Chapter 7. Transportation

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KEY FINDINGS

- The transportation sector of North America released 587 Mt of C into the atmosphere in 2003, nearly all in the form of carbon dioxide from combustion of fossil fuels. This comprises 37% of the total CO_2 emissions from worldwide transportation activity which, in turn, accounts for about 22% of total global CO_2 emissions.
- Transportation energy use in North America and the associated C emissions have grown substantially and relatively steadily over the past 40 years. Growth has been most rapid in Mexico, the country most dependent upon road transport.
- Carbon emissions by transport are determined by the levels of passenger and freight activity, the shares of transport modes, the energy intensity of passenger and freight movements, and the carbon intensity of transportation fuels. The growth of passenger and freight activity is driven by population, per capita income, and economic output.
- Chiefly as a result of economic growth, energy use by North American transportation is expected to increase by 46% from 2003 to 2025. If the mix of fuels is assumed to remain the same, carbon dioxide emissions would increase from 587 Mt C in 2003 to 859 Mt C in 2025. Canada, the only one of the three countries in North America to have committed to specific GHG reduction goals, is expected to show the lowest rate of growth in C emissions.
- The most widely proposed options for reducing the carbon emissions of the North American transportation sector are increased vehicle fuel economy, increased prices for carbon-based fuels, liquid fuels derived from biomass, and in the longer term, hydrogen produced from renewables, nuclear energy, or from fossil fuels with carbon sequestration. Biomass fuels appear to be a promising near- and long-term option, while hydrogen could become an important energy carrier after 2025.
- After the development of advanced energy efficient vehicle technologies and low-carbon fuels, the most pressing research need in the transportation sector is for comprehensive, consistent, and rigorous assessments of carbon emissions mitigation potentials and costs for North America.

Transportation is the largest source of carbon emissions among North American energy end uses. This fact reflects the vast scale of passenger and freight movements in a region that comprises one-fourth of the global economy, as well as the dominance of relatively energy-intensive road transport and the near total dependence of North American transportation systems on petroleum as a source of energy. If present trends continue, carbon emissions from North American transportation are expected to increase by more than one-half by 2050. Options for mitigating carbon emissions from the transportation sector like increased vehicle fuel economy and biofuels could offset the expected growth in transportation activity. However, at present only Canada has committed to achieving a specific reduction in future greenhouse gas emissions: 6% below 1990 levels by 2012 (Government of Canada, 2005).

INVENTORY OF CARBON EMISSIONS

Worldwide, transportation produced about 22% (1.5 Gt C) of total global carbon dioxide emissions from the combustion of fossil fuels (6.6 Gt C) in 2000 (page 3-1 in U.S. EPA, 2005; Marland, Boden and Andres, 2005). Home to 6.7% of the world's 6.45 billion people and source of 24.8% of the world's $55.5 trillion gross world product (CIA, 2005), North America produces 37% of the total carbon emissions from worldwide transportation activity (Fulton and Eads, 2004).

Transportation activity is driven chiefly by population, economic wealth, and geography. Of the approximately 435 million residents of North America, 68.0% reside in the United States, 24.5% in Mexico, and 7.5% in Canada. The differences in the sizes of the three countries' economies are far greater. The United States is the world's largest economy, with an estimated gross domestic product (GDP) of $11.75 trillion in 2004. Although Mexico has approximately three times the population of Canada, its GDP is roughly the same, $1.006 trillion compared to $1.023 trillion (measured in 2004 purchasing power parity dollars). With the largest population and largest economy, the United States has by far the largest transportation system. The United States accounted for 87% of the energy used for transportation in North America in 2003, Canada for 8%, and Mexico 5% (Fig. 7-1) (see Table 4-1 in NATS, 2005). These differences in energy use are directly reflected in carbon emissions from the three countries' transportation sectors (Table 7-1).

Figure 7-1. Transportation energy use in North America, 1990–2003.

Table 7-1. Carbon emissions from transportation in North America in 2003.

Transportation is defined as private and public vehicles that move people and commodities (U.S. EPA, 2005, p. 296). This includes automobiles, trucks, buses, motorcycles, railroads and railways (including streetcars and subways), aircraft, ships, barges, and natural gas pipelines. This definition excludes petroleum, coal slurry, and water pipelines, as well as the transmission of electricity, although many countries consider all pipelines part of the transport sector. It also generally excludes mobile sources not engaged in transporting people or goods, such as construction equipment, and on-farm agricultural equipment. In addition, carbon emissions from international bunker fuel use in aviation and waterborne transport, though considered part of transport emissions, are generally accounted for separately from a nation's domestic greenhouse gas inventory. In this chapter, however, they are included as are carbon emissions from military transport operations because they are real inputs to the carbon cycle. Upstream, or well-to-tank, carbon emissions are not included with transportation end-use, nor are end-of-life emissions produced in the disposal or recycling of materials used in transportation vehicles or infrastructure because these carbon flows are in the domain of other chapters. These two categories of emissions typically comprise 20–30% of total life cycle emissions for transport vehicles (see Table 5.4 in Weiss *et al*., 2000). In the future, it is likely that upstream carbon emissions will be of greater importance in determining the total emissions due to transportation activities.

In addition to carbon dioxide, the combustion of fossil fuels by transportation produces other greenhouse gases including methane (CH_4), nitrous oxide (N_2O), carbon monoxide (CO), nitrogen oxides (NO_x), and non-methane volatile organic compounds (VOCs). Those containing carbon are generally oxidized in the atmosphere to ultimately produce CO_2. However, the quantities of non-CO_2 gases produced by transportation vehicles are very minor sources of carbon in comparison to the volume of CO_2 emissions. For example, North American emissions of CH_4 by transportation accounted for only 0.03% of total transportation carbon emissions in 2003. This chapter will therefore address primarily the carbon dioxide emissions from transportation activities (methane emissions are included in the totals presented in Table 7-1, but they are not included in any other estimates presented in this chapter).

Four main sources of information on carbon emissions are used in this chapter. The estimates shown in Table 7-1 were obtained from the greenhouse gas inventory reports of the three countries, estimated by environmental agencies in accordance with IPCC guidelines. As Annex 1 countries, Canada and the United States are obliged to compile annual inventories under IPCC guidelines. As a non-Annex 1 country, Mexico is not. These inventories are the most authoritative sources for estimates of carbon emissions. The inventory reports, however, do not generally provide estimates of associated energy use and the most recent inventory data available for Mexico are for 2001. Estimates of energy use and carbon emissions produced by the countries' energy agencies are also used in this chapter to illustrate the relationship between energy use and carbon emissions and its historical trends. There are some minor differences between the carbon emissions estimates from the two sources. Finally, future projections of carbon emissions for North America to 2025 were taken from the U.S. Energy Information's Annual Energy Outlook 2005, and projections to 2050 were taken from the World Business Council on Sustainable Development's Sustainable Mobility Project (WBCSD, 2004).

Fuels Used in Transportation

Virtually all of the energy used by the transport sector in North America is derived from petroleum, and most of the remainder comes from natural gas (Table 7-2). In the United States, 96.3% of total transportation energy is obtained by combustion of petroleum fuels (U.S. DOE/EIA, 2005a). Most of the non-petroleum energy is natural gas used to power natural gas pipelines (2.5%, 744 PJ). During the past two decades, ethanol use as a blending component for gasoline has increased from a negligible amount to 1.1% of transportation energy use (312 PJ). Electricity, mostly for passenger rail transport, comprises only 0.1% of U.S. transport energy use. This pattern of energy use has persisted for more than half a century.

Table 7-2. Summary of North American transport energy use and carbon dioxide emissions in 2003 by fuel type.

The pattern of energy sources is only a little different in Mexico where 96.2% of transportation energy use is gasoline, diesel, or jet fuel: 3.4% is liquefied petroleum gas (LPG), and less than 0.2% is electricity (Rodríguez, 2005). In Canada, natural gas use for natural gas pipelines accounts for 7.5% of transport energy use, 91.8% is petroleum, 0.5% is propane (LPG) and only 0.1% is electricity (see Table 1 in NRCan, 2006).

