Transport and its infrastructure

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5.1 Introduction

Mobility is an essential human need. Human survival and societal interaction depend on the ability to move people and goods. Efficient mobility systems are essential facilitators of economic development. Cities could not exist and global trade could not occur without systems to transport people and goods cheaply and efficiently (WBCSD, 2002).

Since motorized transport relies on oil for virtually all its fuel and accounts for almost half of world oil consumption, the transport sector faces a challenging future, given its dependence on oil. In this chapter, existing and future options and potentials to reduce greenhouse gases (GHG) are assessed.

GHG emission reduction will be only one of several key issues in transport during the coming decades and will not be the foremost issue in many areas. In developing countries especially, increasing demand for private vehicles is outpacing the supply of transport infrastructure – including both road networks and public transit networks. The result is growing congestion and air pollution,3 and a rise in traffic fatalities. Further, the predominant reliance on private vehicles for passenger travel is creating substantial societal strains as economically disadvantaged populations are left out of the rapid growth in mobility. In many countries, concerns about transport will likely focus on the local traffic, pollution, safety and equity effects. The global warming issue in transport will have to be addressed in the context of the broader goal of sustainable development.

5.2 Current status4 and future trends

5.2.1 Transport today

The transport sector plays a crucial and growing role in world energy use and emissions of GHGs. In 2004, transport energy use amounted to 26% of total world energy use and the transport sector was responsible for about 23% of world energy-related GHG emissions (IEA, 2006b). The 1990–2002 growth rate of energy consumption in the transport sector was highest among all the end-use sectors. Of a total of 77 EJ5 of total transport energy use, road vehicles account for more than three-quarters, with light-duty vehicles and freight trucks having the lion’s share (see Table 5.1). Virtually all (95%) of transport energy comes from oil-based fuels, largely diesel (23.6 EJ, or about 31% of total energy) and gasoline (36.4 EJ, 47%). One consequence of this dependence, coupled with the only moderate differences in carbon content of the various oil-based fuels, is that the CO₂ emissions from the different transport sub-sectors are approximately proportional to their energy use (Figure 5.1).

Economic development and transport are inextricably linked. Development increases transport demand, while availability of transport stimulates even more development by allowing trade and economic specialization. Industrialization and growing specialization have created the need for large shipments of goods and materials over substantial distances; accelerating globalization has greatly increased these flows.

Urbanization has been extremely rapid in the past century. About 75% of people in the industrialized world and 40% in the developing world now live in urban areas. Also, cities have grown larger, with 19 cities now having a population over 10 million. A parallel trend has been the decentralization of cities—they have spread out faster than they have grown in population, with rapid growth in suburban areas and the rise of ‘edge cities’ in the outer suburbs. This decentralization has created both a growing demand for travel and an urban pattern that is not easily served by public transport. The result has been a rapid increase in personal vehicles— not only cars but also 2-wheelers—and a declining share of transit. Further, the lower-density development and the greater distances needed to access jobs and services have seen the decline of walking and bicycling as a share of total travel (WBCSD, 2002).

Another crucial aspect of our transport system is that much of the world is not yet motorized because of low incomes. The majority of the world’s population does not have access to personal vehicles, and many do not even have access to motorized public transport services of any sort. Thirty-three percent of China’s population and 75% of Ethiopia’s still did not have access to all-weather transport (e.g., with roads passable

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3 Although congestion and air pollution are also found in developed countries, they are exacerbated by developing country conditions.

4 The primary source for the ‘current status’ part of this discussion is WBCSD (World Business Council for Sustainable Development) Mobility 2001 (2002), prepared by Mas-achusetts Institute of Technology and Charles River Associates Incorporated.

