SUSTAINABLE TRANSPORT:

NEW INSIGHTS FROM THE IEA'S WORLDWIDE TRANSIT STUDY

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INTRODUCTION

Over the past year, the IEA has undertaken a study of transit systems in cities around the world. The primary focus has been on bus systems in developing countries, where dilapidated vehicles, old technologies, and rapidly increasing traffic congestion and sprawl are jeopardising the ability of the developing world's premier cities to achieve sustainability. Near-term bus and bus system improvements in these cities - before cars become dominant - could be among the most important, and most cost-effective, approaches to achieving transport sustainability worldwide. Bus transit-dominated transport systems result in much less traffic congestion, lower pollutant and CO_2 emissions, better safety, and improved mobility for all social and economic classes.

This paper describes key findings from the IEA's study: how better bus systems, incorporating better system design and improved technologies, can put urban transportation on a more sustainable path around the world. The study has examined the situation in several large cities in the developing world, while drawing upon experiences from several cities in the developed world. Current snapshots of urban traffic situations have been constructed for several cities, with analysis indicating that buses, even quite dirty buses, already carry a large share of travellers while contributing a small part to the burden of traffic, energy use, and pollution. Consequently, progressive transport policies that encourage the shift of significant numbers of trips from individual modes (e.g. two wheelers and cars) to buses, while simultaneously introducing clean bus technologies, could do much to relieve urban transport problems.

The IEA study has also focused on advanced bus propulsion systems, such as fuel-cell and hybrid buses running on a variety of fuels, and has found that these could eventually provide important pollutant and CO_2 emissions reduction benefits. But currently they are expensive and in need of more testing and development. In developing countries, spending funds for getting more conventional technology buses on the road, and cleaning up present buses, should take priority, at least in the near term. The use of measures that make bus travel more attractive, such as dedicated bus lanes, lead to increased transit ridership. There are also a number of important technology improvement opportunities for bus systems – such as bus tracking and passenger information systems – that can be deployed to further improve systems and attract riders.

URBAN PUBLIC TRANSPORT IN DEVELOPING COUNTRIES: POTENTIAL AND PROBLEMS

Transport systems represent cities' "life blood", providing mobility and access that is critical to the reasonable functioning of most activities. But many transport systems around the world are beginning to threaten the very habitability of the cities they serve, as vehicle numbers and travel begin to outstrip the capabilities of existing infrastructure systems. The resulting traffic congestion has a direct effect on economic growth, not to mention safety, noise, fuel use and air pollution. The problems are particularly acute in the developing world's largest cities. Swollen populations and high densities of vehicles of all types mean major congestion, slow travel speeds, high exposure to polluted air, and very high rates of morbidity and mortality from traffic accidents[1].

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1   World Bank, 1996. Sustainable Transport: Priorities for Policy Reform, Washington, DC.

At the same time, growing incomes lead more and more individuals to choose travel modes that add to these problems. Traditional non-motorised forms of transportation, such as walking and bicycling, give way to motorised transport - first buses, but as incomes grow, increasingly motorcycles and finally cars. The end result is evident in many developed cities - large urban transport systems built around the automobile, requiring large amounts of land and energy to support. Cities like Los Angeles are now attempting to "retrofit" their sprawling landscape with mass transit systems, but this is difficult to do after there are as many cars as driving-age population. However in most developing cities, it may still be possible to steer toward efficient, cost-effective transit systems that serve all segments of society, and curb the shift to private vehicles.

Urban transport in the developing world is becoming an important contributor to both local pollutant emissions and global CO_2 emissions. Motor vehicles now account for more than half of the emissions of carbon monoxide, hydrocarbons, and nitrogen oxides in many developing cities, and a smaller (but increasing) share of particulates, especially if entrained road dust is included. As for CO_2, the IEA projects that in the next 20 years, transport in developing countries will contribute about 60% of the growth in total transport CO_2 emissions worldwide, and about 15% of the growth in total world CO_2 emissions across all energy sectors[2].

These high emission growth rates have been occurring despite the fact that, in many developing cities, a large share of urban passenger transport is already borne by buses. In many large developing cities, buses carry half or more of all motorised passenger trips. Forty to fifty years ago, cities in the developed world had similar shares of bus transport. Especially in European cities, buses carried as much as half of all traffic in urban areas until the 1950s or 1960s. This was followed by a steady decline in bus travel in most developed cities through the present. Buses have been displaced in part by metros, but increasingly by private cars.

In cities around the world at a "middle income" level (such as Mexico City and Bangkok) buses and other forms of collective transport are now losing share of trips and travel to individual modes. This evolution is spreading to even poorer large cities of the developing world, such as Delhi, with two- and three-wheelers becoming more numerous than buses. Just how fast - and how far - this new trend moves in the developing world will depend on many factors: rates of income growth, the price of automobiles, the way cities grow, and the health of the existing bus systems.

Why is it important to preserve and expand bus systems? The answer is fairly simple: they offer the most affordable, cost-effective, space-efficient, environmentally friendly mode of motorised travel on the planet. While rail transit gets attention as a sustainable transport solution[3], rail has several problems. It is expensive: even light rail systems cost up to 10 times as much per kilometre as bus systems[4]. New rail systems often require rights of way to be opened up that are becoming scarce in many cities. Finally, it can take many years to develop rail systems. Rail still offers certain advantages, such as capacity and speed, but given some recent

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2   IEA, 2000, World Energy Outlook 2000, Reference Case, International Energy Agency, Paris.
3   For example, the National Government of Brazil allocates considerable capital funds for assisting rail projects in cities around that country, but very little for bus systems (personal communication, L. Wright).

4   A new report by the US General Accounting office (2001, "Mass Transit: Bus Rapid Transit Shows Progress", GAO, Washington DC) estimates average costs per mile for bus systems to range from 2% of rail transit for buses in bus lanes in urban arterial streets up to about 39% of rail for dedicated busways systems in the few US cities with these. Similar ranges of estimates have been found in developing countries.

advances in bus systems, discussed below, buses are catching up and becoming a better way to achieve sustainable development.

Can recent trends be reversed, and can bus systems be a "growth area" in developing cities in the future? The experience of a few aggressive cities suggests that they can, and that the benefits of doing so are substantial. In Curitiba, Brazil, a large-scale bus system that grew with the city over the past three decades continues to carry a very high share of all motorised travel, as citizens of that relatively wealthy city simply use their cars less than do other Brazilians of similar income. The success of the bus system in Curitiba has spurred other South American cities, such as Porto Allegre (Brazil), Bogota (Colombia), and Quito (Ecuador), to develop similar bus-dominated transport systems. The citizens of Bogota recently voted to make much of the downtown area "car-free" by 2015.