Mode of Transportation

Mode of transportation refers to how people and freight are moved about, whether by road, rail, or air, in light or heavy vehicles. Carbon dioxide emissions from the North American transportation sector are summarized by mode in Table 7-3, and the distribution of emissions by mode for North America in 2003 is illustrated in Fig. 7-2.

Table 7-3. Summary of North American transport energy use and carbon dioxide emissions in 2003 by fuel type.

Figure 7-2. North American carbon emissions from transportation by mode; U.S.A and Canada 2003, Mexico 2001.

Freight Transport

Movement of freight is a major component of the transportation sector in North America. Total freight activity in the United States, measured in metric ton-km, is 20 times that in Mexico and more than 10 times the levels observed in Canada (Figs. 7-3A, 7-3B, 7-3C).

Figure 7-3A. Freight activity by mode in Canada.

Figure 7-3B. Freight activity by mode in Mexico.

Figure 7-3C. Freight activity by mode in the United States.

In Mexico, trucking is the mode of choice for freight movements. Four-fifths of Mexican metric ton-km are produced by trucks. Moreover, trucking's modal share has been increasing over time.

In Canada, rail transport accounts for the majority of freight movement (65%). Rail transport is well suited to the approximately linear distribution of Canada's population in close proximity to the U.S. border, the long-distances from east to west, and the large volumes of raw material flows typical of Canadian freight traffic (see Table 5-2 in NATS, 2005).

In the United States, road freight plays a greater role than in Canada, and rail is less dominant, although rail still carries the largest share of metric ton-km (40%). In none of the countries does air freight account for a significant share of metric ton-km.

Passenger Transport

In all three countries, passenger transport is predominantly by road, followed in distant second by air travel. The rate of growth in air travel in North America is more than double that of road transport, so that air transport's share of carbon emissions will increase in the future. Nearly complete data are available for passenger-kilometers-traveled (pkt) by mode in the United States and Canada in 2001. Of the more than 8 trillion pkt accounted for by the United States, 86% was by light-duty personal vehicles, most by passenger car but a growing share by light trucks (Fig. 7-4A) (motorcycle pkt, about 0.2% of the total, is included with passenger car). Air travel claims 10%; other modes are minor.

Figure 7-4A. Distribution of passenger travel in the United States by mode.

Canadian passenger travel exhibits a very similar modal structure, but with a smaller role played by light trucks and air and a larger share for buses (Fig. 7-4B) (transit numbers for Canada were not available at the time these figures were compiled).

Figure 7-4B. Distribution of passenger travel by mode in Canada.

TRENDS AND DRIVERS

Driven by economic and population growth, transportation energy use has increased substantially in all three countries since 1990. Figures 7-5A and 7-5B illustrate the evolution of transport energy use by mode for Mexico and the United States. Energy use has grown most rapidly in Mexico, the country most dependent on road transport. In the United States, the steady growth of transportation oil use was interrupted by oil price shocks in 1973–74, 1979–80, and to a much lesser degree in 1991. The impact of the attack on the World Trade Center in 2001 and subsequent changes in air travel procedures had a visible effect on energy use for air travel.

Figure 7-5A. Evolution of transport energy use in Mexico.

Figure 7-5B. Evolution of transport energy use in the United States.

The evolution of transport carbon emissions has closely followed the evolution of energy use. Carbon dioxide emissions by mode are shown for the United States and Canada for the period 1990–2003 in Figs. 7-6A and 7-6B. The Canadian data include light-duty commercial vehicles in road freight transport, while all light trucks are included in the light-duty vehicle category in the U.S. data. These data illustrate the relatively faster growth of freight transport energy use. Fuel economy standards in both countries restrained the growth of passenger car and light-truck energy use (NAS, 2002). From 1990 to 2003 passenger kilometers traveled by road in Canada increased by 23%, while energy use increased by only 15%. In 2003, freight activity accounted for more than 40% of Canada's transport energy use. And while passenger transport energy use increased by 15% from 1990 to 2003, freight energy use increased by 40%. The Canadian transport energy statistics do not include natural gas pipelines as a transport mode.

Figure 7-6A. Transport CO_2 emissions in Canada.

Figure 7-6B. Transport CO_2 emissions in the United States.

Carbon emissions by transport are determined by the levels of passenger and freight activity, the shares of transport modes, the energy intensity of passenger and freight movements, and the carbon intensity of transportation fuels. In North America, petroleum fuels supply over 95% of transportation's energy requirements and account for 98% of the sector's GHG emissions. Among modes, road vehicles are predominant, producing almost 80% of sectoral GHG emissions. As a consequence, the driving forces for transportation GHG emissions have been changes in activity and energy intensity. The principal driving forces of the growth of passenger transportation are population and per capita income (WBCSD, 2004). Increased vehicle ownership follows rising per capita income, as do vehicle use, fuel consumption, and emissions. In general, energy forecasters expect the greatest growth in vehicle ownership and fossil fuel use in transportation over the next 25–50 years to occur in the developing economies (U.S. DOE/EIA, 2005b; IEA, 2004; WBCSD, 2004; Nakićenović, Grűbler, McDonald, 1998). The chief driving forces for freight activity are economic growth and the integration of economic activities at both regional and global scales (WBCSD, 2004).

Projections of North American transportation energy use and carbon emissions to 2030 have been published by the U.S. Energy Information Administration (U.S. DOE/EIA, 2005b) and the International Energy Agency (2005a). Historical population growth rates are similar in the three countries, 0.92% per year in the United States, 1.17% per year in Mexico, and 0.90% per year in Canada. Recent annual GDP growth rates are 4.4% for the United States, 4.1% for Mexico, and 2.4% for Canada (CIA, 2005). The U.S. Energy Information Administration's Reference Case projection assumes annual GDP growth rates of 3.1% for the United States, 2.4% for Canada, and 3.9% for Mexico (see Table A3 in U.S. DOE/EIA, 2005b). Assumed population growth rates are United States: 0.9%; Canada: 0.6%; Mexico: 1.0% (see Table A14 in U.S. DOE/EIA, 2005b). Chiefly as a result of economic growth, energy use by North American transportation is expected to increase by 46% from 2003 to 2025 (U.S. DOE/EIA, 2005b). If the mix of fuels is assumed to remain the same, as it nearly does in the IEO 2005 Reference Case projection, carbon dioxide emissions would increase from 587 Mt C in 2003 to 859 Mt C in 2025 (Fig. 7-7). Canada, the only one of the three countries to have committed to specific GHG reduction goals, is expected to show the lowest rate of growth in CO_2 emissions.

Figure 7-7. Projected carbon dioxide emissions from the North American transport sector in 2025, based on EIA IEO 2005 reference case.

The World Business Council for Sustainable Development (WBCSD), in collaboration with the International Energy Agency developed a model for projecting world transport energy use and greenhouse gas emissions to 2050 (Table 7-4). The WBCSD's reference case projection foresees the most rapid growth in carbon emissions from transportation occurring in Asia and Latin America (Fig. 7-8). Still, in 2050 North America accounts for 26.4% of global carbon dioxide emissions from transport vehicles (down from a 37.2% share in 2000).

Table 7-4. Global carbon emissions from transportation vehicles to 2050 by regions, WBCSD reference case projection (Mt C).

Figure 7-8. WBCSD projections of world transportation vehicle CO_2 emissions to 2050.

