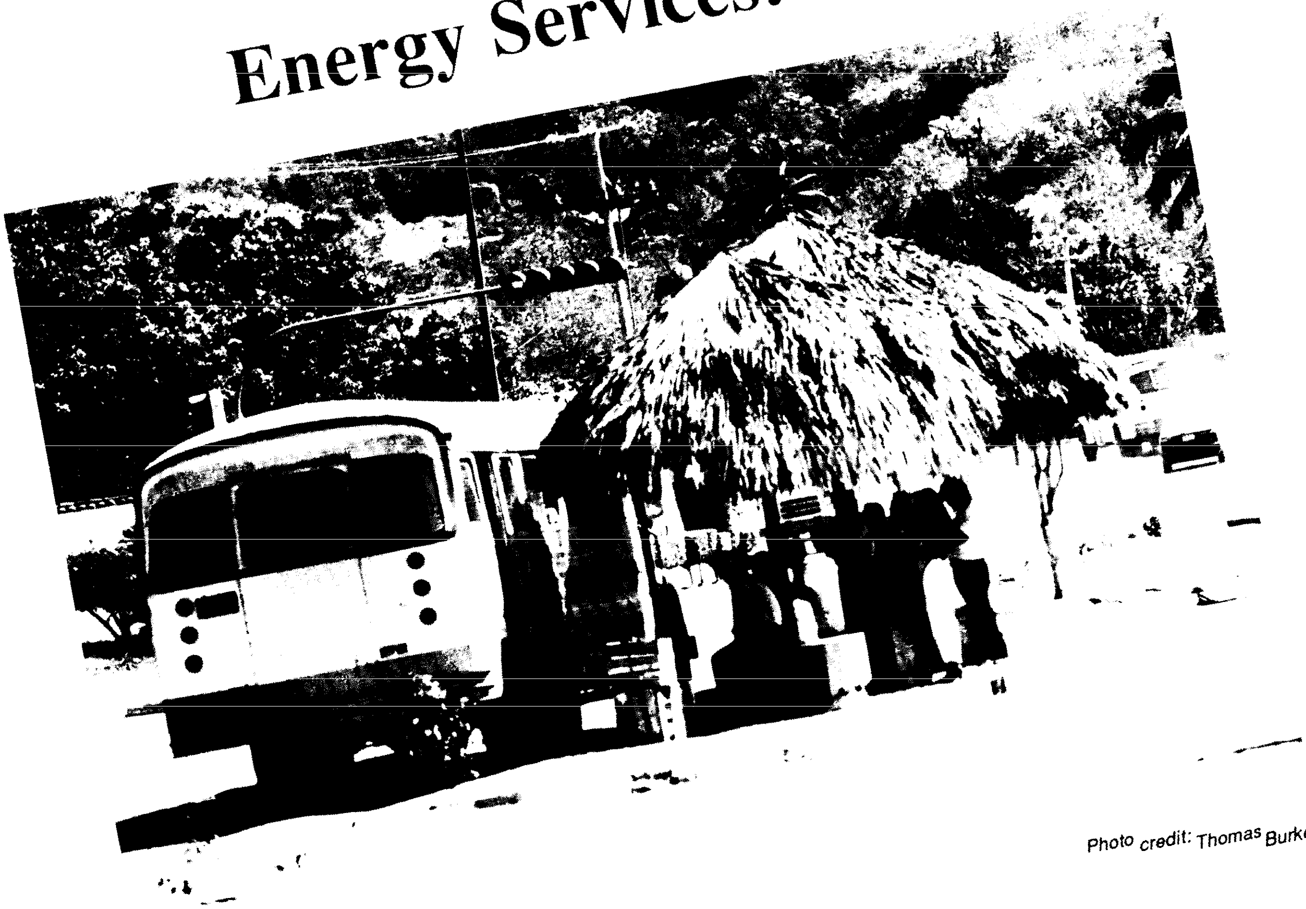
Chapter 5

Energy Services: Transport



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INTRODUCTION AND SUMMARY

Transport services are a key component of economic development. As the economies of the developing world expand, transport services must also grow to supply the raw material, labor, food, and consumer goods needed by the growing economy, and to integrate rural areas into the larger economy. At the same time, higher standards of living associated with economic expansion lead to sharply rising demand for personal mobility, often by automobile.

Providing these services can be difficult and costly. The transport sector, in most developing countries, accounts for one-third of total commercial energy consumption (see table 5-1) and over one-half of total oil consumption. India and China are exceptions. In these countries transportation accounts for under 10 percent of commercial energy consumption.

As many developing countries have little or no domestic oil resources, purchases of imported oil to satisfy transport demand together with imports of transport equipment put considerable pressure on limited foreign exchange resources. In addition, capital requirements for road and railway construction and maintenance take up a significant share of development budgets.

Road vehicles are also major contributors to high levels of urban air pollution currently experienced in developing countries. In Indian cities, for example, gasoline fueled vehicles—mostly two and three wheelers—are responsible for roughly 85 percent of carbon monoxide and 35 to 65 percent of the hydrocarbons in the air from fossil fuels. Diesel vehicles—buses and trucks-are responsible for over 90 percent of nitrogen oxide emissions in urban India.[1] Emissions from the transport sector also account for a significant share of global greenhouse gas emissions.

Along with these high economic and environmental costs, the transport systems in developing countries are frequently unsatisfactory in terms of the quality and quantity of transport services they deliver, inadequately supporting the free flow of goods and people that is vital for economic development. Urban traffic is severely congested[2] and rural areas are poorly served.

This chapter examines ways in which the energy efficiency of the transport system could be improved and environmental pollution could be reduced while still providing the transport services needed for economic development. This can be done by improving the efficiencies of each transport mode, changing the modal mix, moderating the demand for transport through full costing of services, and improving land use planning (see table 5-2). This chapter focuses primarily on technological opportunities for improving transport efficiency.

Commercially available technologies, many of which are widely used in the industrialized countries, could significantly improve transport energy efficiencies in the developing countries. In freight transport, the existing developing-country truck fleet is generally older, smaller, and less technologically sophisticated than the truck fleet of industrial countries. A wide range of retrofits such as rebuilt motors incorporating improved diesel fuel injection systems, cab mounted front air deflectors to reduce wind resistance, turbochargers, and radial tires are available. The rapid diffusion of these and other technologies could yield substantial energy savings.

In passenger transport, automobiles and other modes could benefit from the use of commercially available technologies such as electronic control of spark timing, radial tires, improved aerodynamics, and fuel injection. Many more efficiency improvements are at various stages of development and commercialization.[3] Table 5-3 lists a few of these for the U.S. fleet. The energy efficiency of the rapidly

[1]Tata Energy Research Institute, *TERI Energy Data Directory and Yearbook 1988* (New Delhi, India: 1989), p. 250.

[2]Road vehicles in Lagos and Bangkok, for example, move at only half the speed of road vehicles in London or Frankfurt. World Bank, *Urban Transport*, World Bank Policy Study (Washington DC: World Bank, 1986), p. 3.

[3]These technologies, their costs, and numerous controversies surrounding their implementation are explored in U.S. Congress, Office of Technology Assessment, *Improving Automobile Fuel Economy: New Standards, New Approaches*, OTA-E-504 (Washington, DC: U.S. Government Printing Office, October 1991).

Table 5-l-Total Delivered Energy by Sector, in Selected Regions of the World, 1985 (exajoules)[a]

	Residential/commercial		Industry		Transport		Total		
Region	Commercial fuels	Traditional fuels[b]	Commercial fuels	Traditional fuels[b]	Commercial fuels	Traditional fuels[b]	Commercial fuels	Traditional fuels[b]	Total energy
Africa	1.0	4.0	2.0	0.2	1,5	NA	4.4	4.1	8.5
Latin America	2.3	2.6	4.1	0.8	3.8	NA	10.1	3.4	13.5
India and China	7.3	4.7	13.0	0.2	2.0	NA	22.2	4.8	27.1
Other Asia	1.9	3.2	4.0	0.4	1.9	NA	7.8	3.6	11.3
Developing countries	12.5	14.5	23.1	1.6	9.2	NA	44.5	15.9	60.4
United States	16.8	NA	16.4	NA	18.6	NA	51.9	NA	51.8

NA = Not available or not applicable.

NOTES: This is delivered energy and does not include conversion losses from fuel to electricity, in refineries, etc. The residential and commercial sector also includes others (e.g., public services, etc.) that do not fit in industry or transport. Traditional fuels such as wood are included under commercial fuels for the United States.

[a]Exajoule (10^{18} Joules) equals 0.9478 Quads. To convert to Quads, multiply the above values by 0.9478.

[b]These estimates of traditional fuels are lower than those generally observed in field studies. See references below.

SOURCE: U.S. Congress, Office of Technology Assessment, *Energy in Developing Countries,* OTA-E-486 (Washington, DC: U.S. Government Printing Office, January 1991) p. 49.

Table 5-2—improving the Efficiency of Transportation Services

Efficiency improvement
Remarks

Vehicle technical efficiency:

Automobiles

The technical efficiency of automobiles can be improved by: reducing vehicle weight; reducing vehicle aerodynamic drag; improving engine performance--overhead cam engines, multipoint fuel injection, roller cam followers, low friction engine, etc.; improving vehicle drive trains and transmissions; reducing rolling resistance; etc. (See table 5-3 for additional detail).

Two and three wheelers:

The technical efficiency of two and three wheel vehicles can be improved by converting from two-stroke to four-stroke engines, using improved carburetors and electronic ignition, reducing rolling resistance; etc.

Freight trucks;

Freight truck efficiencies can be improved by using diesel rather than gasoline engines, using improved fuel injectors and injection pumps, using turbochargers, using improved lubricants, reducing aerodynamic drag, reducing rolling resistance, etc.

Freight trains:

Freight train efficiencies can be improved by using diesel-electric locomotives, lighter weight cars, low friction bearings, on-board flange lubricators, steerable trucks, computer directed operations, etc.

Vehicle load factor:

Vehicle operational efficiencies can be improved by: increasing load factors through carpooling and other means for passenger vehicles and by maximizing loads and reducing empty or part-load back hauls for freight vehicles.

Vehicle operational efficiency:

Vehicle operational efficiencies can be improved by: better driving habits; improved traffic control-high-occupancy -vehicle only lanes, timed traffic signals, limited access roads, and other traffic management systems, etc.-for passenger vehicles; efficient routing for freight trucks; sidewalks, bicycle paths, and other means to reduce road congestion; improved roads and related structures to allow higher average speeds, heavier loads, etc; and by other means.

Modal shifts:

Efficiency gains by modal shifts require the movement of freight and passengers to more efficient transport systems. For freight, this typically includes from long-distance truck to rail; for passengers this includes from private automobile to commuter bus or rail mass transit, or to nonmotorized modes such as bicycling or walking.

Transport demand:

The demand for transport services or their equivalent can be satisfied while the demand for transport energy can be dramatically reduced: by land-use planning to better match residences with jobs, schools, shopping, and transport corridors-aiding modal shifts to more efficient transit systems as well as potentially reducing infrastructure costs for water, sewage, etc. and possibly reducing loss of agricultural lands; by improved telecommunications technologies; by charging users the full cost of transport services-including roads, parking, death and injury, pollution, and other costs; etc.

NOTE: These efficiency improvement opportunities are often highly interdependent. For example, technical improvements to freight trucks such as reduced aerodynamic drag, etc. are of little use unless the road infrastructure allows medium to high speeds. The above list does not include air-or water-based transport systems or a variety of land-based modes. The same considerations, however, generally apply.

SOURCE: Office of Technology Assessment, 1992.

Table 5-3—Technologies for Improving the Fuel Economy of Automobiles

Weight reduction. Includes three strategies—substitution of lighter weight materials, e.g., aluminum or plastic for steel; improvement of packaging efficiency, i.e., redesign of drivetrain or interior space to eliminate wasted space; and technological change that eliminates the need for certain types of equipment or reduces the size of equipment.

Aerodynamic drag reduction. Primarily involves reducing the drag coefficient by smoothing out the basic shape of the vehicle, raking the windshield, eliminating unnecessary protrusions, controlling airflow under the vehicle (and smoothing out the underside), reducing frontal area, etc.

Front wheel drive. Shifting from rear to front wheel drive, which allows: mounting engines transversely, reducing the length of the engine compartment; eliminating the transmission tunnel, which provides important packaging efficiency gains in the passenger compartment; and eliminating the weight of the propeller shaft and rear differential and drive axle. Now in wide use.

Overhead cam engines. OHC engines are more efficient than their predecessor pushrod (overhead valve, OHV) engines through their lower weight, higher output per unit displacement, lower engine friction, and improved placement of intake and exhaust ports.

Four valve per cylinder engines. Adding two extra valves to each cylinder improves an engine's ability to feed air and fuel to the cylinder and discharge exhaust, increasing horsepower per unit displacement. Higher fuel economy is achieved by downsizing the engine; the greater valve area also reduces pumping losses, and the more compact combustion chamber geometry and central spark plug location allows an increase in compression ratio.

Intake valve control. Shift from fixed-interval intake valve opening and closing to variable timing based on engine operating conditions, to yield improved air and fuel feed into cylinders and reduced pumping loss at low engine loads.

Torque converter lockup. Lockup eliminates the losses due to slippage in the fluid coupling between engine and transmission.

Accessory improvements. Adding a two-speed accessory drive to more closely match engine output to accessory power requirements, plus design improvements for power steering pump, alternator, and water pump.

Four-and five-speed automatic transmissions, and continuously variable transmissions. Adding extra gears to an automatic transmission increases fuel economy because engine efficiency drops off when its operating speed moves away from its optimum point, and the added gears allow the transmission to keep the engine closer to optimal speed.

Electronic transmission control. Electronic controls to measure vehicle and engine speed and other operating conditions allow the transmission to optimize gear selection and timing, keeping the engine closer to optimal conditions for either fuel economy or power than is possible with hydraulic controls.

Throttle body and multi point fuel injection. Fuel injection allows improved control of the air/fuel mixture and thus allows the engine to continually adjust this mixture for changing engine conditions. Multipoint also reduces fuel distribution problems. in wide use.

Roller cam followers. Most current valve lift mechanisms are designed to slide along the camshaft; shifting to a rolling mechanism reduces friction losses.

Low friction pistons/rings. Lower friction losses result from better manufacturing control of tolerances, reduced ring tension, improved piston skirt design, etc.

Improved tires and lubricants. Continuation of longstanding trends towards improved oil (in near-term, substitution of 5W-30 oil for 10W-40 oil), and tires with lower rolling resistance.

Advanced engine friction reduction. Includes use of light weight reciprocating components (titanium or ceramic valves, composite connecting rods, aluminum lifters, composite fiber reinforced magnesium pistons), improved manufacturing tolerances to allow better fit of moving parts, available post-1995.

Electric power steering. Used only for cars in the minicompact, subcompact, and compact classes.

Lea n-burn engines. Operating lean (low fuel to air ratio) improves an engine's thermodynamic efficiency and decreases pumping losses. Requires a new generation of catalysts that can reduce NO_x in a "lean" environment.

Advanced two-stroke engines. Unlike a conventional engine, there is a power stroke for every ascent and descent of the piston, thus offering a significantly higher output per unit of engine displacement, reduced pumping loss, smooth operation, and high torque at low speeds, allowing engine downsizing and fewer cylinders (reduced friction losses). Also, operates very lean, with substantial efficiency benefits (if NO_x problems are solved). Compliance with stringent emissions standards is unproven.

