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Energy End-Use: Transport

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Executive Summary

The world's demand of fuels for transportation has multiplied over the last decades due to the concurrent fast expansion of population, urbanization, and global mobility. The global transport sector is responsible for 28% of total final energy demand. The majority of the energy used in transportation – 70% – is utilized on the movement of passengers and goods on roads locally, nationally, and across regions. Transportation weighs heavily on climate, energy security, and environmental considerations, as 95% of transport energy comes from oil-based fuels. Transportation is the cause of other critical challenges due to its supporting role in local and global economies, as well as the implications of increasing transportation on human health and social interactions. The immense and multi-faceted challenges of a global transportation system deeply rooted in fossil fuels are compounded by the quickly evolving aspirations of a worldwide population that is increasingly on the move and has learned to regard mobility, in particular by motorized modes, as an important component of the modern lifestyle they have or are seeking to attain.

This chapter evaluates the roots of these challenges and outlines the options for a feasible major transformation of the global transportation system over the next 30–40 years. The goal of this transformation is the development of a robust path for the consolidation of transportation systems around the world that can deliver the mobility services needed to support growing economic and social activity while also creating the conditions for enhanced energy security, rigorous climate change mitigation, improved human health, better environment, and urban and social sustainability. This approach is in line with the GEA normative understanding of the consensus embodied in international negotiated agreements and plans of action, and in the more generally accepted aspirations of the international community. The goals of transforming transportation presented in this chapter cut across technical, planning, and policy issues of interest to public and private sector stakeholders and decision makers. A summary of key findings from the assessment are:

- The transformation of transportation systems locally and globally must start now. Time is of the essence. Immediate steps must be taken to define a multi-goal, multi-level, and multi-actor framework of action to identify context-specific “levers of change,” or areas that are subject to policy intervention and can help sustain a positive rate of change for this transformation. Achieving multiple goals is possible, as transportation impacts all other areas in society. This will require strengthening institutional capacity and the consolidation of knowledge-based decision support systems to inform policy and decision making about impacts, cost, benefits, and potential trade-offs. The strengthening of institutional capacity will be necessary to deal with solutions that require merging concepts to improve energy and transport systems interaction, technology, urban and regional spatial planning, infrastructure development, and economic and social innovation.
- To remain consistent with the GEA multiple objectives, the transformation of the transport sector, requires that oil products peak before 2030 and are phased out over the long term. This is made possible in the medium term by adopting a policy mix to minimize fossil fuel use in transport, as well as rapidly introducing alternative sources such as renewable-based electricity transportation technologies. Technological choice and lifestyle changes in the long term are more uncertain and depend critically on the nature and direction of technological breakthroughs, but they must be made with the intention of complementing policies and in consideration of future climate impacts.
- Transportation goals for reducing fossil fuel consumption need to be pursued while simultaneously increasing and maintaining the provision of satisfactory economical and social levels of transportation services. Technological improvement is vital, but it is equally important to secure a timely and uninterrupted policy and decision making framework for action. This policy framework is necessary to establish clear conditions so that investments can be planned. Similarly, this framework should also provide context-specific feasibility information to assess local opportunities for creating a sustainable interaction between the transport and energy systems. The framework must also adequately assess conditions for the provision of a diversified set of choices and intelligent mobility services that can improve the efficiency of the transportation network for passengers and goods within all cities and regions.

- The many chances available today for improving conventional technologies require sustained attention. Enhancing the energy efficiency of all modes of transportation can help reduce transport fossil fuel use. Increasing efficiency can be effectively and immediately pursued through widespread adoption of current best available technologies and practices. In the longer term, this can be achieved through the subsequent systematic and comprehensive adoption of a range of new vehicle and other modal technologies. For example, introducing incremental efficiency technologies, improving drive train efficiency, and recapturing energy losses and reducing loads (e.g., weight, rolling, and air resistance and accessory loads) on the vehicle can approximately double the fuel efficiency of “new” light-duty vehicles by 2050. Fuel economy standards have been effective in reducing fuel consumption, and therefore should be tightened and adopted worldwide. The overall effectiveness and political feasibility of standards can be significantly enhanced if combined with fiscal incentives and consumer information. Taxes on vehicle purchase, registration, use, and motor fuels, in combination with the revamping of road and parking pricing policies, can influence vehicle energy use and emissions.
- The fuel efficiency of aviation can be improved by a variety of means, including technology, operation, and management of air traffic. Technology developments might offer a 40–50% improvement by 2050. As aviation’s growth rate is projected to be the highest of the transport subsectors, such improvements will not be enough to keep energy use from increasing.
- In the maritime sector, a combination of technical measures could reduce total energy use by 4–20% in older ships and 5–30% in new ships by applying state-of-the-art knowledge, such as hull and propeller design and maintenance. Reducing the speed at which a ship operates brings significant benefits in terms of reduced energy use. For example, cutting a ship’s speed from 26 to 23 knots can yield a 30% fuel saving. A similar rationale can be applied to aircraft. Improving the efficiency of aircraft on a global scale is essential.
- Reducing the use of fossil fuel energy in transport can potentially be achieved through the adoption of alternative energy sources such as advanced biofuels, fuel cells, and electric vehicles. Most of the barriers relate to cost, although there are also substantial performance barriers, especially for advanced batteries and infrastructure. Strong policies can ensure rapid uptake and full use of these technologies and will require encouraging sensible changes in lifestyle and behaviors. Life cycle assessment (LCA), together with social and environmental impact assessments, are useful tools to establish a level playing field comparison between different technologies. Significant uncertainties corresponding to modeling choice of system boundaries and modeling assumptions prohibit straightforward policy implications – especially in the case of biofuels. The future biomass potential strongly depends on production efficiency, the development of advanced techniques, costs, and competition with other uses of land. Current biofuels development needs to resolve its many sustainability challenges. Advanced biofuels are considered to have much greater potential for the future, not only for road transport but also for aviation and shipping.
- Electricity produced from renewable sources can provide a significant stronghold for the global transformation of the transportation system. Plug-in hybrid electric vehicles (PHEVs) allow for zero-tailpipe emissions for small vehicle driving ranges, e.g., in urban conditions. Hybrid electric vehicles (HEVs) can improve fuel economy by 7–50% compared to comparable conventional vehicles, depending on the precise technology used and driving conditions. All-electric or battery-powered electric vehicles (BEVs) can achieve a very high efficiency (up to four times the efficiency of an internal combustion engine vehicle) but have a low driving range and short battery life. If existing fuel-saving and hybrid technologies are deployed on a broad scale, significant fleet-average fuel savings can be obtained within the next decade. Increasing the performance of high-energy batteries for PHEVs could subsequently lead to higher market penetration of BEVs. Hydrogen fuel cell vehicles (FCVs) could alleviate the dependence on oil and reduce emissions significantly. For BEVs and FCVs, the emissions are determined by the production of hydrogen and electricity. Further technological advances and/or cost reductions would be required in fuel cells, hydrogen storage, hydrogen or electricity production with low- or zero-carbon emissions, and batteries. Substantial and sustained government supports are required to reduce costs further and to build up the required infrastructure.