OPTIONS FOR MANAGEMENT

Dozens of policies and measures for reducing petroleum consumption and mitigating carbon emissions from transportation in North America have been identified and assessed (e.g., U.S. DOT, 1998; IEA, 2001; Greene and Schafer, 2003; Greene *et al*., 2005; CBO, 2003; Harrington and McConnell, 2003; NRTEE, 2005). However, there is no consensus about how much transportation GHG emissions can be reduced and at what cost. In general, top-down models estimating the mitigation impacts of economy-wide carbon taxes or cap-and-trade systems find the cost of mitigation high and the potential modest. On the other hand, bottom-up studies evaluating a wide array of policy options tend to reach the opposite conclusion. Part of the explanation of this paradox may lie in the predominant roles that governments play in constructing, maintaining, and operating the majority of transportation infrastructure and in the strong interrelationship between land use planning and transportation demand. In addition, top down models typically assume that all markets are efficient, whereas there is evidence of real-world transportation energy market failures, especially with respect to the determination of light-duty vehicle fuel economy (e.g., Turrentine and Kurani, 2004; NAS, 2002, Ch. 5). Estimates of the costs and benefits of mitigation policies also vary widely and depend critically on premises concerning (1) the efficiency of transportation energy markets, (2) the values consumers attach to vehicle attributes such as acceleration performance and vehicle weight, and (3) the current and future status of carbon-related technology.

A U.S. Energy Information Administration evaluation of a greenhouse gas cap and trade system, expected to result in carbon permit prices of $79/t C in 2010 and $221/t C in 2025, was estimated to reduce 2025 transportation energy use by 4.3 PJ and to cut transportation's carbon emissions by 10% from 225 Mt C in the reference case to 203 Mt C under this policy (U.S. DOE/EIA, 2003). The average fuel economy of new light-duty vehicles was estimated to increase from 26.4 mpg (8.9 L per 100 km) to 29.0 mpg (8.1 L per 100 km) in the policy case, an improvement of only 10%. A 2002 study by the U.S. National Academy of Sciences (NAS, 2002) estimated that "cost-efficient" fuel economy improvements for U.S. light-duty vehicles using proven technologies ranged from 12% for subcompact cars to 27% for large cars, and from 25% for small SUVs to 42% for large SUVs. The NAS study did not include the potential impacts of diesel or hybrid vehicle technologies and assumed that vehicle size and horsepower would remain constant.

The U.S. Congressional Budget Office (CBO, 2003) estimated that achieving a 10% reduction in U.S. gasoline use would create total economic costs of approximately \$3.6 billion per year if accomplished by means of Corporate Average Fuel Economy (CAFE) standards, \$3.0 billion if the same standards allowed trading of fuel economy credits among manufacturers, and \$2.9 billion if accomplished via a tax on gasoline. This partial equilibrium analysis assumed that it would take about 14 years for the policies to have their full impact. If one assumes that the United States would consume 22,600 PJ of gasoline in 2017, resulting in 387 Mt of CO_2 emissions, then a 10% reduction amounts to 39 Mt C. At a total cost of \$3 billion per year, and attributing the full cost to carbon reduction (vs. other objectives such as reducing petroleum dependence) produces an upper-bound mitigation cost estimate of \$77/t C.

Systems of progressive vehicle taxes on purchases of less efficient new vehicles and subsidies for more efficient new vehicles ("feebates") are yet another alternative for increasing vehicle fuel economy. A study of the U.S. market (Greene *et al*., 2005) examined a variety of feebate structures under two alternative assumptions: (1) consumers consider only the first three years of fuel savings when making new vehicle purchase decisions, and (2) consumers consider the full discounted present value of lifetime fuel savings. The study found that if consumers consider only the first three years of fuel savings, then a feebate of \$1000 per 0.01 gal/mile (3.5 L per 100 km), designed to produce no net revenue to the government, would produce net benefits to society in terms of fuel savings and would reduce carbon emissions by 139 Mt C in 2030. If consumers fully valued lifetime fuel savings, the same feebate system would cause a \$3 billion loss in consumers' surplus (a technical measure of the change in economic well-being closely approximating income loss) and reduce carbon emissions by only 67 Mt C, or an implied cost of \$44/Mt CO_2.

The most widely proposed options for reducing the carbon content of transportation fuels are liquid fuels derived from biomass and hydrogen produced from renewables, nuclear energy, or from fossil fuels with carbon sequestration. Biomass fuels, such as ethanol from cellulosic feedstocks or liquid hydrocarbon fuels produced via biomass gasification and synthesis, appear to be a promising mid- to long-term option, while hydrogen could become an important energy carrier but not before 2025 (WBCSD, 2004). The carbon emission reduction potential of biomass fuels for transportation is strongly dependent on the feedstock and conversion processes. Advanced methods of producing of ethanol from grain, the predominant feedstock in the United States can reduce carbon emissions by 10% to 30% (Wang, 2005; p. 16 in IEA, 2004). Production of ethanol from sugar cane, as is the current practice in

Brazil, or by not-yet-commercialized methods of cellulosic conversion can achieve up to a 90% net reduction over the fuel cycle. Conversion of biomass to liquid hydrocarbon fuels via gasification and synthesis may have a similar potential (Williams, 2005). The technical potential for liquid fuels production from biomass is very large and very uncertain; recent estimates of the global potential range from 10 to 400 exajoules per year (see Table 6.8 in IEA, 2004). The U.S. Departments of Energy and Agriculture have estimated that 30% of U.S. petroleum use could be replaced by biofuels by 2030 (Perlack *et al*., 2005). The economic potential will depend on competition for land with other uses, the development of a global market for biofuels, and advances in conversion technologies.

Hydrogen must be considered a long-term option because of the present high cost of fuel cells, technical challenges in hydrogen storage, and the need to construct a new infrastructure for hydrogen production and distribution (NAS, 2004; U.S. DOE, 2005; IEA, 2005b). Hydrogen's potential to mitigate carbon emissions from transport will depend most strongly on how hydrogen is produced. If produced from coal gasification without sequestration of CO_2 emissions in production, it is conceivable that carbon emissions could increase. If produced from fossil fuels with sequestration, or from renewable or nuclear energy, carbon emissions from road and rail vehicles could be virtually eliminated (General Motors *et al*., 2001).

In a comprehensive assessment of opportunities to reduce GHG emissions from the U.S. transportation sector, a study published by the Pew Center on Global Climate Change (Greene and Schafer, 2003) estimated that sector-wide reductions in the vicinity of 20% could be achieved by 2015 and 50% by 2030 (Table 7-5). The study's premises assumed no change in the year 2000 distribution of energy use by mode. A wide range of strategies was considered, including research and development, efficiency standards, use of biofuels and hydrogen, pricing policies to encourage efficiency and reduce travel demand, land-use transportation planning options, and public education (Table 7-5). Other key premises of the analysis were that (1) for efficiency improvements the value of fuel saved to the consumer must be greater than or equal to the cost of the improvement, (2) there is no change in vehicle size or performance, (3) pricing policies shift the incidence but do not increase the overall cost of transportation, and (4) there is a carbon cap and trade system in effect equivalent to a charge of approximately $50/t C. Similar premises underlie the 2030 estimates, except that technological progress is assumed to have expanded the potential for efficiency improvement and lowered the cost of biofuels.

Table 7-5. Potential impacts of transportation GHG reduction policies in the United States by 2015 and 2030 based on the 2000 distribution of emissions by mode and fuel.

The Pew Center study notes that if transportation demand continues to grow as the IEO 2005 and WBCSD projections anticipate, the potential reductions shown in Table 7.4 would be just large enough to hold U.S. transportation CO_2 emissions in 2030 to 2000 levels.

A study for the U.S. Department of Energy (ILWG, 2000) produced estimates of carbon mitigation potential for the entire U.S. economy using a variety of policies generally consistent with carbon taxes of \$25–\$50/t C. In the study's business as usual case, transportation CO_2 emissions increased from 478 Mt C in 1997 to 700 Mt C in 2020. A combination of technological advances, greater use of biofuel, fuel economy standards, paying for a portion of automobile insurance as a surcharge on gasoline, and others, were estimated to reduce 2020 transportation CO_2 emissions by 155 Mt C to 545 Mt CO_2. The study did not produce cost estimates and did not consider impacts on global energy markets.

