solutions

Transportation

in Developing Countries

Greenhouse Gas Scenarios for Delhi, India

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PEW CENTER ON Global CLIMATE CHANGE

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Greenhouse Gas Scenarios for Delhi, India

Prepared for the Pew Center on Global Climate Change

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Contents

Foreword *Eileen Claussen, President, Pew Center on Global Climate Change*

Greenhouse gas emissions in developing countries are increasing most rapidly in the transportation sector. Even people with low incomes are meeting their need for mobility, and projected income growth over the next two decades suggests that many more will acquire personal modes of transportation. How this will affect the earth's climate is a great concern.

In Delhi, India, transportation sector greenhouse gas emissions are expected to soar. There are policy and technology choices that could significantly lower the emissions growth rate while increasing mobility, improving air quality, reducing traffic congestion, and lowering transport and energy costs. To realize these benefits, vision, leadership, and political will must be brought to bear. Delhi has high vehicle ownership rates for the city's income level, increasing congestion, poor air quality, poor safety conditions, and insufficient coordination among the responsible government institutions. Travelers in Delhi desire transportation services, reflected by the increasing numbers of inexpensive but highly polluting scooters and motorcycles.

This report creates two scenarios of greenhouse gas emissions from Delhi's transportation sector in 2020. It finds:

- Greenhouse gas emissions quadruple in the high-GHG, or business-as-usual, scenario; but only double in the low scenario.
- Transportation policies are readily available that will not only slow emissions growth, but also significantly improve local environmental, economic, and social conditions.
- Improved technology would maximize the efficiency of automobiles, buses, and other modes of transportation and could play a key role in reducing emission increases.
- Keeping many travel mode options available — including minicars and new efficient scooters and motorcycles — will help individuals at various income levels meet their mobility needs.
- The time to act is now. The issues facing Delhi represent opportunities for improvement, but the longer authorities wait to address transportation inefficiencies, the more difficult and expensive it will be to produce a positive outcome.

Transportation in Developing Countries: Greenhouse Gas Scenarios for Delhi, India is the first report in a five-part series examining transportation sector greenhouse gas emissions in developing countries. The report findings are based on (1) a regression model developed by TERI to forecast future increases in vehicle ownership and travel by different modes and (2) a Lifecycle Energy Use and Emissions Model developed by the Institute of Transportation Studies at U.C.-Davis which estimates greenhouse gas emissions from the transportation sector.

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Executive Summary

Delhi, India is a rapidly expanding megacity. Like many other cities its size, Delhi faces urban gridlock and dangerous levels of air pollution. Vehicle ownership is still a fraction of that in industrialized countries, but remarkably high considering the population's relatively low income.

Worldwide, energy use is increasing faster in the transport sector than in any other sector, and fastest of all in developing countries. From 1980 to 1997, transportation energy use and associated greenhouse gas (GHG) emissions increased over 5 percent per year in Asia (excluding the former Soviet Union) and 2.6 percent in Latin America, compared to one percent growth in greenhouse gases from all sectors worldwide.

Delhi faces the same transportation, economic, and environmental challenges of other megacities. Population, motor vehicles, pollution, and traffic congestion are all increasing. Air pollution levels greatly exceed national and World Health Organization health-based standards, and transportation is by far the largest source of pollution. In the past 30 years, Delhi's population more than tripled and the number of vehicles increased almost fifteenfold.

By 2000, Delhi had about 2.6 million motor vehicles — 200 for every 1,000 inhabitants, a rate far higher than most cities with similar incomes. Most of these vehicles are small, inexpensive motorcycles and scooters, rather than automobiles. This proliferation of vehicles in a relatively poor city indicates the strong desire for personal transport — a phenomenon observed virtually everywhere. Delhi is an example of how that desire can now be met with relatively low incomes.

Delhi is expected to continue growing at a rapid rate. Its population is expected to surpass 22 million by 2020. Motor vehicles, including cars, trucks, and motorized two- and three-wheelers, are expected to grow at an even faster rate. The domestic auto industry is predicting car sale increases of 10 percent per year. With an extensive network of roads and increasing income, there is every reason to expect vehicle sales and use to continue on a sharp, upward trajectory.

Like most megacities of the developing world, Delhi is not prepared to manage this pent-up demand. If the predicted increase in vehicle use is realized, Delhi may face extreme economic and environmental consequences. Air pollution already threatens human health and could worsen. Traffic congestion could increase to the point of paralysis. Large settlements of poor people on the urban periphery may become even more disenfranchised as transit services dwindle. The cost of doing business and providing transportation infrastructure would soar. GHG emissions could increase dramatically. Rampant growth in vehicles in Delhi and throughout the developing world is overwhelming the capacity and resources of local governments. The proliferation of low-cost, highly polluting scooters and motorcycles exacerbates the situation.

This report attempts to untangle the complexities of Delhi's transport sector, exploring what kind of a future is likely and how it might be altered. The authors interviewed Indian transportation experts and political leaders, analyzed historical data, and examined various policy options and strategies. They found large institutional, political, economic, and technological uncertainties, and limited knowledge of travel behavior and preferences.

The authors created two scenarios to characterize what is likely and what is possible. One scenario — a “business-as-usual” trajectory — is an extrapolation of present trends in Delhi, modified to reflect existing policies and commitments. This scenario results in more than a fourfold increase in transport-related GHG emissions between 2000 and 2020.

A second scenario, resulting in much smaller increases in GHG emissions, is premised on strong political and institutional leadership to enhance the economic, social, and environmental performance of Delhi's transportation system. In this scenario, conventional-sized cars drop from 30 to 19 percent of motorized travel between 2000 and 2020, and mass transit increases its share from 49 to 53 percent. More efficient scooters and minicars account for most of the remaining motorized travel, and bicycling becomes more important, especially for the poor. Even with this aggressive shift toward more environmentally benign transportation, GHG emissions more than double in the 20-year period.

Two important observations stand out. First, under any plausible scenario, greenhouse gases will soar, ranging from a doubling to a quadrupling of emissions. Second, although these increases are disconcerting, they indicate that pursuit of the lower greenhouse gas path leads to far fewer emissions — and much lower transport and energy costs.

The low-GHG scenario does not require revolutionary change. Many opportunities to slow the growth in vehicle use, pollution, greenhouse gases, and traffic congestion are at hand at modest cost. To realize these opportunities, however, vision, leadership, and political will must be brought to bear. Currently, air pollution is the principal motivator for action in Delhi (though it may in part be a proxy for traffic congestion). Leadership comes not from the executive or legislative branches of government, but from India's Supreme Court. In the past few years, the Court has dictated major expansions of rail and bus transit, a series of programs to sharply reduce air pollutant emissions from vehicles, and requirements that vehicles use clean alternative fuels. Though aimed at local air pollution reduction, many of these initiatives also restrain growth in vehicle use and GHG emissions.

Many other initiatives are also available to shift Delhi to a more sustainable path. Low-cost, incremental strategies and investments include the following:

- Building and maintaining sidewalks,
- Separating slow-moving traffic (bicycles and cycle rickshaws) from motorized traffic,
- Enhancing the quality and range of mass transit services,
- Eliminating inefficient and very polluting two-stroke engines in scooters and motorcycles,
- Using cleaner low-carbon natural gas fuels,
- Enhancing rapid transit, and
- Discouraging the use of private vehicles in densely populated areas.

These efforts would provide dramatic improvements in traffic flow, pollution, energy use, GHG emissions, and system costs.

More fundamental system and technology changes could have even deeper, long-term impacts. These include the following:

- Restructuring land development patterns to reduce the demand for transport,
- Accelerating the introduction of highly efficient advanced vehicle technologies, and
- Using information and communication technologies to facilitate new, more efficient forms of transportation, vehicle ownership, and land use that leapfrog today's car-centric patterns.

A wide variety of policy instruments and investments could be used to support these initiatives.

In the end, it must be recognized that all people desire greater access to goods and services, and greater comfort and convenience in accessing them. The challenge facing Delhi and other expanding megacities is to balance the personal transport desires of the more affluent with the minimal mobility needs of the very poor.

In summary, greenhouse gases associated with transportation will increase dramatically in Delhi in the coming decades, but much can be done now to slow that growth, often at little cost. It is no exaggeration to say that the environmental and economic consequences of inaction could be disastrous. The difference between a doubling and quadrupling of GHG emissions from the transportation sector over 20 years is enormous, especially because the higher 2020 emission levels would serve as the basis for further growth. Strong leadership is needed. The good news is that many of the actions described in this report respond to a variety of compelling social, economic, and environmental goals and not just reductions in greenhouse gases.

I. Introduction

Since 1992, the international community has been negotiating reductions in greenhouse gas (GHG) emissions.[1] The primary focus of negotiations has been the responsibility of developed (Annex 1) countries[2] and what measures they will take. The negotiations have yet to confront the growth in GHG emissions from developing nations. Data indicate that countries such as India and cities such as Delhi are experiencing rapid increases in GHG emissions. Increases are greatest in the transport sectors in almost all cities and countries.

While global carbon emissions from energy in all sectors grew 1.2 percent annually between 1980 and 1997, those from transport grew 2.1 percent per year. In the developing countries of Asia (excluding the former Soviet Union), transport emissions grew dramatically at 5.6 percent per year. In all regions, transport emissions growth outpaced growth in all other sectors, with differences accelerating after 1990.[3] Delhi is following this same pattern of rapid growth in transport-related GHG emissions.

Delhi is a sprawling metropolitan area of nearly 1,500 square kilometers that contains much that is old and new. It is home to over 13 million people and the capital of India. Delhi is an international political and cultural center and, increasingly, an important commercial and industrial center.

Delhi has grown rapidly in area, density, and population. Its spatial area has expanded fifteen-fold since 1911. In 1991, 29 new towns were annexed, increasing the area from 445 to 1,483 square kilometers. Most of the Delhi metropolitan area is governed by two units: the New Delhi Municipal Council, an independent city-level administrative body serving as the capital of India, and the Delhi Municipal Corporation whose administrative jurisdiction covers most other areas in the Delhi metropolitan area. Metropolitan Delhi, encompassing New Delhi and other smaller communities, has grown physically in all directions, extending out from Delhi along the corridors of the five national highways that converge in Delhi. Land use is highly mixed with few clearly defined zones of activities.

Population growth has been extraordinary, increasing from 1.7 million in 1951 to over 13 million in 2000. Even with the expanded spatial area, population density continues to increase (roughly doubling between 1971 and 1991). In 1991, the average population density for the entire sprawling Delhi region was 6,352 persons per square kilometer, with a maximum density of 19,866 in the area of the Delhi Municipal Corporation.[4] The average and maximum densities are about one-fourth those of Hong Kong, comparable to Tokyo, and somewhat greater than in London and Paris.[5] The rate of growth is expected to slow, but the population is still expected to reach 22 million by 2020.[6]

Population growth is due largely to migration of rural poor to the city. Over one-third of Delhi residents live in slums and squatter settlements. Most of these people, about four million currently, live in unauthorized settlements without formal arrangements for water and electricity supply.

Delhi's average income is low compared to industrialized countries, though twice that of the rest of India, and increasing. Total gross domestic product for the Delhi region increased over 7 percent per year in real terms from 1980 to 1996, and is forecast to continue that rate of increase through 2020.[7] Delhi per capita income increased about 3 percent per year over the same period, reaching about $800 per year in 1996. It is expected to increase 4.3 percent per year from 2000 to 2010 and 5.4 percent annually the following decade.[8]

Rising incomes, combined with demand for greater personal mobility and inadequate public transport, will inevitably result in continuing increase in personal vehicle use and ownership, especially inexpensive scooters and motorcycles, but also cars. By 2000, Delhi had about 2.6 million motorized vehicles,[9] up from 0.18 million in 1970. This represents 200 vehicles for every 1,000 inhabitants, a rate much higher than most cities with similar levels of per capita income. Most vehicles in Delhi are small, motorized two-wheelers (motorcycles and scooters).

