track, as in Lima, Peru, have had limited success. There are many components to making a bicycle promotion program work, including segregated infrastructure, provision for modal integration with public transport, promotion (particularly through safety and security campaigns), and other incentives. The message, exemplified by long experience in the Netherlands and by the increased bicycle use that has more recently been achieved in Bogotá, is that a comprehensive package of measures, including extensive connectivity in the bicycle network, is necessary in order to make the bicycle attractive and sustainable as incomes rise.

Traffic management

This report distinguishes between traffic management, which consists of supply-side measures to improve performance of roads with existing traffic volumes, and demand management, which consists of measures to improve performance by reducing traffic volumes (World Bank 2002b). The former is discussed in this chapter and the latter in the next chapter. Both may require some physical measures, usually referred to as “traffic engineering.” The engineering involved in traffic management tends to have a short gestation period and low cost. Traffic management has the potential to achieve reductions in air pollution and to be affordable, even by poor countries.

The objectives of traffic management

The adverse impact of local air pollution is highly location-specific and, to a lesser extent, time-specific. It is greatest where most people are exposed and where emissions lead to high ambient concentrations (on account of high emission intensity and low dispersion of pollutants). A high level of exposure is thus the product of a series of decisions or circumstances that determine the number of trips made, their distribution over space and time, the choice of routes, the driving characteristics of drivers, and where people...
spend time. Traffic management in industrial countries has been estimated to reduce emissions by 2–5 percent overall, but by much greater proportions in specific corridors or areas. Because of poor initial traffic conditions, there is considerable potential for traffic management to reduce fuel consumption in many developing country cities.

Both fuel consumption and exhaust emissions vary significantly with variability of vehicle speed. Traffic management can, in principle, reduce fuel consumption and exhaust emissions by making traffic flow more smoothly. Other things remaining the same, it would therefore be desirable to manage traffic to secure uninterrupted movement at free-flow speed. A steady speed is also the key to reducing the emissions of harmful pollutants per unit distance traveled. A number of devices, such as one-way street systems, linked traffic signal systems, and traffic control systems can contribute to smoothing traffic flow. From an environmental point of view, the most important features to address by traffic management are the variability of traffic speed and the location of major traffic flows, particularly congested flows.

Traffic signal systems are the most common traffic management instruments aiming to secure traffic flow objectives. However, their impact on air quality has been controversial. Some have argued that because they achieve their travel flow objectives by systematically bringing some traffic flows to a stop, they are likely to increase air pollution and should be replaced by roundabouts or fly-overs (OECD 1991). Others have challenged this claim, arguing that the impact of traffic signals on pollution is highly situation-specific.

Some conclusions on traffic signals are widely accepted, however. Linking of uncoordinated signals to create “green waves” can reduce travel times by 10 percent and emissions by a similar proportion in the controlled area. Allowing “near-side turn on red” (left turn where vehicles are driven on the left side of the road) gives another 1.5 percent improvement. Cycle lengths that minimize pollutant emissions are 50 percent longer than those that minimize delays, and in heavy traffic conditions these extended cycle times can reduce emissions by up to 3 percent. The most efficient systems are area traffic control (ATC) systems, which link signals across whole networks. These systems can be made traffic-responsive on a real-time basis but are more expensive in terms of capital equipment (partly because of the need for more traffic-sensing equipment). However, in developing countries ATC has a history of contract failure, dispute, and procurement difficulties, as well as operational weaknesses. The Phase I ATC system in Bangkok, installed in 1996, still functioned imperfectly by 2000 because of a lack of sustained cooperation from the traffic police (Cracknell 2000). Effective use of traffic signal systems to improve air quality requires careful design and committed institutional coordination.