- Reducing transport energy use can also be achieved by favoring those modes that are less energy-intensive, both for passenger and freight transport. Strong local and regional urban planning policies, practices, and implementation should aim to enhance the diversification and quality of public modes of transport. Spatial local plans aimed at reducing both the need for travel and the distances traveled can reduce energy demand and also improve the quality of urban life through improved accessibility, affordable mobility services, and improved traffic safety. In cities worldwide, a combination of push and pull measures and traffic demand management can induce a modal shift from cars to the more prevalent use of public transit and cycling, which has multiple benefits. In particular, use of non-motorized transportation (NMT) can improve the efficiency of the transport system and overall people's health. Parking policies and extensive car-sharing options can become key policies to reduce the use of private cars. Cities can be planned more compactly, with less urban sprawl and a greater mix of land uses and local markets. Neighborhood design and street layout can encourage walking and public transport access to schools, hospitals, shopping centers, and other places that attract people on a regular basis. Employers in many sectors can locate themselves strategically, with the goals of enhancing the job-housing balance for their employees and providing incentives for substituting non-essential work-related travel with information and communication technologies.

9.1 Introduction: Transportation and Energy – A Global Perspective

Broad accessibility to services, people, and goods is an essential and basic human need and a precondition to economic well-being in modern societies. The petroleum-fueled motor vehicle and the airplane are technologies that have presented opportunities for greatly increased mobility, flexibility and reduced travel times. Automobility, as a self-reproducing system, has created unprecedented flexibility and fostered profound changes in lifestyles and in the physical landscape of cities worldwide (Whitelegg, 1997; Urry, 2007). The enhanced potential for travel created by these transport innovations resulted in an unprecedented rate of growth of the volume of personal travel and the volume of goods moved (WBCSD, 2002; Schäfer et al., 2009; Sperling and Gordon, 2009).

At the close of the 20th century, the world witnessed both unprecedented urbanization in the developing world and the suburbanization of many cities in the developed world (for more, see Chapter 18). Motorized forms of mobility, particularly automobility, were favored as the principal means for personal and social accessibility in urban areas. Along with technological shifts and economic development, transport activities scaled up in distance and participants. This growth, and the reliance on individual motorized forms of urban transport, has resulted in many local social and environmental consequences, including congestion, air pollution, noise, olfactory and visual intrusion, disruption of ecosystems and landscapes, water and soil degradation, ozone depletion, social and urban fragmentation, road deaths and injuries, asthma, and obesity (Rothengatter, 2003; Whitelegg and Haq, 2003; Gilbert and Pearl, 2007, Schäfer et al., 2009).

The scale of growth in the movement of people and goods around the globe has been immense. But not all populations and geographic regions have participated evenly in the technological advances that facilitated this development. The average citizen in wealthy nations and urban areas can travel faster and further than ever before and overcome long distances in comfortable and reliable ways (van Wee et al., 2006). Conversely, average citizens in poor nations, living in areas with differentiated urban growth characterized by large differences in income levels and social disparities, face hurdles to meet their most basic transportation needs. These citizens witness an urban transport situation that, for the most part, is unbearable and only deteriorates over time (Newman and Kenworthy, 1999; Gwilliam, 2005; Tiwari, 2006; Figueroa, 2010).

The global expansion of mobility encompasses great innovations that have linked transportation and intelligent communications systems, transforming the way in which people organize their travel and communication considerably. The interplay of these systems has redefined the core of social interaction and urban life (Castells, 2001; Sheller and Urry, 2003; Castells 2004). The evolving transport mobility of the last century has converged into a dynamic system that includes new forms of virtual communications and is firmly rooted in a number of key components,

including motorized modes and the automobile, aviation, rail, ships and oil industry, consumerist lifestyles, energy and environmental resource use, global procurement of oil, spatial and infrastructure planning, urban and street design, and societal values that embrace mobility as part of what constitutes high quality of life standards (Urry 2004; 2007).

As economies grow, transport activity continues to increase around the world. In many areas of the developing world where globalization is expanding, trade flows and personal incomes are rising, leading to an increased demand for enhanced personal mobility. Mobility of people and goods has significant global economic benefits. A prime example is global travel for tourism, which constitutes the largest industry in the world. It is worth US\$6.5 trillion and directly and indirectly accounts for 8.7% of world employment and 10.3% of world gross domestic product (GDP) (Urry, 2007).

9.1.1 The GEA Approach to Transportation and Energy: Acting on Multiple Goals to Realize Multiple Benefits

An efficient transportation system is crucial for economic development and an asset for the growing integration of international markets. This assessment follows GEA's normative approach in highlighting the necessity of realizing certain concrete goals that reflect part of the shared aspirations of the international community. These goals are related to economic growth and equity, improved environmental health, climate change mitigation, and enhanced energy security (see Chapters 2–6, as well as Chapter 17, for more detailed definitions). This assessment asserts that a global transformation of the transportation and other energy-using systems can help meet the major GEA goals. A complementary relationship exists between these goals, as summarized in Table 9.1. Two premises follow this approach. First, to meet the larger objectives, multiple goals must be addressed simultaneously and effectively. Strong and immediate actions need to be initiated and sustained at different scales to effectively achieve a radical, global transformation of the transportation and energy systems. Secondly, as transportation is deeply linked to other sectors, actions undertaken to achieve one goal can have directly calculable, and also unintended, effects on the other goals (Goodwin, 2003). Multiple benefits can be calculated in reference to how policies that promote clean air, walking and biking can contribute to control obesity, limit chronic disease and reduce air pollution emissions including greenhouse gases (Alliance for Biking & Walking, 2010; Nazelle et al., 2011). Facilitating walking and biking creates benefits for improved accessibility and energy security. Consequently, extensive follow up assessments to policy implementation are necessary to adequately measure these ripple effects. A framework that clearly outlines the multiple goals and benefits of a sustainable transformation can offer a variety of options and policy leverages for major stakeholders, governmental or otherwise, to take direct and immediate action. The policies, actions and actors are context dependent, but the long-term goals and expectations for this transformation are then made clear.

Table 9.1 | GEA framework for sustainable transportation multiple goals and benefits.