Diesel engines. Compression-ignition engines, or diesels, are a proven technology and are significantly more efficient than gasoline two-valve engines even at constant performance; new direct injection turbocharged diesels offer a large fuel savings. Although the baseline gasoline engine will improve in the future, a portion of the improvements, especially engine friction reduction, maybe used beneficially with diesels as well. Use may be strongly limited by emissions regulations and consumer reluctance.

Electric hybrids. involves combining a small electric motor for city driving and a diesel for added power and battery charging. The small size of the diesel eases emissions limitations, and the substantial use of the electric motors reduces oil use.

SOURCE: U.S. Congress, Office of Technology Assessment, *Improving Automobile* Fuel Economy: New Standards, New Approaches, OTA-E-504 (Washington, DC: U.S. Government Printing Office, October 1991).

growing fleet of two and three wheelers could also be increased, notably through the use of improved carburetors, electronic ignition, and four-stroke rather than two-stroke engines.[4]

Developing countries currently have little influence over the development and commercialization of these technologies, due to the small size of their market. As their market is growing rapidly, however, their influence will most likely grow as well.

Greater use of these technologies could result in significant energy savings-estimated at about 20 percent over current levels[5]—and they are highly cost effective, with short payback periods. The environmental benefits would also be significant. Improved carburetors and electronic ignition in two wheelers, for example, could improve efficiency between 10 and 15 percent, and reduce hydrocarbon emissions by 50 percent. The use of four-stroke rather than two-stroke engines could increase energy efficiency by 25 percent and reduce hydrocarbon emissions by 90 percent.[6] Lower consumption of petroleum products would save foreign exchange (or in the case of oil exporting countries, increase the amount of petroleum products available for export).

Despite the multiple advantages of these technologies there are several factors impeding their diffusion or diluting their potential energy savings (see table 5-4):

- Poor infrastructure. The benefits of aerodynamic improvements and turbocharging accrue only at higher speeds, which are often not possible on the rougher, more congested roads in the developing world. Similarly, poor roadbeds deter the use of larger and therefore more energy efficient trucks. Many of the new technologies depend on high quality fuels and do not operate well with the variable quality fuels often encountered in developing countries.
- Maintenance and training. Several technologies require specialized skills for maintenance that may not now be generally available in developing countries. If truck owners need to seek out specialist firms for routine maintenance, "down time" is increased, thus reducing the benefits from improved energy efficiency. Poor driving habits can also reduce efficiency gains.
- High first costs and high consumer discount rates. As in other end-use sectors, potential users are deterred by the additional cost of the improved technology, which they are apparently willing to undertake only if they can recover their additional cost in a very short period of time. In many cases, the costs of energy are a relatively small part of total operating costs so that the expected benefit may not be large in relation to other considerations, including the effort involved in finding and maintaining a more efficient vehicle as well as the various attendant uncertainties. In transport modes where fuel is a large share of total costs (such as air and maritime transport) and where financial decisions are made on the basis of discount rates closer to commercial bank rates, energy efficient technologies have often been adopted more rapidly than in passenger road transport
- Fuel costs. The length of the payback time is closely related to the costs of fuel. In oil exporting developing countries, prices of transport fuels are often kept well below world prices, offering little incentive to economize on their use. In the oil importing countries, gasoline prices are generally higher than international costs. Diesel prices, however, are often considerably lower than gasoline and/or international prices, which again discourages conservation.
- Import duties. High import duties on vehicles with higher initial costs due to more efficient equipment, and on retrofit equipment, deter their diffusion despite their potential to reduce oil (and/or refinery equipment) imports.
- Low scrappage rates. The high demand for road vehicles generally, relatively cheap labor for maintenance, expensive capital, and other factors have led to low scrappage rates in developing countries, and therefore an older (and less energy efficient) road vehicle fleet.

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[4] "Big Bets On a Little Engine," *Business Week,* Jan. 15, 1990, pp. 81-83.

[5] World Bank, *Urban Transport,* World Bank Policy Study (Washington, DC: World Bank, 1986), p. 2; see also, Mudassar Imran and Philip Barnes, World Bank, *Energy Demand in the Developing Countries,* World Bank Staff Commodity Working Paper #23 (Washington, DC: World Bank 1990).

[6] These improved two-stroke engines, currently under development for use in small automobiles or other applications, could also lower capital costs compared to the equivalent power four-stroke engine.

Table 5-4-Barriers to Transportation Efficiency Improvements

Technical

Availability

High efficiency vehicles and related technologies and their needed support infrastructure of ski lied manpower and spare parts may not be locally available. Foreign exchange may not be available to purchase critical spare parts.

Infrastructure

The available infrastructure within a developing country may not be able to adequately support a particular high-efficiency technology. For example, the benefits of aerodynamic improvements and turbocharging accrue only at higher speeds, which are often not possible on the rougher, more congested roads in the developing world. Similarly, poor roadbeds deter the use of larger and therefore more energy efficient trucks. Many of the new technologies depend on high quality fuels, and do not operate well with the variable quality fuels often encountered in developing countries. The existing infrastructure might also impede the implementation of a more efficient system.

Information

Potential users of energy efficient vehicles may lack information on the opportunities and savings.

Reliability

Innovative high-efficiency vehicles and components may not have a well proven history of reliability, particularly under developing country conditions.

Research, development, demonstration

Developing countries may lack the financial means and the technical manpower to do needed RD&D in energy efficient vehicle technologies, or to make the needed adaptations in existing energy efficient technologies in use in the industrial countries to meet the renditions-such as relatively low highway speed and frequent speed changes-in developing countries.

Technical *manpower*

There is generally a shortage of skilled technical manpower in developing countries for installing, operating, and maintaining energy efficient equipment in vehicles. If truck owners need to seek out specialist firms for routine maintenance, “down time” is increased thus reducing the benefits from improved energy efficiency.

Training

Poor driving habits can also reduce efficiency gains. See *also* Behavior, below. Training in vehicle maintenance and driving habits could promote efficiency.

Financial/economic

cost

As in other end use sectors, potential purchasers of high efficiency vehicles are deterred by the additional cost of the improved technology, which they are apparently willing to undertake only if they can recover their additional cost in a very short period of time. In many cases, the costs of energy area relatively small part of total operating costs so that the expected benefit may not be large in relation to other considerations, including the effort involved in finding and maintaining a more efficient vehicle as well as the various attendant uncertainties. In transport modes (such as air and maritime transport) where fuel is a large share of total costs and where financial decisions are made on the basis of discount rates closer to commercial bank rates, energy efficient technologies have been adopted more rapidly than in passenger road transport.

Currency exchange rate

Fluctuations in the currency exchange rate raises the financial risk to firms who import high efficiency vehicles with foreign exchange denominated loans.

International energy prices

Falls in international oil prices below expected levels can reverse the profitability y of investments in efficiency or alternative fuels. This has happened to some extent with the Brazilian ethanol program.

Scrappage rates

The high demand for road vehicles generally and for used vehicles in particular, combined with inflation (which protects the values of used cars), relatively cheap labor for maintenance, expensive capital, and other factors has led to low scrappage rates in developing countries, and therefore an eider (and less energy efficient) road vehicle fleet. While old vehicles can be retrofit to improve fuel efficiency their owners are likely to be the least able to afford the additional costs. The replacement of old vehicles by new, though contributing to the improved fleet energy efficiency, would in the short run at least incur large foreign exchange costs.

Secondary interest

Energy efficiency is often of secondary interest to potential users. Vehicle acceleration, roominess, comfort, or accessories such as air conditioning may be of greater importance to the prospective purchaser.

Secondhand markets

Low-efficiency vehicles may be widely circulated in secondhand markets in developing countries, including “gifts” or “hand-me-downs” from industrial countries. Further, users who anticipate selling vehicles into the secondhand market after only a few years may not realize energy savings over a long enough period to cover the cost premium of the more efficient vehicle.

Subsidized energy prices

Energy prices in developing countries are often controlled at well below the long run marginal cost, reducing end-user incentive to invest in more efficient vehicles. Energy prices may be subsidized for reasons of social equity, support for strategic economic sectors, or others, and with frequent adverse results. In oil exporting developing countries, prices of transport fuels are often kept well below world prices, offering little incentive to economize on their use. In the oil importing countries, gasoline prices are generally higher than international costs. Diesel prices, however, are often considerably lower than gasoline and/or international prices, which again discourages conservation.

Taxes and tariffs

Unless appropriately designed, taxes and tariffs can bias purchasing decisions away from vehicles, components, or retrofit equipment with higher initial costs due to more energy efficient equipment despite their potential to reduce oil (and/or refinery equipment) imports.

(continued on next page)

Table 5-4-Barriers to Transportation Efficiency Improvements-Continued

Institutional

Behavior

Users may waste energy, for example, by leaving vehicles on. In some cases, such seeming waste may be done for important reasons. Bus drivers in developing countries often leave their engines on for long periods, at a significant cost in fuel, in order to avoid jumpstarting their vehicle if the starter is broken, or to prevent customers from thinking (if the engine is off) that their vehicle is broken and going to a competitor whose engine is running.

Disconnect between purchaser/user

In a rental/lease arrangement, the owner will avoid paying the higher capital cost of more efficient vehicles while the rentor/lessor is stuck with the resulting higher energy bills.

/integration

Poor integration between modes—such as between rail and road systems--can result in shipping delays or simply not using the more efficient rail system due to its lower flexibility and difficulty in door-to-door delivery.

Land use planning

Poor land use planning can prevent the establishment of efficient transportation corridors for mass transit options, and encourages low density urban sprawl dependent on private vehicles.

Political instability

Political instability raises risks to those who would invest in more efficient vehicles that would only pay off in the mid to longterm.

Service

Poor servi ce--crowded, slow, infrequent, etc.-from, for example, buses in congested urban areas encourages people to purchase less energy efficient, but more convenient personal transport such as 2/3 wheelers or autos.

SOURCE: Office of Technology Assessment, 1992.

While old vehicles can be retrofit to improve fuel efficiency, their owners are likely to be the least able to afford the additional costs. The replacement of old vehicles by new, though contributing to the improved fleet energy efficiency, would—in the short run at least—incur large foreign exchange costs.

In addition to efficiency improvements within each transport mode, the energy efficiency of the transport sector as a whole (as measured by energy consumed per tonne-kilometer or per passenger-kilometer) could be improved by encouraging the movement of both freight and passenger traffic to the most energy efficient modes. In *freight* traffic, rail uses about one-fourth to one-third of the operating energy per tonne-kilometer that road vehicles use. If the energy embodied in transport equipment and associated railways and roads is included, the difference is reduced but railways continue to be much more energy efficient than roads for freight traffic, In addition, rail freight is usually cheaper per tonne-kilometer, at least for bulk commodities. This advantage is reduced, however, when door-to-door delivery is considered or as the size of the shipment decreases.

Despite its efficiency and cost advantages, rail's market share in those countries with rail networks has declined. This is due to a number of reasons, including: the greater convenience, flexibility, and reliability of truck transport; structural changes in the economy that favor road transport; and weakening of previously strong government support for rail systems, which has led to deterioration in the systems. Railroads serve well those markets with large volumes of commodities moved between freed points, but are less effective where timeliness or flexibility in delivery are more important, as indicated in table 5-5. Technologies such as containerization and improved scheduling (aided by telecommunications and computing technologies) can help use all elements of the freight transport system in an integrated manner.

The energy efficiency of *passenger* transport can also be improved by greater use of more efficient modes. In the passenger transport sector there is a wide variation in energy use per passenger-kilometer with private auto by far the least efficient and

Table 5-5—Rail and Truck Shares for Different Commodities, India 1978-79

Commodity	Average distance hauled (kilometers)	Rail share (percent)	Road share (percent)
Iron ore	526	99.30/0	0.7%
Coal	699	92.2	7.8
Cement	614	77.9	22.1
Fertilizers	794	71.9	28.1
Iron and steel	841	64.3	35.7
Stone and marble	290	49.4	50.6
Wood and timber	564	38.6	61.4
Building materials	242	13.1	86.9
Fruit and vegetables	532	8.9	91.1

SOURCE: Martin J. Bernard III, "Rail vs. Highway: A Difficult Intercity Transport Decision fora Developing Country," paper presented at the United Nations Center for Science and Technology for Development Workshop on New Energy Technologies and Transportation in Developing Countries, Ottawa, Canada, Sept. 20-22, 1989.

buses—the backbone of the urban passenger transport system in developing countries-the most energy efficient of the motorized forms of passenger transport. The inclusion of energy embodied in associated infrastructure further increases the attractiveness of buses (compared with cars, and two and three wheelers). In addition to the energy benefits of buses, capital costs of bus systems are lower than the alternatives. Despite these advantages, bus systems in developing countries often provide unsatisfactory service, not offering in their present form a sufficiently attractive alternative to private transport for those who can afford it.

Light rail systems, at present under construction or planned in 21 cities of the developing world, are generally more energy efficient than cars though less so than buses. According to a recent evaluation, light rail has achieved mixed results. Travel times were reduced, most systems provided high quality services, and ridership levels were high—although below forecasted levels. These systems require extensive subsidies, however, if fares are kept low enough to provide service to the poor.

Although important, technologies for transport efficiency are just one component of developing an efficient and cost effective transport system. Transport management schemes can also be a cost effective way of relieving congestion and thus improving the overall efficiency of the transport system. The success of such schemes in several cities of the developing world (e.g., Curitiba, Brazil and Singapore) testifies to their potential. Improved telecommunications can reduce the number of needed trips. Improved land use and transport planning-for example, by locating services (e.g., shopping) closer to intended customers, siting major freight terminals away from congested city centers, and promoting the integration of residential and employment centers—can reduce the demand for travel and thereby reduce transport energy use. These options are most promising for cities that are not yet fully developed but are growing rapidly—a common characteristic of cities in the developing world. Without a carefully implemented land use planning program, a private vehicle-based transport system is the likely end result by default. It is easy to add one automobile and one short stretch of road at a time; it is much more difficult to plan a comprehensive urban transport system.[7]

High and rising levels of urban air pollution are also focusing attention on fuels to replace gasoline and diesel in both industrial and developing countries. Several fuels, including CNG (compressed natural gas), ethanol, and methanol, not only reduce pollution but can often use domestic, rather than imported, energy resources. Several of these technologies are particularly suited to centrally fueled fleet vehicles, which form a larger share of the total fleet than in the industrial countries, CNG is an especially promising fuel for those countries with underutilized natural gas reserves. Alcohol fuels, although they are still more expensive than conventional fuels at current oil prices of $20/bbl, are becoming more cost competitive. Several of these fuel replacements are already widely used in some developing countries. Argentina had more than 37,000 CNG vehicles on the road as of July 1989—with the total increasing by 1,300 per month,[8] and Brazil had more than 4 million ethanol-fueled vehicles on the road in 1988.[9]

A substantial number of trips-performed largely by the urban and rural poor—for both passenger and freight traffic are by nonmotorized modes, including walking, push carts, animal drawn carts, and bicycles. Technologies exist-such as improved bullock carts and harnesses-to improve the efficiency of all of these modes. One obstacle to their more rapid diffusion is lack of capital for even the most modest improvements.