A joint study of the U.S. Department of Energy and Natural Resources Canada (Patterson *et al*., 2003) considered alternative scenarios of highway energy use in the two countries to 2050. The study did not produce estimates of cost-effectiveness for greenhouse gas reduction strategies but rather focused on the potential impacts of differing social, economic, and technological trends. Two of the scenarios describe paths that lead to essentially constant greenhouse gas emissions from highway vehicles through 2050 through greatly increased efficiency and biofuel and hydrogen use and, in one scenario, reduced demand for vehicle travel.

INCONSISTENCIES AND UNCERTAINTIES

There are some inconsistencies in the way the three North American countries report transportation carbon emissions. The principal source for Mexican emissions data breaks out transportation into four modes (road, air, rail and waterborne), does not report emissions for pipelines but does report emissions from use of international bunker fuels. The U.S. and Canada report transport emissions in much greater modal detail, by vehicle type and fuel type within modes. The U.S. and Mexico report emissions from international bunker fuels in their national inventory reports while Canada does not. Estimates of international bunker fuel emissions for Canada presented in this chapter were derived by subtracting Air and Waterborne emissions reported by Environment Canada (2005) which exclude international bunker fuels from total air and waterborne emissions as reported by Natural Resources Canada (2006) which include them. Environment Canada reports off-road emissions from mobile sources separately; in the tables and figures in this chapter Canadian off-road emissions have been added to road emissions. Both Canada and the U.S. include emissions from military transport operations in their inventories. It is not clear whether these are included in the estimates for Mexico.

All three countries' greenhouse gas inventories discuss uncertainties in estimated emissions. In general, the uncertainties were estimated in accordance with IPCC guidelines. The U.S. EPA provides only an estimate of a 95% confidence interval for all carbon dioxide emissions from the combustion of fossil fuels (-1% to 6%) which can be inferred to apply to transportation. Mexico's INE estimates a total uncertainty for transportation greenhouse gas emissions on the order of +/- 10%. For carbon dioxide emissions from road transport, the uncertainty is put at +/- 9% (INE, 2003, Appendix B). The Canadian Greenhouse Gas Inventory provides by far the most extensive and detailed estimates of uncertainty. Given the similarity in methods, the Canadian uncertainty estimates are probably also approximately correct for the United States, and therefore may be considered indicative of the uncertainty of North American carbon emission estimates (Table 7-6). Most significant is the apparent overestimation of carbon emissions from on-road vehicles, offset to a degree by the underestimation of off-road mobile source emissions. Still, total mobile source carbon emissions are estimated to have a 95% confidence interval of (-4% to 0%).

Table 7-6. Uncertainty in estimates of carbon dioxide emissions from energy use in transport: Canada 2003.

RESEARCH AND DEVELOPMENT NEEDS

Research needs with respect to the transport sector as a part of the carbon cycle fall into three categories: (1) improved data, (2) comprehensive assessments of mitigation potential, and (3) advances in key mitigation technologies and policies for transportation. The available data are adequate to describe carbon inputs by fuel type and carbon emissions by very broad modal breakdowns by country. Environment Canada (2005) and the U.S. Environmental Protection Agency (2005) annually publish estimates of transportation's carbon emissions that closely follow IPCC guidelines with respect to methods, data sources and quantification of uncertainties (GAO, 2003). The Mexican Instituto Nacional de Ecología has published estimates for 2001 that are also based on IPCC methods. However, that report also notes deficiencies in the data available for Mexico's transport sector and recommends establishing an information system for estimating Mexico's transportation's greenhouse gas emissions on a continuing basis (INE, 2003, p. 21). Knowledge of the magnitudes of GHG emissions by type of activity and fuel and of trends is essential if policies are to be focused on the most important GHG sources.

The most pressing research need is for comprehensive, consistent, and rigorous assessments of the carbon emissions mitigation potential for North American transportation. The lack of such studies for North America parallels a similar dearth of consistent and comprehensive global analyses noted by the Intergovernmental Panel on Climate Change (Moomaw and Moreira, 2001). Existing studies focus almost exclusively on a single country, with premises and assumptions varying widely from country to country. Even the best single country studies omit the impacts of carbon reduction policies on global energy markets. Knowledge of how much contribution the transport sector can make to GHG mitigation at what cost and what options and measures are capable of achieving those potentials is crucial to the global GHG policy discussion.

Continued research and development of vehicle technologies and fuels that can cost-effectively increase energy efficiency and displace carbon-based fuels is essential to achieving major reductions in transportation carbon emissions. Highly promising technologies for reducing transportation GHG emissions include hybrid vehicles, which are available today, and in the future, plug-in hybrid vehicles capable of accepting electrical energy from the grid, and eventually fuel cell vehicles powered by hydrogen. While hybrids are already in the market and fuel cell vehicles are still years away, all three technologies would benefit from cost reduction. Hydrogen fuel cell vehicles also face significant technological challenges with respect to hydrogen storage and fuel cell durability. Technologies exist that could greatly reduce greenhouse gas emissions from other transport modes. For example, blended wing-body aircraft designs could reduce fuel burn rates by one-third. Biofuels in the near term and hydrogen in the longer term appear to be the most promising low-carbon fuel options. To achieve the greatest greenhouse gas reduction benefits, biofuels must be made from plants' lingo-cellulosic components either by conversion to alcohol or by gasification and synthesis of liquid hydrocarbon fuels. Cost reductions in both feedstock production and fuel conversion are needed.

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Table 7-1. Carbon emissions from transportation in North America in 2003

North American Carbon Emissions by Country and Mode, 2003/2001 (Mt C)				
	U.S.A. 2003	**Canada 2003**	**Mexico 2001**	**North America 2003/2001**
Road	399.4	36.7	26.0	462.0
Domestic Air	46.7	1.9	1.8	50.4
Rail	11.7	1.4	0.4	13.5
Domestic Water	15.7	1.6	0.9	18.1
Pipeline	9.5	2.4		11.9
International Bunker	23.0	3.0	0.5	26.4
Off-Road		4.6		4.6
Total	505.9	51.7	29.4	587.0

Sources: U.S. EPA, 2005; Environment Canada, 2005; INE, 2003.
Note: Data for Mexico is 2001, U.S.A. and Canada are 2003.

Table 7-2. Summary of North American transport energy use and carbon dioxide emissions in 2003 by energy source or fuel type

North America energy source	Energy input (Petajoules)	Carbon input (Mt C)
Gasoline	20,923	358.3
Diesel/distillate	7,344	129.5
Jet fuel/kerosene	2,298	68.5
Residual	681	14.5
Other fuels	124	1.3
Natural gas	926	9.7
Electricity	36	0.0
Unalloc./error	466	-
Total	32,798	581.8
United States		
Gasoline	18,520	312.5
Diesel/distillate	6,193	107.1
Jet fuel/kerosene	1,986	62.3
Residual	612	13.1
Other fuels	50	0.2
Natural gas	748	9.7
Electricity	20	0.0
Unalloc./error	466.2	-
Total	28,595.2	504.9
Sources: U.S. EPA, 2005, Tables 3-7 and 2-17; Davis and Diegel, 2004, Tables 2.6 and 2.7.		
Canada		
Gasoline	1,355	26.2
Diesel/distillate	698	13.9
Jet fuel/kerosene	223	4.3
Residual	67	1.3
Other fuels	17	0.2
Natural gas	2	0.0
Electricity	3	0.0
Unalloc./error	0	
Total	2,363	45.9
NRCan, 2006, Tables 1 and 8.		
Mexico		
Gasoline	1,066	19.5
Diesel/distillate	447	8.5
Jet fuel/kerosene	106	1.9
Residual	4	0.1
Other fuels	57	0.9
Natural gas	1	0.0
Electricity	4	0.0
Unalloc./error		
Total	1,685	31.0

Sources: Transportation energy use by fuel and mode from Rodriguez, 2005.

Source: Fulton and Eads, 2004, spreadsheet model, output worksheet.