5 83 EJ in 2004 (IEA, 2006b).
most of the year). Walking more than 10 km/day\(^6\) each way to farms, schools and clinics is not unusual in rural areas of the developing world, particularly sub-Saharan Africa, but also in parts of Asia and Latin America. Commuting by public transport is very costly for the urban poor, taking, for example, 14% of the income of the poor in Manila compared with 7% of the income of the non-poor (World Bank, 1996). If and when these areas develop and their population’s incomes rise, the prospects for a vast expansion of motorization and increase in fossil fuel use and GHG emissions is very real. And these prospects are exacerbated by the evidence that the most attractive form of transport for most people as their incomes rise is the motorized personal vehicle, which is seen as a status symbol as well as being faster, flexible, convenient and more comfortable than public transport. Further aggravating the energy and environmental concerns of the expansion of motorization is the large-scale importation of used vehicles into the developing world. Although increased access to activities and services will contribute greatly to living standards, a critical goal will be to improve access while reducing the adverse consequences of motorization, including GHG emissions.

Another factor that has accelerated the increase in transport energy use and carbon emissions is the gradual growth in the size, weight and power of passenger vehicles, especially in the industrialized world. Although the efficiency of vehicle technology has improved steadily over time, much of the benefit of these improvements have gone towards increased power and size at the expense of improved fuel efficiency. For example, the US Environmental Protection Agency has concluded that the US new Light-duty Vehicle (LDV) fleet fuel economy in 2005 would have been 24% higher had the fleet remained at the weight and performance distribution it had in 1987. Instead, over that time period, it became 27% heavier and 30% faster in 0–60 mph (0–97 km/h) time, and achieved 5% poorer fuel economy (Heavenrich, 2005). In other words, if power and size had been held constant during this period, the fuel consumption rates of light-duty vehicles would have dropped more than 1% per year.

Worldwide travel studies have shown that the average time budget for travel is roughly constant worldwide, with the relative speed of travel determining distances travelled yearly (Schafer, 2000). As incomes have risen, travellers have shifted to faster – and more energy-intensive – modes, from walking and bicycling to public transport to automobiles and, for longer trips, to aircraft. And as income and travel have risen, the percentage of trips made by automobiles has risen. Automobile travel now accounts for 15–30% of total trips in the developing world, but 50% in Western Europe and 90% in the United States. The world auto fleet has grown with exceptional rapidity – between 1950 and 1997, the fleet increased from about 50 million vehicles to 580 million vehicles, five times faster than the growth in population. In China, for example, vehicle sales (not including scooters, motorcycles and locally manufactured rural vehicles) have increased from 2.4 million in 2001 to 5.6 million in 2005\(^7\) and further to 7.2 million in 2006.\(^8\) 2-wheeled scooters and motorcycles have also played an important role in the developing world and in warmer parts of Europe, with a current world fleet of a few hundred million

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\(^6\) 6.21 miles/day.


\(^8\) China Association of Automobile Manufacturers 2007.1.17: http://60.195.249.78/caam/caam.web/Detail.asp?id=359#
vehicles (WBSCD, 2002). Non-motorized transport continues to dominate the developing world. Even in Latin America and Europe, walking accounts for 20–40% of all trips in many cities (WBSCD, 2002). Bicycles continue to play a major role in much of Asia and scattered cities elsewhere, including Amsterdam and Copenhagen.

Public transport plays a crucial role in urban areas. Buses, though declining in importance against private cars in the industrialized world (EC, 2005; Japanese Statistical Bureau, 2006; US Bureau of Transportation Statistics, 2005) and some emerging economies, are increasing their role elsewhere, serving up to 45% of trips in some areas. Paratransit – primarily minibus jitneys run by private operators – has been rapidly taking market share from the formal public-sector bus systems in many areas, now accounting for 35% of trips in South Africa, 40% in Caracas and Bogota and up to 65% in Manila and other southeast Asian cities (WBSCD, 2002). Heavy rail transit systems are generally found only in the largest, densest cities of the industrialized world and a few of the upper-tier developing world cities.

Intercity and international travel is growing rapidly, driven by growing international investments and reduced trade restrictions, increases in international migration and rising incomes that fuel a desire for increased recreational travel. In the United States, intercity travel already accounts for about one-fifth of total travel and is dominated by auto and air. European and Japanese intercity travel combines auto and air travel with fast rail travel. In the developing world, on the other hand, intercity travel is dominated by bus and conventional rail travel, though air travel is growing rapidly in some areas – 12% per year in China, for example. Worldwide passenger air travel is growing 5% annually – a faster rate of growth than any other travel mode (WBSCD, 2002).