The incomplete diffusion of known, cost effective transport technologies with substantial energy and environmental benefits suggests the need for stronger

[7] Martin J. Bernard III, "Rail vs. Highway: A Difficult Intercity Transport Decision for a Developing Country," paper presented at the United Nations Center for Science and Technology for Development Workshop on New Energy Technologies and Transportation in Developing Countries, Ottawa, Canada, Sept. 20-22, 1989.

[8] Jorge Del Estado, "National substitution Plan of Liquid Fuels: Compressed Natural Gas, paper presented at the United Nations Center for Science and Technology for Development Workshop on New Energy Technology+ and Transportation in Developing Countries, Ottawa, Canada, Sept. 20-22, 1989.

[9] Jacy de Souza Mendonca, "The Brazilian Experience With Straight Alcohol Automobile Fuel," paper presented at the United Nations Center for Science and Technology for Development Workshop on New Energy Technologies and Transportation in Developing Countries, Ottawa, Canada, Sept. 20-22, 1989. Note, however, that the fluctuations in oil prices before, during, and after the gulf war have caused some conversions, when oil prices were low, back to gasoline and created some concerns about the direction of the Brazilian program and its cost effectiveness.

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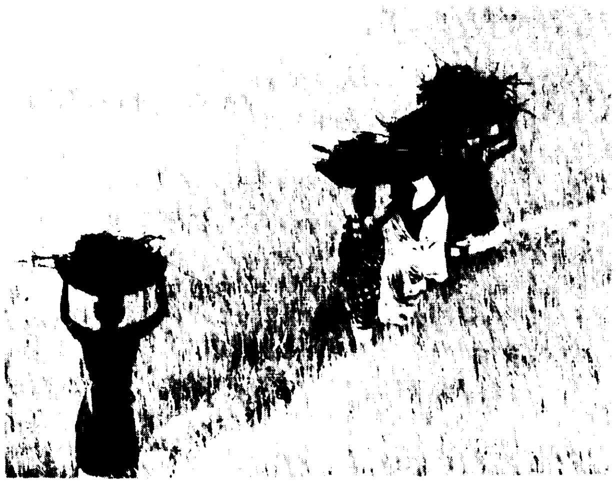


Photo credit: Ed Smith

Many people in developing countries rely on human muscle power for transportation energy.

incentives (or the removal of disincentives) for their adoption (see table 5-6). Such incentives could take the form of providing information on fuel efficient technology; higher fuel prices where appropriate; pricing policies and procedures that incorporate the environmental costs and benefits of transport fuels; acquisition and ownership taxes on motor vehicles inversely proportional to their energy efficiency; and setting standards on energy efficiency or environmental impacts (as seems to be the approach followed by cities such as Mexico City and Sao Paulo concerned about urban air pollution). Driver training and education could also improve energy operating efficiencies in many cases.

It is important to note, however, that people using energy ''inefficiently in a technical sense are nevertheless generally operating logically within their framework of incentives and disincentives. For example, bus drivers in developing countries often leave their vehicles idling for long periods, at a significant cost in fuel. This is not done through lack of training (as commonly suggested), but as a practical response to the problems they face. These problems include: 1) broken starters, requiring a difficult push start; and/or 2) the perception by potential customers that if the vehicle is not running then it must not be in service, resulting in them going to a competitors' vehicle.[10] Thus, as long as a driver's competitors keep their vehicles running, so must he.[11]

As the efficiency of transport energy use is closely correlated with the overall efficiency of the transport sector, policies to promote better and more efficient transport systems could simultaneously have economic and environmental benefits. Segregated bus lanes, truck climbing lanes,[12] traffic management systems, side walks, bicycle paths, and others can all r-educe congestion, thus increasing the average speeds necessary for more fuel efficient operation and making bus services more attractive to potential patrons. These changes can also defer expensive construction of new roads. Making all users pay the full cost of using road space, parking space, accidental injury and death, environmental effects, and other impacts could also encourage more efficient use of existing road space. Integrated freight transport policy could combine the strengths of all the different modes-road, rail, and maritime transport where available.

U.S. policies and programs could assist in some of these initiatives:

- providing information and technical assistance on such topics as the technical and operational characteristics of road vehicles, the connection between transport energy efficiency and urban air quality, and rural transport technologies;
- as the multilateral development banks make major loans for transport infrastructure projects, U.S. influence on the development of these projects could ensure that energy efficiency and environmental considerations are taken into account; and
- although the main barriers to improved energy technology at present do not appear to be related to technology, improvements in fuel efficiency depend critically on developments in those countries-mainly Japan, Italy, France, Germany and the United States—that dominate global road transport technology. Developing countries share of the global market will, however, rise substantially in coming years, giving them increased influence on technology

[10] Personal communication, S. Padmanabhan, Energy and Environmental Policy, Innovation, and Commercialization (EPIC) Program, U.S. Agency for International Development, Office of Energy, June 9, 1991.

[11] This type of situation is explored in depth in studies of game theory.

[12] Special lanes for trucks on steep slopes enable other traffic to pass 'ore quickly.

Table 5-6—Policy Options

Alternative financial arrangements

The high sensitivity of consumers to the initial capital cost of a vehicle often leads to lower levels of investment in efficiency than is justified on the basis of life cycle operating costs. Alternative financial arrangements to redress this might include low-interest loans for the marginal cost of efficiency improvements, rebates, or other schemes. These might be financed by various fuel or other taxes. Note that users that would have purchased efficient equipment anyway, however, also get the loan/rebate--the "free rider" problem. This reduces the effectiveness of the loan/rebate programs by raising the cost per additional user involved. This problem can be minimized by restricting the loans/rebates to only the very highest efficiency vehicles for which there is little market penetration.

Alternative fuels infrastructure investments

See Office of Technology Assessment, U.S. Congress, Rep/acing *Gasoline: Alternative Fuels for Light-Duty* Vehicles, OTA-E-364, September 1990.

Availability

Provide incentives to manufacturers to market high efficiency vehicles within the country when, otherwise, the potential market would be too small to justify the effort on the part of the manufacturer.

Data collection

The range of opportunities for energy efficient transport systems, end-user preferences, and operating conditions are not well known in many countries. Data collection, including detailed field studies, would help guide policy decisions.

Demonstrations

Many potential users of energy efficient vehicles remain unaware of the potential savings or unconvinced of the reliability and practicability of these changes under local conditions. Demonstration programs-such as government purchase of high efficiency vehicles--can show the effectiveness of the equipment, pinpoint potential problems, and in so doing convince potential users of the benefits of these changes.

Inf rastructure investments

Improve roads, railways, etc. to allow higher average speeds, heavier loads, more timely delivery, etc.

Information programs

Lack of awareness about the potential of energy efficient vehicles and related equipment, traffic management improvements, modal shifts, land use planning, or other improvements can be countered through a variety of information programs; competitions and awards for efficiency improvements; etc.

Labelling programs

The efficiency of vehicles and related equipment can be labeled to provide purchasers a means of comparing alternatives. Measuring efficiencies, however, needs to be done in conjunction with standardized test procedures, perhaps established and monitored by regional test centers, rather than relying on disparate and perhaps misleading manufacturer claims.

Land use planning

Land use planning can be a particularly effective, but long term, means of improving system wide transport efficiencies. It does this by better matching residences to jobs, schools, shopping, and transport corridors, etc. to minimize transport distances and maximize the opportunities for using mass transport options. A phased approach-beginning with dedicated busways to hold and maintain right-of-ways and to encourage high density, mixed job and residential land use; followed by the replacement of buses with light-rail systems where necessary--might then be an effective approach (if combined with other policy measures such as appropriate land-use planning; full pricing of automobile use--fuel, roads, parking, congestion, injury and death, etc.; effective traffic control; and others) in developing a comprehensive and effective urban transport system.

Loans/rebates

See Alternative financial arrangements, above.

Marketing programs

A variety of marketing tools might be used to increase awareness of energy efficient vehicles and increase their attractiveness. These might include radio, TV, and newspaper ads, billboards, public demonstrations, product endorsements, and many others.

Non-motorized transport

Provide full consideration, including reasonable investment, in nonmotorized transport design and infrastructure--such as segregated bicycle paths, broad intersections, curb cuts, etc. Provide training to transport designers to assist consideration and incorporation of design features for nonmotorized transport.

(continued on next page)

Table 5-6--Policy Options-Continued

Pricing policies
Energy prices should reflect the full costs of supply. The structure of petroleum product prices should not be distorted; for example, gasoline prices should not be out of line with diesel or kerosene, or else inefficient and unplanned for substitutions will take place. Prices alone, however, are often insufficient to ensure full utilization of cost effective energy efficient vehicle technologies. There are too many other market failures as discussed above. As evidence of this, even the United States has adopted efficiency standards for vehicles.

R&D
Most vehicle R&D is done in the industrial countries with industrial country operating conditions and needs the primary considerations. As developing country markets for vehicles grow, however, they are likely to gain greater leverage over this research agenda.

Secondhand markets-standards, scrappage
Efficiency labels or standards might be set for secondhand vehicles and equipment. Alternatively, registration fees might be increased with the age of the vehicle, bounties might be offered for the oldest of vehicles, or other means employed-such as emissions standards-to retire the worst cars.

Social costs
Users of transportation should be assessed for the full costs of the transport services they receive. These include especially medical and economic rests (leave from job, disruption of office, etc.) associated with death or injury due to car accidents, as well as air pollution, and other social costs.

Standards for vehicles
Many industrial countries have chosen to use minimum efficiency standards for vehicles rather than market driven approaches, due to the difficulty of overcoming the numerous market failures noted above.

Tax credits, accelerated depreciation, tariffs
A variety of tax incentive-tax credits, accelerated depreciation, reduced import tariffs etc.--couid be used to stimulate investment in energy efficient vehicles. Conversely, taxes or tariff-such as gas guzzler taxes/tariffs on vehicle purchases or registration fees that increase as vehicle efficiency decreases-could be used to reduce investment in inefficient vehicles or equipment.

Traffic management
improved traffic management, including, high occupancy vehicle lanes, segregated bus lanes, truck climbing lanes, bicycle lanes, timed lights, etc.

Training programs
Training programs may be needed in order to ensure adequate technical manpower for maintenance of advanced energy efficiency equipment in vehicles. Driver training programs can also be useful.

Transport planning
Transport planning can, in conduction with land use planning, help ensure efficient choice of transport modes, effective integration of different modes, etc.

User costs
Users of transportation infrastructure--roads, parking, etc.--should pay the full cost of using these facilities.

SOURCE: Office of Technology Assessment, 1992.

Table 5-7-Road Vehicle Fleet Growth and Ownership in Selected Countries

	Annual growth (percent/year, 1982-86)				
Country	Autos	Trucks buses	2 and 3 wheelers	Total	Ownership (1986 vehicles/1 ,000 people
Cameroon	11.8	29.5	9.1	13.1	16
Kenya	3.2	3.7	4.0	3.3	11
Bolivia	8.6	24.5	6.9	11.6	37
Brazil	8.9	7.3	35.6	9.8	106
Thailand	8.8	4.4	9.5	8.8	64
India	8.2	11.2	25.4	18.4	10
China	41.6	14.8	44.9	29.8	7
Japan	3.0	4.1	7.0	4.4	538
Us.	2.4	3.5	-5.6	2.4	44
W. Germany	3.3	0.4	-2.2	2.6	511

Vehicle ownership includes autos, trucks, buses, and 2 & 3 wheelers. Nonmotorized transport not included.

SOURCES: Energy and Environmental Anatysis(EEA), "Policy Options for Improving Transportation Energy Efficiency in Developing Countries," contractor report prepared for the Office of Technology Assessment, July 1990, pp. 2-15, 2-16.

development. Advances in alternative fuel technologies could help developing countries in their search for substitutes for petroleum products.

TRANSPORTATION SYSTEMS IN DEVELOPING COUNTRIES

With the important exceptions of rail in China and India, commercial transportation in the developing countries is road based—trucks, buses, motorcycles, and automobiles.[13] Road vehicle fleets are growing rapidly in the developing world (see table 5-7), The expansion of the road vehicle fleet is particularly rapid in India and China, where road transport has until recently played a relatively small role in overall transport services. In several countries, there has been a sharp increase in growth of two and three wheelers. These vehicles provide a high level of personal mobility at less cost to the purchaser than an auto. Ownership of road vehicles in developing countries is growing rapidly, but is still much lower than in industrial countries.

Over 90 percent of the transport energy used in the developing world is in the form of oil, with the remaining 10 percent largely coal for use in rail in India and China (see table 5-8).[14] Over half of the oil consumed for transport is in the form of diesel for freight transport (see table 5-9). This contrasts with the United States, which uses most of its transport fuel in the form of gasoline for autos.

The energy requirements of transport systems in developing Asian countries have grown at an average annual rate of 4.5 percent between 1980 and 1987.[15] According to a recent World Bank study,[16] this rapid growth could well continue, thus exacerbating financial and environmental problems.

Although the commercial transport sector attracts most attention, most of the population in developing countries live in rural and poor urban areas and are largely dependent on local informal transport systems--particularly walking, animal power, and bicycling. As a transport mode, walking is flexible and low cost, but it is slow, tiring, and very limited in hauling capacity. Animal technologies, such as bullock carts, have a much greater ii-eight capacity than walking, but are more costly. They require considerable human effort to maintain the animals, capital investment in a bullock and cart, and operational costs for feed and veterinary services.

Bicycles are widely used. In China, for example, 50 to 90 percent of urban vehicle trips are made by bicycles. Although they are a highly energy efficient mode of transport, bicycles often require more roadway per passenger than buses due to their slower average speeds and less compact seating. Like other

[13] In China most (89 percent) rail energy use is in the form of coal, whale in ~&a rail energy use is split between coal (73 percent) and oil (22 percent).

[14] International Energy Agency, W.ld Energy *Statistics and Balances 1971-1987* (Paris: Organization for Economic Cooperation and Development, 1989), data are for 1985, pp. 120, 124, 128.

[15] 1 bid., pp. 118-128.

[16] M. [reran, op. cit., footnote 5.

Table 5-8-Transport Energy Use, 1985 (percent)

	China[a]	India	Brazil	Nigeria	U.S.
Fuel type (percent)					
Oil	52	79	100	100	100
Coal	47	20	0	0	0
Electricity	1	1	0	0	0
Mode(percent)					
Road	38	65	85	91	82
Rail	52	27	3	0	3
Air	1	7	7	9	14
Water	9	1	5	0	1
Total (exajoules)	1.03	0.92	1.13	0.27	18.65

[a]China mode percent data are for 1980, total is for 1985.

SOURCES: J. Yenny and L. Uy, *Transport in China*, World Bank Staff Working Papers Number 723, 1985, p. 35; International Energy Agency, *World Energy Statistics and Balances 1971-1987*, OECD, Paris, 1989, p. 366 (China), p. 784 (India), p. 256 (Brazil), p. 191 (Nigeria); International Energy Agency, *Energy Balances of OECD Countries 1970/1985*, OECD, Paris, 1987, p. 541.