Data sources differ somewhat by country with respect to modal, fuel, and greenhouse gas definitions so that the numbers are not precisely comparable. Canadian carbon emissions data include all greenhouse gases produced by transportation in CO_2 equivalents, while the U.S. data are CO_2 emissions only. Carbon dioxide emissions for Mexico were estimated by applying U.S. EPA emissions factors to the Mexican energy use data. For Mexico, it is assumed that no transportation carbon emissions result from electricity use.

Table 7-3. Summary of North American transport energy use and carbon dioxide emissions in 2003 by mode of transportation

North America transport mode	Energy use (Petajoules)	Carbon emissions (Mt C)
Road	25,830	463.5
Air	2,667	53.0
Rail	751	13.7
Waterborne	1,386	18.4
Pipeline	990	12.3
	0	23.0
Total	31,624	583.9
United States		
Road		
Light vehicles	17,083	303.8
Heavy vehicles	5,505	95.5
Air	2,335	46.7
Rail	655	11.7
Waterborne	1,250	15.7
Pipeline/other	986	9.5
Internatl./Bunker		23.0
Total	27,814	505.8
Source: U.S. EPA, 2005, Tables 3-7 and 2-17; Davis and Diegel, 2004, Tables 2-6 and 2-7.		
Canada		
Road		
Light vehicles	1,233	23.8
Heavy vehicles	491	12.4
Air	226	4.3
Rail	74	1.6
Waterborne	103	2.1
Pipeline/other		1.8
Total	2,126	46.1
Source: NRCan, 2006; Tables 1 and 8.		
Mexico		
Road	1,518	27.9
Light vehicles		
Heavy vehicles		
Air	107	2.0
Rail	22	0.5
Waterborne	33	0.6
Electric	4	-
Total	1,684	32.0
Source: Rodriguez, 2005.		

Data sources differ somewhat by country with respect to modal, fuel, and greenhouse gas definitions so that the numbers are not precisely comparable. Canadian carbon emissions data include all greenhouse gases produced by transportation in CO_2 equivalents, while the U.S. data are CO_2 emissions only. Carbon dioxide emissions for Mexico were estimated by applying U.S. EPA emissions factors to the Mexican energy use data. Electricity is assumed to produce no carbon emissions in end use.

Table 7-4. Global carbon emissions from transportation vehicles to 2050 by regions, WBCSD reference case projection (Mt C)

	2000	2010	2020	2030	2040	2050
OECD North America	544	623	708	768	824	882
OECD Europe	313	359	392	412	420	428
OECD Pacific	133	142	153	161	169	179
FSU	48	64	88	109	132	153
Eastern Europe	23	28	36	42	52	66
China	69	108	163	225	308	417
Other Asia	98	131	174	220	283	368
India	38	54	80	108	146	203
Middle East	59	71	88	106	122	138
Latin America	95	127	172	216	275	352
Africa	43	58	80	103	127	158
TOTAL - All Regions	1463	1766	2134	2470	2858	3343

Source: Fulton and Eads, 2004.

Table 7-5. Potential impacts of transportation GHG reduction policies in the United States by 2015 and 2030[a] based on the 2000 distribution of emissions by mode and fuel (Greene and Schafer, 2003)

		Reduction potential per mode/fuel (%)		Transportation sector reduction potential (%)	
Management option	**Carbon emission (Mt C) 2000**	**2015**	**2030**	**2015**	**2030**
Research, development and demonstration					
Light-duty vehicles (LDVs)	289	11[b]	38[b]	7[b]	23[b]
Heavy trucks	80	11[b]	24[b]	2[b]	4[b]
Commercial aircraft	53	11[b]	27[b]	1[b]	3[b]
Efficiency standards					
Light-duty vehicles	289	9	31	6	18
Heavy trucks	80	9	20	2	3
Commercial aircraft	53	9	22	1	2
Replacement and alternative fuels					
Low-carbon replacement fuels (~10% of LDV fuel)	27	30	100	2	7
Hydrogen fuel (All LDV fuel)	289	1	6	1	4
Pricing policies					
Low-carbon replacement fuels (~10% of LDV fuel)	27	30	100	2	6
Carbon pricing (All transportation fuel)	489	3	6	3	6
Variabilization (All highway vehicle fuel)	370	8	12	6	9
Behavioral					
Land use and infrastructure (2/3 of highway fuel)	246	5	10	3	5
System efficiency (25% LDV fuel)	72	2	5	0	1
Climate change education (All transportation fuel)	489	1	2	1	2
Fuel economy information (All LDV fuel)	289	1	2	1	1
Total	**489**			**22**	**48**

Notes:

[a]Carbon emissions for the year 2000 are used to weight percent reductions for the respective emissions source and example policy category in calculating total percent reduction potential. The elasticity of vehicle travel with respect to fuel price is –0.15 for all modes. Price elasticity of energy efficiency with respect to fuel price is –0.4.

[b]R&D efficiency improvements have no direct effect on total. Their influence is seen through efficiency standards impacts.

Policies affecting the same target emissions, such as passenger car efficiency, low carbon fuels, and land use policies are multiplicative, to avoid double counting [e.g. (1–0.1)*(1.0–0.2) = 1–0.28, a 28% rather than a 30% reduction.]

Table 7-6. Uncertainty in estimates of carbon dioxide emissions from energy use in transport: Canada 2003

Mode	**% Below (2.5th Percentile)**	**% Above (97.5th Percentile)**
Total Mobile Sources excluding pipeline	-4	0
Road Transportation	-8	-3
On-Road Gasoline Vehicles	-7	-3
On-Road Diesel Vehicles	-13	-1
Railways	-5	3
Navigation	-3	3
Off-Road Mobile Sources	4	45
Pipeline	-3	3

Source: Environment Canada, 2005, table A7-9.

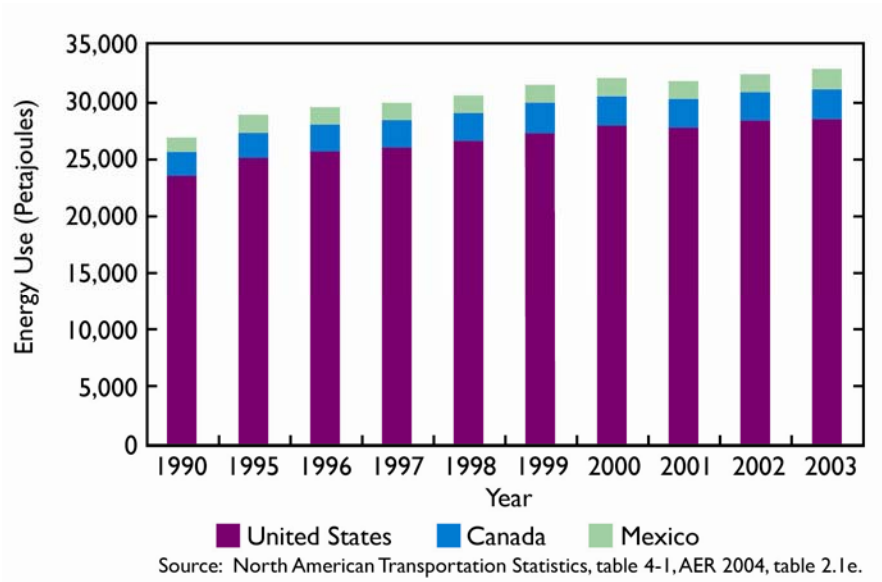

Fig. 7-1. Transportation energy use in North America, 1990–2003.