Road system design

Ring roads and by-passes are not traffic-management strategies per se, but they are often advocated as the basis on which it is possible to introduce environmental traffic management. The argument is that if such roads provide adequate capacity to navigate across a town it will be possible to keep through-traffic out of environmentally sensitive areas. In some small or medium cities that have restricted vehicle access to central areas, this has worked well (Freiburg, Germany, is...
one example). But in many areas, it has not. There are two main reasons for this:

- Improved radial or ring road performance increases the number and length of trips made to such an extent that total traffic and total emissions actually increase. This is sometimes called the “rebound effect.” Both average speeds and journey times may be increasing simultaneously.
- The supporting traffic management necessary to take advantage of the “breathing space” is not implemented. This has been a particular problem in Chinese cities such as Guangzhou and Shanghai.

This experience indicates that increasing infrastructure capacity will result in improved air quality only if embedded in a comprehensive urban transport strategy involving parallel restraint of vehicles and local environmental protection.

Some pollutants, such as CO, are within health-based air quality standards on average but can be extremely high at urban “hot spots,” such as heavily congested traffic corridors and intersections. CO and PM concentrations fall rapidly with increasing distance from these roads. Schools, hospitals, homes for the elderly, and shopping streets should therefore be located several hundred meters away from busy traffic corridors. For existing hot spots, traffic management can be used to minimize the impact of traffic on local air quality. New infrastructure should be designed to minimize chances of creating hot spots.

The influence of hills on emissions can be significant. Emissions do not rise substantially on diesel trucks until the terrain is sufficiently steep to require use of brakes on downhills and power re-supplied on uphills. The situation is made worse if congestion causes stop-start driving on a hill. Major arteries through cities should avoid severe grades where possible.

Local environmental management

Pedestrianization of city centers began to gain popularity in Europe about 40 years ago and is now a feature of most city-center plans. The sort of measures used include the shading of pathways, attractive paving materials, use of materials to dissipate heat, integration with public transport stations, landscaping, and better pedestrian corridor links with major destinations. In contrast, pedestrians are generally poorly served in developing countries, where they tend to be controlled rather than provided for. Footways are often not provided; when they do exist, they are often in a poor state of repair or taken over by traders and parked vehicles. The consequence is that pedestrians are forced to walk in the highway pavement. This is not only unsafe but also contributes to traffic congestion and consequently increased emissions. In many cities the roads are so unsafe for pedestrians that they use motorized transport even for short trips. Provision of adequate pedestrian facilities improves air quality by keeping traffic away from sensitive, high-exposure locations and by encouraging walking as the preferred mode for short trips.

Other restraints on vehicle movements are usually targeted at particularly sensitive areas. The most common spatial restrictions relate to access to central business districts (CBDs). The “cell system,” introduced in Gothenburg and replicated in British towns such as Oxford and Leeds, uses physical restrictions on cross-center movements to keep through-traffic of private vehicles, but not buses, out of the CBD. Some schemes also discriminate by vehicle type. For example, the bus franchising system in Santiago limits the number of buses licensed to operate into the CBD, although it is not well enforced and currently under revision. Many cities such as Delhi specify particular routes for heavy goods vehicles or even ban their access to central areas during the daytime. Discriminating traffic controls can be used to protect environmentally sensitive areas.

The difficulty for many developing countries, however, is that important generators of heavy freight vehicle movements, such as ports (as in Manila) and major markets (as in Dhaka), are located in or close to downtown areas. Relocation of these facilities, as currently being implemented in Ho Chi Minh City in Vietnam, is very costly and can only be achieved over a long time period. The evidence is that integrated planning of urban land use, urban public transport, and traffic management is the best basis for improving air quality in the most sensitive locations.
Incident detection and intelligent transport systems

Much congestion in large cities can be attributed to the dislocation effects of relatively trivial accidents. Traffic incident detection, coupled with prompt appropriate response, can improve traffic flow and reduce congestion significantly. This requires appropriate real-time transfer of information and close collaboration among traffic management, police, health, and rescue agencies. The ability to identify incidents, remove obstructions, and redirect traffic can help reduce traffic congestion and improve air quality.