Table 5-9—Annual Consumption of Diesel and Gasoline Fuel (1986)

Country	Diesel (1,000 metric tons)	Gasoline (1,000 metric tons)	Percent diesel	Diesel (kg per capita)	Gasoline (kg per capita)
Cameroon	296	276	52	28	26
Kenya	515	220	70	24	10
Bolivia	266	308	46	40	47
Brazil	18,004	10,182	64	130	74
Thailand	4,878	1,654	75	93	31
India	16,700	2,508	87	21	3
China	19,785	15,258	56	19	14
Taiwan	2,786	2,269	55	136	111
United States	68,056	290,113	19	282	1,201

Adapted from: Energy and Environmental Analysis (EEA), "Policy Options for Improving Transportation Energy Efficiency in Developing Countries," contractor report prepared for the Office of Technology Assessment, July 1990, pp. A-3, A-6.

forms of animate energy, the range and freight capacity of bicycles are limited, accounting for the decisive popularity of the internal combustion engine for both passenger and freight transport as soon as it can be afforded.

IMPROVING FREIGHT TRANSPORT ENERGY EFFICIENCY

In developing countries, freight transport accounts for a much higher share of total transport fuels--about one half-than in the industrial countries. Freight movement in the developing world is principally by truck, with the exception of India and China, which also use rail. Options for improving the energy efficiency of freight transport include:

1. improving the energy efficiency of trucks;
2. improving the energy efficiency of rail; and
3. greater use of the more efficient of these two modes.

The Truck Fleet

At first sight there appears to be considerable potential for improving the energy efficiency of developing countries' truck fleets. While there is wide variation in the types of trucks used in developing countries, their fleets are, in general, older, smaller, and less technologically sophisticated than trucks found in the industrialized countries-all factors that result in lower energy efficiencies (see table 5-10).

Developing-country truck fleets are older because vehicle scrappage rates (i.e., the fraction of the fleet that is scrapped per year) are much lower than in industrial countries. In developing countries, new trucks are expensive to buy, and if they need to be imported, foreign exchange may not be available. On the other hand, due to low labor costs, repair is relatively cheap. The result of these two reinforcing factors is that it is usually cheaper and easier to repair and patch up a vehicle than to replace it. In general, it is not easy to retrofit trucks with

Table 5-10-Energy Efficiency of Trucks in Selected Countries

Country/ region	Truck name	Capacity (metric tons)	Energy consumption (megajoules per metric ton per kilometer)
OECD	Mercedes Benz 1217 (1979)	7.0	1.0
OECD	Man-VW 9136 (1980)	5.9	1.0
India	TATA 1201 SE/42	5.0	2.1
India	Ashok Leyland Beaver	7.5	1.6
China	Jiefang CA-1OB	4.0	2.3
China	Dongfeng EQ140	5.0	1.8

NOTE: OECD and Indian trucks use diesel, Chinese trucks use gasoline.

SOURCE: J. Yenny and L. Uy, World Bank, *Transport in China,* Staff Working Paper No. 723, 1985, p. 70.

efficiency improvements once they are operating. An exception is periodic engine rebuilding. If this rebuild is done with more modern technology, such as improved fuel injectors and injection pumps, engine efficiency gains of up to 5 percent can be obtained .17

Many local shops in developing countries, however, do not have the technical expertise to rebuild engines with these improved technologies. This leads to increased downtime and transport costs as engines have to be sent to the factory for rebuilding. Increased attention to training in local shops could reduce these costs and make energy saving investments more attractive.

Low scrappage rates could be discouraged by policies such as the introduction of annual registration fees inversely proportional to vehicle age. Such policies could, however, involve heavy foreign exchange costs, at least in the short run. The long lifetimes of trucks in the developing world also emphasizes the importance of building efficiency into new trucks, as these trucks will continue to operate for many years.

The size of a truck has an important bearing on its overall energy efficiency. Small trucks, in particular, generally require more energy to move a ton of freight than large trucks. On average, developing world trucks are smaller than trucks found in the industrialized countries. Chinese trucks are mostly 4 to 5 ton,[18] and the largest Indian trucks are typically rated at 8 to 9 tons (although they routinely carry up to 14 tons) .19 These sizes are considerably less than the 20-ton trucks used in the United States. The poor highway infrastructure in many developing countries, however, constrains the use of larger trucks. Less than 20 percent of China's highways are paved, for example.[20] Increases in truck carrying capacity and the energy efficiency advantages resulting from this, cannot be implemented without corresponding improvements in road carrying capacity.

Developing world trucks are, on average, less technologically sophisticated than industrialized country trucks. Principal truck manufacturers in India build diesel engines comparable in technological sophistication and efficiency with those built in the industrialized countries in the 1960s. This is changing. For example, one of the dominant Indian truck manufacturers now offers an optional Japanese engine with improved fuel efficiency .21 Much of China's truck fleet uses relatively inefficient gasoline engines.[22] The share of more energy efficient diesel trucks is growing,[23] however, and much of the vehicle-related foreign investment in China involves

[17]Energy and Environmental Analysis, Inc., "Policy Options for Improving Transportation Energy Efficiency in Developing Countries, ' contractor report prepared for the Office of Technology Assessment, July 1990, pp. 5-6.

[18]J. Yenny and L. Uy, "Transport in China, ' World Bank Staff Working Papers Number 723 (Washington, DC: World Bank, 1985), p. 39.

[19]Martin J. Bernard III, U.S. Department of Energy, Argonne National Laboratory, *Transportation-Related Energy Problems in India*, Report No. ANL/EES-TM-163 *(Argonne,* IL: Argome National Laboratory, September 1981), p. 7.

[20]J. Yenny, *op.* cit., footnote 18.

[21]Energy and Environmental Analysis, Inc., Op. Cit., footnote 17.

[22]Ibid. In general, diesel engines are more efficient than gasoline engines, due in part to the thermodynamic advantages Of the compression ignition (diesel) cycle over the spark ignition (gasoline) cycle.

[23]In 1978, 13 percent of the trucks in China used diesel; by 1988 this had increased to 18 percent. Motor Vehicle Manufacturers Association of the United States, Inc., *World Motor Vehicle Data, 1990 Edition* (Detroit, MI: Motor Vehicle Manufacturers Association of the United States, Inc., 1990), p. 46.

diesel truck engines.[24] Brazil assembles trucks designed in Western Europe and exports these relatively efficient trucks to all of Latin America. Many countries, particularly in Africa, import modern trucks from Europe and Japan, and therefore in principle have access to the most advanced truck technologies.

In operation, however, the energy benefits of these up-to-date technologies may not be fully realized under developing country conditions. The benefits of aerodynamic improvements and turbocharging accrue primarily at higher speeds, which are often not possible on the rougher, more congested roads in the developing world. High-efficiency engines are often dependent on high-quality fuels, and do not operate as well under the conditions of variable quality fuels frequently encountered in developing countries. Maintenance requirements are more complex and more critical to engine performance. As the share of developing countries in markets for trucks rise, they maybe able to increase their leverage on manufacturers in the industrial world to provide technologies more suitable to the conditions of the developing world.

Further, the cost effectiveness of the various technological options may be compromised by energy pricing policies widely followed in developing countries. For social and development reasons, many governments keep diesel prices as low as possible. In oil exporting countries, prices are generally well below levels reflecting international costs plus distribution costs. In oil importing countries, diesel prices are usually near international prices or slightly higher but often do not bear the high taxes typically imposed on gasoline. The high cost of capital combined with relatively low diesel prices discourages energy efficiency improvements. For example, the installation of a turbocharged engine at a $800 to $1,000 premium for a relatively small (5 percent) benefit in fuel economy is cost effective, but only marginally so: a truck achieving 10 miles per gallon (23 liters/100 km), driven 40,000 miles (64,000 km) per year, and paying $1/gallon ($0.26/liter) for diesel will have a payback of about 4.7 years on such an investment.

Improved lubricants for the gearbox, engine, and axle can provide small benefits (1 to 2 percent) in fuel economy. At the low speeds typical in developing countries, however, aerodynamic improvements are not very effective in reducing fuel consumption. Improved drivetrain matching is also problematic because of the propensity of truck owners to overload vehicles. Tire improvements offer limited potential, as radial tires of modern design provide only a 2 to 3 percent efficiency benefit over bias-ply tires. Total improvements of 5 to 8 percent in diesel fuel economy may be all that is possible with current technologies under developing country conditions when using trucks.

Technology alone thus may have a limited role to play in improving truck efficiencies. Proven efficiency improvements-the use of larger trucks, travel at higher, constant speeds allowing the use of aerodynamic improvements and turbochargers—require smooth, uncontested, paved heavy duty roads. Furthermore the efficiency of diesel engines drops sharply under conditions of varying load and speed, such as are often found on the congested, poorly maintained roads of the developing world. Advanced truck technologies under development in the industrialized countries, such as further improvements in aerodynamics, low rolling resistance tires, and multiple turbochargers, also require smooth, high-speed roads.

Road construction and improvement is expensive, and the benefits are diffuse and often difficult to measure. For these reasons, the public sector, including the international development agencies, has long been the principal source of funds for road building and repair. The energy efficiency effects of improved roads are complex. In the short term, improved roads increase energy efficiency by allowing for higher, sustained speeds. By one estimate, heavy truck operating costs per kilometer (due largely to energy) drop 34 percent when a dirt road is paved.[25] In the longer term, improved roads allow for the use of larger, heavier trucks as well as the use of turbochargers and aerodynamic improvements. Improved roads may also encourage increased traffic (and therefore increased energy use), but this increased traffic may contribute to overall economic development in an efficient manner.

[24] C. Oman, *New Forms of Investment in Developing Country Industries* (Paris: Organization for Economic Cooperation and Development 1989), p. 160.

[25] H. Adler, World Bank, *Economic Appraisal of Transport Projects* (Baltimore, MD: Johns Hopkins University press, 1987), p. 120.

Operational improvements in trucking have the potential to improve freight energy efficiencies. Load factors are often low. Improved communications, route scheduling, and overall coordination of the freight transport system can improve energy efficiency by ensuring full loads and reducing waste. Part of this low load factor, however, is rooted in policy and institutional factors. Many enterprises in developing countries do their own shipping rather than rely on common carrier fleets that they find less reliable. These ''own account' shippers are usually licensed to carry their own products only, resulting in empty backhauls and low average load factors.

Improving Rail Efficiency

Rail systems carry a significant fraction of freight only in India and China, but as these counties account for about half of the developing world's population, their rail systems represent a large part of the developing world's freight system.

The rail systems of India and China use a mix of coal, diesel, and electric locomotives, although coal locomotives are being phased out (see table 5-11). The substitution is more advanced in India than in China. Coal still accounts in China for about 80 percent of total rail freight tonne-kilometers.[26] The energy benefits of this technological change are considerable, as diesel locomotives are about five times more energy efficient than coal locomotives .[27] There appears to be no decisive energy benefit in switching from diesel to electric locomotives,[28] however, which in any event tend to be economically efficient only for high traffic densities.

In addition to the energy efficiency benefits associated with a conversion from coal locomotives, U.S. experiences suggest that there are other opportunities for energy efficiency improvements within the rail sector. Improved operations, such as reducing empty car miles and matching loads and speeds to the locomotive's optimum operating characteristics, can reduce energy use. Lighter weight cars, low resistance bearings, and onboard flange lubricators all contributed to a 32-percent increase in energy efficiency (tonne-kilometers per unit energy) in U.S. freight railroads from 1970 to 1987.[29] Other promising technological innovations include steerable trucks for cars and locomotives. Computers to assist drivers in efficient operation can reduce consumption by up to 25 percent.[30]

Table 5-1 l-Characteristics of the Indian Rail System

	Number of locomotives	
	1971	1987
Steam (coal) . . . . . ., ...	9,387	4,950
Diesel	1,169	3,182
Electric	602	1,366

SOURCE: Tata Energy Research Institute (TERI), *Teri Energy Data Directory and Yearbook, New* Delhi, 1988, pp. 165, 170.

Modal Shifts

In principle it is possible to improve the energy efficiency of the entire freight transport system by ensuring that the bulk of freight is carried in the most efficient mode. The relative operating energy efficiencies of rail and road for freight depend on several factors, including how heavily the vehicles are loaded and whether or not the vehicles are loaded for the return trip. Although estimates vary, it is generally agreed that, on average, rail is more energy efficient than road for freight.[31] The trend away from rail therefore represents a loss in energy efficiency. The magnitude of this loss depends on the specific system, but a rule-of-thumb number is that operating energy efficiencies in rail freight transport are 3 to 4 times as energy efficient as truck freight transport.[32] If the comparison of energy efficiencies between the two systems is expanded to include not only the amount of energy used for operating the train or

26J. Yenny op. cit., footnote 18.

27J. Dunkerley, *Trends in* Energy Use *in Industrial Societies,* Resources for the Future, Inc., research paper R-19,1980, p.149.

28The efficiency of electric locomotives depends on the fuel used to generate the electricity. For electricity produced from fossil fuels the energy efficiency of diesel and electric locomotives are comparable. See L. Alston, *Railways and Energy,* World Bank Staff Working Paper Number 634 (Washington DC: World Bank, March 1984), p. 31.

29U.S. Department of Energy, Oak Ridge National Laboratory, *Transportation* Energy *Data* Book: *Edition 10,* Report No. ORNL-6565 (Springfield, VA: National Technical Information Service, September 1989), pp. 4-23. During this time period the average trip length increased 34 percent, therefore at least part of this increase in efficiency was probably due to the inherent efficiency of longer trips.

30L. Alston, op. cit., footnote 28, pp. 14-15.

31 According to a World Bank report, ". . railways have a substantial energy advantage for large volumes of bulk commodities, but for passenger transport they are generally no more energy-efficient than buses. " Ibid., p. I.

32M. Bernard, op. cit., footnote 7. Also L. Alston , Op. cit., footnote 30* p. 7.

Table 5-12--Systemwide Energy Use by Alternative Transportation Systems

	Operating energy	Linehaul energy	Modal energy
		United States	
Freight	(Btu/ton-mile[a])	(Btu/ton-mile)	(Btu/ton-mile)
Rail	660	1,130	1,720
Truck	2,100	2,800	3,420
Barge	420	540	990
Passenger	(Btu/pass-mile[b])	(Btu/pass-mile)	(Btu/pass-mile)
Auto	8,490	10,790	10,790
Bus	2,740	2,950	3,220
Metro	3,570	4,550	6,690
		Latin America	
Passenger	(Btu/pass-mile[b])	(Btu/pass-mile)	(Btu/pass-mile)
Auto	4,820	7,130	7,130
Bus	603	660	660
Metro	760	990	1,130

"Linehaul" is the total energy of the vehicle plus its related highway or rail infrastructure.
"Modal" includes the total energy to get door to door using primarily the mode listed. This also includes related infrastructure energy requirements as for linehaul.
[a]To convert to Joules/tonne-km, multiply by 595.
[b]To convert to Joules/passenger-km, multiply by 656, pass-mile=passenger mile.

SOURCE: Damian J. Kulash, "Energy Efficient Modes of Transportation: Comments on Urban Transportation in the United States and Latin America," (Washington, DC: Congressional Budget Office), February 1982, pp. 6, 220.

truck, but also the amount of energy contained in the manufacture of the transport equipment and associated railways and roads, and the amount of energy needed to gain access to each mode, then the gap between them is reduced. Railways then appear to be about twice as efficient as roads rather than the 3 or 4 times when only operating efficiencies are taken into account (see table 5-12).[33]

Despite the fact that rail transport is more energy efficient and cheaper than road freight transport, its share of total freight is declining in both India and China (see table 5-13). Road transport has the advantage of being more flexible and accessible. For rural areas it is essentially the only transport mode available. Door to door delivery possible with road transport avoids the risk of delay due to transshipment when using rail. As the demand for consumer goods increases, the demand for transport services that can deliver high value-added goods to many areas quickly increases.