Efforts to manage this rapid growth in vehicles have not been successful. Greenbelts of open space specified in the 1962 Delhi Master Plan[10] have largely fallen victim to uncontrolled land development, and roads in the planned communities and industrial areas of the 1970s are now among the most congested in the region.

Delhi has an unusually extensive road network for a city of its income level. In 1996, it had 26,582 kilometers of roads, with many new high-quality arterials and highways under construction. There will soon be over 1,000 kilometers of high-quality divided roads, most with six lanes. The rest of the network is less impressive. Sidewalks are either absent or poorly maintained. Slow-moving, non-motorized vehicles (bicycles and cycle rickshaws) travel with large, motorized vehicles. Buses receive no special treatment on any roads, including the new arterials. The overall effect is poor use of roads and related infrastructure investments.

Delhi is well connected to the extensive national rail network through several intercity rail lines. These intercity rail lines serve passengers and freight traveling long distances between cities. The rail lines are not well located to serve metropolitan travel patterns, and have only a few stations within the Delhi area. Plans are underway to create an urban passenger rail network.

Delhi experiences high traffic fatality rates and, given the expansiveness of the road network and the relatively low number of vehicles per kilometer of road, a surprising amount of traffic congestion. The third largest city in India, Delhi has the most arterial roads and motorized vehicles, highest average speeds, and most land devoted to transport infrastructure (20 percent, compared to 6 percent in Calcutta and 17 percent in Mumbai). The extensive road network design did not take into account the wide variety of vehicles or the large number of pedestrians or animals on the streets. Traffic management has not evolved to handle this diversity in traffic.

II. Delhi's Transportation Picture

A. Motivations for Change

Traffic Congestion and Roadway Management[11]

Congestion in Delhi is severe at times and places, and worsening. Average speeds during peak periods range from 10 to 15 kilometers per hour in central areas and 21 to 39 kilometers per hour on arterial roads. Congestion is generally not severe during off-peak hours. Mid-block speeds are relatively high, averaging about 50 and 70 kilometers per hour for buses and private motorized vehicles, respectively.

The wide variety of vehicles is daunting. The current road infrastructure cannot safely or efficiently serve all users. Vehicles sharing the same road space vary in width from 0.6 to 2.6 meters, with maximum speeds ranging from 15 to over 100 kilometers per hour. Traffic is generally characterized by lack of effective channeling, mode segregation, or speed control. In congested spaces, vehicles appear to be in chaotic disarray: lanes are ignored or nonexistent, and vehicles of all sizes slide into available spaces. Congested roadways look like jigsaw puzzles (see Figure 1).

The Delhi road system was not designed and is not managed with this disparate vehicle mix in mind. The diverse traffic characteristics, modal mix, and land use patterns have overwhelmed the capabilities of the authorities. It is widely believed among local transportation professionals that modest efforts at managing traffic flows and separating motorized and non-motorized vehicles would greatly reduce congestion. None, however, could cite successful local examples during interviews.

Figure 1

Traffic in Delhi

Road congestion can be particularly unpleasant in Delhi. The hot climate, absence of air conditioning, and dense exhaust fumes can turn congested traffic delays into disagreeable and dangerous experiences, especially for packed bus passengers and riders of two-wheeled vehicles exposed to the elements. Congestion can also be expensive. A study by the Petroleum Conservation Research Association estimated in 1998 that Delhi wastes $300,000 in fuel daily just through vehicles idling at traffic lights.[12]

Local experts, planners, policy-makers, and environmental advocates indicate that a large share of the problem with the transportation system in Delhi is that too many organizations are making disjointed decisions. Even within government offices, there are many disagreements about who is responsible for what. No single agency at the central, state, or local level has responsibility to plan, finance, build, and manage transportation projects and vehicular traffic. As many as a dozen agencies influence the supply, maintenance, and management of transportation infrastructure (city roads, highways, overpasses, underground crosswalks, etc.).

One small example of the lack of coordination is the recent construction by the Public Works Department of tunneled pedestrian walkways under several arterial roads. Most pedestrians still cross busy surface roads instead because the location of these underground walkways was not coordinated with the location of bus stops, which is handled by the Traffic Police and Delhi Transport Corporation. The Traffic Police are now trying to remedy the problem by relocating bus stops close to the underground pedestrian walkways.

Most major cities have this same multiplicity of agencies and governments. What is unusual in Delhi is the lack of coordination and accountability. A draft bill has been proposed to enable the establishment of a unified metropolitan transport authority, and a high-powered road safety and traffic engineering committee is functioning under the chairmanship of the Chief Secretary of Government of the National Capital Territory of Delhi. With the exception of these initiatives and recent Supreme Court decisions, there appears to be no serious effort to overcome this institutional handicap.

Air Pollution

Air quality is emerging as a principal motivation for enhancing Delhi's transport system. Pollutant levels are often several times higher than the ambient standards set by the Central Pollution Control Board and they are increasing.[13] For example, from 1995 – 1999, particulate matter and carbon monoxide standards were violated over 85 percent of the time, and only sulfur dioxide levels became compliant during this period. The greatest success story to date is the phasing out of leaded gasoline. Vehicles are estimated to account for about 70 percent of the city's air pollutant emissions.[14]

In recent years, a series of initiatives has been launched to reduce pollution. These initiatives have come not from the legislative or executive branches of government, but the Supreme Court. Under a constitutional provision that ensures a certain quality of life to residents of India, the Supreme Court heard several environmental lawsuits — a series of successful public interest litigation actions filed in 1996 and 1997. In response, the Indian Ministry of Environment and Forests created the Environment Pollution (Prevention and Control) Authority in January 1998. The Authority's mission is to reduce pollution in the National Capital Region. It recommended the following strategies for immediately improving air quality, all of which were approved by the Supreme Court:

- Augment public transport,
- Reduce vehicle emissions by setting standards for fuels and auto emissions,
- Establish inspection and maintenance of in-use vehicles, and
- Use clean alternative fuels.

These Court-approved directives are now driving the planning and management of Delhi's surface transport system. One outcome has been the adoption of increasingly stringent emission standards for new vehicles.[15] These standards are bringing Indian vehicles close to emission levels for new vehicles in OECD countries.[16] The new Indian standards will require the use of the most advanced emissions control technology on the world market. Enforcement has been weak, but the ready availability of this technology and the relative ease of regulating a limited number of vehicle suppliers suggest that compliance is likely to improve.

Table 1 lists recent directives regarding alternative fuel use in Delhi that will affect GHG levels. Only one will meet its deadline, but considerable progress is being made. Directives related to buses are most likely to be realized — though not on schedule — since buses are scrapped at a far faster rate in India than in OECD countries. They are scrapped faster because they are built locally at lower cost to lower standards, costing about $22,000, one-tenth that of buses in Europe and the United States.

However, compliance with these directives can be expensive. On the one hand, compressed natural gas (CNG) and liquefied petroleum gases (LPG) are less expensive than gasoline. Depending largely on how much a vehicle is driven, the full lifecycle cost of owning and operating CNG and LPG vehicles could eventually be less than for comparable gasoline vehicles. On the other hand, the initial cost of a vehicle outfitted for these fuels is somewhat greater due to the cost of the high pressure tank needed to store the fuels. Each CNG bus, for example, currently costs about 60 percent more than a diesel bus (about $12,000 extra). This initial cost is so high that it outweighs for many purchasers the long-term cost savings. As the technology matures, this cost differential is expected to diminish, but not disappear. So far, debate over cost has been muted.

Table 1

Supreme Court Directives Affecting Buses and Fuel Use

Supreme Court Directives (July 1998)	Status of Implementation (February 2001)
The number of buses must increase to 10,000 by April 1, 2001 and must operate on CNG.	About half the required 10,000 buses are in service, with over 95 percent operating on diesel.
All pre-1990 taxis and autorickshaws (including those owned by individuals) must be replaced with new vehicles running on clean fuels by March 31, 2000.	All pre-1990 taxis and autorickshaws were successfully removed from the road by the deadline.
Local governments must provide financial incentives to replace all post-1990 autos and taxis with new vehicles that operate on clean fuels by March 31, 2001.	Substantial financial incentives are being offered for new vehicles operating on clean fuels.
All public sector buses older than 8 years must be scrapped by April 1, 2000 unless they operate on CNG or other clean fuels. The entire city bus fleet (public and private) must be steadily converted to CNG.	About 137 CNG buses are in operation (all publicly operated) and 1,200 are on order. Thirteen diesel buses have been retrofitted with CNG. Only a few private charter buses (mainly school buses) have been retrofitted with CNG.
The Gas Authority of India must create a network of 80 CNG refueling stations by March 31, 2000.	35 CNG refueling stations are open.

Note that most of the changes the Supreme Court directives call for or require a “technical fix”: altering the engine or fuel to reduce emissions, as opposed to altering traveler behavior. This strategy mimics that of the United States, where large reductions in transport-related air pollutants were accomplished almost totally by altering the engines and fuels. Considerable effort has been expended in the United States to reduce vehicle use, largely without success.

The CNG bus initiative illustrates this technical fix approach. The April 2001 deadline imposed by the Supreme Court is resulting in accelerated scrappage of diesel buses and purchases of cleaner, but more expensive CNG buses. Indeed, switching buses to CNG may weaken the bus system, since the high cost of CNG buses must be accommodated in some way, presumably resulting in cutbacks in bus service or quality. During this transition, transit service will undoubtedly be adversely affected.

Note that the Delhi pollution programs target conventional air pollutants — reactive hydrocarbons, oxides of nitrogen, carbon monoxide, sulfur oxides, particulates, and lead — not CO_2, methane, and other greenhouse gases (though some regulated air pollutants have minor climate change effects). The result of these air pollution programs is likely to be a significant reduction in conventional pollution, a modest dampening of petroleum use, and only a small reduction in GHG emissions.

Even the alternative fuel directives will have little effect on GHG emissions. The primary thrust is use of natural gas fuels. Although CNG combustion clearly provides air quality benefits relative to gasoline and diesel combustion, the effect on greenhouse gases is not necessarily positive. The greatest GHG benefit of using natural gas results when a vehicle is designed and manufactured to run on CNG. The benefits are substantial: a net reduction of about 20 percent per vehicle-kilometer relative to a comparable gasoline vehicle (on a full fuel cycle basis).[17] However, if a factory-built gasoline vehicle is not designed and manufactured for CNG but later retrofitted, the effect is much smaller and can be negative.[18] Buses in Delhi do not use gasoline.

From a GHG perspective, CNG combusion is relatively less attractive in diesel engines than in gasoline engines — whether in cars, buses or trucks.[19] A diesel engine may be designed and optimized for either CNG or diesel fuel use. For buses and trucks, a CNG-optimized diesel engine running on CNG will have about the same emissions as a diesel-fuel-optimized engine running on diesel fuel, and somewhat higher emissions in cars. However, as with gasoline engines, if a diesel engine is designed to be run on diesel fuel, but is later retrofitted to run on CNG, then GHG emissions would increase. Note that most cars and light trucks have gasoline engines, and most buses and large trucks have diesel engines.

The most important implication of the Court's intervention in transportation may be to strengthen local institutions and the resolve of local authorities to make the transport system more sustainable. While the effect of current Court directives on greenhouse gases is minimal, they provide hope and direction for further changes to come.

Energy Consumption

India has domestic reserves of oil and natural gas, but imports account for over half of all oil consumption, and natural gas imports are expected to begin soon. Domestic oil production in 1999 was 4.5 million barrels per day (b/d) and oil imports 5.3 million b/d. National security continues to be a major motivation for energy policy-making in India. As fuel consumption and oil imports rise and prospects for higher oil prices become more likely, energy is likely to become an even greater concern.

Transportation is a large and growing user of petroleum in India, already accounting for 46 percent of all oil consumed in the country. In Delhi, transport fuel use more than tripled between 1980 and 1999. The rapid increases were due to increased vehicle ownership and utilization. While buses carry half of all Delhi's passengers (measured in passenger-kilometers), they consume less than 20 percent of transport energy.