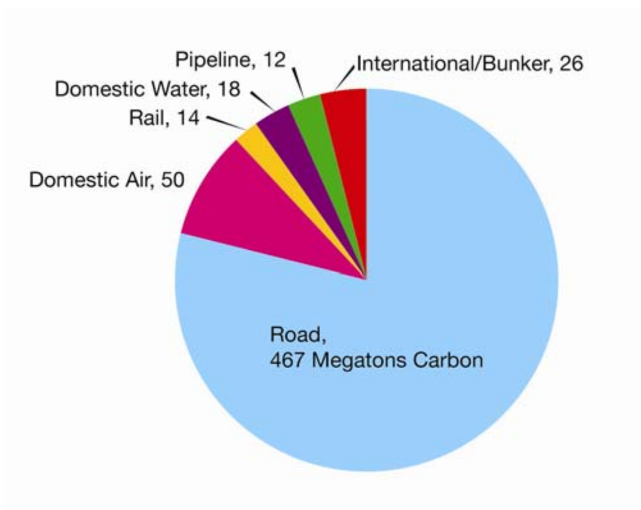

Fig. 7-2. North American carbon emissions from transportation by mode; U.S.A and Canada 2003, Mexico 2001. *Sources*: U.S. EPA, 2005; Environment Canada, 2005; INE, 2003.

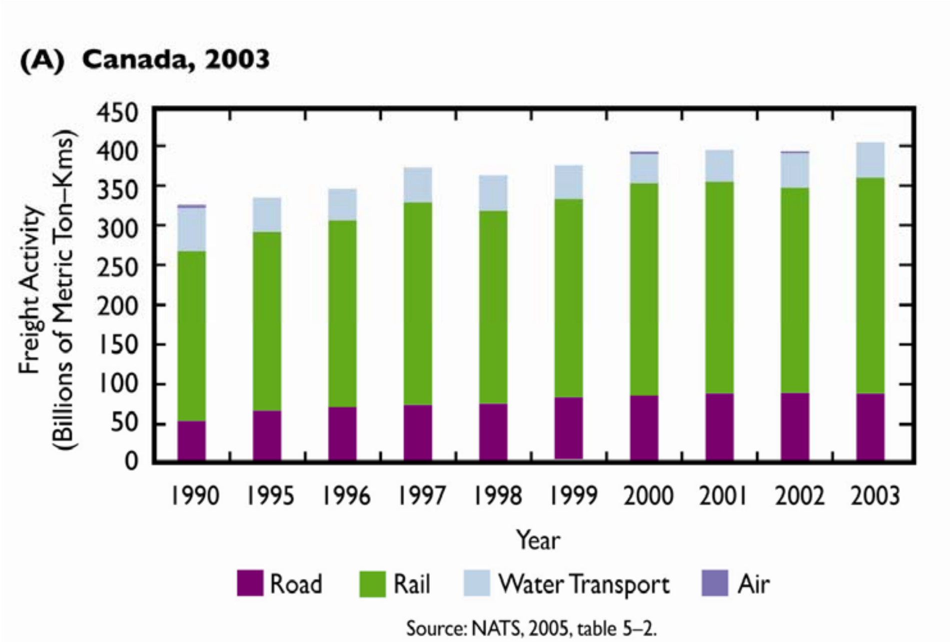

Fig. 7-3A. Freight activity by mode in Canada.

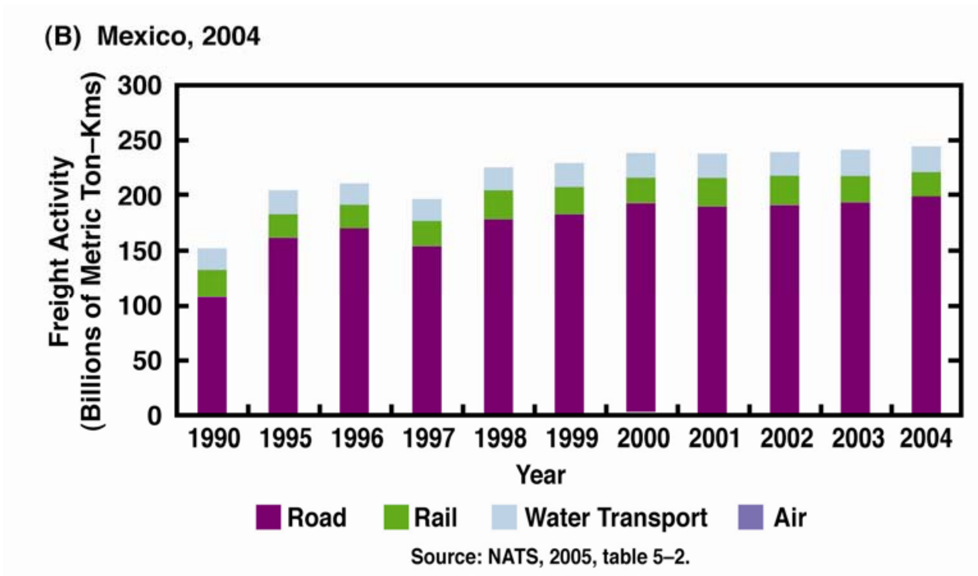

Fig. 7-3B. Freight activity by mode in Mexico.

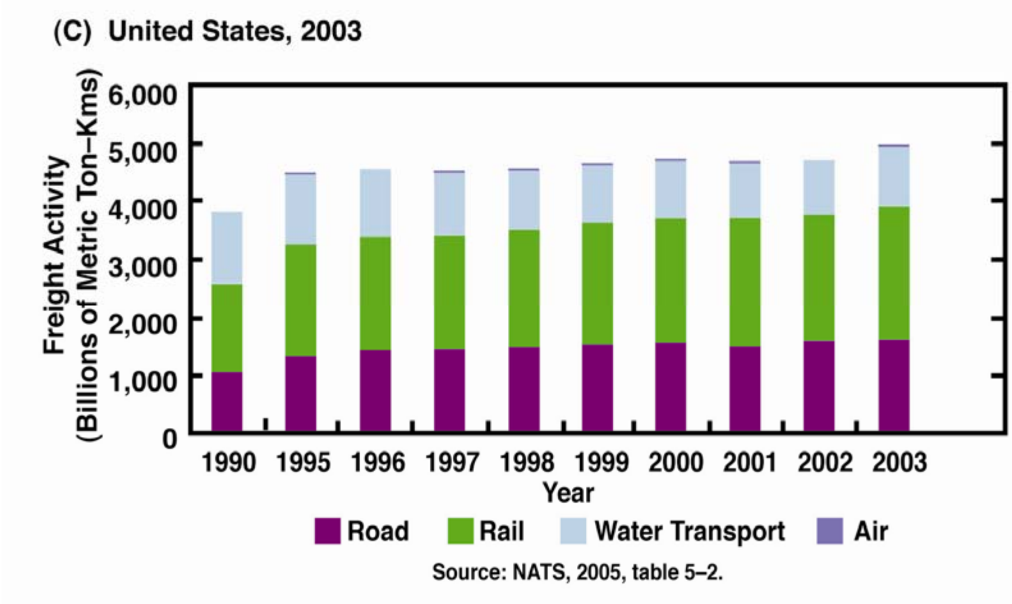

Fig. 7-3C. Freight activity by mode in the United States.

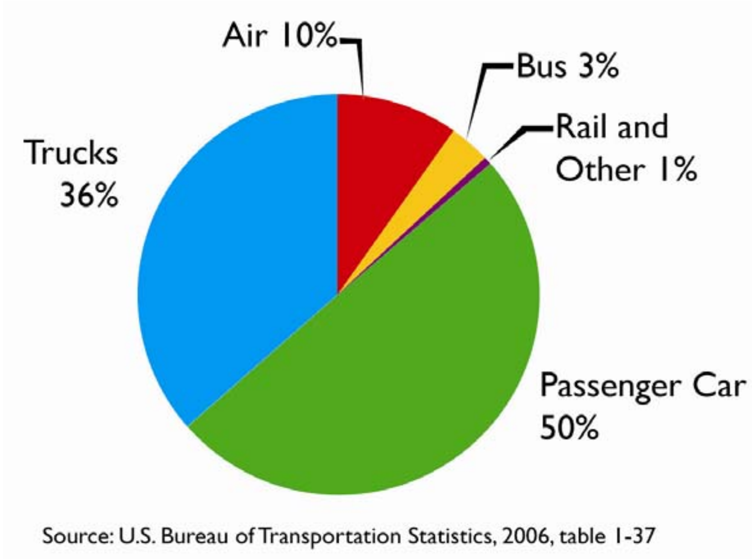

Fig. 7-4A. Distribution of passenger travel in the United States by mode.