Changes in government policy with regard to freight transport have also played a part in the relative decline of rail. In many countries throughout the world—in Europe as well as the developing countries-railways are State owned. Strenuous efforts have been made by governments through investment and pricing policies and regulations to reserve a dominant share for railways in the freight transport system. In recent years, however, this policy has been reversed. Investments in the railway system have failed to rise as they did previously. In India, for example, railroad's share of public investment in transport has decreased,[34] leading to poorer service and maintenance. At the same time some deregulation was introduced into the road transport system. Given the declining performance of rail freight and the growing opportunity to ship by road, customers have chosen road transport despite its frequently higher cost per tome-kilometer (and its higher energy intensity).

The key issue is, however, to use all elements of the freight transport system in an integrated reamer. The two systems have strong complementarities as railways (and waterways and coastal carriers where available) have a decisive advantage in the transport of large loads, especially of bulk commodities like coal, cereals, steel, fertilizer, etc., over long distances between fixed points, while road transport is preferred for the transport of small- and medium-sized loads over relatively small distances to dis-

[33]These concepts were developed and further explained in Damian J. Kulash, U.S. Congress, Congressional Budget Office, ' 'Energy Efficient Modes of Transportation: Some Comments on Urban Transportation in the United States and Latin America*' (Washington, DC: February, 1982), p. 6.

[34]Tata Energy Research Institute (TERI), op. cit., footnote 1, p. 161.

Table 5-1 3-Market Share of Road and Rail for Freight (percent of frelght ton-kilometers, excluding water, air, and pipeline)

	1977		1983	
	Road	Rail	Road	Rail
China	5	95	14	86
India	37	63	51	49
Us.	37	63	41	59

SOURCES: J. Yenny and L. Uy, *Transport in China,* World Bank Staff Working Papers No. 723, 1985, p. 4; Tata Energy Research Institute (TERI), *Teri Energy Data Directory and Yearbook, New* Delhi, 1988, p. 163. U.S. data are for intercity freight traffic in 1980 and 1987, from Association of American Railroads, *Railroad Facts, 1989* edition, Washington, DC, November 1989.

persed recipients (see table 5-5). Technologies such as containerization, which facilitates transshipment between different modes, encourage such integrated systems. Historically, the separate elements of the freight transport system—road, rail, ports etc.—developed independently and often opposed integration. In many countries, major changes in institutions and administrative procedures will be required to fully implement efficient integrated systems.

IMPROVING PASSENGER TRANSPORT ENERGY EFFICIENCY

The demand for passenger transport, particularly private transport such as autos and two and three wheelers, rises rapidly as incomes grow (see figure 5-l). At the same time, there is wide variation in vehicle ownership rates even in countries with similar standards of living. Bolivia and Cameroon, for example, have similar standards of living (in terms of their purchasing power) but car ownership rates in Bolivia are twice as high as in Cameroon. Similarly car ownership in Thailand is more than nine times higher than in China, although Thailand's standard of living is only one-third higher (taking into account purchasing power). These disparities are due to a variety of factors—the degree of urbanization, the nature of the vehicle stock, and government polices towards motor vehicle ownership. Table 5-14 illustrates the mode share of motorized passenger trips in selected countries.

The energy efficiency of the passenger transport sector can be improved in three primary ways. First, the vehicles themselves can make use of technologies that increase energy efficiency. Second, their operational efficiencies can be improved by carrying larger loads or through improved traffic management. Third, there could be increased use of those modes, such as buses and rail-based systems or walking/bicycling that use less energy per passenger mile. These modes already provide a significant share of trips in some areas (see table 5- 15). Land use planning and other government policies strongly influence the viability of these mass transit or nonmotorized modes.

Automobiles

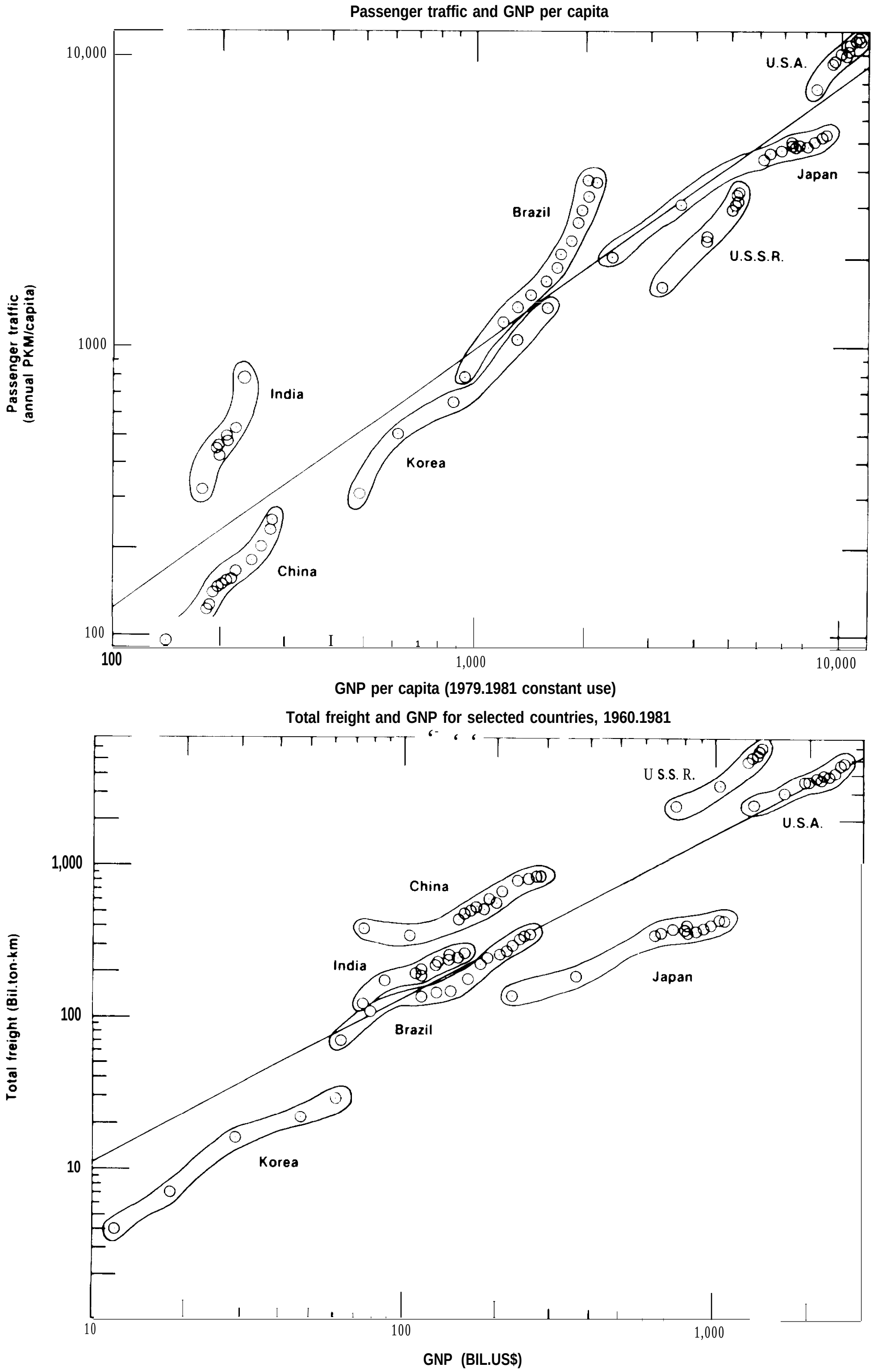
The energy efficiency of automobiles-the most energy intensive of all forms of passenger transport—is of crucial importance due to the rapid rate of growth of automobile ownership. As for trucks, the average energy efficiency of the automobile fleet is held down in many developing countries by low scrappage rates. The reasons for this are much the same-low labor costs for repair, minimal quality requirements for annual registration, and the high cost and limited availability of new vehicles.[35] Measures to increase scrappage rates—through registration fees that are inversely proportional to age, offering bounties for old cars, or establishing safety emissions standards-would increase the average energy efficiency of the auto fleet, but at a financiaI cost to users. The long life of the average car in developing countries also puts a premium on high standards of energy efficiency in the new cars that are being added to the fleet.

The vehicles currently being sold in the developing countries vary widely in energy efficiency, depending largely on whether such vehicles are manufactured at home or imported. In India, for example, the most popular car until recently was the domestically produced "Ambassador." This vehicle, based on a 1954 British Morris, is still being produced, although the fuel consumption is about twice that of a current and comparably sized Japanese or German car.[36] Energy efficiencies of cars produced in China are similarly low. In both countries, however, new automotive technologies

[35] Energy and Environmental Analysis, Inc., Op. Cit., footnote 17, p. 5-1.

[36] J. Sathaye and S. Meyers, "Transport and Home Energy Use in Cities of the Developing Countries: A Review," *The Energy Journal,* vol. 8, special issue, 1987, pp. 85-103.

Figure 5-1—Passenger and Freight Transport v. GNP for Selected Countries, 1960-81



This figure shows how passenger and freight transport energy use have increased with GNP for seven countries. The individual data points are for specific years.

SOURCE: J. Venny and L. Uy, *Transport in China, World* Bank Staff Working Paper, No. 723 (Washington, DC: World Bank, 1985).

Table 5-14-Mode Share of Motorized Passenger Trips in Selected Cities, 1980

	Modal Share (percent)					
City	Auto	Taxi	Bus	Para-transit	Rail/subway	Other
Bangkok	25	10	55	10	NA	NA
Bombay	8	10	34	13	34	NA
Calcutta	NA	2	67	14	10	4
Hong Kong	8	13	60	NA	19	NA
Jakarta	27	NA	51	NA	1	21
Karachi	3	7	52	18	6	13
Manila	16	2	16	59	NA	8
Seoul	9	15	68	0	7	0
Bogota	14	1	80	0	0	5
Mexico City	19	NA	51	13	15	2
Rio de Janeiro	24	2	62	2	11	NA
Sao Pablo	32	3	54	NA	10	1
Abidjan	33	12	50	NA	NA	5
Nairobi	45	NA	31	15	0	9
Cairo	15	15	70	NA	NA	NA
Tunis	24	4	61	NA	10	NA
Amman	44	11	19	26	NA	NA
Ankara	23	10	53	9	2	2

NOTE: Excludes nonmotorized modes.
NA = not available.
SOURCE: A. Faiz, et al., *Automotive Air Pollution,* Infrastructure and Urban Development Department, The World Bank, WPS 492, August 1990, p. 39.

have been introduced in recent years, sharply increasing the fuel efficiencies of domestically manufactured cars. The fuel efficiencies of cars produced by other developing country producers—Mexico, Brazil, and South Korea—are at current international standards for their size, accessories, and other factors.

Most developing countries, however, import their autos from the industrialized world, either in finished form (as is the case with small African and Central American nations) or in the form of completely knocked down kits (CKD) from which cars and trucks are assembled. In the latter case, local industry provides many components such as tires, batteries, and light bulbs. Examples of CKD production include Thailand for cars, and Thailand and Taiwan for heavy-duty trucks.

Autos produced in the industrialized countries and then exported to the developing countries are similar but not identical to those sold in the industrialized countries. In general, models sent to the developing world have smaller engines, fewer luxury accessories (e.g., air conditioning), lower compressions ratios (to allow for the use of lower octane gasoline), and often do not use proven efficiency technologies such as fuel injection and electronic engine controls. The lack of luxury accessories increases efficiency (air conditioning, for example, adds weight and requires engine power); however, the lack of electronic engine controls and other similar technologies decreases efficiency. The net effect is that autos produced in the industrialized countries and then exported to the developing countries are of comparable energy efficiency (in terms of kilometers per liter of fuel) to similar models produced and sold in the industrialized countries.[37]

Table 5-15-Motorized and Non-Motorized Mode Shares.

	Percent of passenger trips		
City	Walk	Bicycle	Motorized
Bangalore, India	44	12	44
Delhi, India	29	17	54
Jakarta, Indonesia	23	17	60
Shanghai, China	43	13	44

SOURCES: V. Setty Pendakur, "Urban Growth, Urban Poor and Urban Transport in Asia," Occasional Paper No. 39, The Centre for Human Settlements, The University of British Columbia, 1986, p. 33; J. Sathaye and S. Meyers, "Transport and Home Energy Use in Cities of the Developing Countries: A Review," *The Energy Journal,* Special LDC Issue, vol. 8, 1987.

[37]Energy and Environmental Analysis, Inc., op. cit., footnote 17, pp. 4-15.

These vehicles' energy efficiency could benefit from the use of readily available proven technologies, although at an increased first cost. Electronic control of spark timing and idle speed found in almost all industrialized country vehicles, for example, provides a 4 to 5 percent fuel efficiency gain at a cost of about $75 to $100.[38] Radial tires, improved aerodynamics, and fuel injection also offer similar energy savings. The cost effectiveness of such an investment is strongly dependent on retail fuel price-in Ethiopia, with high fuel prices, the payback is a relatively quick 2 or so years; in the United States, with low fuel prices, the payback is a little over 5 years. Table 5-16 gives payback times for the installation of electronic spark controls.

Such calculations incorporate only increased first costs and fuel savings, and do not account for the environmental and safety benefits. Nevertheless, it illustrates that investments in increased auto efficiency can provide a reasonable return. Evidence from the industrialized world, however, indicates that consumers often demand a payback of 2 years or less from efficiency investments,[39] and consumers in developing countries might be expected to have an even shorter payback period. Although gasoline prices in oil exporting countries are low (see table 5-17), in oil importing countries they are already well above international levels and there is a limit to how much further gasoline prices can be increased without unduly widening the gap between them and diesel prices. In most countries, purchase taxes on autos are already structured to discourage the purchase of large autos, suggesting a role for auto efficiency standards.

Some efficiency features, such as fuel injection, are considerably more complex than the present practice (carburetors), and therefore would require skilled (or differently skilled) labor for repair. Some efficiency features offer benefits in addition to fuel savings. Fuel injection is more reliable, does not require adjustment, and results in lower emissions than carburetors.[40] Radial tires offer improved handling and safety as well as increased tire life.

Developing countries are largely dependent on the industrialized countries for vehicle design. Thus, further improvements in fuel efficiencies will depend on advances in automotive technologies in the industrial countries. Vehicles currently being sold in both the developing and the industrialized world are not nearly as efficient as is technically possible. Several manufacturers, including GM, Volvo, and

Table 5-16-Simple Payback From the Addition of Electronic Spark Controls to Automobiles.

Country	Retail gasoline price (U.S. $/gallon,[a] Jan. 1990)	Simple payback for electronic spark controls (years)
Thailand	1.24	4.1
Brazil	1.41	3.6
India	1.92	2.6
Ethiopia	2.93	1.7
Us.	1.04	4.9
U.K.	2.55	2.0
Japan	3.05	1.7

Assumptions: First cost is $87.50, initial mpg is 25; efficiency increase due to electronic control is 4.5%, annual mileage is 10,000 miles.
[a]To convert to $/liter, multiply by 0.2642.

SOURCE: Energy and Environmental Analysis (EEA), "Evaluation of Policies Influencing Road Transport Fuel Consumption in Developing Countries," Report to AID, March 1986, p. 4-17; Energy Information Agency, *International Energy Annual 1989*, DOE/EIA-0219(89), February 1991, p. 91.