The shift from mass transit to personal vehicles will have a large effect on energy use — as well as traffic congestion, pollution, and GHGs. In Delhi, buses use only about one-sixth as much energy per passenger-kilometer to transport people as cars, about one-third as much as motorized three-wheelers (autorickshaws), about three-quarters as much as two-wheelers with two-stroke engines, and slightly less than two-wheelers with four-stroke engines. These fuel consumption rates assume the following occupancy factors, based on the authors' estimates: 1.5 people for motorized two- and three-wheelers, 2.5 people per vehicle for cars, and 36 people per bus.

Fuel consumption rates have been improving slowly and are expected to continue to improve. One factor motivating these fuel economy advancements is increasing fuel prices. The price of gasoline rose from 8.5 rupees per liter in 1989 to 16.8 rupees in 1995, 24.0 rupees in 1999 and 28.4 rupees in 2000 (about U.S. $2.20 per gallon). Subsidized diesel prices increased from 3.5 rupees per liter in 1989 to 7.0 rupees in 1995, 10.0 rupees in 1999 and 16.6 rupees in 2000. These price increases were due to high world oil prices (over $30 per barrel in 2000) and continuing fuel tax increases. If fuel prices remain at 2000 levels, continued fuel economy improvements are likely. However, because world oil prices are expected to subside in the following decade, these (or higher) fuel prices will be sustained only if Indian governments continue to raise fuel taxes.

Note that fuel efficiency (amount of “work” per unit of energy) will not necessarily yield greater fuel economy (improvement in miles per gallon). Major efficiency improvements in technology are certain in both the domestic and international automotive industry. As trade barriers are lowered, efficiency improvements will disseminate faster. However, it is not guaranteed that these technical efficiency improvements will translate into fuel economy improvements. In some countries, such as the United States, large technical improvements have been used since the mid-1980s not to improve fuel economy, but to provide more power, size, and accessories. Scenarios presented in Section IV of this report consider the rate at which fuel economy improvements might be realized in Delhi.

Looking toward the future, Delhi's rapid population growth will lead to rapid increases in transportation demand and energy use. If most increases in transportation demand are met by conventional cars, then GHG emissions will soar. However, if vehicles are smaller, more energy efficient, or use low-GHG emitting fuels (in the case of gasoline engines), or if a large share of the increase in travel demand is served by mass transit, then growth in emissions could be dampened.

Safety

Safety could be another motivation for improving the transport system, with uncertain implications for GHG emissions. Both anecdotal and recorded data tell the same story: Travel in Delhi is dangerous. The number of traffic deaths increased from about 500 per year in the early 1970s to over 2000 in the late 1990s.[20] Delhi fatality rates are high compared to more industrialized countries, in large part due to the ubiquity of motorized two-wheelers, which are much less safe than most other forms of transport. Reliable data are not available in India, but motorized two-wheelers in the United States have death rates 14 times higher than cars.[21] On a more positive note, deaths are increasing slower than vehicle travel — about 2 percent slower per vehicle kilometer.[22] Still, many pedestrians and drivers are being killed and the number continues to increase as personal vehicles become more prevalent.

Relative declines in road crash fatalities in Delhi may be due to slower speeds resulting from increasing congestion. The reductions could accelerate if appropriate road designs, vehicle standards, and traffic management techniques are implemented. These improvements would include segregated bicycle and bus lanes on major arterial roads, safer walking conditions and improved road infrastructure for pedestrians, and speed limit enforcement on arterial roads.

The political constituency for improved road safety is growing; traffic safety has become a concern with the public and authorities alike. Evidence includes mandatory use of helmets by drivers of motorized two-wheelers. Other important government measures include guidelines for school buses that limit the number of children allowed on board. Traffic police have begun to collaborate with non-governmental organizations (NGOs) to conduct traffic safety education programs in schools and enforce speed limits.[23] Other initiatives, motivated at least partly by safety concerns, include construction of grade-separated intersections and underground crosswalks, and the widening of roads.

The net effect of safety measures on travel and vehicle use is uncertain. Many of these measures have resulted in increased speeds of motorized vehicles, making vehicles more attractive, while apparently increasing safety risks to pedestrians and bicyclists. Likewise, discouraging the use of motorized two-wheelers for safety reasons results in travelers switching sooner to cars. In general, it appears that travelers progress from two-wheelers to inexpensive used cars. It may be that the net effect of safety concerns is to encourage car purchases.

In summary, while economic growth increases the capability of countries to attend to safety and environmental issues, it does not by itself resolve them. The task of creating an enabling framework falls inevitably to government.

B. Travel Characteristics and Vehicle Ownership

Small shifts in travel behavior can have large effects on the design, performance, and impacts of the transport system. In this section, opportunities are explored for reducing GHG emissions and other negative side effects from the transportation sector. A fundamental premise is that travelers formulate their preferences based on differences in performance, convenience, quality, economics, safety, and other factors. Few travel choices are motivated by pollution, resource consumption, or climate change concerns. The challenge is to formulate public policies that serve both private and public interests.

Passenger Travel

A wide variety of modes and vehicles are used for passenger travel in Delhi. As in other Indian cities, non-motorized travel and mass transit account for the vast majority of trips. Buses account for about half of all passenger travel. But this share is dropping and expected to continue to drop into the future (see Table 2). The planned rapid transit system, using rail and busways (road lanes dedicated to buses), is expected to temporarily slow the drop in transit share. However, the overall trend for the share of travel by mass transit is downward.

Table 2

Mobility Indicators for Selected Metropolitan Areas, Work Trips Only

Cities	Population	Modal split for travel to work, percent of trips			Average trip length, km	Vehicle ownership	
		Public Transport	Private Transport	Bicycling & Walking		Vehicles/1000 persons	Passenger cars/ 1000 persons
Amsterdam (1990)	804,711	26	40	35	6.6	342	308
London (1991)	6,679,699	40	46	14	7.5	356	288
New York (1990)	18,409,019	54	35	11	16.7	459	412
Paris (1990)	10,661,937	54	18	28	8.3	383	338
Tokyo (1990)	31,796,702	49	29	22	NA	266	156
Delhi (1998)	13,418,000	54	23	23	10.0	200	63

Note: Data are not exactly comparable for several reasons, including use of different time periods and inconsistent definition of metropolitan boundaries.

Sources: Kenworthy and Laube (1999), *An International Sourcebook of Auto Dependence in Cities 1960-1990*, for OECD cities. Data from OECD cities are mostly from the early 1990s. Delhi data are mostly from Operations Research Group, "Household Travel Surveys in Delhi: Final Report," September 1994; population and vehicle ownership data are from Bose and Nesamani, "Urban Transport, Energy and Environment: A Case of Delhi," New Delhi, 2000.

Delhi's experience with personal vehicles is instructive to other large cities in the developing world. In India, Delhi is the third largest city, but it ranks first in total number of vehicles and vehicles per capita. Indeed, its vehicle ownership rate approaches that of many affluent OECD cities. About 81 percent of households own a vehicle, though only 13 percent own cars.[24] Most vehicle-owning households possess small scooters and motorcycles. Motorized two- and three-wheelers represent two-thirds of the total vehicle fleet in Delhi. As indicated in Table 3, they have maintained that share for over a decade, and are expected to continue to do so.

This high level of vehicle ownership is an important phenomenon that bears examination because it illustrates that personal vehicles can play a large role in urban transport at very low income levels. Although average per capita income is about 35 times less than that of the United States, most Delhi households own a personal vehicle. About two-thirds of these vehicles are low-powered and highly inefficient mopeds, scooters, and motorcycles, with 50-150 cc engines costing $400 to $1,200. Used two-wheelers (and many used cars) cost even less. While neither comfortable nor reliable, motorized two-wheelers do provide convenient, inexpensive travel.

Rickshaws

Indian cities have many three-wheeled autorickshaws, which are motorized, and cycle rickshaws, which are not. All are used for commercial purposes. Most carry passengers, but some occasionally carry freight. Cycle rickshaws are registered separately from motorized vehicles.

Current policies regarding cycle rickshaws and other non-motorized vehicles are restrictive, based on the notion that efficient ("modern") transport systems do not include these vehicles. Traffic management experts and traffic police have proposed area and time restrictions on the movement of cycle rickshaws in Delhi. The number of cycle rickshaws that can be registered in the city is fixed at 99,000. The registration procedure requires the owner to have a valid registration card, and to register these vehicles only during stipulated times twice a year. Not surprisingly, a large number of cycle rickshaws are unregistered. The authors estimated that as many as 300,000 cycle rickshaws currently travel on Delhi roads. Cycle rickshaws are used for delivery of large goods such as furniture, refrigerators, and washing machines. Several case studies have documented the poor, often exploitative working conditions of cycle rickshaw operators. The vehicles are usually owned by contractors who demand a fixed rental payment from the operators, often with little regard to the state of the equipment or the road conditions.

Although both types of rickshaws are widely viewed as a principal cause of congestion and chaos, they have been ignored in traffic planning and road design.

The entire vehicle fleet — motorized and non-motorized — is growing rapidly. From 1975 to 1998, the car population increased from about 68,000 to almost 800,000, and motorized two-wheelers from about 100,000 to over 1.5 million. With continued income growth, the motor vehicle population is expected to continue expanding at a high rate (see Table 3). The number of bicycles and cycle rickshaws is also very large and increasing, though the number is uncertain since many owners do not comply with the requirement for annual registration.

Table 3

Motor Vehicles in Use in Delhi (thousands)

Year	Scooters and motorcycles	Cars/jeeps	Autorickshaws	Taxis	Buses	Freight	All motor vehicles
1971	93	57	10	4	3	14	180
1980	334	117	20	6	8	36	521
1990	1077	327	45	5	11	82	1,547
2000	1568	852	45	8	18	94	2,584
2010	2958	1472	103	14	39	223	4,809
2020	6849	2760	209	28	73	420	10,339

Note: Historical data are from *Delhi Statistical Handbook* and Transport Department, Delhi. Except for 1971 and 1980, they have been revised downward to reflect scrappage of vehicles over time. There are no registration data for 1971 and 1980 to estimate attrition. Projections are from Bose and Nesamani, 2000.

Public Transportation

Buses form the backbone of the transport system in Delhi. Generally, buses are the most economically and environmentally efficient means of providing transport services to the most people. In Delhi, buses constitute less than one percent of the vehicle fleet, but serve about half of all travel demand.

Since 1992, Delhi has turned increasingly to the private sector to help expand and improve bus service. This decision was a response to the widely acknowledged shortcomings of public bus service, including escalating costs, poor maintenance, high labor costs, an aging bus fleet, and erratic service.

Bus service was expanded in 1996 by adding more buses, with buses per route increasing from 0.8 to 1.7. The regular fixed-route bus system now comprises about 4,000 privately operated buses and 3,760 publicly operated buses. It is complemented by 5,000 private charter buses that provide point-to-point service during peak hours to subscribers who pay a monthly fee for a guaranteed seat. In addition, there are about 5,000 school and tourist buses.

Public buses provide a low level of service and comfort, with passengers often traveling on foot-boards and bus roofs. Large-scale privatization has increased capacity but buses continue to be overcrowded and poorly maintained. Although buses carry half of all passenger travel, they receive no preferential treatment in terms of dedicated lanes or traffic management.