GEA systemic goal for Transport	Multiple goals and benefits of sustainable transportation systems (a)	Indicative approach to assess progress toward goal
Economic Growth and Equity	Functionality, Efficiency	Reduced travel time, cost and uncertainty, secures operationality and resilience
	accessibility	ease of reaching opportunities throughout the urban area (jobs, shops, medical and social activities); reduced access time, travel cost, and trip uncertainty
	affordability	% of income used to pay for transport services (<20%)
	acceptability	public acceptability; participation in decision-making process
Health and Local Ecosystems Protection	road safety	reduction of traffic deaths and injuries
	universal access	access provided for the elderly, very young, and people with disabilities
	personal physical activity	increased public health benefits from more physical activity
	reduce air pollution	air pollution reduction and public health benefits of reduced air pollution
	reduce noise	noise reduction
Climate Change	reduce GHG	GHG mitigation
Energy Security	diversification of fuel sources	use of alternative fuels
	independence from fossil fuels	% reduction in use of fossil fuels

(a) The general GEA goals for the global energy system are here adapted in attention to the specific services and goals that transportation systems deliver.

This multi-goal, multi-benefit approach aligns with the early approach labeled as co-benefits or ancillary benefits in the literature. It requires that a transport system is not only devised with the aim of maximizing mobility, but is also concerned with reaching other goals simultaneously. The concept of co-benefits has been pushed mostly in combination with climate change mitigation goals (Krupnick et al., 2000; Anun et al., 2004; Bollen et al., 2009; Nazelle et. al., 2011), and has been applied particularly to urban transport (Creutzig and He, 2009; Bongardt et al., 2010; Creutzig et al., 2011b; UNEP, 2011), serving as the foundation for the systematic assessment of future scenarios and policy instruments.

Climate change mitigation is an important driver of envisaged improvements to transport systems. Fortunately, appropriate policies can be designed such that actions to reduce greenhouse gas (GHG) emissions also deliver other environmental and social benefits (EEA, 2008a). In addition to climate change mitigation, sustainable transportation solutions must also consider the multiple goals listed in Table 9.1. This perspective is also presented in other studies (EEA, 2008a, EEA, 2008b; Creutzig and He, 2009; Bongardt et al., 2010). The multi-goal, multi benefit approach maintains that meeting the social needs of growing urban populations requires affordable transportation services that efficiently facilitate accessibility to work, study, and leisure activities, and suggests that this can be designed with attention to operational efficiency to support economic development, low-carbon, energy security and environmental goals and for improving social and healthy living.

9.1.2 Overview of Energy use in Transportation

The concurrent fast expansion of population, urbanization, and global mobility has multiplied the world’s demand for fuels for transportation and city-wide energy services. As shown in Figure 9.1, energy use in the transport sector in 2007 was high, 28% of total final energy use.

During the last several decades, the energy use of transport sectors in both Organisation for Economic Co-operation and Development (OECD) and non-OECD countries have increased substantially, as shown in Figure 9.2. In developing countries, the increase in recent years has become more prominent due to rapid urbanization and motorization. And, although a major increase in energy use was caused by road

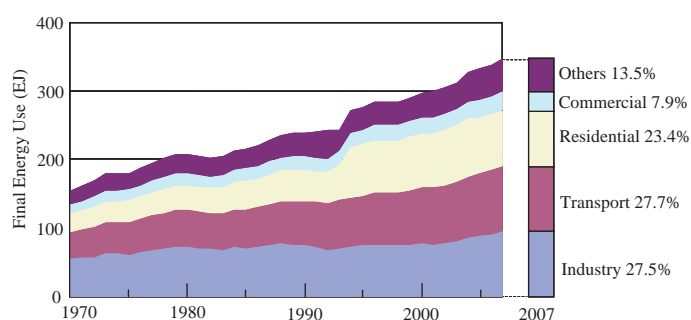


Figure 9.1 | Global energy use in various end-use sectors (others include agriculture/forestry, fishing, and non-energy use). Source: based on IEA, 2009b.

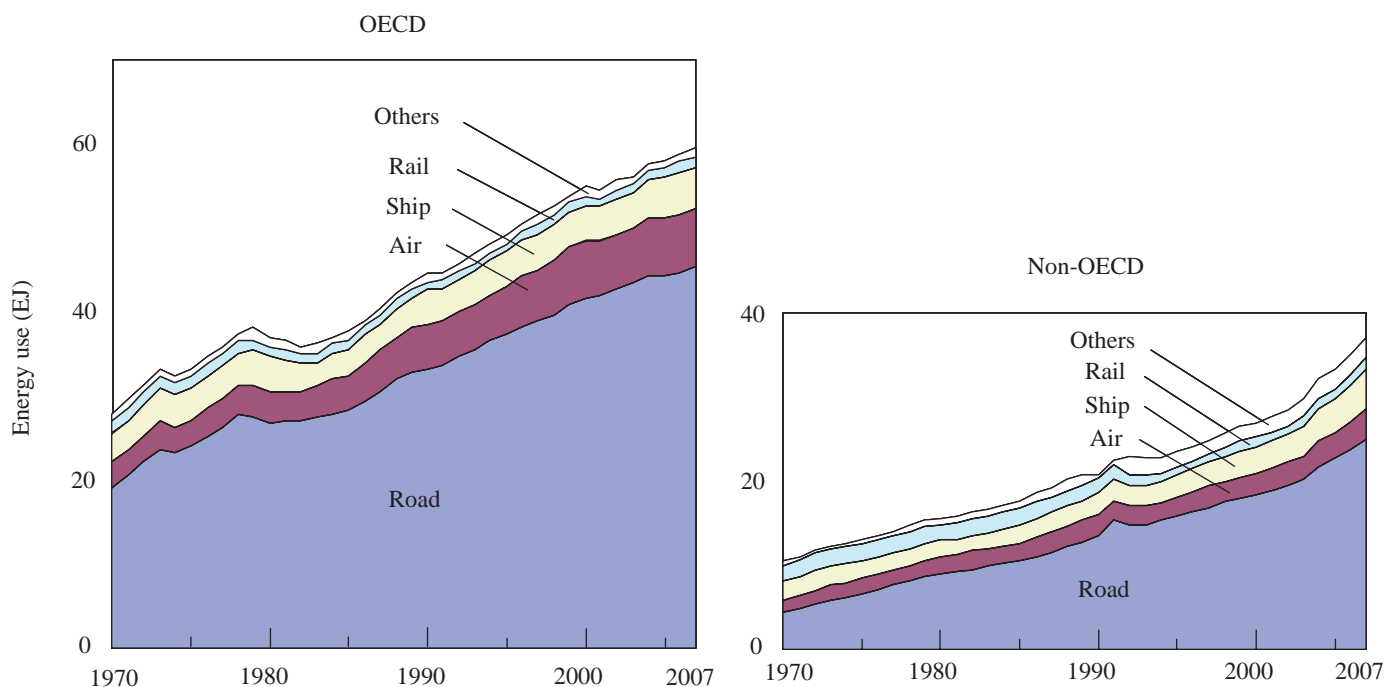


Figure 9.2 | Transport energy use in OECD and non-OECD countries by mode (others include pipeline and non-specified). Source: based on IEA, 2009b.

transport, the actual phenomenon of motorization is quite different between OECD and non-OECD countries. Non-OECD countries started later and still show motorization rates significantly below OECD countries. However, the speed of their concurrent urbanization and motorization is unrivalled, especially in China, and puts significant demands on adapting transport infrastructures.