Table 5-17-Diesel and Gasoline Prices in Selected Countries, as of Jan. 1, 1990, in U.S.$/gallon (including taxes)

	Gasoline	Diesel
Brazil	1.41	0.69
Ecuador[a]	0.52	0,37
Mexico[a]	0.88	0.67
India	1.92	0.78
Thailand	1.24	0.89
Ethiopia	2.93	1.44
Ghana	0.76	0.69
Venezuela[a]	0.24	0.06
Peru	1.28	0.39
Indonesia[a]	0.81	0.42
Pakistan	1.52	0,68
Japan	3.05	1.75
Us.	1.04	0.99
W. Germany	2.72	1.91
Reference price[b]	0.87	0.70

[a]Oil exporters.
[b]USA refiner sales price of premium gasoline, excluding taxes, and #2 diesel, excluding taxes.

SOURCE: Department of Energy/Energy Information Administration, *International Energy Annual 1989*, February 1991, and Department of Energy/Energy Information Administration, *Annual Energy Review 1990*, May 1991, p. 157.

[38]Ibid., pp. 4-17.

[39]H. Rude-, M. Levine, and J. McMahon, "The Behavior of the Market for Energy Efficiency in Residential Appliances Including Heating and Cooling Equipment," *The Energy Journal*, vol. 8, No. 1, 1987, p. 101.

[40]Fuel injection, however, requires gasoline with low levels of dirt and other con taminants; and the gasoline sold in some developing countries may not meet this requirement.

Volkswagen have built prototype automobiles that achieve from 66 miles per gallon (3.5 litres/100 km) to 70 miles per gallon (3.3 lires/100 km).[41] A prototype automobile introduced by Toyota in 1985 achieves 98 miles per gallon (2.4 litres/100 km, while providing room for 4 passengers. This vehicle uses a direct-injection diesel engine, a continuously variable transmission (CVT), and plastics and aluminum to reduce weight,[42] These vehicles are not ' n production; nevertheless, the long term technical potential for energy efficiency improvements in automobiles is large, and improvements made in the industries of the major producers will rapidly become the global standard. The rapid growth in the auto fleet in developing countries will give these countries increasing influence over the major car developers.

Motorized Two- and Three-Wheelers

The two-wheeler has appealed to many Asian and other developing nations as an inexpensive technology for providing personal transportation for a growing urban middle class. In many Asian cities, two- and three-wheelers vastly outnumber autos, and are responsible for a large fraction of total gasoline consumption (see table 5-18). The relative efficiency in terms of energy per passenger-mile of two-wheelers falls between that of autos and buses (see table 5-19).

Two-wheeler engines are either "two-stroke" or "four-stroke. In the early 1960s, virtually all but the largest motorcycles had two-stroke engines, since these engines are simple to manufacture and inexpensive. In addition, they produce more power for a given displacement and require little maintenance. Two-stroke engines, however, have emissions (largely unburned gasoline) 10 times greater and fuel efficiencies 20 to 25 percent lower than four-stroke engines of equal (or near equal) power (see table 5-20).

The problems associated with the two-stroke engine are still more acute for three-wheelers, of which India is a large producer. These vehicles are underpowered and the engine is usually operated at near wide-open throttle. Under these conditions, two-stroke engines produce high emissions and have poor fuel economy, with fuel consumption equivalent to that of some modern small cars. Yet there is a widespread perception in India and in some Asian countries that these "auto rickshaws' are very efficient modes of public transport. Two-stroke two-and three-wheelers are now a significant source of gasoline consumption and emissions in several developing counties.

Improved technologies are available, although at increased first cost to the user, which could drastically reduce emissions and fuel consumption. The use of improved carburetors and electronic ignition could improve efficiency 10 to 15 percent, and would reduce hydrocarbon (HC) emissions by 50 percent.[43] The use of four-stroke rather than two-stroke engines would reduce HC emissions by 90

Table 5-18--Estimated Fraction of Gasoline Consumption Attributable to Two- and Three-Wheelers (1987)

Country	Percent of gasoline
India	45
Thailand	30
Taiwan	50
China	12
Bolivia	8
Brazil	2
Kenya	<2
Cameroon	12
Japan	14
U.S.A.	<1

SOURCE: Energy and Environmental Analysis (EEA), "Policy Options for Improving Transportation Energy Efficiency in Developing Countries," contractor report prepared for the Office of Technology Assessment, July 1990.

Table 5-19-Relative Energy Consumption of Passenger Transport Technologies, United States

Technology	Energy use per passenger-mile (MJ/passenger-km)	Load factor assumed (passengers/vehicle)[a]
Private auto	2.5	1.7
Motorcycle	1.5	1.1
Rail	1.5	24.8
Bus	0.6	10.2

[a]Load factors in developing countries will generally be much higher than those listed here for the United States.

SOURCES: Oak Ridge National Laboratory, Transportation *Energy Data Book: Edition* 70, ORNL-6565, 1989, p. 2-23; M. Lowe, "Reinventing the Wheels," *Technology Review,* May/June 1990.

[41]M. Ross, "Energy and Transportation in the United States," *Annual Review of Energy,* vol. 14, 1989, p. 158.
[42]J Goldemberg et al. *Energy for Development* (Washington, DC: World Resources Institute, 1987), p. 54.
[43]Energy and Environmental Analysis, Inc., Op. cit., footnote 17, p. 3-11.

Table 5-20--A Comparison oft he Performance Characteristics of a Two- and a Four-Stroke Motorcycle Engine

Engine size (cm^3)	Engine type (stroke)	Emissions HC (g/km)	Emissions NO_x (g/km)	Fuel economy (miles/gallon)
400 , ...	2	11.1	0.1	50
500	4	1.2	0.1	67

SOURCE: Energy and Environmental Analysis (EEA), "Policy Options for Improving Transportation Energy Efficiency in Developing Countries," contractor report prepared for the Office of Technology Assessment, July 1990, p. 3-6.

percent and increase fuel efficiency by 25 percent (see table 5-20). The increased first cost **for this technology is about $lOO.**[44] **The cost effectiveness of this investment depends on fuel price, but at a gasoline price of $1.50/gallon ($0.40/liter) the simple payback is about 1.6 years, even without taking into account environmental benefits.**[45]

Buses

Buses are the backbone of urban passenger transport in the developing world, providing essential low cost transport, particularly for low income groups. They provide over half of all motorized trips in many cities (see table 5-14).

As for other road vehicles, there are a variety of technologies available to improve bus energy operating efficiencies, including turbochargers, smaller engines in some cases, automatic timing advances, lighter bodies through use of aluminum or plastic components rather than steel, and others. But the effectiveness of these technologies in conserving fuels is constrained by their operating environment. Most urban buses operate on congested streets, and the resulting low speeds and frequent speed changes are associated with low operating efficiencies. Turbochargers are often ineffective, for example, as they require higher, sustained speeds. In so far as unsatisfactory bus service has contributed to the rapid increase in ownership of autos and two and three wheelers, faster bus service could slow the increase in private vehicle ownership.

In an effort to improve bus services by increasing speed and reducing the number of stops, some cities have introduced exclusive or priority bus lanes. Abidjan has 5 kilometers of priority bus lanes,[46] Porto Alegre has exclusive busways, and Sao Paulo is paving and improving its bus routes in low-income areas.[47] In 1978, Porto Alegre, Brazil, with World Bank assistance, designated 30 kilometers of road for exclusive use by buses. The roads were paved, barriers to other vehicles were built, and bus signs and stops were added. The cost was about $500,000 per kilometer-or about 4 percent that of the Manila light rail system (see below). The system has a peak capacity of about 28,000 passengers per hour (slightly higher than the capacity of Manila's light rail system), and yielded an increased bus speed of about 20 percent.

Modal Shifts in Urban Passenger Transport

The high capital, energy, and environmental costs of a private auto-based urban transport system raises issues of how urban passenger traffic should be served, and what role different modes—buses, cars, two- and three-wheelers, light rail, walking, and bicycles—should play in an efficient urban transport system. These issues are closely interconnected with the broader issues of land-use and transport planning.

The energy intensities of the different passenger transport modes (measured by the amount of fuel required to move one passenger 1 kilometer) varies widely (see table 5-19). Buses use only one-fourth as much energy per passenger-mile as private cars according to U.S. data, and the difference is estimated to be much greater (one-eighth) in the developing countries because of the higher load factors on buses. Light rail fuel use is estimated to be some 30 percent higher per passenger-kilometer than buses, but still well below private passenger cars. If the indirect energy-the energy used in

'Ibid., pp. 3-5.

45Assuming 10,000 mi/year annual mileage, efficiency her== from 50 to 63 mpg.

46R. Barrett, *Urban Transport in West Africa*, World Bank Technical Paper Number 81 (Washington, DC: World Bank, 1988), p. 7.

47World Bank, *Urban Transport* (Washington, DC: World Bank, 1986), p. 30.

associated infrastructure such as roads and railbeds—is included, buses use less than one-tenth as much energy per passenger mile as private cars, Light rail, including energy in roadbeds and other indirect consumption, uses twice as much energy per passenger kilometer as a bus system but still one-fifth that used by private cars (see table 5-12).

Given the high energy and other costs of a private auto-based system, one of the most important and difficult issues facing those in charge of urban planning is the role of the private auto. The advantages of private cars-flexibility, comfort, and convenience—have led to unprecedented increases in car ownership. This has led to severe congestion in many areas. In many countries, car ownership and operation are already made expensive through high gasoline taxes, and high ownership and acquisition taxes. Demand has proven remarkably resilient in the face of such policies. A notable exception is Singapore, where an area licensing scheme has proven effective in controlling congestion in its central business district (see box 5-A).

A growing concern over the contribution of private cars to urban air pollution has led to new policy initiatives: both Mexico City and Sao Paulo, for example, have responded with mandatory installation of catalytic converters, bans on using cars on various days, and other measures. These actions could limit car use in the future.

In addition to saving energy and reducing pollution, a larger role for public transport could reduce transport costs, As table 5-21 shows, the total costs—including costs of road and metro construction, vehicles, etc.—are 2 to 3 times higher for private autos than for buses on segregated highways or paratransit[48] systems. Improvements in bus services could therefore release resources that could instead be used to finance improvements in efficiency, transport infrastructure, or other development needs. Buses have additional advantages. They are flexible in routing and scheduling. They can make use of existing roads or segregated 'bus only' lanes. Buses usually use diesel engines, which are already familiar to most mechanics, and they are quite sturdy—able to go long distances with minimal repairs.

Despite the many advantages of buses, however, bus systems in developing (and industrialized) countries have a mixed reputation. This is usually due to managerial, institutional, and infrastructural shortcomings rather than technical failures. Many systems are poorly run--overstaffed, inefficiently operated, and with very high costs. Some systems provide poor service-infrequent service at peak hours, overcrowded and unclean buses, and undependable schedules. Many publicly run bus systems require large government subsidies to operate.

Box 5-A—Singapore's Area Licensing Scheme: Carrot and Stick

Congestion in Singapore's central business district (CBD) led the government to institute an 'area licensing scheme" in 1975. This program was intended to reduce congestion and increase bus ridership through the use of financial disincentives for private vehicle use. Private vehicles were charged an "entrance fee" (currently about $1.50 per day per vehicle) upon entering the central business district during peak hours.

The initial effect of the program was a 51 percent drop in the number of cars entering the CBD in morning peak hours. From 1975 to 1989, the vehicle population in Singapore grew by 68 percent, yet traffic in the CBD is still below the levels found prior to the program's inception.

The program has been modified a number of times. The peak hours have been changed, the restrictions have been extended to all vehicles, including motorcycles and taxis, the fees have changed, and the boundaries of the restricted zone have been enlarged. Although the program is not popular with motorists, it is seen as inexpensive and highly effective in reducing congestion. Energy savings are difficult to measure, but the modal shift from cars to buses, as well as the increased vehicle speeds, are thought to reduce energy use by about 30 percent. The fees charged to drivers more than cover the operating costs of the program.

SOURCES: B. W. Ang, "Traffic Management Systems and Energy Savings: The Case of Singapore," paper presented at the New Energy Technologies Transportation and Development Workshop, Ottawa, Canada, September 1989, p. 13; Hagler, Bailly, and co., "Road Transportation Energy Conservation Needs and Options in Developing Countries," contractor report to the U.S. Agency for International DevelopmentWashington, DC, September 1986, p. Al 1.

[48]Paratransit is a blanket term for shared taxis, jitneys, minivans, and other similar systems that provide shared transport services.

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The World Bank has examined bus services in cities of the developing world, and several World Bank reports point to the potential benefits of an increased private sector role in providing bus services. World Bank studies of public and private ownership found that the costs of private bus services were roughly half those of public systems, that little evidence could be found showing different levels of safety in the two systems, and that private systems offered more dependable and comfortable service.[49] Others argue, however, that safety and service to the poor are neglected by private operators; and that the need for central depots, special "bus only" lanes, and the difficulties involved in importing buses and spare parts all argue for a government role in urban bus systems.

In the longer term, bus services may find it difficult to compete effectively with automobiles due to their lower average speeds under typical urban conditions. A study of 32 cities in Asia, Australia, Europe, and North America found typical average bus speeds of about 20 kilometers per hour (km/h) compared to average speeds for automobiles of about 40 km/h in the United States and Australia.[50] However the use of segregated busways or bus only lanes can increase average bus speeds.

Rail-based light transit systems have become increasingly popular in North America, and are beginning to be seen in the developing world as well. Urban rai1[51] systems—including metros, subways, and similar light rail systems—are operating, under construction, or being planned in 21 cities in the developing world. These systems offer the advantages of relatively high speed, smooth, and dependable service-but at a cost. According to a recent evaluation, rail-based transit systems in the developing world have achieved mixed results. Travel times were reduced, most systems provided high quality service, and ridership levels were high, although below forecasts. These systems are expensive, however. As fares are kept low to allow the poor access to the system, fare revenue cannot cover costs. As discussed above, however, a full accounting of the costs of a private auto-based system may

Table 5-21—Total Costs of Passenger Transport Options, as Estimated by the World Bank

System type	Total rests in US$/passenger-km (1986)
Bus on segregated busway	0.05 to 0.08
Paratransit	0.02 to 0.10
Surface rail	0.10 to 0.15
Private car	0.12 to 0.24
Underground rail	0.15 to 0.25

NOTE: Total costs include initial and operating costs. Bus data include estimates for roadway construction.

SOURCE: A. Armstrong-Wright, *Urban Transit Systems,* World Bank Technical Paper No. 52, 1986, p. 49.

increase the comparative economic attractiveness of a rail-based system.

Manila's light rail system illustrates some of these points. Severe congestion and a growing urban population in Manila led the Philippine government to decide in 1980 to build a light rail system in Manila. This light rail system was completed in 1985, at an initial cost of $212 million, or about $14 million per kilometer. By 1988,28 percent of urban trips were by light rail. Fares are set at a flat rate of 14 cents. The income from fares is sufficient to meet operating expenses, but does not cover interest and principal on the initial construction costs. It has been calculated that a fare of about 28 cents would be necessary to allow the system to be financially self-sufficient, however, it has also been shown that this fare would be unaffordable to most patrons. The Manila system, like many light rail systems, provides reliable, safe, and fast service at a reasonable price. However, it requires a large government subsidy; and the effects on urban congestion and energy use are unclear.[52]

A key issue is to use all elements of a transport system in an integrated manner. For example, the use of dedicated busways to hold and maintain right-of-ways, the encouragement of mixed employment and residential land use, and appropriate use of light rail systems could be considered. Related policy options might include full pricing of all transport options (including fuel, roads, parking, congestion, and injury), effective traffic control, and others; all with

[49] World Bank, *Urban Transport* (Washington, DC: World Bank, 1986), p. 23.