The low quality of service is due largely to the extreme poverty of so many riders. Many Delhi residents cannot afford to pay even the low, subsidized fares. Consider that a single one-way bus fare for people living on the outskirts of the city is $0.20 – $0.25 (Rs.8 to Rs.10), depending on the number of transfers. For the poorest 28 percent of households with monthly incomes of less than Rs.2,000 (about U.S. $40), a single worker would spend 25 percent or more of their entire income on daily round trip bus fare. For those with incomes much less than Rs.2,000, the already low bus fare is prohibitively expensive.[25]

One market response, at the bottom of the service scale, is privately operated, indigenously designed autorickshaws and four-wheeled vehicles (sometimes referred to as jeeps) with 8 to 12 seats. These vehicles comprise an estimated 3 percent of the total vehicle fleet.[26] They operate without a schedule and sometimes without a fixed route. They must register with the Transport Authority, which requires meters to measure distance and fares, but many are known to evade these requirements. The vehicles are generally highly polluting, inefficient, and noisy. They do not adhere to safety or emission standards and very little effort has been made to improve them. The government of Delhi recently issued restrictions on the age of these vehicles, but enforcement is spotty.[27]

An upper end market response is chartered buses, mentioned above. These private buses provide point-to-point service to individual subscribers, schools, and companies and are playing an expanding role in Delhi.[28] They accounted for 4 percent of total bus trips in 1982, increasing to 11 percent in 1997. Users are in roughly the wealthiest 15 percent of the population. These buses are in many ways in direct competition with personal vehicles. Indeed, 43 percent of the charter bus commuters own motorized two-wheelers and 11 percent own cars. Charter buses are in many cases replacing the use, and perhaps even purchase, of private vehicles.

Despite these expanded transit services, overall mass transit continues to lose market share. Buses accounted for 57 percent of total passenger-kilometers in 1990, dropping to about 49 percent in 2000 (see Table 4). This drop is largely due to increased use of motorized personal vehicles (mostly two-wheelers but also cars) in upper-income households, and the expanding population of very poor immigrants who cannot afford to ride buses.

Table 4

Historical and Forecasted Travel Demand in Delhi, 1990-2020, motorized travel only (billion passenger-kilometers)

Year	Two-wheelers	Cars & jeeps	Autorickshaws	Taxis	Buses	Rail Transit	Total
1990	8.0	8.6	3.4	0.3	27.2	0.0	47.5
	(17%)	(18%)	(7%)	(<1%)	(57%)	(-)	(100%)
2000	14.8	29.0	3.5	0.4	46.8	0.0	94.4
	(16%)	(31%)	(4%)	(<1%)	(49%)	(-)	(100%)
2010	33.8	61.6	7.6	0.6	105.0	10.4	219.1
	(15%)	(28%)	(3%)	(<1%)	(48%)	(5%)	(100%)
2020	102.6	153.3	15.8	1.3	220.0	10.4	503.4
	(20%)	(30%)	(3%)	(<1%)	(44%)	(2%)	(100%)

Source: Bose and Nesamani, 2000.

Automobile Industry and Vehicle Sales

The national automobile sector has passed through three distinct phases:

- Tight government control and licensing until 1983,
- Partial liberalization in 1983 and 1984 that led to increased foreign investment and proliferation of two-wheelers and light commercial vehicles, and
- Sweeping economic reforms through the 1990s that sustained foreign investment and increased vehicle sales.

Through 1983, the industry was limited by strict controls on imports and foreign investment. The first multinational company to enter the Indian market was Suzuki, in collaboration with an Indian partner company, Maruti, in the mid-1980s. This event initiated a period of rapid growth in the industry. Suzuki and Maruti were granted a variety of concessions, including lower import and excise duties, on the condition that they steadily increase the local content of the vehicles. Liberalization of the economy in the early 1990s led to a further increase in domestic and foreign investment in the automobile sector. Table 3 shows the rapid growth in the vehicle population.

Car sales have been increasing about 10 percent per year since the mid-1970s, though with large fluctuations. This is considerably faster than population growth. The auto industry expects continued growth at that level into the future. Continued 10 percent growth is plausible if income and population continue expanding near their historic rates.[29] Greater availability of easy financing will also play a role. As the Indian economy synchronizes with the world, the current high interest rates (about 16 percent) are expected to drop and thereby encourage vehicle purchases. Evidence from other Indian cities and elsewhere indicates that car ownership in cities at Delhi's income level increases somewhat faster than per capita income.[30]

Cars in India are small. Most have engine sizes of around one liter (ranging typically from 800 cc to 1.4 liters, compared to typical engine sizes of 2-5 liters in the United States). They cost $5,000 to $12,500. A small number of “luxury” cars, including a 1.7-liter Opel Astra and 2.4-liter Mercedes Benz are also available at higher prices.

Even faster growth in vehicle ownership is possible if transit services continue to erode, major infrastructure investments in rail transit and busways are not forthcoming, and income grows more rapidly. A large number of carless households already owning motorized two-wheelers are poised to begin purchasing cars. Motorized two-wheeler sales may also continue a pattern of high growth, especially in the rural fringes of Delhi, where two-wheelers are well suited to the poorer roads and are valued for their ease of transporting small quantities of goods. Conversely, vehicle sales could slow if chartered bus services become more common, the proposed rail system and busways continue to expand, and taxes and other incentives are established to restrain vehicle growth.

Freight

Freight movement is a highly decentralized business activity; consequently, data are sparse and understanding of freight activity is poor outside each industry. It is clear that intra-city movement of freight is almost entirely by truck and increasing at a rapid rate. Freight movement is forecast to increase fivefold from 2000 to 2020 (see Table 5), and the number of freight vehicles more than four times (see Table 3).

Table 5

Historical and Forecasted Freight Movements within Delhi, 1990-2020 (billion tonne-kilometers)

Year	Freight Movement
1990	0.52
2000	0.66
2010	1.73
2020	3.62

Source: Bose and Nesamani 2000.

Goods are carried by various vehicles, ranging from small three-wheelers for local deliveries to large tractor trailers. The authors estimate that freight vehicles constitute only about 3 percent of all vehicles. However, freight vehicles outnumber buses five to one, and use about 11 percent of the transport energy consumed in Delhi.

About one-fourth of total goods movements in Delhi are believed to be trans-shipments that originate elsewhere and pass through the city. Trans-shipments are mostly by rail.

Many changes are occurring in urban freight operations. Most freight from outside Delhi enters by rail on the nation's extensive network, but trucks are quickly increasing their share of freight transport into the city. The National Planning Commission estimates freight traffic by road will increase from 807 billion tonne-kilometers in 1997 to between 1,276 and 1,700 tonne-kilometers by 2002.[31] The transport of most grains, fruits, and vegetables has shifted to trucks and other road vehicles. These shifts from rail to truck imply more trucks passing through the city. The Delhi government is considering a proposal to build a ring road around the city to divert these trucks away from the city. Renewed efforts to enhance the decaying rail system could stem this shift to trucks.

Because demand for freight is growing faster than the economy and because trucks consume far more energy per tonne-kilometer than rail, the net effect is rapid increases in energy use and greenhouse gases from the freight transport sector. Unfortunately, there has been little research on how to enhance the delivery of goods in an economically and environmentally attractive manner.

III. Policies and Strategies

Personal vehicles provide unmatched benefits – not only faster door-to-door service, but also greater comfort, convenience, and security. Personal vehicles are also seen as a sign of wealth and status. In Delhi, as elsewhere, these attributes translate into increasing numbers of vehicles on the road.

Motorized personal vehicles cause far greater environmental impacts, and require far more road infrastructure, than collective and non-motorized travel modes. The switch from two-wheelers to conventional cars triggers a sharp increase in energy use, pollution, road space demand, and GHG emissions. The challenge for public authorities, therefore, is twofold: enhance the attractiveness of collective and non-motorized modes, and reduce the impact of personal vehicles.

A. Baseline Forecasts of Vehicles and Travel

Bose and Nesamani constructed a regression model[32] to forecast future increases in vehicle ownership and travel by different modes.[33] They based their model on government projections that population would increase 3.2 percent per year from 2000 to 2010 and 1.6 percent the following ten years, and that per capita income would grow 4.3 percent per year from 2000 to 2010 and 5.4 percent the following decade.[34]

Based on these population and income projections and on travel patterns of the past two decades, the model predicts that total motorized passenger travel would increase from 94 billion passenger-kilometers in 2000 to 503 billion in 2020 (see Table 4). This represents an 8.7 percent annual increase — a somewhat faster rate than the 7 percent rate experienced in the 1990s.[35] The major factors behind this rapid increase in travel are higher levels of per capita income, more people, overall economic growth, greater access to personal vehicles, and greater distances traveled per vehicle.

Accounting for the likely effects of the Supreme Court directives, planned rapid transit investments, and vehicle usage patterns, Bose and Nesamani converted projections of travel and vehicles into specific forecasts for each travel mode based on surveys of distance traveled by vehicle type and countrywide data on vehicle occupancy.[36]

Freight travel increased 2.4 percent per year from 1990 to 2000, but is forecast to grow at a much faster rate of 8.9 percent from 2000 to 2020 (see Table 5), roughly 4 percent per year faster than regional economic growth.

B. Vehicle Technology

Three waves of technological innovations are sweeping through the international automotive industry. While these innovations may take hold in Delhi and throughout India later than in OECD countries, they will in the long term play a role in determining transportation sector emissions of greenhouse gases and conventional air pollutants.

Two waves of technological innovations are of an incremental nature. The first wave is aimed at reducing air pollutant emissions from conventional internal combustion engines. These changes are coming to India in response to the country's adoption of more stringent emission standards and greater foreign investment. They include improvements in combustion processes, treatment of exhaust gases (i.e., with catalytic converters), and use of cleaner burning fuels. However, improved engine combustion and exhaust gas treatment will have virtually no effect on energy efficiency or GHG emissions. The use of natural gas, alcohol fuels, and propane in gasoline engines will provide reductions of about 20 to 30 percent in GHG emissions, but their use in diesel engines will not reduce GHG emissions and may even increase them. Efforts are underway by auto manufacturers in India to introduce improved technologies for engines running on alternative fuels. But additional incentives and fuel supply infrastructure are needed before substantial shifts will occur in all areas other than buses.

A second wave of innovation is aimed at increasing the energy efficiency of conventional engines. Vehicles operating today in India are not energy efficient by international standards. If the Indian auto industry were to adopt technology already available in the international market, energy efficiency would be substantially improved. The average fuel economy for new, small cars sold today in India is over 30 miles per gallon (mpg) (8 liters/100 kilometers). Small two-stroke motorcycles achieve over 80 mpg (3 liters/100 km) and buses over 7 mpg (34 liters/100 km). These impressive fuel economy numbers are not the result of state-of-the-art technology, but lower power and smaller size. With more advanced technology, considerable improvements are possible. Automakers are continuing to increase vehicle efficiency in response to existing fuel economy standards in Japan and the United States, voluntary CO_2 standards in Europe, and high fuel prices in most countries. They are fighting to extend the life of internal combustion engine technology through incremental improvements.

A third wave of innovations is more radical. It involves a transition away from internal combustion engines to electric drive propulsion technology. These innovations have the potential for the greatest reductions in GHG emissions. The use of electric-drive systems — fuel cells, batteries, and hybrid electric systems — would improve energy efficiencies by 50 percent or more, with much less pollution. These technologies are still novel and expensive, but costs are dropping quickly and could be cost-competitive with conventional technologies within one to two decades. Battery electric vehicles made in India with U.S. collaboration are expected to be marketed in India in 2001. Several international automakers are likely to sell small, mass-produced, two-seat battery electric vehicles in many countries by 2002. Competitively priced hybrid electric vehicles became available internationally from Honda and Toyota in 2000. Other automakers have announced plans for mass production of hybrid vehicles by 2004. Fuel cell buses will be available from DaimlerChrysler in 2002, though at high prices.

Table 6 presents estimates of energy consumption and GHG emissions for each travel mode and technology. These estimates assume adoption of existing and state-of-the-art efficiency innovations and small increases in fuel prices over time. If fuel prices were to be substantially higher than at present or the government were to impose fuel economy standards, then fuel consumption (and GHG emissions) would be lower.