Industrialization and globalization have also stimulated freight transport, which now consumes 35% of all transport energy, or 27 exajoules (out of 77 total) (WBSCD, 2004b). Freight transport is considerably more conscious of energy efficiency considerations than passenger travel because of pressure on shippers to cut costs, however this can be offset by pressure to increase speeds and reliability and provide smaller ‘just-in-time’ shipments. The result has been that, although the energy-efficiency of specific modes has been increasing, there has been an ongoing movement to the faster and more energy-intensive modes. Consequently, rail and domestic waterways’ shares of total freight movement have been declining, while highway’s share has been increasing and air freight, though it remains a small share, has been growing rapidly. Some breakdowns:

Urban freight is dominated by trucks of all sizes.
Regional freight is dominated by large trucks, with bulk commodities carried by rail and pipelines and some water transport.

National or continental freight is carried by a combination of large trucks on higher speed roads, rail and ship.
International freight is dominated by ocean shipping. The bulk of international freight is carried aboard extremely large ships carrying bulk dry cargo (e.g., iron ore), container freight or fuel and chemicals (tankers).
There is considerable variation in freight transport around the world, depending on geography, available infrastructure and economic development. The United States’ freight transport system, which has the highest total traffic in the world, is one in which all modes participate substantially. Russia’s freight system, in contrast, is dominated by rail and pipelines, whereas Europe’s freight systems are dominated by trucking with a market share of 72% (tkm) in EU-25 countries, while rail’s market share is just 16.4% despite its extensive network. China’s freight system uses rail as its largest carrier, with substantial contributions from trucks and shipping (EC, 2005).

Global estimates of direct GHG emissions of the transport sector are based on fuel use. The contribution of transport to total GHG emissions was about 23%, with emissions of CO₂ and N₂O amounting to about 6300–6400 MtCO₂-eq in 2004. Transport sector CO₂ emissions have increased by around 27% since 1990 (IEA, 2006d). For sub-sectors such as aviation and marine transport, estimates based on more detailed information are available. Estimates of global aviation CO₂ emissions using a consistent inventory methodology have recently been made by Lee et al. (2005). These showed an increase by approximately a factor of 1.5 from 331 MtCO₂/yr in 1990 to 480 MtCO₂/yr in 2000. For seagoing shipping, fuel usage has previously been derived from energy statistics (e.g., Olivier et al., 1996; Corbett et al., 1999; Endresen et al., 2003). More recently, efforts have been committed to constructing inventories using activity-based statistics on shipping movements (Corbett and Köhler, 2003; Eyring et al., 2005a). This has resulted in a substantial discrepancy. Estimated CO₂ emissions vary accordingly. This has prompted debate over inventory methodologies in the literature (Endresen et al., 2004; Corbett and Köhler, 2004). It is noteworthy that the NOₓ emissions estimates also vary strongly between the different studies (Eyring et al., 2005a).

5.2.2 Transport in the future

There seems little doubt that, short of worldwide economic collapse, transport activity will continue to grow at a rapid pace for the foreseeable future. However, the shape of that demand and the means by which it will be satisfied depend on several factors.

First, it is not clear whether oil can continue to be the dominant feedstock of transport. There is an on-going debate about the date when conventional oil production will peak, with many arguing that this will occur within the next few decades.
Box 5.1: Non-CO₂ climate impacts

When considering the mitigation potential for the transport sector, it is important to understand the effects that it has on climate change. Whilst the principal GHG emitted is CO₂, other pollutants and effects may be important and control/mitigation of these may have either technological or operational trade-offs.