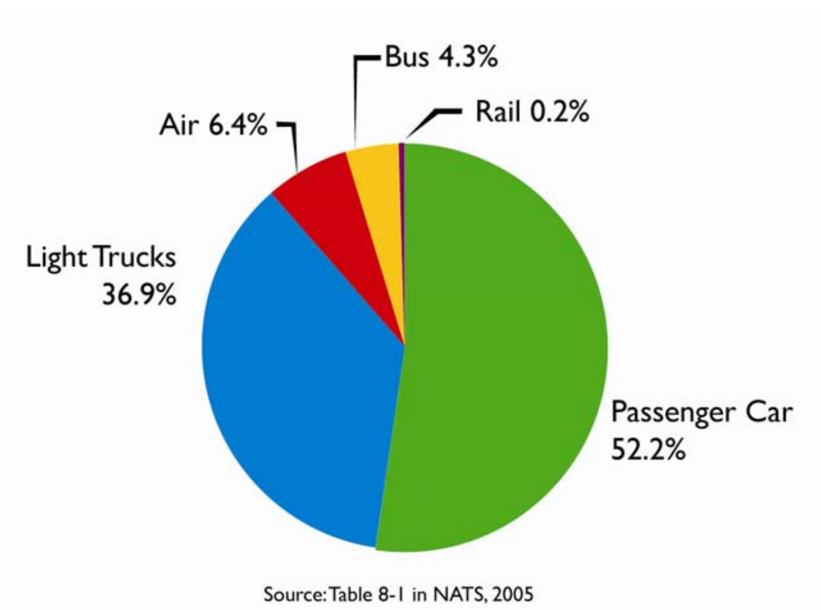

Fig. 7-4B. Distribution of passenger travel by mode in Canada. *Source*: Table 8-1 in NATS, 2005.

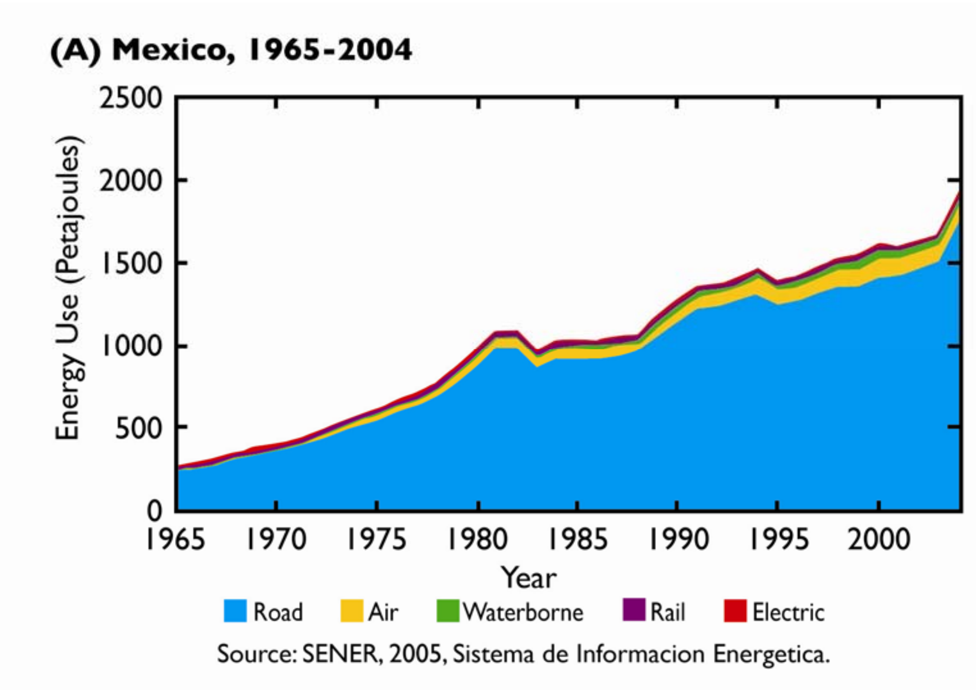

Fig. 7-5A. Evolution of transport energy use in Mexico.

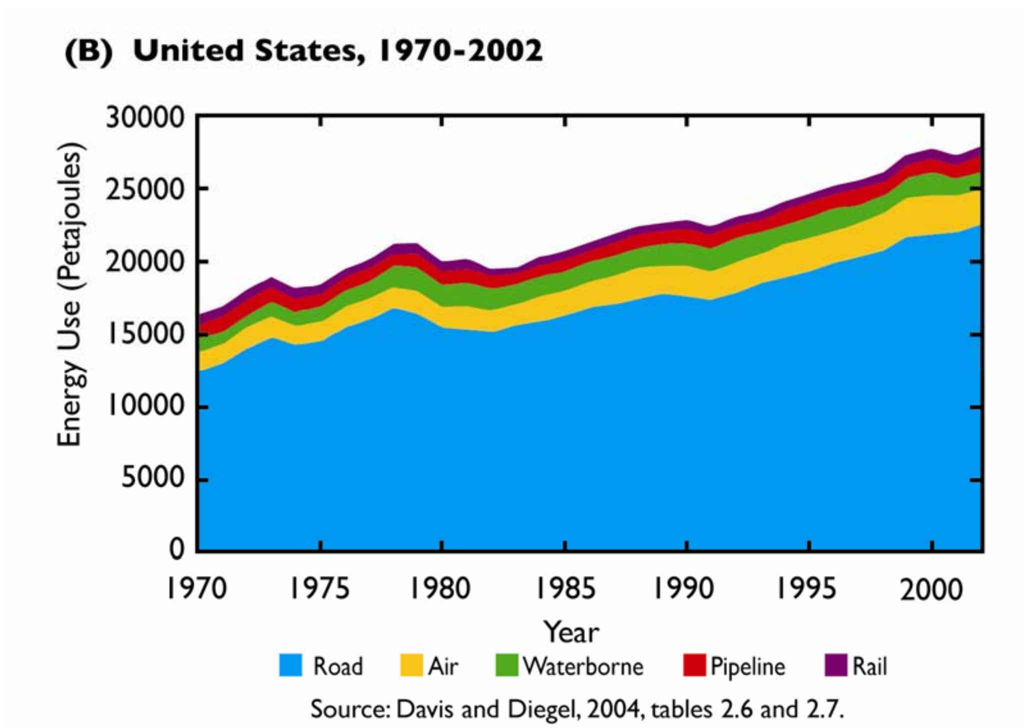

Fig. 7-5B. Evolution of transport energy use in the United States.

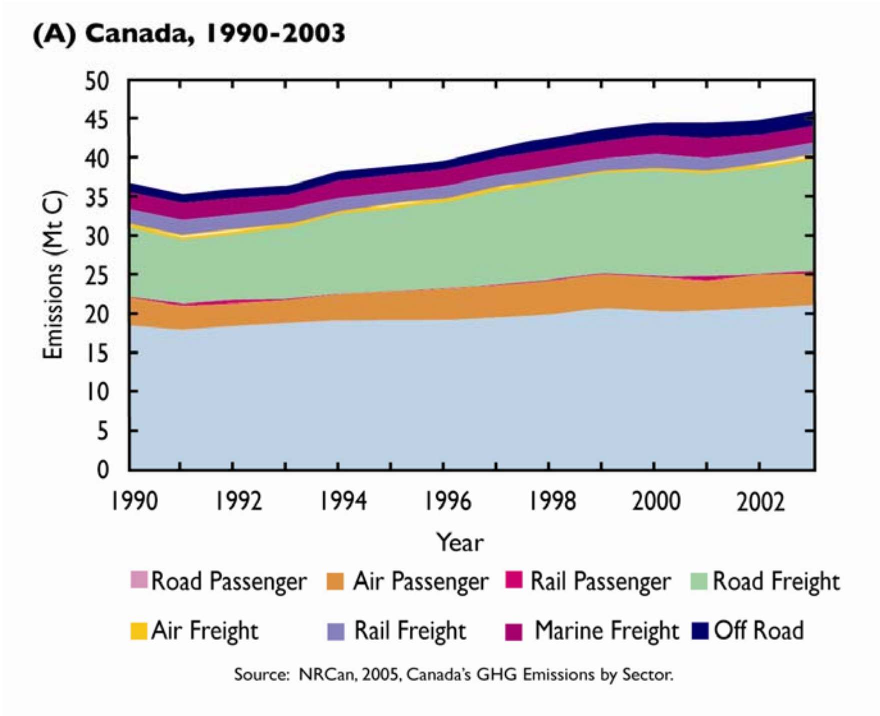

Fig. 7-6A. Transport CO_2 emissions in Canada.