But in many other cities in Latin America and around the developing world, buses are seen as inefficient and as major sources of pollution, noise, and road hazards. City authorities seek efficient, clean and affordable urban bus transit systems that can improve this image and maintain or even improve total mobility, even as incomes grow and cities expand. This is feasible, providing bus systems are reformed and modernised so that potential riders consider bus travel to be comparable to or better than personal vehicles in terms of speed, service and convenience.

The stakes for sustainability are high. For example, the difference in total CO_2 emissions for a developing city with a bus-dominated future versus a private vehicle-dominated future could be 100%. Figure 1 shows possible scenarios for Delhi, where in 2020 there is a 100% difference in the city's transport energy use and CO_2 emissions depending on whether buses in that year carry 75% of motorised travel and are large and fairly full (average load of 60 passengers), or if they only carry 40% of motorised travel and are smaller and/or emptier (35 passengers per trip).

FIGURE 1: TWO FUTURE VISIONS FOR DELHI[5]
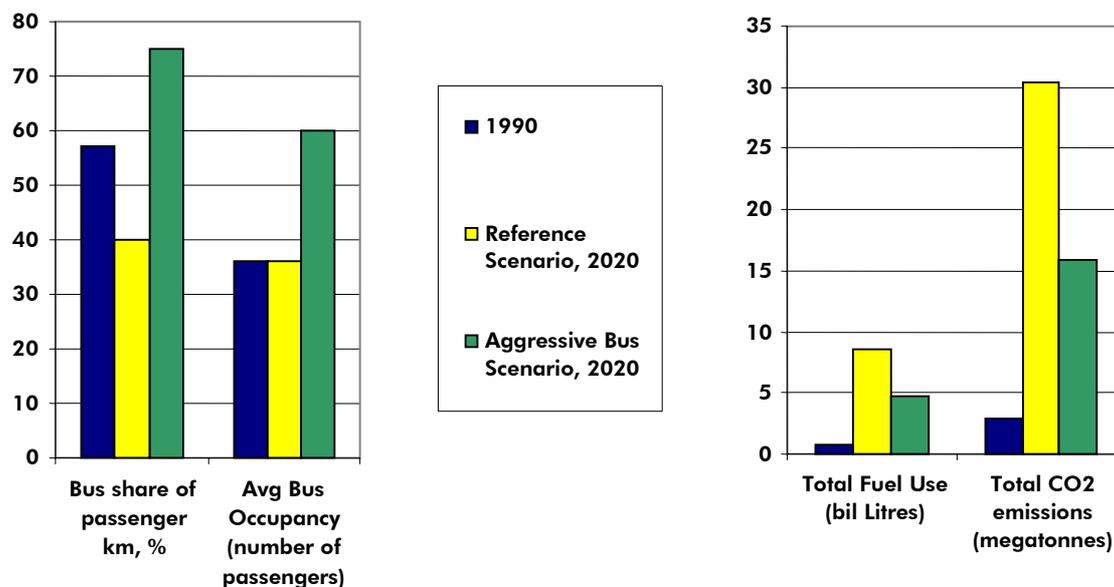
5   Source: Scenarios developed by IEA based on similar scenarios from Bose, R. and D. Sperling, 2001, Transportation in Developing Countries: Greenhouse Gas Scenarios for Delhi, India published by Pew Centre on Global Climate Change, Arlington VA.

IMPROVED BUS SYSTEMS: EXAMPLES FROM AROUND THE WORLD

In many developing cities, most of the growth in bus travel in recent years has been in smaller buses or min-buses, run by private organisations. Conventional systems using large, efficient buses have typically been in decline. However a few cities have gone in the opposite direction. Most of these cities have followed the Curitiba approach to build "busways" systems (also called "bus rapid transit", or BRT) rather than letting buses languish in increasingly bad traffic congestion. BRT systems put buses in dedicated bus lanes, physically separated from other traffic. This both dramatically improves average bus speeds and, in some cases, reduces the capacity available for other modes of traffic. In Curitiba, buses running in busways form the main element of the transport system, carrying nearly 50% of all daily motorised trips with very high average bus speeds[6]. The dedicated "trunk lines" in Curitiba run along major avenues with up to three lanes that allow access only to buses. Combined with large buses (double-articulated, holding up to 225 passengers), relatively long distances between stations, and specially-designed stations that ensure rapid loading and unloading of passengers, the system delivers more "throughput" (passengers per hour past any given point) than most rail systems are able to achieve[7].

In another Brazilian city, Sao Paulo, busways play a less prominent role, but several routes are in place and are integrated with the metro, other bus lines, and the system of mini-vans that serve as feeders to the bigger system. Even in the developed world there are a number of cities developing extensive busway systems. In Ottawa, Canada, the highly successful BRT system, consisting of three main routes, is linked to a rail network, and to park-and-ride stations at the fringes of the city. Ridership and average load factors on these systems is much higher than on typical bus systems in other cities. What makes these systems work is their increased attractiveness to potential riders, through their high average speeds and good reliability, and improved ride comfort. The high visibility and high regard of the systems has also probably raised the acceptability of bus travel among the local population, and created a general consciousness that bus travel is an acceptable choice for any given trip.

While cities like these are leading the way in terms of developing their transport infrastructures around rapid bus systems, other cities are starting from scratch, attempting to get buses - currently stuck in the same congestion as all other traffic - moving again.

In Los Angeles, a recent "Rapidbus" initiative to jump-start bus transit is based on a signal synchronisation system along the 40km Wilshire-Whittier corridor that gives buses priority at intersections - providing an "advanced green" or "delayed green" to reduce bus waiting time at red lights. New stations were also built for these rapid bus lines, with real-time displays indicating the waiting time until the next bus. While there are no dedicated lanes, this approach has raised average bus speeds 15%, attracting more passengers, and even lowering fuel use/km slightly, relative to other buses in the same region of Los Angeles[8]. This type of bus priority system is well known in Sweden, where many cities have employed elements such as signal prioritisation for years.

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6   Rabinowitch, J. and J. Leitman, 1993, "Environmental Innovation and Management in Curitiba, Brazil". Washington DC, UNCP/UNCHS World Bank Urban Management Programme, Working Paper #1.
7   Meirelles, A., 2000, "A Review of Bus Priority Systems in Brazil: From Bus Lanes to Busway Transit", Smart Urban Transport Conference, Brisbane, Australia, 17-20 October 2000. Throughputs on Curitiba busways often exceed 10 000 passengers per hour per direction.
8   Los Angeles Department of Transportation, 2001, "Transit Priority System Evaluation".

Another change to bus systems that can substantially improve the experience for riders is bus tracking and passenger information systems. By tracking the position of each bus, either through global positioning systems, transponder systems, or other means, bus companies can do two things: ensure that buses are properly spaced, and inform passengers waiting at bus stops (or even via cell phones or the internet) about the real-time schedule of approaching buses, down to the minute. Even well functioning systems such as in Paris, France, have found that providing this information to passengers is a welcome improvement.