Individual sectors have not been studied in great detail, with the exception of aviation. Whilst surface vehicular transport has a large fraction of global emissions of CO₂, its radiative forcing (RF) impact is little studied. Vehicle emissions of NOₓ, VOCs and CO contribute to the formation of tropospheric O₃, a powerful GHG; moreover, black carbon and organic carbon may affect RF from this sector. Shipping has a variety of associated emissions, similar in many respects to surface vehicular transport. One of shipping’s particular features is the observed formation of low-level clouds (‘ship-tracks’), which has a negative RF effect. The potential coverage of these clouds and its associated RF is poorly studied, but one study estimates a negative forcing of 0.110 W/m² (Capaldo et al., 1999), which is potentially much larger than its positive forcing from CO₂ and it is possible that the overall forcing from shipping may be negative, although this requires more study. However, a distinction should be drawn between RF and an actual climate effect in terms of global temperature change or sea-level rise; the latter being much more complicated to estimate.

Non-CO₂ emissions (CH₄ and N₂O) from road transport in major Annex I parties are listed in UNFCC GHG inventory data. The refrigerant banks and emission trend of F-gases (CFC-12 + HFC-134a) from air-conditioning are reported in the recent IPCC special report on Safeguarding the Ozone Layer and the Global Climate System (IPCC, 2005). Since a rapid switch from CFC-12 to HFC-134a, which has a much lower GWP index, is taking place, the total amount of F-gases is increasing due to the increase in vehicles with air-conditioning, but total emission in CO₂-eq is decreasing and forecasted to continue to decrease. Using the recent ADEME data (2006) on F-gas emissions, the shares of emissions from transport sectors for CO₂, CH₄, N₂O and F-gases (CFC-12 + HFC-134a+HCFC-22) are:

<table>
<thead>
<tr>
<th>Region</th>
<th>CO₂ (%)</th>
<th>CH₄ (%)</th>
<th>N₂O (%)</th>
<th>F-gas (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>88.4</td>
<td>0.2</td>
<td>2.0</td>
<td>8.9</td>
</tr>
<tr>
<td>Japan</td>
<td>96.0</td>
<td>0.1</td>
<td>2.5</td>
<td>1.4</td>
</tr>
<tr>
<td>EU</td>
<td>95.3</td>
<td>0.3</td>
<td>2.8</td>
<td>1.7</td>
</tr>
</tbody>
</table>

Worldwide F-gas emissions in 2003 were reported to be 610 MtCO₂-eq in IPCC (2005), but more recent ADEME data (ADEME, 2006) was about 310 Mt CO₂-eq (CFC-12 207, HFC-134a 89, HCFC-22 10 MtCO₂-eq), which is about 5% of total transport CO₂ emission. It can be seen that non-CO₂ emissions from the transport sector are considerably smaller than the CO₂ emissions. Also, air-conditioning uses significant quantities of energy, with consequent CO₂ emissions from the fuel used to supply this energy. Although this depends strongly on the climate conditions, it is reported to be 2.5–7.5% of vehicle energy consumption (IPCC, 2005).

Aviation has a larger impact on radiative forcing than that from its CO₂ forcing alone. This was estimated for 1992 and a range of 2050 scenarios by IPCC (1999) and updated for 2000 by Sausen et al. (2005) using more recent scientific knowledge and data. Aviation emissions impact radiative forcing in positive (warming) and negative (cooling) ways as follows: CO₂ (+25.3 mW/m²); O₃ production from NOₓ emissions (+21.9 mW/m²); ambient CH₄ reduction as a result of NOₓ emissions (−10.4 mW/m²); H₂O (+2.0 mW/m²); sulphate particles (−3.5 mW/m²); soot particles (+2.5 mW/m²); contrails (+10.0 mW/m²); cirrus cloud enhancement (10–80 mW/m²). These effects result in a total aviation radiative forcing for 2000 of 47.8 mW/m², excluding cirrus cloud enhancement, for which no best estimate could be made, as was the case for IPCC (1999). Forster et al. (2007) assumed that aviation radiative forcing (0.048 W/m² in 2000, which excludes cirrus) to have grown by no more than 10% between 2000 and 2005. Forster et al. (2007) estimate a total net anthropogenic radiative forcing in 2005 of 1.6 W/m² (range 0.6–2.4 W/m²). Aviation therefore accounts for around 3% of the anthropogenic radiative forcing in 2005 (range 2–8%). This 90% confidence range is skewed towards lower percentages and does not account for uncertainty in the aviation forcings.