Regulation and Control of Public Road Passenger Transport

Public transport affects urban air pollution both directly, through emissions of public transport vehicles, and indirectly, by providing an alternative to a much larger number of private cars (World Bank 2001). Operation of public transport vehicles may result in losses of car speed, resulting in slightly higher emissions from cars. If public transport is not efficient, it is unlikely to contribute effectively to the reduction of urban air pollution. However, provided that public transport is sufficiently attractive to draw passengers away from private vehicles to high-occupancy public transport vehicles and is well maintained, on balance public transport promotion can bring significant environmental benefits (though these benefits should be calculated and not simply assumed). Policy for public transport can minimize its direct air pollution impacts by making it clean and maximize its indirect benefits by making it sustainable and attractive.

Traffic management for public transport

Buses typically move at only about two-thirds the speed of cars because they must frequently stop and re-enter the traffic flow. Given the limited density of bus networks, taking buses also involves longer terminal walking times than using private cars, with the overall result that a bus journey usually takes at least twice as long as an equivalent car journey. This discrepancy accentuates the advantage of the private car and encourages its use. Although auto-rickshaws offer point-to-point service, they also add to congestion. Mixing public transport vehicles, whether buses or auto-rickshaws, with other vehicle categories reduces the average speed of traffic compared with what could be achieved if traffic were segregated. Public transport priorities—dedicated lanes or totally segregated busways—are essential to counteract the problems of mixed traffic.

The simplest measures are priority bus lanes. But they have major limitations. They make roadside access to premises more difficult. When they are operated in the same direction as the main traffic flow, they are particularly susceptible to invasion by other traffic. Operation against the direction of flow is more self-enforcing but can increase pedestrian accidents. Simple non-segregated bus lanes have proven difficult to enforce, thus providing limited improvements in bus efficiency and air quality.

Totally segregated busways using central lanes, along with protected pedestrian crossings at stations, overcome the problems of accidents and problems of access to roadside premises associated with bus lanes. Furthermore, by developing busways as trunk links in a physically and commercially integrated network, the travel time and cost of public transport can be made more competitive with that of the private car. Although schemes that dedicate existing road space to public transport may be opposed by car users, ex-
The internal efficiency of formal bus operating companies in developing countries can usually be improved by more efficient design of route networks, better cost control, and better control of performance on the road. Some of these involve relatively modern technology (such as automatic vehicle location) that is likely to be employed only by large, possibly area-mono- nopoly, companies. But this has to be balanced against the losses of efficiency inherent in monopoly operation. While there are some scale economies in staff training, supply procurement, and management information systems, international experience indicates that these are not of a magnitude to justify monopoly operation of large urban systems. The advantages of integrated systems planning, also frequently considered to justify monopoly, can be equally well achieved by separation of planning from the operation of ser-


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vices, which can be competitively procured by the planning agency. The most important requirement is usually the need for internal incentives to efficiency, the most effective of which is some competitive threat.

**Public transport franchising**

Most public sector operations of public transport are politically controlled and inefficient. Yet allowing small informal sector operators to enter the market to supplement or compete with the existing operator has often been associated with excessive supply (as in Santiago until the early 1990s), the use of old, polluting vehicles (as in Lima today), or dangerous operating practices (as in Delhi). Unregulated competition can clearly be dangerous, inefficient, and environmentally damaging.

But this is not inevitable. Several countries, including Denmark, Sweden, and the United Kingdom, have awarded monopoly franchises of limited duration and scope on the basis of a competitively bid tender. 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. It has shown reductions in cost per bus kilometer between 20 percent and 40 percent and is now the preferred form of competition in large cities (Halcrow Fox 2000). 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 by simply setting minimal pollutant emission standards as a condition for holding any franchise, as well as by using environmental quality above the minimum as one of the criteria on which competitively tendered franchises are awarded (see International Experience 6).

For competitive tendering to be effective, a franchising authority must be technically and administratively able to design and award franchises with sen-

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**INTERNATIONAL EXPERIENCE 6**

**Addressing the Environmental Impacts of Bus Competition in Santiago, Chile**

At the end of 1977, public road passenger transport in Santiago was provided by a public sector operator with 710 large (90-seat) buses, a number of strictly regulated private associations operating 3,167 regular (78-seat) buses, and 1,558 (40-seat) “midi”-buses. The public operator lost money and service was mediocre. Between November 1979 and June 1983, both entry to the market and fares were deregulated. 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 11.6 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 rectify the situation included banning 20 percent of the bus fleet from operation on each day of the week and banning buses more than 22 years old. These measures gave little relief. So, in the early 1990s, the government introduced a system of competitive tendering for franchises to operate buses on routes entering the city center. The capacity was thus constrained by the authorities. The fare to be 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 a 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.