Such technologies are not particularly expensive, even in developing countries, compared to the costs of buses themselves and other infrastructure associated with bus systems. There is no technical or financial reason why advanced bus systems could not be installed in cities around the world, yielding much more viable and popular mass transit. In fact, there are several even cheaper improvements that would make a great difference to many systems, such as better system maps and signage, strong marketing and customer service, better system integration with other modes, and well-designed bus stops (and buses) that allow rapid boarding/alighting. Improvements in these areas can mean more to transit success than much more expensive improvements to roadways or to buses themselves.

But the potential for revitalising bus systems is hampered by a number of factors, not least by the manner in which bus systems are managed and the way individual bus routes and buses themselves are regulated. Although the organisation, management, and licensing of bus services vary considerably from city to city, a number of problems are commonplace (see box). These problems play a major role in preventing buses from producing significant revenues; this in turn represents a major hurdle in the viability of improving the technology and operation of buses themselves.

Getting on Track: The Bus Demonstration Project in Surabaya, Indonesia

As part of the study, IEA staff visited cities that are attempting to improve their bus systems, and are working closely with a subset of cities that are poised to implement bus demonstration projects. These include Mexico City, Mexico, Sao Paulo, Brazil, Bangalore, India, Dhaka, Bangladesh, Jarkarta, Indonesia, and Surabaya, also in Indonesia. Surabaya's effort is an example of the promising efforts being launched around the world.

Located on the north coast of Java, Surabaya is the second largest city in Indonesia (population 2.5 million). It has experienced rapid economic and transport growth in the past 10 years, with car ownership continuing to accelerate despite the Indonesian "economic crisis" of 1997. A 1998 World Bank study predicted that if no actions are taken, congestion will worsen over coming years, with a declining public transport share of motorised trips, from 35% in 1998 to 23% in 2010.

Local officials feel that this is a critical time for Surabaya in planning transport policy – political support for making public transport a viable alternative to the use of private cars and motorcycles is strong. The city government, in co-operation with GTZ (www.sutp.org), is working to improve the transport system in Surabaya, with an emphasis on improving bus transit services. Currently less than 400 buses operate on about 20 fixed bus routes in Surabaya, with around 5000 microbuses dominating public transport services. A recent review of service on the routes revealed that few provide bus service more than once every 10 minutes. The current licensing system imposes no obligations on licence-holders to provide a minimum service to users, and when combined with the lack of a policy framework for systematic decision-making on fares, routes, and other matters, it has paralysed the route planning process and appears to be a principal cause of the current poor and declining service levels.

The new initiative is centred around a new demonstration bus route, running north-south on the major arterial through central Surabaya. It involves:

- Establishing a new policy basis and institutional strengthening for better regulation and management of the transit sector;

- Developing a new route licence system ("Quality licensing"), where the government sets service criteria, which become conditions in the route licence, and service is then provided by the private sector, with one operator per route, selected through competitive, transparent tender.

- Deregulation of the current (complicated and inflexible) bus-level regulatory system.

- Physical route improvements, including bus stops and shelters, footpaths, terminal improvements, and bus priority measures. Bus priority measures on the pilot route will cover a 5.5 km length. Bus priority will be implemented along with car restrictions and a non-motorised transport lane in the same area.

The improvements are expected to begin in 2001 and the route will be fully operational by 2002. The IEA is working with representatives of Surabaya to develop additional elements for a second implementation phase, such as bus priority at traffic signals, bus arrival information systems at bus stops, and the testing of modern, low floor buses with a clean diesel configuration or using alternative fuels.

THE IMPORTANCE OF GETTING BUSES MOVING

Increasing bus speeds is very important for two reasons: it is critical to providing an improved service that encourages ridership, and it is critical to raising bus revenues – which in turn affects the quality and type of bus that can be employed. Slow bus speeds reduce the total kilometres that a bus can travel each day, and therefore the number of passengers that board – in turn lowering the revenues that the bus generates.

In terms of the travel experience for riders, it is clear that faster moving buses, with shorter waiting times and reliable service, are the key factors toward increasing ridership. Cities like Curitiba have shown that even many car owners will ride the bus – and leave their cars at home much of the time - if they have an alternative that can come close to matching their car in terms of these attributes. In cities with bad traffic congestion and low average speeds for all vehicle types, getting buses moving can give them a clear edge over other forms of travel.

In terms of the impact of bus speeds on revenue, Table 1 provides some indicative parameters reflecting the impacts of different bus speeds and ridership levels on the revenue generated by a typical bus in South Asia, reflecting typical bus speeds and fare prices in a city like Delhi. A comparison is also shown with a "typical" bus in an OECD country (real values, of course, vary considerably and data on the actual averages is quite poor). This table shows that the revenue generated by a bus in South Asia is likely to be much lower than in the OECD, mainly because fares are much lower – perhaps only one tenth as high. It also shows that this revenue could be tripled by increasing bus speeds substantially and increasing the average number of passengers carried on each bus.

TABLE 1: INDICATIVE BUS OPERATING CHARACTERISTICS AND REVENUES, SOUTH ASIA VERSUS OECD[9]

	South Asia Current	South Asia Improved	OECD Current
Fare ($ / boarding)	$0.10	$0.10	$1.00
Average number of riders	40	*60*	25
Average boardings / km	10	15	5
Average speed km / hr	8	*16*	16
Distance km / day	150	300	300
Daily revenues per bus	$150	$450	$1,500
Annual revenues per bus	$54 000	$162 000	$540 000

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9   Sources for data vary, but the assumptions for fare, average ridership and speed are indicative assumptions used to demonstrate the point; distance per day, daily revenues and annual revenues are calculated based on these assumptions.

Regulating and Licensing Bus Systems Around the World: What Needs Fixing?

- In many developing cities, most buses are run by independent bus companies. In some cities private companies have grown up to fill vacuums created by the inability of public bus systems to provide adequate service. There are often many independent bus providers, often quite small, surviving on a day-to-day basis. These companies are not able to make major investments in buses or bus systems. Some consolidation of bus service provision is probably needed in such cities to improve service both in terms of bus systems and buses themselves.

- In many cities regulators licence each individual bus to operate on a specific route. These regulations do not specify what the service level must be for the overall route, so different buses serving the same route often do not work together to provide co-ordinated service. Rather, buses compete with each other for passengers, behaving more like taxis than buses – e.g. often waiting in lines at bus stops or terminals until full, and backing up other buses in the process, while people along the route wait long periods of time for the next bus to come.

- Bus operating companies often sub-lease their buses to drivers, ensuring that payment is made for use of the bus (rather than employing drivers and risking that fares will not be fully transferred by drivers to the company). This reinforces the tendency of drivers to act independently.