(though others, including some of the major multinational oil companies, strongly oppose this view). Transport can be fuelled by multiple alternative sources, beginning with liquid fuels from unconventional oil (very heavy oil, oil sands and oil shale), natural gas or coal, or biomass. Other alternatives include gaseous fuels such as natural gas or hydrogen and electricity, with both hydrogen and electricity capable of being produced from a variety of feedstocks. However, all of these alternatives are costly, and several – especially liquids from fossil resources – can increase GHG emissions significantly without carbon sequestration.
Second, the growth rate and shape of economic development, the primary driver of transport demand, is uncertain. If China and India as well as other Asian countries continue to rapidly industrialize, and if Latin America and Africa fulfil much of their economic potential, transport demand will grow with extreme rapidity over the next several decades. Even in the most conservative economic scenarios though, considerable growth in travel is likely.

Third, transport technology has been evolving rapidly. The energy efficiency of the different modes, vehicle technologies, and fuels, as well as their cost and desirability, will be strongly affected by technology developments in the future. For example, although hybrid electric drive trains have made a strong early showing in the Japanese and US markets, their ultimate degree of market penetration will depend strongly on further cost reductions. Other near-term options include the migration of light-duty diesel from Europe to other regions. Longer term opportunities requiring more advanced technology include new biomass fuels beyond those made from sugar cane in Brazil and corn in the USA, fuel cells running on hydrogen and battery-powered electric vehicles.

Fourth, as incomes in the developing nations grow, transport infrastructure will grow rapidly. Current trends point towards growing dependence on private cars, but other alternatives exist (as demonstrated by cities such as Curitiba and Bogota with their rapid bus transit systems). Also, as seen in Figure 5.2, the intensity of car ownership varies widely around the world even when differences in income are accounted for, so different countries have made very different choices as they have developed. The future choices made by both governments and travellers will have huge implications for future transport energy demand and CO₂ emissions in these countries.

Most projections of transport energy consumption and GHG emissions have developed Reference Cases that try to imagine what the future would look like if governments essentially continued their existing policies without adapting to new conditions. These Reference Cases establish a baseline against which changes caused by new policies and measures can be measured, and illustrate the types of problems and issues that will face governments in the future.

Sustainable Development, ‘Mobility 2030’, also developed a projection of world transport energy use. Because the WBCSD forecast was undertaken by IEA personnel (WBCSD, 2004b), the WEO 2004 and Mobility 2030 forecasts are quite similar. The WEO 2006 (IEA, 2006b) includes higher oil price assumptions than previously. Its projections therefore tend to be somewhat lower than the two other studies.

The three forecasts all assume that world oil supplies will be sufficient to accommodate the large projected increases in oil demand, and that world economies continue to grow without significant disruptions. With this caveat, all three forecast robust growth in world transport energy use over the next few decades, at a rate of around 2% per year. This means that transport energy use in 2030 will be about 80% higher than in 2002 (see Figure 5.3). Almost all of this new consumption is expected to be in petroleum fuels, which the forecasts project will remain between 93% and slightly over 95% of transport fuel use over the period. As a result, CO₂ emissions will essentially grow in lockstep with energy consumption (see Figure 5.4).