[50] Peter W.G. Newman and Jeffrey R. Kenworthy, *Cities and Automobile Dependence: A Sourcebook* (Brookfield, VT: Gower Technical, 1989).

[51] This discussion is based in part on, World Bank, "Metros in Developing Cities-Are They Viable?" *The Urban Edge,* vol. 14, No. 1, January/February 1990.

[52] A. Gimenez, "The Manila Light Rail System," paper presented at the New Energy Technologies Transportation and Development Workshop, Ottawa, Canada, September 1989.

the goal of developing a comprehensive and effective urban transport system.

THE DEMAND FOR TRANSPORT SERVICES

Although the emphasis in this report has been on improving the energy efficiency with which services are delivered, the high societal costs (as well as benefits) of the transport sector raise the question of whether or not economic growth could be sustained with lesser rates of growth in passenger-kilometers and freight tonne-kilometers. In the past, transport services have increased at about the same rate as economic growth or slightly faster (see figure 5-l). Although freight transport intensity (number of tonne-kilometers per unit of gross national product) declines at high levels of economic development, most of the developing countries are expected to continue experiencing rising or at least constant freight intensities as they continue the transformation from rural agricultural economies to urban industrial economies. The rapid rise in urban passenger transport services stems from the increase in urban population—between 1970 and 1980 the population of several major developing country cities doubled—and the spread of urban areas. Further, journeys tend to lengthen as cities grow; in Bogota, the average commuting distance increased by 13 percent between 1972 and 1978.

There are a number factors that could moderate these rapid increases. Improved communications (better telephone systems and fax machines, for example) could displace a certain amount of business travel.[53] Improved communications and overall logistics can ensure full loads and most efficient truck routing, and thereby improve overall efficiency. Traffic management schemes, such as segregated bus lanes, truck climbing lanes, and limited vehicle access to city centers, could reduce congestion and thus promote more fuel efficient vehicle operations. Several cities of the developing world have already instituted successful traffic management systems (see box 5-A).

In so far as an appreciable amount of demand for transport services arises because users do not pay the true costs of using the roads, efforts to reflect these costs (through road pricing, area licensing, user taxes on fuels, parking fees, import duties, sales taxes, and annual licensing taxes), could moderate the demand for transport services. Physical restrictions on access to certain areas have also been introduced.

In the longer term, careful attention to the physical layout of residences, employment centers, and services could allow for a less expensive and more efficient transport system. Locating employment closer to residences, locating public services (e.g., shopping and recreation) closer to intended users, siting major freight terminals away from congested city centers, and controlling the density of land occupation (as is done in Curitiba, Brazil and Bombay, India) could reduce travel needs. These options are especially promising for developing countries whose cities are not yet fully in place but are growing rapidly, in contrast to cities of the industrialized world, which are already largely built.

Without a carefully implemented land use planning program, however, a private vehicle-based transport system is the likely end result by default through ‘‘creeping incrementalism." It is easy to add one automobile and one short stretch of road at a time; it is much more difficult to plan a comprehensive urban transport system.[54] The end result can be an energy inefficient system that is difficult to change (see box 5-B).

NONMOTORIZED MODES

Much of the discussion on transport in the developing world focuses on motorized technologies—autos, trucks, trains, buses, and motorcycles. It is important to recognize, however, that many trips are by nonmotorized modes-walking, animal-drawn carts, or bicycles (see table 5-15)--used in rural areas and by a large part of the urban poor. While nonmotorized modes by definition do not use transport fuels, they have many shortcomings. They can be relatively uncomfortable under a variety of circumstances, they are slow, and they have limited freight capacity when compared to automobiles and trucks.[55]

[53] See, for example, P. Mokhtarian, "The State of Telecommuting," *Institute of Transportation Studies Review,* vol. 13, No. 4, August 1990). However, in most developing countries labor is largely physical rather than information-related, making telecommunications of less relevance.

[54] M. Bernard, op. Cit., footnote 7.

[55] World Bank, "Gridlock Weary, Some Turn to Pedal pOWer,' *The Urban Edge,* vol. 14, No. 2, March 1990.

Box 5-B—Urban Design and Transport Energy Use in North America

A private vehicle based transport system, such as that found in many U.S. cities, tends to have an urban core with few residents and many high-rise office buildings surrounded by farflung suburbs. Because there is little overlap between jobs and residences, most people travel relatively long distances to work; because suburban areas have low population densities, effective and low cost mass transit systems are difficult to support and, where available, may require driving to feeder stations. Finally, because the urban core must support a high density of roads and parking spaces for commuters, there is less space for parks, central plazas, or other amenities. This could encourage the flight of residents to the suburbs.

In the low density suburbs of this system, the distances between houses and shops are great leading to dependence on private vehicles (rather than walking, bicycling, etc.) for transport to schools, shopping, and so on. Houses are often widely scattered, with the result that water, sewage, police, fire, and other public sector services must be extended long distances at considerable cost. Concerns of social equity could be raised, in that low suburban densities often require private vehicles, thereby excluding those not able to afford them. On the other hand, this form of land use has many well known attractions in terms of personal convenience, living space, and other factors.

The private-vehicle based urban design that results by default from these processes has high capital costs and energy use. For example, per-capita fuel use for transport is four times greater for U.S. cities than for European cities (see figure 5-2). Numerous studies have examined various problems raised by the private vehicle-based urban design, and a number of cities in North America are now taking steps to reverse this trend. For example some 22 cities in North America now have light rail systems recently put into place, upgraded, or under construction.

SOURCES: Peter W.G. Newman and Jeffrey R. Kenworthy, Cities *and Automobile Dependence:* **A** ***Sourcebook*** **(Brookfield, VT: Gower Publishing Co., 1989); Jeffrey Mora, "A Streetcar Named Light Rail,"** *IEEE Spectrum,* **February 1991, pp. 54-56; Transportation Research Board, National Research Council, "Light Rail Transit: New System Successes at Affordable Prices, " Washington DC, 1989.**

The bicycle plays an important intermediate role between animate and motorized transport systems. In Beijing, for example, bicycles are the major form of passenger transport. Bicycles have many advantages. They do not contribute to air pollution, they are much less expensive per unit, and (in contrast to autos) they can often be produced domestically in relatively small quantities—providing local employment. Providing bicycles, and the infrastructure to support them (e.g., paved bike paths separated from motorized traffic) may provide improved transport to those who would otherwise walk. Such a policy could relieve pressure on overloaded buses, may delay or offset the transition towards motorized forms of private transport, or may supplement motorized transport in areas with appropriate land use planning,

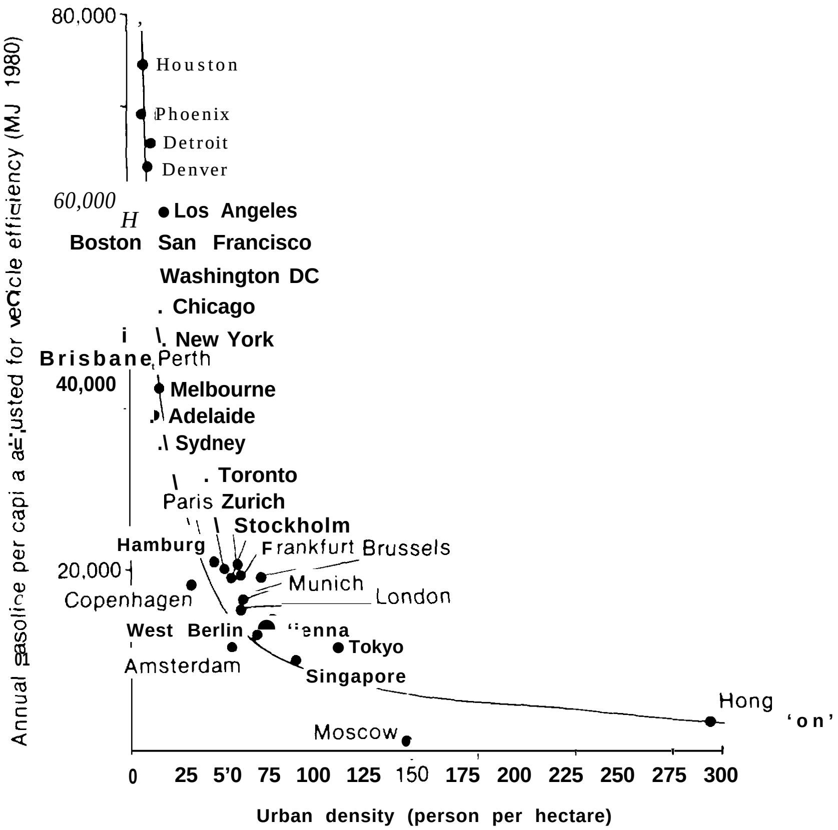
Photo credit: Denise Mauzerall

Bicycles are a major form of transport in Beijing.

Rural transport needs pose particular problems. Lack of transport services in rural areas means delays in delivering essential agricultural inputs such as seeds and fertilizers, and inability to bring harvested crops to market,[56] thus frustrating increases in agricultural productivity and rural industry. Technical improvements to cars, two and three wheelers, and buses and trucks also benefit rural areas, but these modes form only a small part of local rural traffic, In India, for example, trucks account for

[56] In some regions of Tanzania for example, the rudimentary state of the transport system has prohibited the development of cash crops. I.J. Barwell et al., International Labor Office, World Employment Program, *Rural Transport in Developing Countries* (Worcester, UK: Intermediate Technology Publications, 1985) pp. 93-108.

Figure 5-2—Urban Density v. Gasoline Use Per Capita, Adjusted for Vehicle Efficiency



This figure shows a rapid decrease in transport energy requirements with increasing population density. Even for the same population density, however, transport energy requirements are shown to vary by a factor of two—Zurich v. Amsterdam—depending on local conditions.

SOURCE: Peter W.G. Newman and Jeffrey R. Kenworthy, *Cities and Automobile Dependence: A Sourcebook* (Brookfield, VT: Gower Publishing Co., 1989).

under 10 percent of total tonnage, and bullock carts for over two-thirds. Technologies for improving the efficiency of animal powered transport are available, but have diffused slowly due to the absence of rural credit.

ALTERNATIVE FUELS

Concern over high levels of urban air pollution and the high import costs of transport fuels have directed attention in developing countries to alternative transport fuels—fuels not derived from crude oil-especially those based on indigenous resources. Such a transition is desirable, in part, because of the emissions associated with gasoline and diesel combustion. Alternative fuels offer the potential to decrease the local and global pollution currently associated with vehicles.

According to the World Bank, "motor vehicles cause more air pollution than any other single human activity. The primary pollutants emitted by motor vehicles are hydrocarbons (HC) and nitrogen oxides (NO_x), the precursors to ground level ozone, and carbon monoxide."[57] In the most polluted American cities, highway vehicles alone are estimated to contribute about 40 to 45 percent of the total emissions of manmade volatile organic compounds

[57] A. Faiz et al., World Bank, Infrastructure and Urban Development Department, *Automotive Air Pollution: Issues and Options for Developing Countries,* working paper No. 492 (Washington, DC: World Bank, August 1990), p. 14.

(a key ingredient of smog). Although data are not widely available, the percentages may be even higher for a number of cities in the developing world. Gasoline combustion also results in other toxic emissions, including benzene, lead,[58] gasoline vapors, 1,3-butadiene, and polycyclic organic matter. Particulate emitted from vehicles cause visible air pollution and some adverse health effects, with diesel-fueled vehicles emitting 30 to 70 times more particulate than gasoline. Diesel vehicles also emit SO_x and NO_x. Due to their fewer numbers, however, diesel vehicles-in aggregate-emit less pollutants than do gasoline vehicles.[59]

Vehicle emissions have not only contributed dramatically to local air pollution problems in many developing countries, such as Mexico and India, but have also contributed to the global accumulation of greenhouse gases in the atmosphere. Of all the carbon dioxide resulting from the burning of fossil fuels, 15 to 20 percent is estimated to come from motor vehicles. Carbon monoxide, another vehicle emission, is likewise a greenhouse gas and also causes harmful local pollution.[60] Vehicles account for over 90 percent of the carbon monoxide pollution in many urban areas. Alternative fuels, with the exception of methanol from coal, would contribute less to the accumulation of greenhouse gases.

Chapters 6 and 7 discuss supplies and conversion of such fuels. Here their potential use in the transport fleet is examined. Although alternative fuels are often assessed as a replacement for gasoline, some types can also be used to replace diesel in trucks and buses. Indeed, for those developing countries with refinery capacity, the need to find a replacement for diesel is often more pressing than for gasoline. Changes in product demand in past years-a more rapid increase in demand for diesel compared with gasoline-has led to severe refinery imbalances. As a result, several countries have a surplus of gasoline that has to be exported-often at distress prices.

A recent OTA report[61] describes in detail the advantages and disadvantages of alternative fuels to replace gasoline used in private automobiles (see table 5-22). This report summarizes some of the issues raised in that report, and discusses issues specific to alternative fuels applications in developing countries, particularly for diesel vehicles. The focus is on transport fuels that can be produced from resources found in the developing world, with existing technology-methanol made from natural gas, ethanol from biomass, and natural gas used directly (either as CNG or LNG).[62]

Methanol is a liquid fuel that can be produced from natural gas, coal, or biomass; natural gas appears to be the most likely feedstock in the near future. One major advantage of methanol is that it would require fewer changes in vehicle design than would some other alternative fuels. Flexible-fueled vehicles, which can operate on methanol, ethanol, gasoline, or a mixture of these fuels, are already being produced in limited numbers in the United States.[63] The use of such vehicles would ease the transition away from gasoline, This may be less of a problem in developing countries, however, as their vehicle fleets are growing so rapidly and much of their infrastructure is only now being put into place—and could be more readily switched to alternative fuels or flexible-fuel capability.[64] Although methanol is frequently discussed as a replacement for gasoline, it can also be used to replace diesel. The cost for diesel engine modifications to accommodate methanol is estimated at $500 to $800 per vehicle.[65]

As discussed in chapter 6 of this report, the major disadvantage of methanol is its high cost of production. The cost of methanol made from natural gas is of course tied to the price of natural gas, but if a

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[58] Although lead is no longer a major pollutant in the industrialized countries, many developing countries still use leaded gasoline.

[59] A. Faiz et. al., op. cit., footnote 57, pp. 41, 75; U.S. Congress, Office of Technology Assessment, *Replacing Gasoline: Alternative Fuels for Light-Duty* Vehicles, OTA-E-364 (Washington DC: U.S. Government Printing Office, September 1990), p. 35.

[60] A. Faiz et al., op. cit., footnote 57, p. 25.

[61] U.S. Congress, Office of Technology Assessment, *Replacing* Gasoline: *Alternative Fuels for Light-Duty Vehicles,* OTA-E-364 (Washington, DC: U.S. Government Printing Office, September 1990).

[62] Other fuels often discussed as alternatives to gasoline and/or diesel include electricity, LPG, and hydrogen,

[63] U.S. Congress, office of Technology Assessment, op. cit., footnote 61, p. 25.