- Many cities rely heavily on bus terminals as changing points for passengers. This is considered efficient since passengers can choose from many different bus routes at a terminal. But the terminal system in many cities is plagued with problems and inefficiencies, such as high terminal entry fees for buses, and long waiting periods as each bus waits until it is full before leaving. Conditions for travellers are often unsafe and unhealthy. Terminals may be overrated in importance, and are not an important part of some of the most successful bus systems around the world. For terminals to work, a high degree of co-ordination is needed between different routes and bus companies, in order to efficiently manage bus arrivals and departures.

- Bus stops are often infrequent and not properly used; buses tend to stop anywhere to pick up a passenger (wave-downs are common), which often blocks traffic and slows travel speeds.

As a result of the lack of revenues available to pay for better buses, many cities and bus companies are stuck with older, poorly maintained buses with little or no pollution control; they are typically outmoded vehicles converted from truck frames or bought second-hand from developed countries. Poor fuel quality - in the form of very high sulphur diesel fuel - combined with poor engines means most buses in the developing world are major sources of particulate matter and NOx emissions, and therefore of ozone (smog) as well. Buses are often seen as a major part of the problem, not part of the solution.

Budgets available for upgrading buses or replacing them, or even replacing worn parts, are often tiny. And while cities and other governments around the world often provide subsidies to transit systems, financial pressures and competing obligations often make it difficult to preserve existing subsidies, not to mention increase them. It appears that in many cities bus operators will need to generate their own revenues in order to afford better buses.

Given the low bus fares in South Asia and elsewhere in the developing world, bus speeds below 10 kilometres per hour are simply too low for drivers and operators to recover the

costs of new, large buses that provide reasonable levels of service. Medium size buses (seating 24-40 people) in South Asia typically cost USD 20 000 to 30 000, and are built by local manufacturers that sometimes build new bus bodies onto recycled truck chassis. In order to recover the capital costs and higher maintenance costs of a modern 80 passenger capacity bus, costing USD 100 000 or more, revenues would probably need to increase at least three-fold, of which only a part can be achieved through the fact that these larger buses can hold more passengers. Increased revenues could result from a combination of four changes: fare increases, increased load factors, increased average travel speeds and daily travel distances, and other revenue sources such as advertising. It may be possible to raise fares somewhat if the quality of service improves, but increasing fares could also push riders onto other modes - hence any changes must be considered carefully.

THE ROLE OF IMPROVED BUS TECHNOLOGY

While getting more buses onto the roads of cities around the world is a high priority, the quality - and size - of buses must not be neglected either. Current buses in many developing countries are relatively small (often in the 24-40 seat capacity range) and are gross emitters of pollutants. In the worst cases the emissions of some pollutants by some buses – even when fully loaded with passengers - are not much lower, per passenger kilometre, than emissions from other modes of transport.

A range of engine technologies is available to improve bus performance and better bus designs exist that allow increased bus capacities, as well as improved durability and longer service-lives. Bus technology improvements focus on three areas: better diesel buses and fuel quality, alternative fuel buses, and advanced propulsion systems. A number of alternative fuels and technologies are being developed, including compressed natural gas, or CNG, used in many US and European cities; ethanol in Stockholm and Sao Paulo; liquid petroleum gas, or LPG, in Vienna, and di-methyl ether, or DME (not yet field tested). Advanced technologies like hybrid electric systems have been tested using diesel fuel in New York, and fuel-cell buses, running on hydrogen, have been tested in a number of cities in North America (such as Vancouver) and will soon be tested in Europe[10].

Despite the effort to develop alternative fuels, heavy-duty engine manufacturers continue to focus much of their effort on improving diesel engines for large buses, with the primary goal of meeting future emissions standards of OECD countries. Diesel buses still comprise 93% of the US transit bus fleet, and a similar share in Europe. CNG buses represent by far the most popular alternative fuel, and have grown in number in the US from about 100 in 1992 to over 4 000. But with a commitment by the NY City Transit agency to purchase 350 hybrid electric buses over the next three years, market introduction of this advanced technology has arguably begun. Fuel-cell buses are now being tested (or tests are planned) in small quantities (typically 2 or 3) in about 15 cities in North America and Europe.

The prospects for several of these various technologies and fuels are discussed below[11].

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10   Electrified buses connected to overhead electricity systems represent another important option that can be a good choice for some cities. We do not address it here.

11   Note that several technologies not discussed here, such as LPG and DME, will be included in a more detailed IEA report on this topic that is forthcoming.

Diesel Technologies

Although diesel engines have historically produced high levels of NOx and PM, they are recognised and favoured worldwide for their excellent fuel efficiency and durability. In addition, they offer the convenience of using a liquid fuel that is easily dispensed through an established fuelling infrastructure. Furthermore, the technology is mature and benefits from economies of production and competitive pricing. The very large truck market for diesels ensures continued attention and improvements in this technology, an advantage that other bus engine technologies and fuels generally lack.

The current "standard" OECD diesel bus, meeting Euro II emissions standards (Table 2) and providing many other amenities for passengers, represents a major improvement over the average bus currently operating in most developing cities - but it also represents a significant increase in cost. These buses tend to be larger (with up to twice the seating capacity of the standard bus sold in Asia), have better reliability and durability, and provide a variety of amenities, such as low-floor access, more powerful engines (with better acceleration/deceleration profiles for faster trips), and better safety features.

Most importantly, a properly maintained OECD Euro II bus, running on diesel fuel containing moderate amounts of sulphur (no more than several hundred PPM) and a basic oxidation catalyst, will provide substantial reductions in emissions of CO, PM and HC, and some reductions in NOx, compared to a poorly maintained bus with no emissions controls, running on diesel fuel containing several thousand PPM of sulphur (typical in the developing world). However, even moving toward modern OECD-style buses, and improved diesel fuel, is not likely to be easy or cheap. In India buses typically are built from second-hand truck chassis and are sold "new" in the price range of USD 25 000 - 40 000. This compares with a cost of over USD 200 000 per bus for the typical bus sold in Europe, and still higher for buses sold in North America. However, somewhat scaled back versions of OECD buses, assembled in developing countries, are often sold at a much lower price in the range of USD 100 000. Buses meeting Euro II standards but without many of the amenities present on standard OECD-style buses are available in many parts of the developing world for prices below USD 100 000. The cost of improving diesel fuel is dependent on the refining capabilities of each country, and the desired extent of sulphur removal, but in many cases may be in the range of several cents per litre.