Another important conclusion is that there will be a significant regional shift in transport energy consumption, with the emerging economies gaining significantly in share (Figure 5.3). EIA’s International Energy Outlook 2005, as well as the IEA, projects a robust 3.6% per year growth rate for these economies, while the IEA’s more recent WEO 2006 projects transport demand growth of 3.2%. In China, the number of cars has been growing at a rate of 20% per year, and personal travel has increased by a factor of five over the past 20 years. At its projected 6% rate of growth, China’s transport energy use would nearly quadruple between 2002 and 2025, from 4.3 EJ in 2002 to 16.4 EJ in 2025. China’s neighbour India’s transport energy is projected to grow at 4.7% per year during this period and countries such as Thailand, Indonesia, Malaysia and Singapore will see growth rates above 3% per year. Similarly, the Middle East, Africa and Central and South America will see transport energy growth rates at or near 3% per year. The net effect is that the emerging economies’ share of world transport energy use would grow in the EIA forecasts from 31% in 2002 to 43% in 2025. In 2004, the transport sector produced 6.2 GtCO₂ emissions (23% of world energy-related CO₂ emissions). The share of Non-OECD countries is 36% now and will increase rapidly to 46% by 2030 if current trends continue.

In contrast, transport energy use in the mature market economies is projected to grow more slowly. EIA forecasts 1.2% per year and IEA forecasts 1.3% per year for the OECD nations. EIA projects transport energy in the United States to grow at 1.7% per year, with moderate population and travel growth and only modest improvement in efficiency. Western Europe’s transport energy is projected to grow at a much slower 0.4% per year, because of slower population growth, high fuel taxes and significant improvements in efficiency. IEA projects a considerably higher 1.4% per year for OECD Europe. Japan, with an aging population, high taxes and low birth rates, is projected to grow at only 0.2% per year. These rates would lead to 2002–2025 increases of 46%, 10% and 5%, for the USA, Western Europe and Japan, respectively. These economies’ share of world transport energy would decline from 62% in 2002 to 51% in 2025.

The sectors propelling worldwide transport energy growth are primarily light-duty vehicles, freight trucks and air travel. The Mobility 2030 study projects that these three sectors will be responsible for 38, 27 and 23%, respectively, of the total 100 EJ growth in transport energy that it foresees in the 2000–2050 period. The WBCSD/SMP reference case projection indicates that the number of LDVs will grow to about 1.3 billion by 2030 and to just over 2 billion by 2050, which is almost three times...
higher than the present level (Figure 5.5). Nearly all of this increase will be in the developing world.

**Aviation**

Civil aviation is one of the world’s fastest growing transport means. ICAO (2006) analysis shows that aviation scheduled traffic (revenue passenger-km, RPK) has grown at an average annual rate of 3.8% between 2001 and 2005 despite the downturn from the terrorist attacks and SARS (Severe Acute Respiratory Syndrome) during this period, and is currently growing at 5.9% per year. These figures disguise regional differences in growth rate: for example, Europe-Asia/Pacific traffic grew at 12.2% and North American domestic traffic grew at 2.6% per year in 2005. ICAO’s outlook for the future forecasts a passenger traffic demand growth of 4.3% per year to 2020. Industry forecasts offer similar prospects for growth: the Airbus Global Market Forecast (Airbus, 2004) and Boeing Current Market Outlook (Boeing, 2006) suggest passenger traffic growth trends of 5.3% and 4.9% respectively, and freight trends at 5.9% and 6.1% respectively over the next 20 or 25 years. In summary, these forecasts and others predict a global average annual passenger traffic growth of around 5% – passenger traffic doubling in 15 years – with freight traffic growing at a faster rate that passenger traffic, although from a smaller base.

The primary energy source for civil aviation is kerosene. Trends in energy use from aviation growth have been modelled using the Aero2K model, using unconstrained demand growth forecasts from Airbus and UK Department of Trade and Industry. The model results suggest that by 2025 traffic will increase by a factor of 2.6 from 2002, resulting in global aviation fuel consumption increasing by a factor of 2.1 (QinetiQ, 2004). Aero2K model results suggest that aviation emissions were approximately 492 MtCO$_2$ and 2.06 MtNO$_x$ in 2002 and will increase to 1029 and 3.31 Mt respectively by 2025.

Several organizations have constructed scenarios of aviation emissions to 2050 (Figure 5.6), including:

IPCC (1999) under various technology and GDP assumptions (IS92a, e and c). Emissions were most strongly affected by