*Sources: World Bank 2002f, López 2002.*
sible environmental conditions and to monitor performance—including vehicle emissions—effectively. There is now a wealth of experience in doing this, both in industrial countries (for example, in Copenhagen and London) and developing countries (in such cities as Bogotá and Santiago). Furthermore, effective competition, either in the market or for the market, is dependent on the commercialization or full privatization of the incumbent parastatal operator, as private operators are understandably reluctant to compete with an agency that can rely on deficit finance from its owner to ensure that it retains its position in the market. The cities that have most satisfac-

**FAQ 6**

**Does privatization of public transport lead to worsening urban air pollution?**

In industrial countries, publicly owned public transport operators are subject to stringent quality standards (including for emissions) that are satisfied adequately in many countries. But the operators usually achieve this on the basis of substantial, and open-ended, public subsidies. Where those subsidies are not available, as is now the case in many of the independent republics that emerged from the former Soviet Union, publicly owned buses are old, poorly maintained, and heavily polluting. It is thus the subsidy, rather than the public ownership, that allows stringent quality standards to be met.

In many countries, both industrial and developing, the size of the subsidies has become so great that governments have begun to seek methods of reducing the subsidies by introducing competition among private sector operators. Where, as now in Lima or as in the late 1980s in Santiago, this liberalization took the form of free entry with little attempt at regulation of quality, many old and polluting buses took to the streets. But where, as in many of the industrial countries, the competition took the form of competition “for the market”—that is, for the right of private companies to operate regulated franchised services—air pollution was well contained. It is thus the lack of quality regulation in privately operated bus sectors, not private ownership per se, that is the cause of pollution.

The lesson is clear. Both unsubsidized public sector operations and unregulated private operations can be very polluting. For poor countries that cannot afford heavy subsidies to public sector operations, regulated competition for the market is an intermediate path that can better reconcile affordability with service quality than either free entry or public monopoly can.

**Emission standards for public transport vehicles**

A number of countries have embodied high aspirations for the environmental quality of public transport by enacting strict standards for public service vehicles. In some cities, such as Kuala Lumpur, this has had the perverse effect of reducing the commercial viability of public transport. In others, such as Bangkok, environmentally clean vehicles have been put in service only at premium fares that reduce the availability of service to the poor. Conversely, cities such as Bogotá—which have concentrated on giving priority to public transport vehicles but have not enforced very high environmental standards per se—have been able to reduce air pollution by attracting passengers into large buses and eliminating many of the oldest, most polluting, vehicles. Imposing stringent vehicular emission standards without attention to the financial sustainability of public transport operations can undermine the viability of public transport and have counterproductive effects.

**Bus priorities and bus rapid transit**

Bus priority systems change the relative travel times by bus and car and, particularly if supported by parking restraints, encourage people to use the more space-efficient public transport modes. Congestion levels may thus be reduced. More important, they increase the average speed and reduce the variability of speed of bus movements. For turbocharged diesel engines, the importance of maintaining steady engine load (steady speed or gentle speed changes) to reduce particulate emissions cannot be overemphasized. A range of priority measures was shown to reduce bus exhaust emissions in London by 7–60 percent (table 3).

As table 3 shows, the segregated busway, or bus rapid transit (BRT) system, is the most environmentally effective although there is minimal use of the segregated busway in London. BRT has been developed extensively as the core of mass transit systems in Bogotá and Curitiba. Such systems make it possible to replace four or five small vehicles with one larger ve-
CHAPTER 4. REDUCING FUEL CONSUMPTION PER UNIT OF MOVEMENT

vehicle, which can then operate more rapidly and smoothly with shorter dwell times. When trunk lines are integrated, physically and in ticketing arrangements, with a system of feeder services they have proved capable of maintaining or increasing the public transport share of trips even when incomes are increasing. The secret of their success has been that both involved a combination of public infrastructure planning with private operation that has made it profitable for the private sector. This experience has shown that good transport planning and service integration is the essential prerequisite on which environmental improvement of bus services has been founded.