A single fossil resource- petroleum- supplies 95% of the total energy used by world transport. This dependence results in two major areas of global concern: the long-term security of energy supplies and the fast-rising contribution of the transport sector to greenhouse gas (GHG) emissions (IEA 2009a; Stern, 2007). The carbon dioxide (CO₂) emissions and energy use of different transport sub-sectors are proportional (see Figure 9.3.).

The transport sector has the highest rate of growth in energy use and related CO₂ emissions of all final end-user sectors. This rate is expected to increase up to 1.7% a year between 2004 and 2030 (IEA 2009a).¹ In 2007, the global transport sector produced 6.6 GtCO₂ emissions, corresponding to 23% of world energy-related CO₂ emissions and, road transport, mostly passenger transport, accounts for 73% of this total.

A much higher rate of growth of 3.7%/year (between 1990–2003) corresponds to freight transport, this trend is expected to continue (see Figure 9.4) (McKinsey Global Institute, 2009).

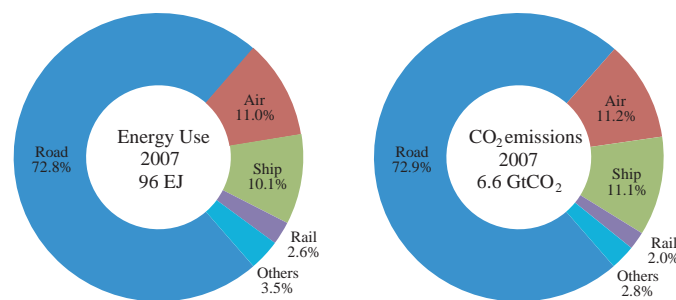


Figure 9.3 | Modal share of global energy use and CO₂ emission in transport sector (2007). Others include pipeline transport and non-specified use. Source: based on IEA, 2009a; 2009b.

Urbanization has been extremely rapid in the past 60 years, with a 2.6% annual average growth rate (UN, 2009). More than half of the world now lives in urban areas (UN, 2007; UN, 2008). In 2010, twenty one cities reported having a population over 10 million compared with two cities in 1950 (UNDP, 2010). Rapid growth in suburban areas and the rise of “edge cities” in the outer suburbs has been a common form of development facilitated by the rise of personalized motor transportation (see Chapter 18). The greater distances replicated through the low-density development discourage walking and bicycling as a share of total travel and are not easily served by public transport (WBCSD, 2002; 2009). A growing demand for travel and a declining share in the use and quality of public transportation services have been the observed result across developed and developing cities alike (Gwilliam, 2005; Tiwari, 2006, Hidalgo and Carrigan, 2010; Buehler and Pucher, 2011).

¹ Transport appears to be the highest energy-using sector in Figure 9.1 because the buildings sector is divided into residential and commercial.

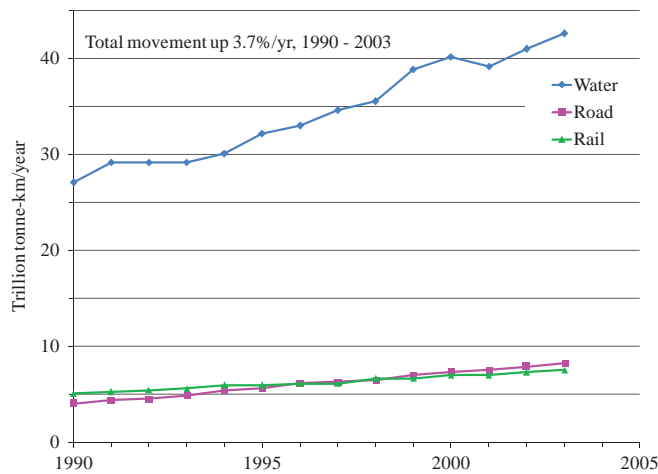


Figure 9.4 | Global freight movement in trillion tonne-km/year (t-km/yr). Source: Gilbert and Pearl, 2007.

The rapid motorization of many of the world cities has not been a global phenomenon. Many low-income urban areas in developing countries do not even have access to motorized public transport services of any sort (Tiwari, 2006; Vasconcellos, 2010). In developing country rural areas in sub-Saharan Africa, but also in parts of Asia and Latin America, walking more than 10 km/day each way to collect water or fuels, work on farms, and attend schools and health services is not unusual. Walking can be also prevalent for the urban poor, when commuting by public transport becomes very costly. For example, commuting accounts for 14% of the income of a poor family in Manila compared with 7% of the income of a higher income family in the same city (World Bank, 1996; Gwilliam, 2002).

The extent of global motorization explains only part of the increasing trends in energy use and carbon emissions from transport worldwide. Other contributing factors relate to consumer preferences for larger, heavier and more powerful passenger vehicles, particularly in the industrialized world, which have resulted in larger energy use for transport, despite the sustained technological improvement on car fuel efficiency attained on new passenger vehicles during the last decades. By 2008, more than half of all vehicles purchased in the United States were SUVs (sport utility vehicles) or light trucks. A weight reduction of the average car sold in the United States to European levels would bring about a 30% reduction in fuel intensity (Schipper, 2007). The average fuel economy of the new light-duty vehicle (LDV) fleet² in the United States in 2005 would have been 24% higher had the fleet remained at the weight and performance distribution it had in 1987 (Khan Ribeiro, et al., 2007). In addition a drop of fuel consumption rates of more than 1%/year would have resulted during

2 In the United States, fuel economy refers to the number of miles (distance) travelled/gallon of fuel (miles/gallon). The expected trend is for fuel economy to increase. In Europe, and elsewhere, the equivalent metric is the fuel intensity measured in liters of fuel used/100 km (liters/100 km); the expected trend is for the fuel intensity of the vehicle fleet to decrease over time.

that same period, contrary to the fast rate of increase that has continued until today. (Heavenrich, 2005; Sperling and Gordon, 2009).

Another contributing factor is the switch to relatively faster speed modes of travel, particularly motorized vehicles and air transportation, which has led to an increase in the total yearly distance travelled (Schäfer, 2000). The switch to faster speed modes has been facilitated by a considerable decline in the share of income spent in transportation during the last decades (Berri et al., 2010). Faster modes and larger transport infrastructural investments enabled the expansion of urban areas and the process of suburbanization, allowing people to maintain the average time budget for their daily travel roughly constant (van Wee et al., 2006). Simultaneously, increasing income allowed commuters to choose the more expensive modes, e.g., motorized vehicles. In developing countries, where income increases have been less significant, a relative decrease in car purchase cost in the early 1990s, and a relaxation of restrictions or even the imposition of minimal restrictions on imports of second-hand cars has sustained a progressive diffusion of motorized modes of transport (Berri et al., 2010). Countries with different land use and transportation policies, including fuel prices, have different rates of auto mobility per unit of GDP per capita (Millard-Ball and Schipper, 2011; see Figure 9.5). Vehicle use (km per capita) differ for example between the United States and Japan by a factor of about 3 (Schipper, 2009).