Future emission standards such as Euro IV (see Table 2) are spurring further advances in diesel technologies. Several manufacturers, such as Volvo, are already introducing diesel buses that appear to meet future standards through a combination of advanced catalytic trap systems (such as the Johnson Matthey "continuously regenerating trap", or CRT^{TM} system), exhaust gas recirculation systems (to reduce NOx) and very low sulphur diesel fuel (below 50 PPM sulphur is required and below 10 PPM is considered optimal). These advanced after-treatment systems are expected to cost between USD 5 000 and 10 000 per bus (Table 3).

**TABLE 2. BUS EMISSIONS STANDARDS FOR NOx AND PM THROUGH 2010, US AND EU (G/KWH)[12]**

	NOx		PM	
Model Year	US	EU	US	EU
2000	5.8	5	0.075	0.1
2001	5.8	5	0.075	0.1
2002	5.8	5	0.075	0.1
2003	2.9	5	0.075	0.1
2004	2.9	5	0.075	0.1
2005	2.9	3.5	0.075	0.02
2006	2.9	3.5	0.075	0.02
2007	0.16	3.5	0.0075	0.02
2008	0.16	2	0.0075	0.02
2009	0.16	2	0.0075	0.02
2010	0.16	2	0.0075	0.02

Note EU limits: Euro II from 2000, Euro III from 2005, Euro IV from 2008

Advanced diesel technologies are currently being tested throughout North America and Europe. RATP Paris operates 700 buses utilising a catalytic particulate filter (Euro III Standard) and ultra-low sulphur diesel fuel (ULSD, <50 PPM Sulphur). New York City recently completed testing and has switched to ULSD for its entire diesel bus fleet, and will complete a retrofit programme to put catalytic filters on all diesel buses by the end of 2003. Results from these programmes indicate that the technologies appear to meet durability requirements and provide substantial reductions in CO, HC and PM, although with little NOx reduction benefit. (See Figure 2 below for NYC tests). PM levels were comparable to the low levels customarily associated with CNG buses. Similar results were also borne out in a detailed study of test hybrid-electric diesel fuelled buses in New York City, which used similar after-treatment technologies and ULSD.

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12   Source: European Conference of Ministers of Transport, 2001, "Vehicle Emission Reductions", OECD/ECMT, Paris

FIGURE 2: RESULTS OF NYCT DIESEL BUS EMISSIONS TESTS[13]
(IMPACTS FROM ADVANCED CATALYST-TRAP SYSTEM AND ULSD, COMPARED TO BASE BUS WITH OEM OXIDATION CATALYST AND 350 PPM SULPHUR FUEL)
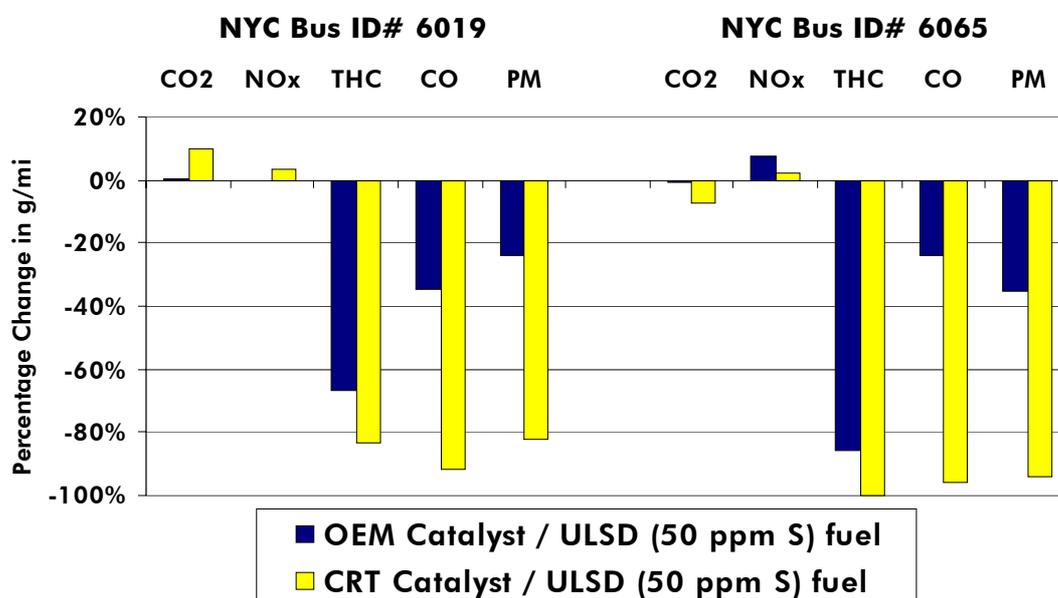
Using current OECD Euro II style buses in the developing world will be expensive, perhaps more than USD 50 000 above what is currently spent in some countries (Table 3). Going to the more advanced Euro IV designs is even more problematic. Among the obstacles for successful implementation of these buses are the required ULSD (<50 PPM Sulphur) fuel and the expected poor durability of after-treatment systems in many countries. ULSD fuel is not available in most countries, and is currently limited to a few targeted markets primarily in the US and Europe. Fuel costs may be higher for acquisition of relatively small amounts of ULSD for use in city bus systems, especially if this fuel must be brought in from a distant refinery. Another problem in many countries is fuel adulteration - for example in India kerosene is often mixed with diesel fuel since it is cheaper and current vehicles tolerate some mixing. But such adulteration may severely damage advanced emissions control systems. This coupled with generally poor bus maintenance practices in many cities suggests that the durability of emissions control systems may be a problem, and the lifetime emissions of diesel buses may continue to be much higher than "inherently clean" alternatives such as CNG or LPG.

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13   Source: Lanni et al., 2001, Society of Automotive Engineers, SAE Paper #2001-01-05110.

TABLE 3. TECHNOLOGY COST ESTIMATES (THOUSAND US DOLLARS)

Category	Bus Cost	Other Costs
Second hand bus in developing countries (or conversions from diesel trucks), seating 25-40	10-40	
New diesel bus produced by indigenous bus companies in developing countries	30-75	
New diesel bus produced in developing countries by international bus companies that meets Euro II	100-150	Some retraining costs and possibly higher spare parts costs
Standard OECD Euro II diesel bus[14]	180-350	
Diesel with advanced emissions controls	5-10 *more* than comparable diesel bus	If low sulphur diesel, up to 10 cents per litre higher fuel cost (for small imported batches)
CNG, LPG buses	25-50 *more* than comparable diesel bus (less in developing countries)	Fuel infrastructure costs could be up to several million USD per city
Hybrid electric buses (on a limited production basis)	100-150 *more* than comparable diesel bus (less in DCs)	Significant costs for retraining, maintenance and spare parts
Fuel-cell buses (on a limited production basis)	1 000 (1 million USD) more than comparable diesel buses, even in LDCs at this time.	With up to USD 5 million per city for refuelling infrastructure and other support system costs

Source: IEA data

Compressed Natural Gas—CNG

CNG buses are now in commercial production and many manufacturers offer a line of CNG buses, although production volumes are generally small. The main advantages of CNG derive from its simple chemical structure, the absence of sulphur, and that it is clean burning, relatively inexpensive and abundant in many countries worldwide. Its use in vehicles is extensive due to its low comparative price, its potential for reduced emissions and its relative ease of use with minor modifications to existing internal combustion engines. As a result, transit agencies have increased the percentage of annual natural gas buses purchased to 30% of the US

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14   Note that this range of prices includes transit buses in both Europe and North America. Buses in Europe are generally less expensive than in North America, with the prices in Europe for non-articulated buses generally below USD 275 000.

market. A growing number of transit agencies have made a commitment to purchase only "clean" buses – i.e. no new diesel buses. These include, among others, transit agencies in Los Angeles, Sacramento, and Atlanta.