The fuel economy and GHG emission factors presented in Table 6 are based on typical vehicles likely to be operating through 2020 in Delhi.[37] The GHG emission factors are CO_2-equivalent measures (see Appendix). They include the principal greenhouse gases and emissions from the full fuel cycle (from “well to wheels”).[38]

Table 6

Greenhouse Gas Emissions for Vehicles and Fuels in Delhi, CO_2-equivalent grams/vehicle-kilometer

	2000		2020	
	Fuel (km/liter)	GHG (g/vehicle-km)	Fuel (km/liter)	GHG (g/vehicle-km)
Gasoline Motor Scooter (2-stroke)	38.4	118	42.4	86
Gasoline Motor Scooter (4-stroke)	53.8	70	39.9	52
Electric Motor Scooter	N/A	51*	N/A	48*
Gasoline Minicar	24.9	140	28.7	119
Gasoline Car	13.6	293	14.5	265
Diesel Car	20.0	172	21.3	162
CNG Car	N/A	234	N/A	198
Electric Car	N/A	182*	N/A	155*
Diesel Bus	3.27	963	3.36	975
CNG Bus	N/A	1050	N/A	970
Fuel Cell Bus (methanol)	N/A	N/A	N/A	686

*The average electricity generating mix for India is used for calculating GHG emissions for battery electric vehicles as follows: 70 percent coal, 15 percent hydroelectric, 10 percent natural gas, and 5 percent other (mostly petroleum and biomass).

Source: Fuel consumption estimates are adjusted from Bose and Nesamani (2000) and GHG calculations are by M.A. Delucchi (see appendix).

Note: Diesel vehicles have better fuel economy than gasoline vehicles because diesel engines are more efficient and diesel fuel contains more energy per liter.

C. Rapid Transit

To reduce traffic congestion and air pollution, the Delhi and national governments are building an integrated multi-modal rapid transit system known as MRTS. This system includes 198.5 kilometers of electrified rail lines and is estimated to cost 150 billion rupees (U.S. $4 billion) at 1996 prices.[39] The first phase calls for 55 kilometers of rail and busways by 2005, one-fifth of them underground with projected passenger loads of 3 million passengers per day. The plan includes 115 new feeder bus routes on existing roads. The second phase is scheduled for completion in 2021 and is forecast to carry 22 million passengers per day.

Local and national governments are making only a small financial commitment. Fifty-six percent of financing for the first phase comes from a Japanese bank, while the national government and regional governments will contribute 15 percent each, plus revenue from land development along the corridors and tax breaks that provide incentives to suppliers to participate. Additional concessions and incentives being considered for the first and later phases include deferral of debt payments, exemptions from income, capital gains, and property taxes, and exemptions from customs duties for equipment and rolling stock. Full deployment of the MRTS system is not assured.

D. Road Infrastructure Enhancements

Roads can be redesigned with separate dedicated lanes for non-motorized vehicles and buses. This would increase speeds for all vehicles, especially buses, improve safety, and likely enhance transport capacity. A detailed study found that many roads could be altered within the existing right of way to provide dedicated lanes for bicycles and non-motorized cycle rickshaws.[40] The study found that a bicycle lane would increase vehicle capacity by 19 to 23 percent on typical arterials, and that a dedicated bus lane would lead to capacity improvements of 56 to 73 percent with road capacity, including all modes, increasing from 23,000 to 45,000 passengers per hour.[41]

A successful example of separating motorized and non-motorized traffic is the Indo-Japanese friendship bridge over the Yamuna River connecting the Ring Road to East Delhi. The original bridge design successfully segregated vehicles. Attempts to modify existing roads have been less successful. Attempts to create dedicated lanes for non-motorized vehicles have increased vehicle speeds, but have also increased congestion when vehicles break down and create safety hazards for non-motorized traffic.

Dedicated lanes could have profound effects. They would expand existing road space capacity and benefit the most environmentally benign transportation modes. The ultimate effect would be to attract ridership away from motorized personal vehicles. This would result in less need for expensive road infrastructure, better use of existing roadway capacity, and less environmental impact.

E. Restraining Demand and Improving Supply

There are many ways to restrain the rapid growth in vehicle use in Delhi. Experience worldwide has shown that an approach aimed at both demand and supply is most effective. The demand approach discourages the use of personal vehicles and encourages the use of alternative travel modes. This can be accomplished by increasing the cost of driving to reflect the large infrastructure costs of accommodating vehicles and the costs they impose on the environment. Increased parking fees, fuel taxes, registration fees, and greater incentives for carpooling are options.

The supply approach is to enhance the supply and quality of infrastructure for modes other than cars. This includes building and maintaining sidewalks, bicycle lanes, and rail and bus infrastructure. Traffic management techniques such as downtown pedestrian zones, dedicated bus lanes, and traffic signals that favor buses could also be successful. Because earlier attempts at making downtown areas more pedestrian friendly have failed, future attempts would likely require education programs such as outreach to downtown shop owners.

In practice, many of these policies and strategies are difficult to implement. Difficulties can arise from limited data and information, weak administrative and enforcement mechanisms, limited financial and human resources, and political opposition. Creativity is needed in fashioning effective initiatives.

One suggestion for mitigating opposition to new taxes and fees is a polluter-pays system that rewards environmentally friendly technologies and fuels while imposing charges on more polluting vehicles. But even this intuitively attractive policy instrument faces difficulties. For instance, owners of cars and motorized two-wheelers pay a one-time registration fee in Delhi when the vehicle is newly purchased, and never again. This practice makes it very difficult to monitor vehicles, and almost impossible to levy progressive pollution taxes or other usage fees. It may therefore be desirable for this and other reasons to institute an annual registration process.

Another means of reducing demand is to remove government incentives that support the use of company cars. Most senior officials in government and private corporations are provided cars for private use, often including a chauffeur. Given traffic conditions in Delhi, this is a valued fringe benefit, but it has three deleterious effects. First, it results in much more vehicle usage than even a personal car, since it essentially has zero cost to the user. (Even gasoline is free). Second, it prevents leaders from experiencing first-hand the troubles of the public transportation system. Third, and of greatest concern, it has cascading effects through the used car market, since these large and inefficient cars are usually re-sold while still rather new. Good public policy would at least eliminate taxes and other incentives that encourage the purchase and use of company cars.

Mass transit is often considered one of the best low-polluting alternatives to cars and motorized two-wheelers, and Delhi's investment in the multi-modal transit system of rail and busways enjoys strong support from policy-makers. However, the World Bank and many transportation experts remain skeptical of the cost-effectiveness of rail transit projects in low-income countries and regions with low population densities. One respected report concludes the following:

> "[C]ontrary to expectations, [heavy rail] metros do not appear to reduce traffic congestion. The passengers are mostly captured from the buses, but the reduction in bus traffic is not proportional and represents only a small part of the total traffic. The relief to traffic congestion is short lived because private traffic rapidly grows to utilize the released road capacity. There has been very little shift from car use... In most cities in most developing countries, it will not be possible to justify metros rationally... In these cities we have sought to direct attention to their priorities and actions to improve the bus and paratransit system which will result in achievable improvements."[42]

The lesson for Delhi is that rail transit investments are not a guaranteed success. They could be a wise investment given the large population and relatively high population density if accompanied by supporting policies. These policies would assure good connections with other transit services, complementary land use development near stations, fares that divert riders from personal vehicles but also accommodate poorer people, and financing strategies that minimize the public tax burden.

Even initiatives that appear attractive are not always so. There is a fundamental need for strong institutions that plan, finance, and implement ambitious initiatives that improve the efficiency of the transport system. These initiatives include dedicated lanes for bicycles and high occupancy vehicles, and some mix of regulatory and market instruments that restrain the use of private vehicles and enhance collective modes. At present, strong institutions and strategic plans are lacking.

IV. Scenarios for the Future

Delhi is expanding rapidly. How will the city evolve, and what will be the implications for GHG emissions? A definitive response is not yet possible. Careful research on policies that are socially, economically, and environmentally desirable and attainable is needed. Much more information needs to be gathered on economic growth, technological improvement, and travel and vehicle purchase behavior.

Scenarios are a commonly employed technique for dealing with complexity and uncertainty in forecasting. Ideally, one generates relevant information using credible research methods and objectively analyzes it with alternative scenarios of the future. The scenarios reflect believable, but often quite contrary, descriptions of the prospective development pathways. This approach can provide a useful context for the development of "no regrets" public policy and business strategy.

To generate scenarios, the authors interviewed Indian transportation experts and political leaders, analyzed historical data, and examined various options and strategies. From this research, the authors developed two visions of the future: a high GHG emissions scenario, and a low GHG emissions scenario.

A. High Greenhouse Gas Emissions Scenario

The high GHG emissions scenario is an extrapolation of observable and emerging trends. No major new policy initiatives or public investments are incorporated. Past economic trends, rates of technological change, and behavioral patterns are assumed to continue into the future. A gradual shift toward personal vehicle travel continues. Combined with other factors, including an expansive road network, this shift results in a fourfold increase in GHG emissions from the transport sector. However, the increase could be even greater. In both scenarios, the same government forecasts of population and income were used. With faster economic and/or population growth, the quantity of transport-related GHG emissions would be proportionately higher.

Government plays a passive role in this scenario. There is a gradual introduction of the proposed rapid transit initiative, but progress is slower than anticipated and ridership is less than projected.

Compliance with past Supreme Court directives is also delayed. Bus transit increases its share of travel somewhat from 2000 to 2010, mostly in response to Supreme Court directives to increase the bus fleet and bus service. Bus transit then drops sharply to a combined bus-rail market share of 39 percent in 2020. Cars increase market share from 30 percent of travel in 2000 to 34 percent in 2020, though 8 percent are minicars. (Minicars weigh less than about one half tonne and have engines smaller than 660 cc.) Scooter and motorcycle use increases from 16 to 24 percent. As Table 7 indicates, many newer cars and buses operate on natural gas and diesel fuel.

Table 7

Key Parameters for Scenarios

	2000	2020	
		Low	High
Passengers Per Vehicle			
Passenger car	2.5	2.8	2.5
Scooter	1.3	1.5	1.3
Minicar	1.5	1.8	1.5
Bicycle	1.0	1.0	1.0
Bus	36	40	36
Passenger Modal Split (percent)			
Gasoline cars	21	2	12
Diesel cars	8	7	8
CNG cars	1	10	6
Minicars (gasoline & electric)	0	5	8
Taxis	<1	<1	<1
3-wheelers	4	3	3
2-stroke scooters/motorcycles	14	0	6
4-stroke scooters/motorcycles	2	20	18
Diesel bus	47	13	20
CNG bus	2	12	18
Fuel Cell bus	0	24	0
Rail transit	0	4	1
	100	100	100
Total Travel (billion passenger-kilometers)			
Motorized	94	400	503
Non-motorized	9	40	25

The elements of this business-as-usual scenario closely follow the forecasts developed by Bose and Nesamani, discussed in Section III as "baseline forecasts." Total motorized passenger travel increases over fivefold from 94 billion passenger-kilometers in 2000 to 503 billion passenger-kilometers in 2020 (see Table 4). Non-motorized travel also increases, but at a slower rate, from 9 to 25 billion passenger-kilometers. The most important parameters used in generating the scenario calculations appear in Tables 6 and 7.

Dr. Mark Delucchi of the University of California, Davis converted the modal split, load factor, and energy use factors into GHG estimates. The appendix describes Delucchi's calculations of fuel cycle CO_2-equivalent measures for each scenario. He adapted for Delhi a detailed model developed earlier for OECD countries that is widely used by governments and companies in those countries.

In summary, the high emissions scenario is one of rapid expansion in vehicles, energy use, and GHG emissions. It approximates a business-as-usual trajectory, not necessarily an upper bound. GHG emissions could grow even faster if per capita income grows faster than 4.3 and 5.4 percent and if population grows faster than 3.2 and 1.6 percent during the next two decades.

This scenario, though it has rapid growth in vehicle use and greenhouse gases, would not necessarily lead to economic or environmental disasters in the next 10-15 years. Supreme Court directives could control air pollution through regulations and technical solutions, with most of the cost borne by vehicle manufacturers. These pollution control costs would be modest since the technologies are developed elsewhere and widely disseminated. This pollution control element of the scenario is plausible, even likely.