If these historic trends continue, there will be a vast worldwide expansion of motorization and a resulting increase in fossil fuel use and GHG emissions from transport. The local impacts of congestion, noise, air pollution, health, safety, and energy security are of immediate concern. Globally, climate change – the atmosphere’s sink capacity – and limited resources pose huge inter-temporal challenges. However, as the least developed areas become economically mature and their populations’ incomes rise, the evidence suggests that individuals will tend to favor private motorized vehicles. This is in part because these vehicles promise to provide a faster and more flexible, convenient, and reliable form of travel than the available local and intercity public transport, but it is also because the car’s

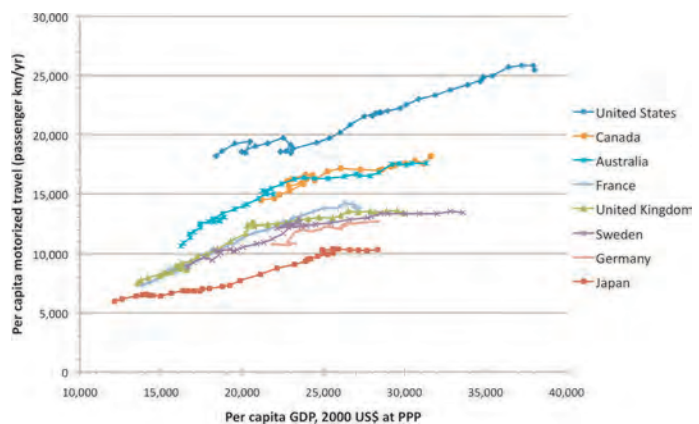


Figure 9.5 | Passenger motorized travel in some OECD countries. Passenger travel levels off with income. Developing countries, such as China and India (see Figure 9.8) start from low levels but are rapidly motorizing. Source: Millard-Ball and Schipper, 2011.

attractiveness and seductiveness is deeply embodied in the culture and psychology of modernity (Whitelegg, 1997; Thomsen, et al., 2005; Urry, 2007). The car industry is strategically positioned in quickly emerging markets, notably in China and India, to tempt these new potential customers with simpler and affordable models (Sperling and Gordon, 2009).

In addition, the largely unregulated massive scale importation of used vehicles to developing countries, and the fact that these vehicles are kept running with great ingenuity for longer than the manufacturer's estimated lifetime, aggravates the energy requirements, local environmental problems, and carbon emissions contributions from the sector. Finally, a number of influential converging factors such as economic policies that maintain fuel subsidies and planning practices that incentivize suburban residential developments, large malls, and retail centers with extensive free parking all can play an important role in increasing motorization and energy use in transport.

The world auto fleet increased from about 50 million vehicles in 1950 to 580 million vehicles in 1997 (WBSCD, 2002). China's vehicle sales have already overtaken car sales in the United States by a huge margin increasing from 2.4 million in 2001 to around 17 million by 2010 (ADB, 2009). Two-wheeled scooters and motorcycles are important in the developing world and in parts of Europe. (WBSCD, 2002; Tiwari, 2006; Zegras and Gakenhaimer, 2006; ADB, 2009).

Non-motorized transportations (NMTs) are dominant in developing countries. Walking accounts for 20–40% of all trips in many cities (WBSCD, 2002), while bicycles are important means of transportation in Asia and also in industrialized cities like Amsterdam and Copenhagen. Research and data for walking and cycling pale in comparison to research on motorized transport (Methorst et al., 2010).

Public transportation, especially buses, though declining in share in favor of private cars in the industrialized world and some emerging economies, have a high modal share elsewhere. For example, it is estimated that buses make up 61% of the motorized trips in Santiago, Chile (Estache and Gómez-Lobo, 2005). The public transportation share in 2007 in 15 cities in Latin America is 43% of the total trips, and 60% of the motorized trips. Of total public transport, 15% is by rail, 52% in formal buses, and 33% in informal minibuses and jitneys³ (CAF, 2010). Public transport in many developing cities is characterized by hundreds of separate bus companies. For instance, it is estimated there are 200 operators on average for a single minibus route in Lagos, Nigeria (Gwilliam, 2005).

Intercity and international travel is growing rapidly and is dominated by auto and air modes. In Europe, Japan and in China intercity passenger travel is combined with fast rail travel. Worldwide passenger air travel is growing by 5% annually, a faster rate of growth than any other travel mode (WBSCD, 2002).

³ Jitneys are vans or small buses that transport passengers on a route for a small fare, follow somewhat regular routes (but generally not on a published schedule), and often allow for ad hoc route deviations to accommodate passenger needs (Small and Verhoef, 2007).

Industrialization and globalization have also stimulated freight transport, which now uses 35% of all transport energy (WBSCD, 2004a). The truck-transport sector has a continuously high demand for petroleum, particularly diesel. Truck-transport accounted for 12.5% of global petroleum demand and 45% of global diesel demand in 2006 (McKinsey Global Institute, 2009). Freight transport is more conscious of energy efficiency considerations than passenger travel because of pressure on shippers to cut costs (Larsen and Peterson, 2009). However, the historic rapid growth of truck-transport energy use reflects in large part that the truck sector has limited efficiency improvements opportunities for diesel engines (McKinsey Global Institute, 2009). The increasing demand for fast, reliable, smaller, "just-in-time" and door-to-door shipments contributes to the rapid growth of energy use for freight transport. The result has been similar to the case of passenger vehicles in that, although the energy efficiency of specific modes has been increasing, the movement to the faster and more energy-intensive modes translates into faster rates of energy use. The opportunities for switching from truck to rail apply to only a small number of truck shipments (those involving sufficiently large volumes and long distances), which represent a small percentage of truck-transport volume; for example, this will be an option for only 4% of shipments in Europe (McKinsey Global Institute, 2009). Worldwide the trends show rail and domestic waterways' shares of total freight movement declining, and highways' shares increasing, while air freight, though remaining a small share, growing rapidly. Furthermore, environmental harm continues to increase as fuel efficiency improvements are offset by increased freight kilometers.

Freight transport can be summarized as follows:

- the majority of international freight transported worldwide comes from a few countries. In 2008, more than three-quarters of exported freight were from only 25 countries (US DOT, 2010);
- 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 (i.e., tankers);
- 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;
- urban freight is dominated by trucks of all sizes (Khan Ribeiro, et al, 2007); and
- from mid-2008 to mid-2009, as global economic activities slowed, goods transported worldwide by ocean carriers and airlines fell (US DOT, 2010).