One interesting characteristic of BRT systems is that they have achieved their substantial environmental impacts without initial emphasis on advanced clean technology. The passengers are attracted by the affordability, travel time, security, safety, comfort, cleanliness, and ease of use of the system. For example, conventional diesel bus technology has been used in both Bogotá and Curitiba systems. In Bogotá more stringent environmental requirements on vehicles are proposed to be introduced in the next phase of development. The lesson (IEA 2002) appears to be that development of a BRT system has environmental benefits by itself but can also provide an economically viable platform for the introduction of improved technologies.

The Role of Mass Transit

Electrically propelled transit modes are without doubt the least locally polluting form of mass transit. That would include electric or fuel-cell powered road vehicles as well as the more traditional electric railway. Very often, however, mass transit is thought of only in terms of rail-based systems. These have the advantage of giving a perception of permanence and quality on the basis of which people in many large industrial countries, particularly in Europe, have been willing to choose residential locations from which they can make their regular journeys to work by rail rather than by car. Unfortunately these are very costly. Recent new underground railways have cost between US$40 and $100 million per kilometer, which is beyond the resources of most developing country cities (JJ&B Consultants 2001). Electric rail transport is very clean at the point of use, but expensive.

The cost of rail transport is important to individuals making these joint decisions on residential location and choice of transport mode. In the absence of direct charges for road use (see International Experience 7 in chapter 5) many European cities have subsidized urban rail transport heavily to compensate for its high cost. This has three main drawbacks. First, it is difficult to get a sufficiently large road/rail fare charging differential by increasing subsidies whereas in principle any size of differential can be obtained by raising road charges. Second, whereas road pricing generates revenue for the public authority, a public

<table>
<thead>
<tr>
<th>Measure</th>
<th>Proportion of buses affected</th>
<th>Exhaust emission reduction per bus affected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak period bus lane</td>
<td>5%</td>
<td>20%</td>
</tr>
<tr>
<td>Contra-flow lane, all day</td>
<td>2%</td>
<td>35%</td>
</tr>
<tr>
<td>Signal pre-emption</td>
<td>20%</td>
<td>12%</td>
</tr>
<tr>
<td>Segregated busway</td>
<td>2%</td>
<td>60%</td>
</tr>
<tr>
<td>Priority turns</td>
<td>5%</td>
<td>7%</td>
</tr>
</tbody>
</table>


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.
transport subsidy is a drain on city budgets, which is particularly important for typically cash-strapped cities in developing countries. Third, a compensating subsidy to public transport has the effect of encouraging longer trip lengths, more sprawling development patterns, and hence a higher long-term tendency to rely on private transport. *Rail mass transit subsidies are likely to have only a weak influence on urban air quality and should be relied on only in the context of a comprehensive urban transport strategy.*

Fortunately there are some more affordable mass transit alternatives. Where rail tracks exist, surface rail or light rail transit systems can be constructed more cheaply, but usually have lower capacity (Halcrow Fox and Traffic and Transport Consultants 2000). Segregated busway systems can yield almost equivalent mobility benefits at about 10 percent of the capital cost for traffic volumes of up to 20,000 peak passengers per lane per hour in the peak direction, albeit at a lower speed than rail mass transit (though in the right circumstances BRT may produce speeds that are comparable with those of light rail transit). By combining busways with cleaner vehicle technology (such as electric trolleys or buses fueled by CNG), large environmental benefits can be achieved without conflict with system financial sustainability. For example, operators of the Bogotá TransMilenio system were required to buy new, high-quality vehicles to compete for franchises, but claim that the increased efficiency of movement has allowed them to vastly improve service and to increase their profitability without an increase in fares (Hidalgo 2001). *More affordable mass transit alternatives can often yield substantial environmental benefits at much reduced cost.*