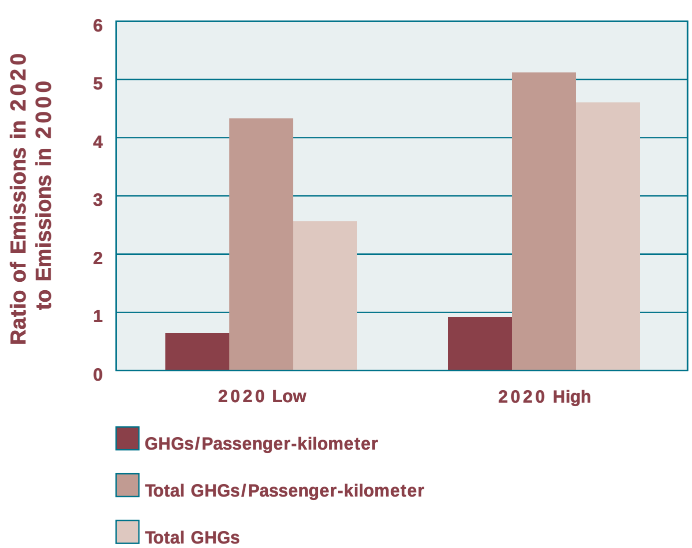
Other elements are more problematic and troubling. Traffic congestion would increase as more people travel in personal vehicles. Deterioration of traffic conditions could continue for some time since Delhi benefits from an expansive road system. Small fixes such as improved traffic signals and widening of bottlenecked roads are possible and would help defer major investments and a sense of urgency. With more people driving, the political constituency for better roads would strengthen, and the constituency for mass transit would weaken. At some point, traffic congestion would become stifling, and the disenfranchisement of the very poor intolerable. However, this might not occur for two decades. By 2020, the economic and environmental consequences of this scenario would likely be severe: high levels of traffic congestion would require large investments in road infrastructure, requiring more land, causing more noise, and generating more greenhouse gases. In summary, this scenario is plausible. The eventual outcome, though, is worrisome, even catastrophic — economically, environmentally, and socially.

B. Low Greenhouse Gas Emissions Scenario

The low GHG emissions scenario is premised on strong local leadership that restrains vehicle use and creates a transportation system that is economically, environmentally, and socially sustainable for the long term. This scenario is possible if ambitious initiatives are mounted in the near future to reduce vehicle and energy use. It results in substantial increases in greenhouse gases — about a doubling from 2000 to 2020 — but only about half that generated in the business-as-usual scenario (see Figure 2).

Figure 2

GHG Emissions from Passenger Transport in Delhi (2020)



The low emissions scenario entails a shift away from current trends. It requires aggressive leadership and strong support from a frustrated populace. In this scenario, the motivation for change comes from worsening air quality and a realization that Delhi is too poor to divert a large share of its resources to a transportation system that does not serve the needs of a large share of the population. Local leaders and institutions embrace a series of reforms aimed at enhancing transit services, managing land use growth, restraining car and energy use, and accelerating the use of leapfrog technologies and concepts. It is a future of creativity, urban organization, efficient growth, and improved quality of life.

Steps are taken to improve mass transit to discourage the purchase and use of personal vehicles. The planned busways and rail transit lines are completed on time in 2020-2021. Importantly, local government institutions work together to link bus service to the new rail lines and busways. They also direct dense commercial and residential activities to areas immediately adjacent to rail stations.

Private charter bus services are strengthened and expanded. Incentives are provided to private companies to offer these services, and to travelers to use them. Traffic managers provide special dedicated lanes for private and public buses to increase their speed relative to personal vehicles. Ridership on high quality charter bus services increases from 12 percent of total bus ridership in 2000 to 18 percent in 2020, and continues to increase thereafter.

Use of non-motorized vehicles is encouraged as well, mostly to serve the very poor who cannot afford even low-cost mass transit. Subsidies for bicycle use also slow the purchase and use of motorized vehicles by the more affluent. A network of protected lanes for bicycle use is provided, often separated from motorized vehicle roadways, to reduce congestion and increase the safety of bicycle riders.[43]

Innovative transport services are created to provide personalized transport services at less cost and greater system efficiency than cars. Ideally, they are linked to conventional transit services. One important component is car sharing, practiced to some extent now in Europe.[44] In its most simple form, a group of neighbors join together to form a "club" in which they each have rights to use a pool of vehicles located at one or more sites in their neighborhood. In more elaborate versions that are assumed (in the low GHG scenario) to proliferate through Delhi, thousands of vehicles are scattered in clusters throughout the city, at apartment buildings, shopping and employment centers, and rail stations. Users pay a monthly fee plus a usage fee whenever they drive these vehicles. Since these are largely short term "rentals," the vehicles tend to be used for several trips by several people each day. Initially, transactions are routinized through sign-up sheets and telephone reservations, but electronic reservations and billing systems are eventually instituted.

Car-sharing services respond to the desire for personal transport in a manner that is attractive from a societal perspective. Travelers gain access to vehicles when they want them — for special errands (e.g., to deliver furniture), and social, business, and work trips — without having to purchase them. The immediate benefit of car sharing is access to personal transport at reduced costs. Importantly, participants do not become wedded to the use of a personal vehicle. It is widely observed around the world that once a person buys a personal vehicle, his or her use of mass transit falls significantly. Many car owners no longer consider alternatives to their vehicle, even when mass transit is easily accessible and convenient. Car sharing also reduces demand for parking since the vehicles do not stay in one location very long. Car sharing may be the first step in creating other non-conventional personalized transport services.

Incentives and disincentives are provided to restrain the purchase and use of personal vehicles. An effort is made to assure that vehicle owners pay their fair share of building and maintaining roads. These measures include an annual registration fee tied to the size of the vehicle and variable vehicle purchase taxes, also based on vehicle size and engine efficiency.

The use of cleaner burning natural gas fuels by light duty vehicles is accelerated. All taxis and one-fourth of all personal cars are powered by CNG by 2005. By 2020, half of all cars run on CNG. All scooters switch from two-stroke to efficient four-stroke engines, and three-wheelers gradually shift to propane use. After 2005, fuel cell buses begin penetrating the fleet. By 2020, they account for half of all buses.

The net effect of these initiatives is greater access to higher quality mass transit for most people at reduced cost to individuals and society, with less environmental impact. As Table 7 indicates, ridership for buses and rail increases from 49 percent of all passenger travel (measured as passenger-kilometers) in 2000 to 53 percent in 2020, and would continue increasing thereafter. Meanwhile, car travel drops from 30 percent of all motorized travel to 24 percent (of which 5 percent are more efficient minicars) in 2020. Total motorized travel increases from 94 to 400 billion passenger-kilometers, 20 percent less than the business-as-usual scenario. Non-motorized travel increases from 9 to 40 billion passenger-kilometers, more than 50 percent higher than the business-as-usual scenario.

By 2020, there is a sharp reduction in air pollution — primarily the result of new emission standards, abandonment of two-stroke engines, and use of natural gas fuels and fuel cell buses. The story for greenhouse gases is also positive, compared to the business-as-usual scenario. But even if all these changes are incorporated, energy use and GHG emissions continue to increase at a rapid rate. As indicated above, GHG emissions more than double by 2020 — equivalent to a 40 percent increase per capita.

This scenario is plausible if ambitious measures are adopted. However, unless the institutional problems for decision making and accountability are resolved, implementation of these measure is unlikely.

V. Conclusion

Delhi faces the same transportation challenges as other megacities of the developing world: how to balance limited resources with the strong desire for personal transport. Already, all but the poorest households in Delhi own a motor vehicle, usually a two-wheeler. This fact illustrates the sea change underway in many Asian cities, with Delhi among those cities at the vanguard. Past studies have focused on cars. The widespread availability of low-cost motorized two-wheelers has created a new reality: The desire for personal transport can now be accommodated at even very low income levels.

Strong initiatives aimed at restraining vehicle and energy use (and therefore greenhouse gases) have been scarce in Delhi. The Supreme Court has issued directives to reduce air pollution — premised on hazards to the health of Delhi residents — that are part of any well-conceived strategy to enhance the quality of a transport system. But these actions only address a small slice of the problem. In the case of pollution reduction, most actions are technical fixes with only minimal effect on travel behavior. Delhi officials need to place much more emphasis on managing demand and encouraging alternatives to personal vehicle use. This requires greater cooperation between governments and a stronger commitment by the entire community. Current road infrastructure investments enhance the attractiveness of cars over walking, bicycling, and public transportation.

Only the most aggressive strategies can slow the increase in GHG emissions. In Delhi, transport-related GHG emissions will at least double in the next two decades whether or not policymakers adopt aggressive transportation measures. However, without assertive leadership, emissions will easily quadruple. The principal lessons, therefore, are the following:

- Rapid growth in GHG emissions in Delhi and other expanding megacities of the developing world is unavoidable in the foreseeable future,
- The gap between high and low emissions trajectories is vast, and
- The opportunity is at hand to reduce forecasted GHG emissions in Delhi by 50 percent.

Transportation Objectives

Transportation sector objectives must consider both personal aspirations and societal impacts. Cost, convenience, safety, and the environment should play a central role in defining these objectives. The overall thrust must be threefold: (1) enhance the quality and availability of mass transit services; (2) impose the full social cost on vehicle users; and (3) facilitate the availability of high quality transit, para-transit, and quasi-personal services to those who might otherwise opt to buy and use personal vehicles.

Specific objectives include the following:

Provide attractive transportation options. Energy-efficient automobiles, motorized two-wheelers, and public and private transit modes should be available. Transportation services should be enhanced by improved coordination and integration.

Prioritize transportation modes that address the needs of most residents and minimize negative societal impacts. Energy-efficient buses and motorized two-wheelers should be at the top of the list.

Balance the demand for personal automobiles with management of their impacts. While cars are a desirable option from the perspective of the individual, personal automobile use creates significant societal impacts such as traffic congestion, pollution, and the need to dedicate land to roads and parking. Government agencies need to increase their capacity to achieve this balance.

Improve options for individuals.

- Automobiles, including company cars, should be fuel-efficient and come in a range of sizes, including minicars,
- All scooters and motorcycles should have efficient four-stroke engines,
- Charter bus services should be expanded,
- Public buses should offer safety features to reduce overcrowding and ease of access. Clearly marked stops should be located at transfer points to other modes of transportation. Buses should have dedicated lanes to reduce travel time and prevent congestion, and
- Bicyclists and pedestrians should have designated lanes and crosswalks. Right-of-way laws should be enforced.

Policy Options

The policy options available to transportation authorities to meet these objectives include the following:

Regulate traffic levels to reduce congestion. Authorities could limit vehicle entry into neighborhoods and city centers through permits or fees, control parking with fees, impose road tolls and fuel taxes to raise the cost of driving to reflect actual costs to society, and designate lanes for non-motorized traffic and high occupancy vehicles.

Use of information and communication technologies. These technologies could facilitate more efficient forms of transportation and vehicle use that leapfrog today's car-centric patterns.

Improve coordination among transportation authorities. Overlapping responsibilities and disjointed decision-making complicate coordinating responses to transportation issues. The Supreme Court could be part of a framework for transportation-related decision-making to ensure that environmental impacts are considered.

Raise public awareness. Campaigns to educate the public about the impacts of transportation choices will encourage support for new policies to improve services.

Require technological improvements. Improved fuel economy of all motorized vehicles, especially scooters and cars, will reduce the environmental impact of transportation on society. Accelerating introduction of cleaner-burning natural gas fuels into cars and light trucks and speeding deployment of minicars and leapfrog vehicle technologies such as fuel cells would improve the long-term performance of Delhi's transportation system.

Emphasize mass transit and land use control. Maximize the value of new investments in rail and busway infrastructure. Link rail and bus service. Direct dense commercial and residential activities to areas immediately adjacent to the rail and bus stations.

Encourage non-motorized vehicles. Policies that support bicycle use will help serve the needs of the very poor, and will slow the purchase of motorized vehicles by the more affluent. Bicycle use could be encouraged by subsidizing bicycle purchases and providing a network of protected lanes for bicycle use.