Transporting freight around the world depends on geography, available infrastructure, and economic development. All modes participate

in the United States' freight transport system, which has the highest total traffic in the world. Russia's freight system is dominated by rail and pipelines. Europe's freight systems are dominated by trucking and shipping with a market share of 47% and 42% (in tonne-kilometers [t-km]), respectively, in European Union-27 countries, while rail's market share is only 11%, despite its extensive network (EC, 2008; EC, 2010). This rather small share of freight on rail in Europe is the result of priority given to passenger transport, divergent requirements for operability of urban rail systems, and market fragmentation between rival national rail systems, affecting the overall intermodality and a consolidation for rail freight in the European market (EC, 2008). China's freight system uses shipping as its largest carrier, with substantial contributions from rail (UNESCAP, 2004). Figure 9.6 shows the share of modes for passenger and freight.

9.2 Energy Use in Different Modes of Transportation

9.2.1 Road Transportation

From 1971 to 2007, global transport energy use rose steadily, with an average growth rate of 2.5%/year, which closely paralleled growth in economic activity around the world. The road transport sector (including

both LDVs and trucks) used the most energy and grew most in absolute terms (IEA, 2009b).

For passengers, road transport represents the most important mode (see Figure 9.7). The sums of passenger kilometers (p-km) for two- and three-wheelers, cars, minibuses, and buses are much higher than other modes in every single region of the world. For freight, trucking used about 23% of total energy used by the transport sector in 2005. Data on surface freight movement in many countries is poor, but most freight transport moved by road and rail appears to be domestic rather than international. In the European Union, for example, available data for 2005 indicates that only around 30% of all road freight (in terms of tonne kilometers) crossed an international border. The corresponding figure for rail freight, which accounted for 19% of all surface freight in the same year, was 51%.

Travel surveys and fuel use statistics indicate that passenger car travel per capita is approaching saturation⁴ levels in most OECD countries (Cresswell, 2006; Dennis and Urry, 2009; Millard-Ball and Schipper, 2011), and that distances traveled by each vehicle each year may be declining as the total number of vehicles on the road and levels of congestion increase. Car ownership rates have risen above one LDV for every two people on average in OECD countries, nearly 1.5 vehicles for every two people in the United States, and an increasing number

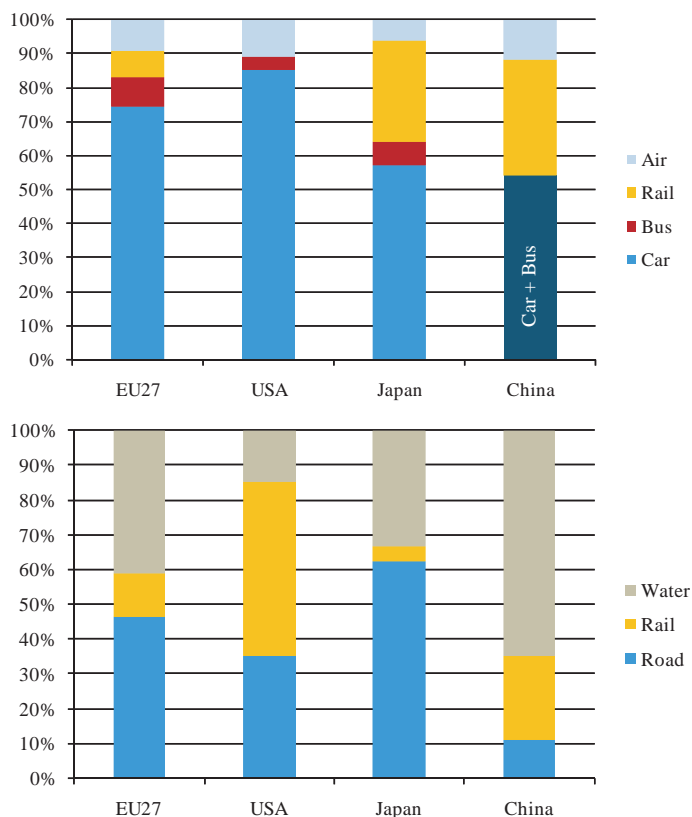


Figure 9.6 | Modal split of passenger (top) and freight transport (bottom; air freight transport not included) in terms of passenger-km (p-km) and t-km, respectively (2005). Source: based on EU, 2010.

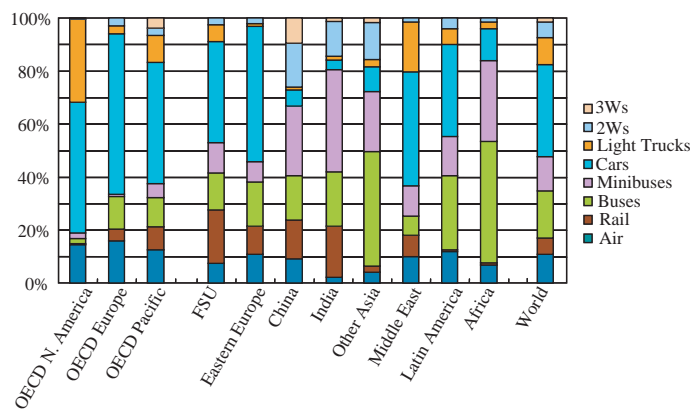


Figure 9.7 | Estimated motorized passenger travel split by mode (2005). Source: IEA, 2009c. ©OECD/International Energy Agency 2009.

4 Saturation here refers to several observed trends: a) a slow turnover and penetration of vehicles due to low population growth in OECD countries. An equivalent slow turnover in developing countries can be attributed to long vehicle life plus extensive market penetration of second-hand vehicles; b) little or no variation in the number of trips and the time people use for travel daily. The value across travel surveys in OECD countries over time has been remarkably stable – between 2, 7 and 3 trips per day. Similarly, the per capita “time budget” shows a stable trend at about one hour/day (Lyons and Urry, 2005; van Wee et al., 2006). Comparatively, in developing countries, time series travel survey statistics are lacking, but the reported values vary within a similar range from 2.2 trips/day (Padam and Singh, 2001) to 4.0 trips/day and an average time between 70–90 minutes/day (Hu and Reuscher, 2004); c) Finally, the average distance travelled/day/ person (work related) has also remained unchanged, around 10–60 km/day globally (see Chapter 18 for a similar discussion).

of households own two or more vehicles. This leads to a flattening of, or even a decrease in, the average distance travelled by each vehicle each year (IEA, 2009c). For long-distance travel, faster modes such as air travel are growing more rapidly than passenger car travel, accounting for the majority of the increase in total distance travelled per year (Axhausen et al., 2003).