CNG's environmental advantages over diesel consist of inherently lower emissions of NOx and PM. Even Euro IV diesels equipped with catalytic particulate filter systems do not typically outperform original equipment (non-conversion) CNG buses without such after-treatment systems. However, CNG buses that are converted from diesel buses are often plagued by much higher NOx levels. CNG hydrocarbon emissions are typically quite low except for (non-reactive) methane. CNG buses do not appear to offer greenhouse gas emission benefits compared to diesel buses, when evaluated on a "life cycle" or "full fuel cycle" basis (taking into account upstream emissions)[15].

Despite increasing demand for CNG buses, transit authorities provide a mixed report on the costs of buying, fuelling, and maintaining them compared to diesel. The City of Los Angeles found that operating and capital costs of CNG buses are significantly higher than the cost of operating similar-age diesel buses. Maintenance was more costly due in part to a higher rate of parts failures on CNG buses, indicating that the technology may not be fully mature (which suggests that these costs may decline as products are improved). The Paris metro and bus authority, RATP, operates a 53 CNG bus fleet and reports that total CNG costs over diesel are roughly USD 0.25 per vehicle km.

Agencies such as Sunline Transit and Sacramento Regional Transit, however, which have large numbers of CNG vehicles in their fleets, report operating costs comparable to or lower than those of diesel buses. They attribute their success with CNG to high levels of worker training, experience with CNG buses, and lower maintenance costs resulting from CNG's cleaner combustion process. It should be noted that the agencies compared new CNG buses to older diesel buses in their calculations.

In OECD countries, CNG buses cost USD 25 000 to 50 000 more than comparable diesel buses (Table 3), but the cost difference between CNG and diesel buses has declined in recent years and may fall further as commercial production expands, and as increased use of catalytic filters and other after-treatment systems pushes up the price of diesel buses. However, at least in the near term, it appears that adding advanced after-treatment systems to diesel buses (and switching to low-sulphur diesel fuel) will be a less expensive way to achieve low emissions than switching to CNG - at least for those cities that are able to properly maintain diesel emissions control systems and ensure the supply of clean diesel fuel.

A key factor in using CNG buses is developing a natural gas refuelling infrastructure. The costs of doing so are determined primarily by five factors: space availability, climate, cost of materials, fire safety and building construction codes, and cost of labour. Diesel bus depots may need to be retrofitted to accommodate CNG buses and refuelling facilities have to be built. CNG infrastructure costs in the US and Europe cover a wide range; transit agencies report refuelling station costs at USD 950 000 to USD 5 million and depot modification costs at USD 320 000 to USD 15 million (depending on what these costs include). These costs may be much lower in developing countries, in part due to fewer

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15   The life cycle emissions comparison between CNG and diesel takes into account, among other things, diesel's efficiency advantage, diesel refining and other upstream energy loses, CNG's compression energy requirements, methane emissions from CNG buses and upstream production, and the processing and transportation of natural gas.

building codes and requirements - but since such requirements help to ensure safety, cost savings from lack of regulations could result in other societal costs, such as increased accidents from mishandling of fuels.

Hybrid-electric Vehicles

Hybrid-electric drive systems on transit buses are being investigated as a means of improving fuel economy and reducing emissions, especially in urban applications. They may also eventually cut maintenance and operating expenses compared to diesel, though this is unclear. Hybrid drive buses can be configured to run on diesel or most alternative fuels. Several major research and development projects are currently testing the viability of these drive systems on buses. A number of demonstrations are underway or have been recently completed by transit agencies. With the rapid pace of development and improvement of hybrid-electric drive technology, many transit agencies are becoming interested in evaluating hybrid-electric drive systems for their fleets. Several manufacturers are now offering hybrid drive buses on at least a semi-commercial basis[16].

Hybrid electric engines combine a power plant (such as a conventional internal combustion engines using fuels such as diesel or natural gas) and electric drive components. For large-scale transit bus applications, the hybrid/diesel, combined with catalytic particulate traps for added emissions control, has been the most tested option. Pilot programmes indicate that hybrid-electric diesel buses have much lower emissions than conventional diesel buses. Hybrids have showed the greatest reductions when operated on ultra-low sulphur diesel (ULSD, <50 PPM Sulphur). In New York, PM emissions from diesel hybrids with ULSD fuel were 50% to 70% lower than conventional diesel while NOx emissions were 30% to 40% lower than conventional diesel[17]. The hybrid electric buses also emitted 70% less carbon monoxide (CO) than conventional diesel buses. Fuel consumption of diesel-hybrid buses in New York is on average around 20% lower than for comparable non-hybrid versions, with the savings increasing for more severe operating conditions (more stop-and-start driving). These results are especially encouraging since heavy-duty hybrid technology is relatively new and will improve as the technology matures. In addition to increased fuel economy, hybrid/diesel electric buses avoid special fuel handling challenges associated with other potential feedstocks such as CNG or methanol.

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16   Orion is setting up commercial-scale facilities in upstate NY to produce the "Orion VII" hybrid bus, and has its first large order from NYC. Marcopolo buses, Brazil, in collaboration with Volvo and Eletra, recently began to sell a low-cost hybrid bus in the USD 200k range (personal communication W Vergara, World Bank). This is about USD 100 000 more than their similar diesel bus model, although this differential is expected to come down with eventual large-scale production of hybrids.

17   NY City Transit (Dept. of Buses), 2000, "NYCT Operating Experience with Hybrid Transit Buses", Presentation at SAE International Truck and Bus Meeting, Portland, OR, Dec 4-6 2000. Slides provided by Dana Lowell, NYCT.

Stepping up the Technology Ladder

The following are some of the key steps up the bus "technology ladder":

- **Basic bus maintenance:** many bus companies do not maintain their existing buses well, leading to high emissions and low fuel economy. Maintenance systems could be strengthened quite cheaply. If moderately low-sulphur diesel is available (<500 PPM), low-cost oxidation catalysts could be added to existing buses to reduce CO and HC emissions, and to a small extent PM emissions.