Run pilot projects to test experimental new programs, such as car sharing. Car sharing is a new idea not only to Delhi, but to the rest of the world as well. Customizing programs such as car sharing to the needs of Delhi residents would help them succeed.

A wide variety of policy instruments and investments could be used to support these initiatives. In short, there are many opportunities for improvement.

Reducing Greenhouse Gas Emissions

Because of more pressing needs to reduce poverty and improve public health, Delhi and other cities of the developing world are unlikely to devote many resources to reducing GHG emissions. Fortuitously, GHG reduction strategies overlap with many strategies to create an economically efficient and socially desirable transportation system. Sound transportation policies and investments usually translate into reduced GHG emissions.

Delhi need not choose between social, economic, and environmental goals when designing its transportation policies. Many strategies serve all these goals. But as time passes, problems worsen and action becomes more urgent. Delaying such action is costly; every day the cost of recovering from inaction is ever higher.

Glossary

Autorickshaw: A motorized three-wheeler that transports paying passengers or freight.

Busway: One or more lanes dedicated to the use of buses.

Four-stroke engine: Almost all cars and light trucks and some motorized two-wheelers use four-stroke engines. In these engines, fuel and air enters the cylinder, is compressed by the piston, ignited by a spark from the spark plug (the power stroke), and then exhaust gases are pushed out. These engines are generally more expensive than two-stroke engines, but more energy efficient and cleaner burning.

Load factor: Average number of occupants in a vehicle, sometimes expressed as a fraction of capacity, sometimes as number of people. Also used for freight vehicles, expressed as fraction of capacity or number of tons.

Metro: Short for "metropolitan railway." Passenger rail transit system with dedicated right-of-way that often is partly underground and within a metropolitan area. Some cities have other names. San Francisco uses "BART," New York uses "subway," and London uses "underground."

Minicar: Car designed for urban use, with engine capacity of about 660 cc or less.

Modal split: The shares of total passenger or freight travel on different kinds of transportation, usually measured as percentages or fractions.

Paratransit: Transit service provided by vehicles, usually smaller than full transit buses, that carry passengers on routes or schedules that are not fixed.

Passenger-kilometer: One passenger moving one kilometer.

Rickshaw: A three-wheeled vehicle with covered sides used for commercial purposes. Most carry passengers, but occasionally freight. Cycle rickshaws are propelled by human power, like bicycles; autorickshaws are motorized.

Rupee: Indian currency, abbreviated as Rs. In 2000, the exchange rate was Rs.46.75 per U.S. dollar.

Scooter: Generally, these are motorized two-wheelers that tend to have less power and speed and smaller wheels than motorcycles. In Delhi, most motorcycles are so small that scooters and motorcycles are roughly equivalent in size and performance.

Two-stroke engine: These internal combustion engines burn a mixture of gasoline and oil. These engines are used mostly in small, inexpensive scooters and motorcycles. They are generally simpler and less expensive than four-stroke engines, but less energy efficient and more polluting, especially when fuels are not pre-mixed correctly and kerosene or other inexpensive substitutes are used.

Two-wheeler: Motorized two-wheelers include mopeds, scooters, and motorcycles.

Vehicle-kilometer: One vehicle moving one kilometer.

Appendix

Research Methods

This report was a collaboration principally between researchers at the University of California, Davis and Tata Energy Research Institute (TERI) in New Delhi. Additional input was received from Dr. Geetam Tiwari, Indian Institute of Technology-Delhi (IITD) and Dr. Lee Schipper of the International Energy Agency. The report is based on an extensive review of the literature, a series of interviews in December 1999 with Indian experts and leaders in Delhi, further review of reports and other materials identified during interviews, and data analyses conducted by Dr.Bose of TERI and Dr. Mark Delucchi of the Institute of Transportation Studies at the University of California, Davis. Dr. Bose generated the first set of travel and energy assumptions and parameters for the scenarios. After extensive consultation among the authors, and with others, the final set of parameters was specified. These numeric measures were converted by Dr. Delucchi into quantitative greenhouse gas emissions estimates for the two scenarios.

Interviewees

Mr. P.K. Agarwal — Executive Director, Oil Coordination Committee
Dr. Y. P. Anand — Director of the National Gandhi Museum, New Delhi
Mr. B. Bhanot — Director, Automotive Research Association of India
Mr. K. R. Bhati — Additional Secretary, Ministry of Surface Transport
Mr. Dilip Biswas — Chairman, Central Pollution Control Board
Mr. Kaushik Deb — Research Associate, TERI, New Delhi
Mr. Atanu Ganguli — Executive Officer, Society of Indian Automobile Manufacturers, New Delhi
Mr. D. P. Gupta — Director (Research), Asian Institute of Transport Development, New Delhi
Mr. Ranjender Gupta — Former Transport Minister, Delhi
Dr. Karl Hausker — Visiting Senior Fellow, TERI, New Delhi
Mr. A. S. Lakra — Director, Engineering Department, Association of State Road Transport Undertakings
Prof. Dinesh Mohan — Indian Institute of Technology, Delhi
Mr. P. Panda — Assistant General Manager, Engineering Division, Maruti Udyog Ltd., Gurgaon, India
Dr. G.K. Pandey — Director, Ministry of the Environment
Dr. Krishna Paul — General Manager, Rail India Technical and Economic Services, New Delhi
Mr. Ashok Pradhan— Principal Secretary, Transport Commissioner, Delhi Government
Mr. B.N. Puri — Planning Commission, Delhi
Mr. I.V. Rao, General Manager (R&D), Maruti Udyog Ltd., Gurgaon, India
Dr. T. S. Reddy — Head, Traffic & Transportation Division, Central Road Research Institute, Delhi
Mr. S. Reghunathan — Principal Secretary to the Chief Minister, Government of Delhi
Ms. Anju Sharma — Center for Science and Environment, New Delhi

Prof. A. K. Sharma — Head, Department of Transport Planning, School of Planning and Architecture

Mr. Virendra Singh — Former Transport Commissioner, Delhi Government

Mr. K.C. Sivaramakrishnan — Center for Policy Research, New Delhi

Mr. K. L. Thapar — Director, Asian Institute of Transport Development, New Delhi

Mr. K. L. Thukral — Senior Fellow, Asian Institute of Transport Development, New Delhi

Ms. Pamela Tikku — Executive Officer, Society of Indian Automobile Manufacturers, New Delhi

Overview of Lifecycle Energy Use and Emissions Model (LEM)

There are many ways to produce and use energy, and many sources of emissions in an energy-production-and-use pathway. Several kinds of greenhouse gases are also emitted at each source. An evaluation of GHG emissions associated with transportation activities must be broad, detailed, and systematic. It must encompass the full "lifecycle" emissions of a particular technology or policy, and include all of the relevant pollutants and their effects. To this end, Dr. Mark Delucchi has developed a detailed, comprehensive model of lifecycle emissions of air pollutants and greenhouse gases from various transportation modes. Many governments and companies use this model. The model was updated and adapted for Delhi, India for this report by Dr. Delucchi.

The Lifecycle Energy Use and Emissions Model (LEM) considers motorized two-wheelers, cars, buses, and trucks operating on a range of fuel types and propulsion technologies; bicycles; heavy-rail and light-rail transit; ships; and freight railroads. The LEM estimates energy use GHG emissions, and air pollutants for the transportation modes listed above. The model includes lifecycles for fuels and electricity (end use, fuel dispensing, fuel distribution, fuel production, feedstock transport, and feedstock production), vehicles (materials production, vehicle assembly, operation and maintenance, and indirect support infrastructure), and infrastructure (materials for infrastructure, and construction of infrastructure). Greenhouse gas results mentioned in this report include only emissions associated with fuels and electricity since accurate data are unavailable in India for materials, manufacturing, and construction.

The LEM characterizes emissions of greenhouse gases and criteria pollutants from several sources: fuel combustion, evaporation and leakage of liquid fuels, venting or flaring of gas mixtures, chemical transformations, and changes in the carbon content of solid or biomass. It estimates emissions of CO_2, CH_4, N_2O, CO, NO_X, nonmethane organic compounds, SO_2, particulate matter, CFC-12, and HFC-134a. The LEM estimates emissions of each pollutant individually, and also converts the GHG emissions into CO_2-equivalent GHG emissions. To calculate total CO_2-equivalent emissions, the model uses CO_2-equivalency factors (CEFs), that convert mass emissions of all non-CO_2 gases into an equivalent mass amount of CO_2. Delucchi derived these CEFs using a variety of sources and methods, including but not limited to research by others on global warming potentials (GWPs) and Economic Damage Indices (EDIs). GWPs relate different gases to CO_2 in terms of their relative effects on global warming. EDIs relate the gases to CO_2 in terms of their relative warming-induced economic damages. As a sensitivity analysis, the LEM model was also run taking into account only those gases for which the IPCC has published GWPs relative to CO_2, and using those GWPs instead of the CEFs. This made about a 3-4 percent difference in the greenhouse gas emission estimates and did not affect the relative difference between the scenarios.

Travel:

Data specific to India and Delhi used for this report come primarily from Bose and Nesamani (2000). Reddy et al. (2000) also report useful information for India: the energy intensity of different modes (p. 74), modal shares of total vehicle-kilometers (p. 70), the electricity use of Indian rail (p. 38), vehicle emission factors (p. 39), fuel economy (p. 37), and data on bicycling (p. 32). Delucchi used Bose and Nesamani's estimates of electricity use by Indian rail as a guide. The International Energy Initiative and Centre for Monitoring Indian Economy Pvt. Ltd. (2000) reports national energy use in India (p. 7). Delucchi used the U.S. 1993 Commodity Flow Survey (Bureau of the Census, 1996), which reports tonnage, ton-mile, and average miles by mode as a basis for estimating freight traffic flows in India. The model assumes that the characteristics of rail transit do not change over time.

Electricity:

The U.S. Energy Information Administration's (EIA's) *International Energy Outlook* (1999) reports fuel-use shares for electricity generation in 1996 and 2020. According to the EIA (India, 2000), the electricity transmission and distribution system in India is relatively inefficient. Delucchi assumes 86 percent efficiency (compared with about 92 percent in the United States) in 1995, increasing at 0.1 percent (in relative terms) per year. The EIA (*India*, 1999) reports that the government of India is trying to reduce incentives for relatively old, inefficient, and polluting coal-fired plants to generate electricity. Delucchi assumes that in 1995, Indian coal-fired plants were 29 percent efficient (compared with about 32 percent in the United States), and that the efficiency increases 0.4 percent per year (in relative terms). Rajan and D'Sa (2000) report emission factors for different types of power plants, which Delucchi uses as a guide for LEM assumptions.

Oil and gas:

The EIA (India, 2000) states that in 1998, India imported more than 60 percent of its oil. The report implies that by 2012, India might import 70 percent of its oil. Delucchi assumes that India imports 40 percent of its oil from the Persian Gulf, 10 percent from North Africa, 10 percent from Indonesia, and 33 percent from "Asian exporters" (a category including India and China as domestic producers). The EIA (India, 2000) also says that in the 1990s, India imported a large quantity of refined products, but that it had "closed the gap" by the end of 1999. Delucchi assumes that in 1970, India refined only 45 percent of its total consumption of finished products, but that this percentage grows by 1 percent per year to a maximum of 80 percent.

Data References for LEM

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Energy Information Administration. 1999. *India: Environmental Issues*. Country Analysis Brief. U.S. Department of Energy, Washington, D.C. November. www.eia.doe.gov/emeu/cabs/indiaenv.html.

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Rajan, S.C., and A. D'Sa. 2000. "Captive Power Generation — Air Pollution Impacts Due to Increased Capacity Utilization." *Energy for Sustainable Development* IV (June): 77-89.

Reddy, A. K. N., Y. P. Anand, and A. D'Sa. 2000. "Energy for a Sustainable Road/Rail Transport System in India." *Energy for Sustainable Development* IV (June): 29-44.