There is a close, bidirectional interaction between urban transport, land use, and urban form (Gordon et al., 1989; Anas et al., 1998; Wegener and Fürst, 1999; Small and Verhoef, 2007). Cities of similar wealth often have very different levels of motorization, reflecting the effect of other factors such as urban form, design, and density on transportation modes (Næss, 2006; Merriman, 2009; for more see Chapter 18 on urbanization). Modal shares vary dramatically across cities. The share of trips by walking, cycling, and public transport is 50% or higher in most Asian, African, and Latin American cities, and even in Japan and Western Europe. The use of bicycles in cities like Amsterdam and Copenhagen demonstrate that coordination of land use and transport planning can be key to maintaining high levels of safe use of NMT (Beatley, 2000; Spinney 2009).

The prevalence of NMT in most developing country regions and in Eastern Europe is partially the result of low levels of economic growth and infrastructure investment. Data for Africa, Asia, and Latin America shows walking to be the major transport mode among the poorest city residents (World Bank, 1996; Gwilliam, 2002; Tiwari, 2006; Vasconcellos, 2010). Starting in the 1970s, Western Europe has made a conscious effort, to restrict urban sprawl and motorization, and to invest in improved NMT infrastructure (Banister, 2005).

Motorization does not necessarily imply the increase of passenger four-wheeled automobiles. Motorized two- and three-wheelers are among the most popular means of transport in Asian countries and are important elements of motorization in parts of Africa (Nagai et al., 2003). Most cities in India have a rate of private motor vehicle ownership similar to the wealthier cities of Latin America, where motorized four-wheeled vehicles are predominant. By this same account, cities like Kuala Lumpur and Bangkok are already exhibiting motorization levels close to those of Western European countries (ADB, 2006; see Figure 9.8).

The increase in the number of two- and three-wheeled vehicles in developing countries is much more accelerated as compared with the increase of four-wheeled vehicles (Gwilliam, 2003; Zegras and Gakenhaimer, 2006). Once individuals have gained mobility with a two- or three-wheeler motorized vehicle, it is likely that many will shift to four-wheeled vehicles when they attain higher levels of income. If this condition is fulfilled, it can be expected that the ownership and number of four-wheeled vehicles in developing countries, particularly in China and great parts of Asia, will increase dramatically (Nagai et al., 2003; Wang et al., 2006; ADB, 2009). Reasons cited by these authors for the motorcycle motorization phenomenon in many countries include lower capital and operating costs than automobiles coupled with lower levels of real purchasing power; superiority in time and door-to-door

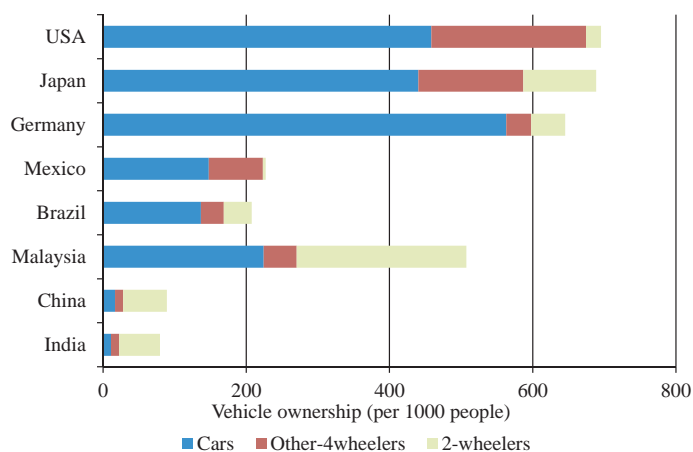


Figure 9.8 | Vehicular penetration in 2006 of several developed and developing countries (other four-wheelers include busses and trucks). Source: based on MoRTH, 2009.

convenience relative to automobiles in congestion; and superiority to an often deteriorating public transport system. Despite their prevalence, rapid growth and safety considerations, until recently motorcycles have been ignored both in planning and infrastructure implementation, including traffic counts and pollution control efforts, but this is changing (see, i.e., the Clean Air Initiative for Asian Cities, 2011). As motorcycles and three-wheelers are light vehicles, their overall fossil fuel consumption is not as large as conventional cars. Furthermore, new technologies such as electric and hybrid engines are being introduced, further reducing their fossil fuel consumption. Nevertheless, traffic safety concerns need to be thoroughly addressed.

For example, electric bikes (e-bikes) in China emerged from virtual non-existence in the 1990s to achieve annual domestic sales of 13.1 million in 2006, which is equal to the sales of gasoline two-wheelers (ADB, 2009). As it is likely that electric two-wheelers will continue to substitute for bicycles and public transport as incomes rise in China, appropriate policy initiatives may lead to wider electrification of the Chinese transport system (ADB, 2009). The rapid parallel development of new traffic safety rules and regulations to accommodate e-bikes is necessary, and it can serve as inspiration for other Asian cities experiencing the same trends.

9.2.2 Railways

Railway traffic systems are unique in terms of location and technology. Railway traffic systems are highly concentrated in a few world regions. Approximately 90% of all freight and passenger railway traffic can be found in North America, Russia (freight oriented), Japan (passengers), China, India, and Europe (see Figure 9.10). In total, in 2007 there were slightly over 960,000 km of rail lines globally, carrying over 28 billion passengers (2495 billion p-km) and 11.4 billion tonnes (8845 billion t-km) of freight (Thompson, 2010). The top five passenger rail systems

Box 9.1 | Case Study of Urban Mobility in Developing Countries

The World Business Council for Sustainable Development (WBCSD) Mobility for Development project has researched the state of mobility in rapidly growing cities at various stages of economic development (WBCSD, 2009). With three billion people surviving on less than US\$2/day and not adequately served by existing mobility systems, the urgent challenge is to expand transport benefits to those currently excluded from urban transport systems and reduce transport's environmental impact. The project set out on a process of research, dialogue, and learning in four cities: Bangalore in India, Dar es Salaam in Tanzania, Sao Paulo in Brazil, and Shanghai in China.

Each of the cities has experienced rapid urban and economic growth, accompanied by growth in transportation, both passenger and freight, public and private – but in quite different ways. Public transport remains a major and sometimes overwhelmingly dominant provider of personal mobility. In these cities, the public transport share of all motorized trips ranged from 45% in Sao Paulo to 71% in Dar es Salaam. In Bangalore and Dar es Salaam, informal paratransit is an important provider of access (see Figure 9.9). Indeed, in the latter, public transport is currently being provided almost exclusively by approximately 9,000 privately-owned and operated minibuses known as *dala dalas*. It is also apparent that non-motorized modes still provide a major share of personal mobility in each city. In Shanghai in 2004, trips by foot and by bicycle accounted for 31% and 25% of the daily total, compared to 31% and 33%, respectively, in 1995. In Sao Paulo in 2002, 37% of daily trips were by foot and 1% was classified as “other” (it is assumed that this category includes trips by bicycle).