[64] For example, as shown in table 5-7, India's vehicle fleet is growing at an annual rate of 18.4 percent. If all new vehicles were built to accommodate methanol, for example, then within about 4 years half the fleet would be methanol-fueled.

[65] Energy and Environmental Analysis, Inc., Op. Cit., footnote 17, pp. 4-13.

Table 5-22—Pros and Cons of Alternative Fuels

Fuel	Advantages	Disadvantages
Methanol	• Familiar liquid fuel. • Vehicle development relatively advanced. • Organic emissions (ozone precursors) will have lower reactivity than gasoline emissions. • Lower emissions of toxic pollutants, except formaldehyde. • Engine efficiency should be greater. • Abundant natural gas feedstock. • Less flammable than gasoline. • Can be made from coal or wood (as can gasoline), though at higher cost. • Flexfuel "transition" vehicle available.	• Range as much as one-half less, or larger fuel tanks. • Formaldehyde emissions a potential problem, especially at higher mileage, requires improved controls. • More toxic than gasoline. • M100 has nonvisible flame, explosive in enclosed tanks. • Costs likely somewhat higher than gasoline, especially during transition period. • Greenhouse problem if made from coal.
Ethanol	• Familiar liquid fuel. • Organic emissions will have lower reactivity than gasoline emissions (but higher than methanol). • Lower emissions of toxic pollutants. • Engine efficiency should be greater. • Produced from domestic sources. • Flexfuel "transition" vehicle available. • Lower carbon monoxide with gasohol (1 O percent ethanol blend). • Enzyme-based production from wood being developed.	• Higher cost than gasoline. • Food/fuel competition possible at high production levels. • Supply is limited, especially if made from corn or sugar. • Range as much as one-third less, or larger fuel tanks.
Natural gas	• Excellent emission characteristics except for potential of somewhat higher nitrogen oxide emissions. • Gas is abundant worldwide. • Modest greenhouse advantage. • Can be made from coal.	• Dedicated vehicles have remaining development needs. • Retail fuel distribution system must be built. • Range quite limited, need large fuel tanks with added costs, reduced space (liquefied natural gas (LNG) range not as limited, comparable to methanol; LNG disadvantages include fuel handling problems and related safety issues). • Dual fuel "transition" vehicle has moderate performance, space penalties. • Slower recharging. • Greenhouse problem if made from coal.
Electric	• Fuel is domestically produced and widely available. • Minimal vehicular emissions. • Fuel capacity available (for nighttime recharging). • Big greenhouse advantage if powered by nuclear or solar. • Wide variety of feedstocks in regular commercial use.	• Range, power very limited. • Much battery development required. • Slow refueling. • Batteries are heavy, bulky, have high replacement rests. • Vehicle space conditioning difficult. • Potential battery disposal problem. • Emissions for power generation can be significant.
Hydrogen	• Excellent emission characteristics, minimal hydrocarbons. • Would be domestically produced. • Big greenhouse advantage if derived from photovoltaic energy. • Possible fuel cell use.	• Range very limited, need heavy, bulky fuel storage. • Vehicle and total costs high. • Extensive research and development effort required. • Needs new infrastructure.
Reformulated gasoline	• No infrastructure change except refineries. • Probable small to moderate emission reduction. • Engine modifications not required. • May be available for use by entire fleet, not just new vehicles.	• Emission benefits remain highly uncertain. • Costs uncertain, but will be significant. • No energy security or greenhouse advantage.

SOURCE: Office of Technology Assessment, 1992.

natural gas price of $1.00/mmBtu ($0.95/GJ) is assumed—not an unreasonable assumption for those countries with gas resources that are not presently fully used—then the wholesale methanol cost per gallon of gasoline equivalent could be at about $1.05 ($0.28/liter) if production volumes are high.[66] This compares with wholesale gasoline prices today in the range of 60 to 70 cents per gallon ($0.16 to 19/liter) for crude oil at $16 to $20 per barrel. Methanol from cheap natural gas is therefore substantially more expensive than gasoline from crude at present, but it does have environmental and supply security benefits. Methanol produced from coal or biomass is thought to be considerably more expensive.[67] By one estimate, manufacturing costs alone—excluding the costs of feedstock—for methanol from coal are about $1.00/gallon ($0.26/liter).[68]

Methanol could reduce air pollution, particularly urban smog. Tests have yielded mixed results, however, making the actual environmental benefits of methanol difficult to quantify.[69] Methanol may reduce carbon monoxide and nitrogen oxides, and may provide a small greenhouse gas benefit over gasoline. Any greenhouse gas benefits are highly dependent on the feedstock, however. Methanol from coal, for example, would result in higher greenhouse gas emissions.[70] Methanol does have some environmental disadvantages, particularly greater emissions of formaldehyde, which could require special emission controls. The liquid fuel itself is toxic, corrosive, and highly flammable, making methanol difficult to handle and distribute.[71]

Ethanol, like methanol, is a liquid fuel that can be used with minor modifications in gasoline engines. It can be produced from biomass—about one-third of Brazil's automobile fleet, for example, runs on straight ethanol produced from sugar (see box 5-C).[72] The vehicle-related technical issues for ethanol are essentially the same as with methanol—it requires only minor modifications for use in gasoline engines, but requires more complex changes for use in diesel engines. The major issue with ethanol is the cost of production. It is heavily dependent on the cost of the feedstock (corn in the United States, sugar in Brazil, molasses in Kenya) and on the market value of the byproducts. Research by the Solar Energy Research Institute, U.S. (now the National Renewable Energy Laboratory) and others into wood-to-ethanol processes is promising, but not yet commercial (see ch. 6).[73]

Ethanol is used either as an additive to gasoline or directly. As an additive, its primary environmental benefit is a reduction of carbon monoxide. Directly, ethanol may reduce concentrations of urban ozone, though probably not to the same extent as methanol. The net environmental effects of ethanol, however, are not yet clear.[74] If carefully done, ethanol would not add to net carbon dioxide emissions.

Compressed Natural Gas (CNG) is simply natural gas under pressure. It can be burned in gasoline engines with minor modifications, and in diesel engines with more complex modifications. Natural gas is a cleaner fuel than gasoline, with lower emissions of most pollutants. The major drawback of CNG as a transport fuel is the difficulty of transporting, storing, and delivering it.

The use of CNG in gasoline engines requires the installation of gas cylinders, high pressure piping, and appropriate fittings to the carburetor. In order to take full advantage of CNG, the compression ratio should also be raised to about 12:1.[75] An automobile designed for CNG would cost about $700 to $800 more than a comparable gasoline-fueled vehicle, due in large part to the pressurized tanks.

@u.s. Congress, Office of Technology Assessment, op. cit., footnote 61, p. 16. Note that these are wholesale prices, excluding @m.

67 Ibid., p. 13.

'Ibid., p. 78.

69 Ibid., p. 61.

70 Ibid., p. 71.

71 U.S. Congress, Office of Technology Assessment, *Delivering the Goods: Public Works Technologies, Management and Financing,* OTA-SET-477 (Washington, DC: U.S. Government Printing Office, April 1991), p. 101.

72 World Bank, "Alcohol Fuels from Sugar in Bred, ' *The Urban Edge,* vol. 14, No. 8, October 1990, p. 5.

73 U.S. Congress, Office of Technology Assessment, *Renewable Energy Technology: Research, Development, and Commercial Prospects,* forthcoming.

74 U.S. Congress, Office of Technology Assessment, op. cit., footnote 61, p. 108.

75 R. Moreno, Jr. and D. Bailey, World Bank, Industry and Energy Department, *Alternative Transport Fuels from Natural Gas,* World Bank Technical Paper No. 98, Industry and Energy Series (Washington DC: World Bank, 1989), p. 11.

Box 5-C—Brazil's Ethanol Fuels Program: Technical Success, Economic Distress?

Brazil has long used ethanol as a replacement fuel for gasoline. As early as 1931, Brazil used ethanol-gasoline blends to fuel vehicles. In the early 1970s, the drop in world sugar prices combined with the 1973 jump in world oil prices led to an expansion of ethanol production from sugar cane. The program was intended to produce a mix of 20-percent ethanol and 80-percent gasoline. In response to the second oil price jump in 1979, the program was changed to promote vehicles that would operate on 100-percent ethanol.

To encourage the purchase of ethanol-fueled vehicles, the government set up strong financial incentives. Ethanol prices were initially set at 65 percent of gasoline prices, yearly licensing fees were lower for ethanol vehicles, and generous vehicle financing was offered. Consumer acceptance was low at first, due to problems with cold-starting and fuel system corrosion, but by 1983, 89 percent of new light duty vehicles sold used ethanol. From 1979 to 1988, ethanol's share of total transportation fuel market jumped from 11 percent to 52 percent, and gasoline consumption in Brazil dropped 46 percent.

The remarkable technical success of the program-fleet conversion to a domestically produced alternative fuel-has been overshadowed by a number of economic questions. World sugar prices have increased to the point where Brazilian sugar growers find it more profitable to export than to produce ethanol. This has led to shortages of ethanol, and has forced Brazil to import some ethanol. Ethanol shortages at the pump have angered consumers and led to a sharp drop in the sales of new ethanol-fueled vehicles. And domestic oil exploration has been successful, bringing into question one of the primary motivation of the program-to reduce dependence on imported oil.

The program did reduce gasoline use, but at a cost—the economic losses of the program have been estimated as high as $1.8 billion, although these figures remain controversial. The program did demonstrate that it is technically feasible to convert a significant fraction of the fleet to an alternative fuel. Whether or not this was economically desirable is less clear.

SOURCES: Jacy de Souza Mendonca, "The Brazilian Experience with Straight Alcohol Automobile Fuel," paper presented at the Ottawa Workshop on New Energy Technologies Transportation and Development Workshop, September 1989, p. 9; S. Trindade, "Non-fossil Transportation Fuels: The Brazilian Sugarcane Ethanol Experience,' paper presented at the Energy and Environment in the 21st Century Conference, Cambridge, MA, March 1990, p. A-142; World Bank, "Alcohol Fuels from Sugar in Brazil, ' *The Urban Edge,* October 1990, p. 5.

Using CNG in diesel engines is more complex. Retrofitting existing diesels to run on CNG is possible but difficult. A more practical option is modifying the design of diesels to use CNG. Buses in Hamilton, Ontario use diesel engines redesigned to use CNG; this engine is estimated to cost about 10 percent more than the standard diesel engine.

Transporting, storing, and delivering CNG will be the major barrier to widespread CNG use, Natural gas, unlike liquid fuels, cannot be easily moved by truck or ship.[76] Most developing countries do not have a natural gas supply infrastructure, and the construction of such a system is expensive. Using the gas for other end uses, such as process heat or electricity generation, would improve the economic attractiveness of pipeline construction. Transferring natural gas from a pipeline to a vehicle can also be expensive, as a compressor is required. For fleet vehicles that make use of central refueling facility, the cost per vehicle for the compressor system will be reduced somewhat.

Unlike methanol and ethanol, natural gas reduces emissions contributing to urban smog, although it may increase nitrogen oxide emissions. Natural gas vehicles also should contribute less to greenhouse gases than petroleum or coal-based transport fuels. The lower emissions of carbon monoxide and carbon dioxide by natural gas compared to petroleum or coal may be offset, however, by methane leaks—methane is a potent greenhouse gas-during the production and distribution of gas. Although natural gas presents some special handling problems, it is neither toxic nor corrosive, unlike methanol and gasoline.

Liquefied Natural Gas (LNG) is natural gas that has been liquefied by cooling it to –161 'C. The advantage of LNG over CNG is its energy density—a given volume of LNG will provide about 3 times the vehicle range between refueling than the same volume of CNG.[77] The liquefaction process is expensive, however, and the fuel must be kept at –160 °C to prevent boiling off. The practical

[76] Unless it is converted to LNG.

[77] U.S. Congress, Office of Technology Assessment, op. cit. footnote 61, p. 99.

difficulties of maintaining these low temperatures, along with the high cost of containers capable of storing LNG, make LNG less promising as a fuel for road vehicles .78 Furthermore, LNG requires an expensive conversion process to liquefy it from natural gas. This costs about $1 to $3 per thousand cubic feet of natural gas, plus the process consumes about 10 percent of the incoming gas as fuel.[79]

Electric vehicles are under development in the United States, and several prototypes exist. Major limitations are short range due to limited battery storage, and the cost of electricity. Advanced battery technologies, although not yet commercially available, may allow for greater energy storage and longer battery life. Many developing countries are now electricity-short and electric vehicles would aggravate this problem. If in the future electricity supplies are ample then electric vehicles may be a more realistic option. Electric vehicles hold special promise in congested urban areas, where most trips are short and therefore the limited range of electric vehicles is less of a problem.

Electric vehicles have essentially no direct emissions and therefore may alleviate urban air quality problems. The overall contribution to pollution depends, however, on the nature of the electricity generation process. Electricity generated from a coal-freed power plant will contribute significantly to local and global pollution. Vehicles powered with electricity from nuclear, hydroelectric, or solar technologies, however, will generate less pollution than conventional gasoline-powered vehicles. In any case, electric vehicles may contribute less to urban pollution as power plants are frequently located outside of urban areas.

Electric vehicles may pose an additional environmental hazard, unique among the alternative fuels. The batteries required by electric vehicles typically have short lifetimes and present a disposal problem. The battery technologies under development also require special disposal procedures for production wastes as well as for spent batteries.[80]

Hydrogen has been discussed as an alternative fuel for transport. Hydrogen is an extremely clean fuel,[81] and is compatible with internal combustion engines. The two largest barriers to widespread use are storage and costs of production. Hydrogen has a very low energy density. Therefore, a hydrogen-fueled vehicle would require very large on-vehicle storage tanks. Hydrogen could be produced from natural gas or coal; however, a more environmentally appealing idea is to produce hydrogen from electrolysis of water using renewable energy generated electricity. This would, like electric vehicles, require an inexpensive source of electricity. Due to its various limitations, hydrogen is a speculative and very long term option.

CONCLUSION

The demand for transport services will continue to grow rapidly in developing countries, driven by population growth, economic growth, structural change, such as the transition to urban industrial economies, and other factors. The energy needed to meet these transport service demands, however, can be moderated through improvements in vehicle technical and operational efficiencies, and shifts to more energy efficient transport modes. Land-use planning can also substantially reduce the underlying need for transport services and assist the movement to more efficient modes by better matching residences with jobs, schools, shopping, and transport infrastructures. In contrast to the industrial countries whose infrastructure is largely in place, developing countries are only now building their infrastructures for the next century. Thus, they have a particular opportunity to redirect urban growth with appropriate incentives and disincentives towards more efficient and environmentally sound forms.

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[78] R. Moreno, Jr. and D. Bailey, Op. cit., footnote 75, p. 11.

[79] U.S. Congress, Office of Technology Assessment, op. cit., footnote 61, p. 103. Natural gas at the wellhead costs about $1/million Btu, or $1/thousand cubic feet, so the LNG process will, at a minimum, double the fuel cost.

[80] U.S. Congress, Office of Technology Assessment, op. cit., foonote 61, p. 119.

[81] Hydrogen-powered vehicles emit only water vapor and small amounts of nitrogen oxides. U.S. Congress, Office of Technology Assessment, op. cit., p. 128; also J. MacKenzie and M. Walsh, *Driving Forces* (Washington, DC: World Resources Institute, December 1990), p. 42.