References for LEM Documentation

The 1997 version of the model is documented in several reports, shown below. Complete, up-to-date working documentation is available from the author (note Dr. Delucchi changed the spelling of his name from DeLuchi in the mid-1990s).

DeLuchi, M. A. 1991. Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity. Vol. 1. Center for Transportation Research, Argonne National Laboratory, Argonne, Illinois. November. ANL/ESD/TM-22.

DeLuchi, M. A. 1993. Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity Vol. 2, Appendices A-S. Center for Transportation Research, Argonne National Laboratory, Argonne, Illinois. November. ANL/ESD/TM-22.

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Delucchi, M. A. 1997. A Revised Model of Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity. Institute of Transportation Studies, University of California, Davis. November. UCD-ITS-RR-97-22.

Endnotes

1. Intergovernmental Panel on Climate Change, *The Science of Climate Change: Contribution of Working Group I to the Second Assessment of the Intergovernmental Panel on Climate Change*, New York: Cambridge University Press, 1995; United Nations Framework Convention on Climate Change, Report of the Conference of Parties on its Third Session, Held at Kyoto from 1 to 11 December 1997, Document FCCC/CP/1997/7/Add.1, 18 March 1998; Kyoto Protocol, December 1997.

2. The countries listed in Annex I of the UN Framework Convention on Climate Change are: Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, European Economic Community, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom of Great Britain and Northern Ireland, United States of America.

3. Data from the International Energy Agency, Paris. Compiled in "Flexing the Link between Transport and Greenhouse Gas Emissions: A Path for the World Bank," by Lee Schipper, Celine Marie, and Roger Gorham. Washington, DC: World Bank Environmental Program, 2000, http://www.iea.org/pubs/free/articles/schipper/flexing.htm.

4. Sustainable Development Foundation, Delhi, *Factorial Ecology and Social Space in Million Cities of India*, New Delhi, India, 1998.

5. Jeffrey Kenworthy and Felix Laube, *An International Sourcebook of Auto Dependence in Cities 1960-1990*, 1999. See also Jeffrey Kenworthy and Felix Laube, "Patterns of Automobile Dependence in Cities: An International Overview of Key Physical and Economic Dimensions with Some Implications for Urban Policy," *Transportation Research* A: 33, 691-723, 1999.

6. National Capital Region Planning Board, *A Fact Sheet*, Delhi, 1999. Population projections for 2011 are by Registrar General, Census of India; projections for 2021 are by Shri K.S. Natrajan, Former Deputy Registrar General, Census of India.

7. Ministry of Home Affairs, *Population Projection for India and States 1996 - 2016*, Registrar General of India, Controller of Publications, 1996.

8. It is difficult to characterize income levels accurately over time since exchange rates vary and do not necessarily represent purchasing power. In 1995-96, the exchange rate was 33.45 rupees per U.S. dollar, and in 2000, 46.75 rupees per dollar.

9. See note to Table 3.

10. To provide better administrative and financial support for planning, Delhi was declared a Union Territory in 1956. The Delhi Development Authority (DDA) was constituted in 1957 by an Act of Parliament "to check the haphazard and unplanned growth of Delhi... ." The Town and Country Planning Organization, guided by experts from the Ford Foundation, developed a Master Plan for Delhi that was submitted for public review and eventually adopted and sanctioned in 1962, soon becoming known as MPD-62. The Delhi Development Authority revised and updated the plan in 1990 for 2001.

11. Abundant data are available in Delhi, more so than in most developing countries, but they are not always reliable. For instance, the number of registered vehicles does not represent the actual number of vehicles present in Delhi. This is because many vehicles registered outside Delhi flow into and out of Delhi on a daily basis. Also, motorized vehicles are registered only once when they are new and not thereafter. There is no record of vehicle scrappage and attrition. Also, non-motorized vehicles, which are required to register annually and pay a nominal fee, often do not. Where possible, authors adjusted data to be more accurate — by making rough estimates of vehicle scrappage, for example — and used their judgment to determine data reliability.

12. "Losses of Petroleum Products at Traffic Intersections Due to Idling of Vehicles," Central Road Research Institute, October 1996, Delhi. Sponsored by the Petroleum Conservation Research Association.

13. India has distinct ambient standards for industrial, residential, and environmentally sensitive areas. The standards for residential areas tend to be similar to World Health Organization standards for particulate matter, and more stringent for nitrogen oxides.

14. Central Pollution Control Board (CPCB), *Parivesh Newsletter* 6 (1), Delhi, 1999.

15. The Indian automobile industry participated in developing a timetable for implementing the progressive tightening of air emissions standards. The timetable dramatically accelerates the reduction of vehicle emissions, bringing Indian standards close to European, Japanese, and U.S. standards. Standards equivalent to Europe's 1993 Euro I standards, requiring the use of three-way catalysts, were adopted in India in 1999 for non-commercial four-wheeled vehicles using gasoline or diesel. More advanced Euro II standards took effect in April 2000, with proposals to adopt Euro III standards in 2004 and Euro IV standards in 2007. In comparison, note that Euro IV standards take effect in 2005 in Europe, and similar "Tier 2" standards in the United States take effect in 2004. India's emission standards for commercial vehicles lag passenger vehicles by one year. Even more impressive are the stringent new standards (stronger than those in effect in Europe) being imposed on the notoriously dirty two- and three-wheelers. Also, rules are being adopted to improve fuel quality (which is important to ensure that catalytic converters in automobile pollution control systems function efficiently and are not fouled). By 2005, fuel sulfur content must be less than 150 parts per million and by 2009, less than 50 ppm (0.005 percent). These are aggressive targets that approach the efforts of OECD countries.

16. Until the late 1990s, the Organization for Economic Cooperation and Development (OECD) included the United States, Canada, Australia, New Zealand, Japan, and Western Europe. Qualitative and quantitative references to OECD in this report are to these countries. In the late 1990s, the Republic of Korea and Mexico joined the OECD.

17. All GHG emissions analyses presented in this report were conducted by Dr. Mark Delucchi based on an adaptation of his greenhouse gas model. For documentation of the model see the Appendix to this report.

18. Post-factory retrofits are problematic for several reasons: the quality of the conversion is usually mixed, in part because mechanics are not expert on all engine types; not all mechanics are well qualified; and an engine system optimized for one kind of fuel is being converted to run (sub-optimally) on a very different fuel. With the advent of electronic controls, the challenge is even greater.

19. CNG has very high octane and therefore is well-suited to spark-ignited gasoline engines, but has very low cetane, a key attribute for fuels burned in diesel engines. Because diesel engines are also inherently more energy-efficient than gasoline engines, CNG is relatively less attractive in diesel-like engines from an energy efficiency (and therefore GHG) perspective.

20. *Delhi Statistical Handbook*, Directorate of Economics & Statistics, Government of National Capital Territory of Delhi, various issues.

21. National Highway Traffic Safety Administration, *Traffic Safety Facts 1998*, Washington, DC: U.S. Department of Transportation, 1999.

22. Bose and Nesamani, "Urban Transport, Energy and Environment: A Case of Delhi," Project code 2000 UT 41, New Delhi: Tata Energy Research Institute (TERI), 2000. Also available as Bose and Nesamani, *Urban Transport, Energy and Environment: A Case of Delhi*, Institute of Transportation Studies, University of California, Davis, 2000, UCD-ITS-RR-00-11.

23. One notable example is the Institute of Traffic Education, an NGO. It has been operating speed cameras mounted on vehicles that circulate in traffic. They photograph speeding cars and their license plate numbers and pass the information to the traffic police who issue tickets. The appeal process is the same as for all speeding tickets.

24. Indian Institute of Technology, unpublished survey of 2000 households in 1999-2000.

25. Source of ridership income is Indian Institute of Technology - Delhi, Operations Research Group, *Household Travel Surveys in Delhi*, September 1994, 6-7.

26. Ministry of Surface Transport, Transport Research Wing, *Motor Transport Statistics of India*.

27. These autorickshaws and four-wheeled vehicles are assembled locally. In many Indian cities (but not Delhi), these vehicles do not have closed cabins and use inexpensive one-cylinder diesel engines, many designed for agricultural purposes.

28. Data on charter buses are from Rail India Technical and Economic Service Ltd., "Route Rationalization and Time-table Formulation Study for Bus System of Delhi," Final report prepared for GNCTD, 1998, 7-7.

29. Income for the region is projected to continue growing at over 7 percent per year. Per capita income is projected to grow by over 4 percent per year from 2000 to 2010 and over 5 percent the following decade.

30. Norbert Wohlgemuth, "World Transport Energy Demand Modeling: Methodology and Elasticities," *Energy Policy* 25: 15, 1997; and Joyce Dargay and Dermot Gately, "Income's Effect on Car and Vehicle Ownership Worldwide: 1960-2015," CV Starr Center for Applied Economics, New York University, RR# 97-33, 1997, 1.

31. Ministry of Surface Transport, *Report of the Working Group on Road Transport for the Ninth Five-Year Plan (1997-2002)*, New Delhi, 1996.

32. A regression model statistically determines the mathematical relationships among existing or historical phenomena and makes forecasts assuming these relationships continue to hold.

33. Bose and Nesamani, 2000.

34. Ministry of Home Affairs, *Population Projection for India and States 1996 - 2016*, Registrar General of India, Controller of Publications, 1996.

35. Ministry of Surface Transport, Motor Transport Statistics of India, 1997.

36. Engineering Consultancy Pvt. Ltd (ENCON), 1987.

37. Fuel economy data are from analyses by Bose and Nesamani (2000), with minor modifications based on additional information from elsewhere and, for minicars and electric-drive vehicles, from algorithms embedded in the Delucchi GHG model.

38. “Well-to-wheels” refers to all energy production and distribution activities, from the oil or gas well or coal mine to the final user of the energy. Additional calculations were conducted to include energy used to manufacture and maintain vehicles, build and maintain infrastructure, and manufacture materials for vehicles and infrastructure. These additional calculations would not significantly alter the net calculations of GHG emissions conducted as part of the scenario analyses and thus are not presented here. Inclusion of material and manufacturing emissions would significantly alter the results only if massive modal shifts or massive shifts to electricity use were considered.

39. E. Sreedharan, “The Present Status of Delhi Metro Project,” *Urban Railways: A Journal of Rail and Road Transport*, October 2000, 22-23.

40. Indian Institute of Technology, *Bicycle Master Plan for Delhi: Proposed Network Plan and Detailed Design*, prepared for the Transport Department, Transportation Research and Injury Prevention Programme, Delhi, 1998.

41. G. Tiwari, “Planning for Non-motorized Traffic: A Prerequisite for Sustainable Transport System,” *IATSS Research* 23(2), 1999, 70-77.

42. R.J. Allport and J.M. Thomson, *Study of Mass Rapid Transit in Developing Countries*, Report 188, Crowthorne, U.K.: Transport Research Laboratory, 1990.

43. For an analysis of the demand for non-motorized vehicles and incentives and strategies to support their use, see Michael Replogle, *Non-Motorized Vehicles in Asian Cities*, World Bank Technical Paper 162, Washington, DC, 1992.

44. See Susan D. Shaheen, D. Sperling, and Conrad Wagner, “Car Sharing in Europe and North America: Past and Future,” *Transportation Quarterly* 52(3), 35-52, 1998; and Chris Zegras and Ralph Gakenheimer, “Car Sharing in Latin America,” *The Journal of World Transport Policy and Practice* 5(3), September 1999, 151-170.

notes

This report looks at the greenhouse gas emissions from the transportation sector in Delhi, India, to identify policies and technologies to simultaneously reduce emissions growth while improving air quality, reducing congestion, improving safety and enhancing transportation services. The Pew Center on Global Climate Change was established by the Pew Charitable Trusts to bring a new cooperative approach and critical scientific, economic, and technological expertise to the global climate change debate. We intend to inform this debate through wide-ranging analyses that will add new facts and perspectives in four areas: policy (domestic and international), economics, environment, and solutions.

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