- **Clean technology buses:** standard buses built for OECD countries are far cleaner than many buses built in developing countries. Creating a demand for OECD type buses through demonstration projects could yield substantial air quality and CO_2 benefits. OECD-calibre buses built in the countries that will use them would be an even better alternative and would provide cheaper buses and help develop the vehicle manufacturing industries in each country. Improvements should begin with better engines.

- **Clean diesel fuel:** ultra-low sulphur diesel (50 PPM sulphur rather than the typical 1000+ PPM sulphur fuels found in most developing cities), or even blends of standard diesel with 10% water, can reduce bus emissions substantially. Combined with advanced emissions control systems these can result in diesel buses with emissions comparable to most alternative fuels.

- **Alternative fuel buses:** several fuels offer the possibility of "inherently" clean bus travel. These include CNG, LPG, DME and alcohol. For optimal performance, engines should be used that are designed to run on these fuels rather than converted from diesel. The viability of different fuels in different cities would depend in part on fuel availability and fuel supply infrastructure.

- **Hybrid electric buses:** while providing something close to an inherently clean diesel technology, this technology is still being tested. But it is increasingly seen as part of the transition to fuel cells since it employs an electric-drive system, that fuel-cell buses will also use, and because this technology appears likely to approach "commercial" cost levels soon. As prices come down, more cities will experiment with hybrids given their potential benefits, and in order to gain experience with electric drive systems.

- **Fuel-cell buses:** Once experience is gained with electric-drive systems, and if possible with gaseous-fuel vehicles and refuelling systems, cities should be more prepared to deal with operating and maintaining fuel-cell buses. This is still a big step, since fuel-cell systems are complex. If buses with on-board reforming are introduced then the complexity level and importance of good maintenance practice will increase, although handling gaseous fuel systems with high compression is not simple either. Developing cities may find it useful to partner with developed cities that have experience with fuel-cell buses in order to speed the learning and competence building process.

Several cities are testing hybrid technologies. Genoa, Italy, was among the first cities to test hybrid buses, putting into service a 10 bus fleet in 1998. New York City Transit's (NYCT's) programme is the first to place a large number of hybrid buses into revenue service. NYCT began with 10 buses in 1999 and following a promising demonstration programme will increase this number to 135 by 2002 and to 385 by 2004[18]. In Europe, the Sagittaire project is running demonstrations of hybrid buses in eleven cities: Luxembourg (GD Luxembourg), Besançon (France), Alicante (Spain), Sintra (Portugal), Stavanger (Norway), Savona, Belluno and Trento (Italy), Athens (Greece), and Bruges and Leuven (Belgium)[19]. In each city, the hybrid-electric bus fleet will be tested under different operational and practical conditions. Marcopolo of Brazil has begun selling a hybrid model that will be tested in several South American cities.

Although hybrids look promising, they are not yet a sound commercial option. In New York, test buses have been hampered by problems with short battery life, and issues with optimal engine/motor control and correct application of catalytic filters are being addressed. Still, if NYCT's overall experience with hybrid buses is good, they may achieve significant sales in other cities within a few years.

Fuel-cell Systems

Over the past decade, the fuel cell has gained prominence as an option for sustainable transportation. In particular, polymer electrolyte membrane (PEM) fuel cells could be an ideal power source for transportation applications, and have emerged as a potential replacement for the internal combustion engine (ICE) in vehicles. Like batteries, they are efficient, quiet, and have no moving parts. They also approach the long range, power density, and short refuelling time characteristics of the ICE. Unlike batteries, fuel-cell systems can be powered by almost any liquid or gaseous fuel (used to derive hydrogen). Vehicle emissions range from nothing but heat and water if hydrogen is used as the fuel, to about half of the CO_2 emissions of an ICE (with still very low pollutant emissions) if methanol is used. Upstream emissions of CO_2 for hydrogen buses depend on how the hydrogen is obtained, and can be substantial if it is derived from electrolysis using electricity generated from fossil fuels.

Fuel-cell bus technologies have attracted considerable attention as the "solution" to achieving sustainable transportation, but many other intermediate technologies are available, and fuel cells are not yet viewed by transit bus companies as commercially viable options. Recent bus demonstration projects indicate the fuel-cell buses are likely to be technically viable, but the large-scale introduction of fuel-cell buses in *developed countries* is probably at least five years away. Achieving a level of market penetration approaching 5% of the urban transit bus market worldwide could take much longer, probably 10 years or more. As outlined below, it is unclear whether any additional actions taken over the next two-to-three years can significantly speed the rate of fuel cell development. Thus the possibility of a new, advanced-technology driven and sustainable alternative to conventional, fossil-based transportation fuels is clearly visible; however, before fuel cell commercialisation is established, worldwide bus acquisitions will exceed two million. It is therefore important to encourage purchase of the best diesel, alternative fuel and hybrid technologies and not neglect these technologies because of the long-term superiority of fuel-cell technology.

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18   Dana Lowell, NYCT, personal communication.
19   Sagittaire project web site: http://www.energie-cites.org/sagittaire/panneau2.html

For pure hydrogen fuel cells to become commercially viable they will need mature and reliable fuel-cell stack technology, electric drive train and system control technology, and on-board hydrogen gas storage systems. They will also need considerable transit agency experience with transporting, handling and storing gaseous fuels and operating and maintaining electric-drive buses.

Today's generation of fuel cells is comparable to the internal combustion engine for transportation applications in terms of power output. But while the fuel cell stacks themselves are reaching maturity, many of the supporting systems such as electric drive trains and various infrastructure issues are still being developed, and different companies are moving in different directions in an effort to improve technology. Cost, along with refuelling infrastructure challenges, are factors that may prevent significant market penetration of fuel cells over at least the next five years.

Current fuel-cell bus testing programmes and plans around the world will place up to 100 fuel-cell buses into operation (including nearly 50 in developing countries[20]) over the next two-to-three years, and these tests will help to speed technical improvements and cost reductions. The current test programmes appear sufficient for the industry to face and hopefully resolve a number of key challenges:

■   Direct hydrogen stored on board the vehicle is the fuelling option that many experts believe will be the long-term choice for transit bus fuel-cell vehicles (using PEM). However, since hydrogen can be produced from many feedstocks, it is not clear whether one global "fuel" choice will emerge, as with gasoline and diesel for internal combustion engines today. Different geographical regions will likely select the hydrogen feedstock that is most appropriate for that area (geothermal electrolysis in Iceland, ethanol in Iowa, CNG in Texas, for example).

■   On-board hydrogen storage represents a major engineering challenge, and advances in storage technology could have a big impact in accelerating the acceptance and commercialisation of fuel-cell vehicles.