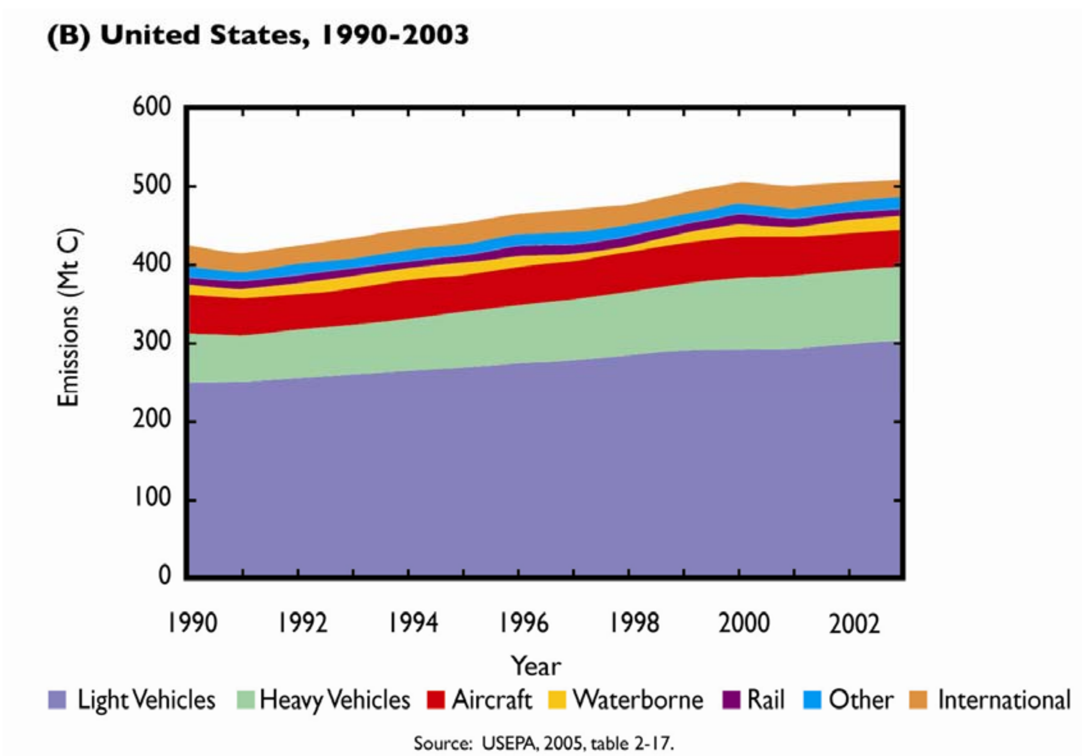

Fig. 7-6B. Transport CO_2 emissions in the United States.

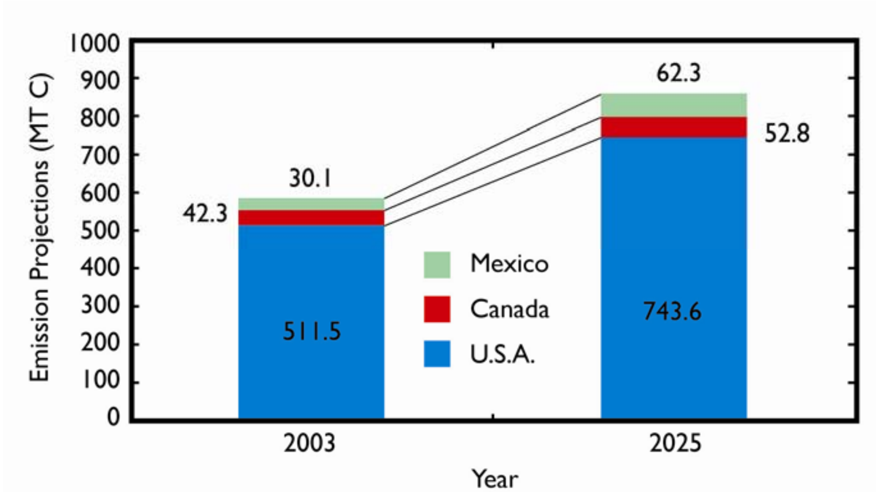

Fig. 7-7. Projected carbon dioxide emissions from the North American transport sector in 2025, based on EIA IEO 2005 reference case. *Source*: U.S. DOE Energy Information Administration, 2005b.

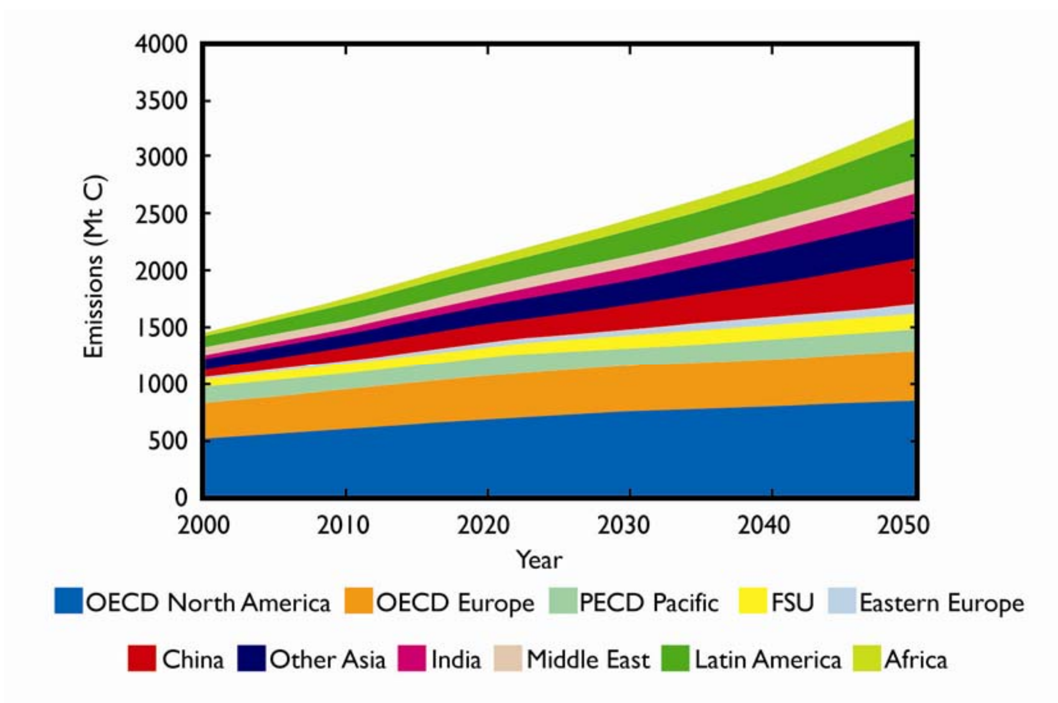

Fig. 7-8. WBCSD projections of world transportation vehicle CO_2 emissions to 2050. *Source*: Fulton and Eads, 2004.