■   Codes and standards related to hydrogen storage and transportation must be established before fuel-cell buses can achieve significant market share. A useful analogy is the case of CNG bus technology, which is a relatively straightforward, proven technology. Nonetheless, its market development often confronts hurdles in existing fire marshal codes and standards. Depots not equipped to handle gaseous fuels will have to be modified and retrofitted with equipment that can detect and ventilate hydrogen in the event of leaks. Experience with CNG may prove beneficial since CNG depots are already equipped to handle gaseous fuels and already have detection and ventilation systems in place.

■   Fuel-cell buses currently are very expensive. Those tested in recent programmes have cost more than USD 1 million per bus, several times the price of a standard diesel bus. After a few more years of development and testing, the resulting technological refinements could bring the price of fuel-cell buses down substantially. Large scale production will also likely help to reduce some per-unit costs. But whether they will ever be comparable in price to a conventional diesel bus or even CNG or hybrid bus remains an open question.

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20   Forty-six fuel-cell buses will be put on the roads of 6 developing cities through a project by the United Nations Development Programme and the Global Environment Facility. See http://www.undp.org/dpa/pressrelease/releases/2001/october/1oct01.html

CONCLUSIONS

A number of key messages have emerged from IEA's study:

■ **Each additional bus provides large benefits.** Regardless of whether a bus is "clean" or "dirty", if it is reasonably full it replaces anywhere from 10 to 40 other motorised vehicles (including 2-wheelers as well as cars; in some developing cities the primary displacement is of 2-wheelers). The consequent fuel savings, CO_2 reductions, and pollutant reductions can be large – our preliminary analysis suggests that they can be much larger than the potential benefits of making a fuel or technology upgrade to the bus itself. So getting buses on the road, and getting riders onto buses (mainly by offering a service that riders want) is the best strategy for providing efficient, sustainable transportation systems.

■ **Transit system improvements pave the way for bus technology improvements.** If bus companies are to justify the expense of advanced technology (or even Euro II compliant) new buses, these buses must earn considerably higher revenues than current buses. Revenues can be increased through fuller buses (carrying more passengers per kilometre), faster buses (more kilometres per day), and higher fares. The first requires system improvements and policies that promote public transit (like fuel pricing). The second can benefit both from system improvements (such as dedicated bus lanes) and better buses (newer technologies with better engines can help improve acceleration and average speeds). The third, higher fares, may be justified once actions taken on both the system side and bus side sufficiently improve the quality of bus travel: faster, safer and more comfortable rides, greater reliability and predictability. Thus improvements to the "system" side of the equation help pave the way to better buses, and vice versa. It will be very difficult to sustainably implement a "more expensive" bus without system improvements.

■ **The institutional, financial, and governance aspects of bus systems must be strengthened.** In many developing cities, most buses are run by independent bus companies. In some cities private companies have grown up due to the inability of public bus systems to provide adequate service. There are often many small independent bus providers, surviving on a day-to-day basis. These companies are not able to make major investments in buses or bus systems. Systems must be reformed to move from "bus versus bus" competition on the same route to competition for gaining the licence to serve entire routes, at a level of service for the entire route specified by the contract. And greater co-ordination of transit service is needed system-wide, as well as with other modes of traffic, in order to optimise the convenience and speed of the entire system for travellers.

■ **Development of demonstration "Bus Rapid Transit" (BRT) corridors appears to be an important step.** In many developing cities the task of modernising bus systems and increasing ridership is daunting. Pilot or demonstration projects that focus on a single bus corridor enable testing a different approach to delivering bus services, and create the "seed" that can later grow into a fully established system of bus rapid transit routes. Demonstration projects include dedicated bus lanes, improved infrastructure such as bus stops and terminals, and a new system of regulating and licensing bus services on the route. They can also offer a showcase for advanced technologies, or simply new, modern buses.

- **Bus system technologies can help.** By giving over lanes and entire corridors to buses, bus travel becomes increasingly attractive relative to other modes (notably 2- and 4- wheel private vehicles as well as unregulated minibuses). With additional features such as bus priority at traffic signals (holding or advancing the green light to speed bus journeys), buses can become the premium form of urban travel, rather than a last resort. Other technologies, such as global positioning systems (GPS) to track bus position and relay this information to travellers in real time, are also becoming cost-effective. These may be cases where technology "leapfrogging" makes good sense for developing cities.

- **Cities should "move up the ladder" to advanced bus technologies.** The most advanced propulsion technologies (fuel-cell buses, even hybrids) are too expensive today for most developing countries. But there is a variety of strategies to clean up buses in the near term, including better bus maintenance and incremental improvements to diesel engines and after-treatment systems, to bring diesel bus emissions down to Euro II and eventually Euro IV emissions levels. Shifts to low-sulphur diesel fuel will be important in this process. These approaches could reduce emissions substantially in the coming years, while waiting for more advanced technologies to become cheaper. In some cities, it may make more sense to place emphasis on alternative fuels such as CNG, LPG or DME, depending on the availability of these fuels and the ability of bus companies to maintain diesel after-treatment systems.

- **Decisions regarding clean and alternative fuels must take into account energy supply, cost and infrastructure considerations.** Decisions regarding alternative fuels are often made on the basis of energy, rather than strictly environmental, considerations. These include the supply and local availability of different fuels, local fuel distribution infrastructure, and relative fuel prices. Even in a move toward cleaner diesel buses, a major question is the availability and cost of ultra-low sulphur diesel (ULSD) fuel from domestic refineries or imported. In recommending any clean or alternative fuels initiative, the IEA is sensitive to these considerations. Cities must also decide whether they want to embark down a particular path toward "next generation" buses, such as fuel cells which may require CNG, electricity, or other alternative fuel or feedstock. Decisions made now can help make this transition easier.

- **Field tests of options and in-situ data gathering is essential.** Using antiquated emissions models from one city (with one kind of fuel specification) to simulate emissions in another is unsatisfactory. Ignoring local fuel and road conditions, driver training and behaviour, real passenger loads, etc. gives results that have little resemblance to real emissions or measures of durability. Given the costs of improved systems and bus technologies noted above, it is important to have good estimates of the benefits of investing in improvements.

- **Some sticks must accompany the carrots.** Although improving buses and bus systems will play a central role in increasing the bus share of passenger travel in cities around the world, unless strong policies to dampen the growth in car (and motorcycle) are applied, it may be a losing battle. Aggressive vehicle and fuel tax policy, strong land use controls, and strict parking policy will be important to ensure a sustainable urban transport future.
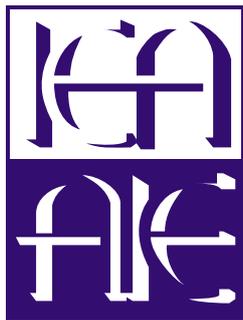
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