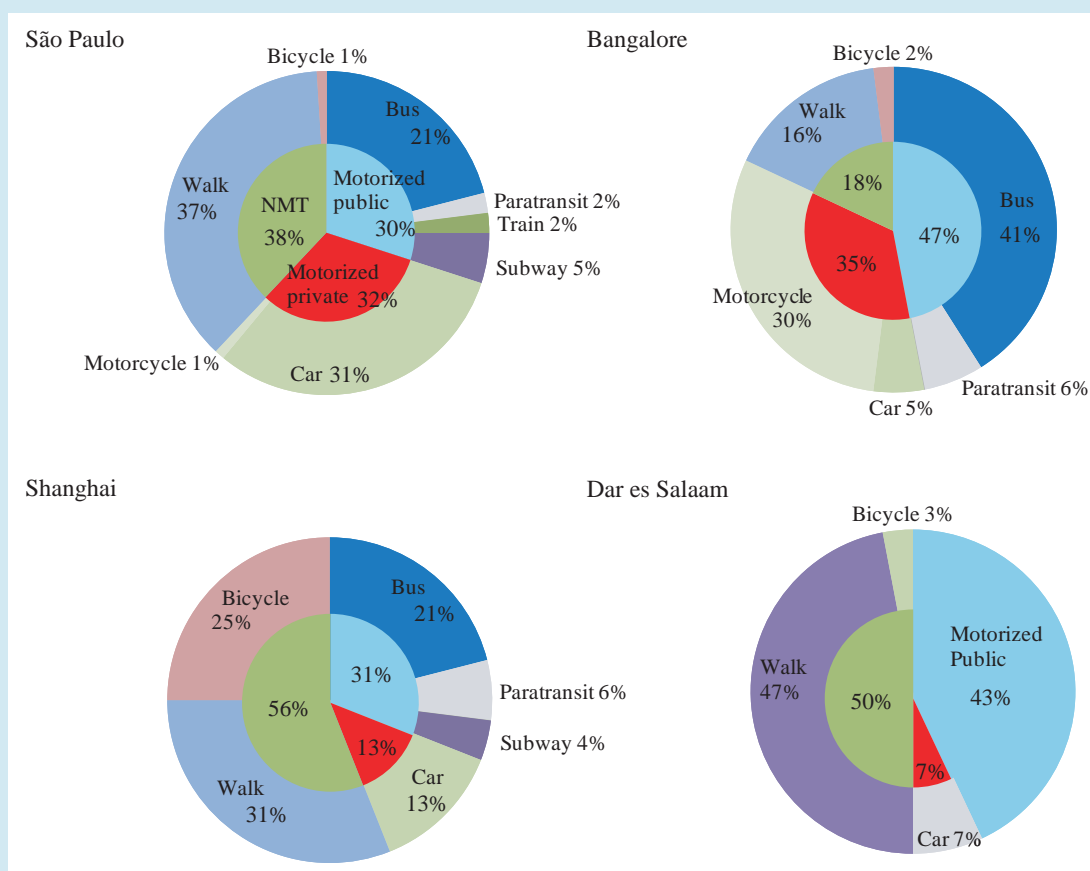


Figure 9.9 | Passenger transport modal shares of several cities in developing countries. Source: based on WBCSD, 2009.

carry 85% of the world's rail passenger traffic. Only three railway systems account for 79% of the world's railway t-km (Statistics Bureau of Japan, 2010).

Rail's main activities are high speed passenger transport between large cities, high-density commuter transport in the city, and freight transport over long distances. Heavy rail transit systems are generally

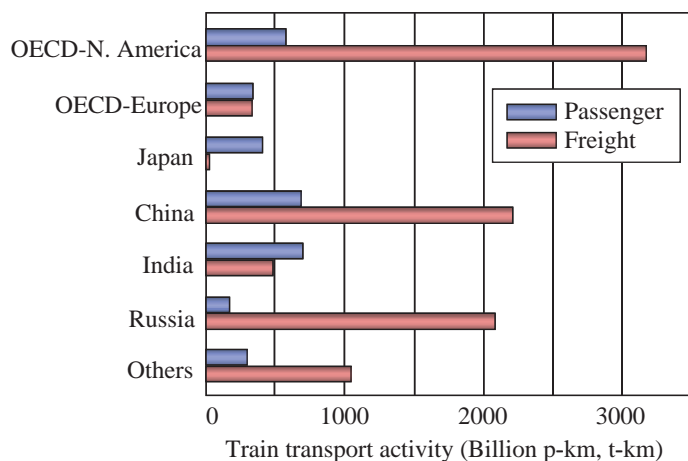


Figure 9.10 | Railway traffic in the major regions. Source: based on Statistics Bureau of Japan, 2010.

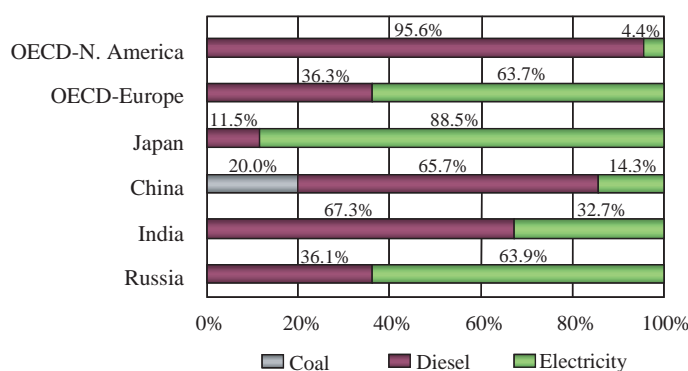


Figure 9.11 | Energy use in railway transport systems in the major regions. Source: based on IEA, 2009b.

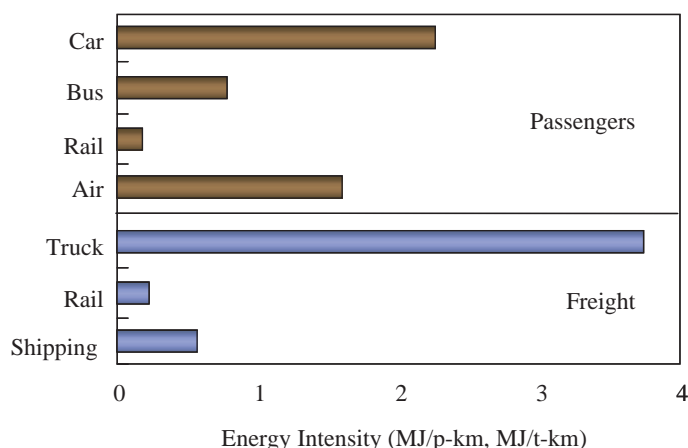


Figure 9.12 | Energy intensity of domestic transport system in Japan (2008). Source: based on ANRE, 2010.

found only in the largest, densest cities of the industrialized world and a few developing-world cities, like Beijing, Delhi, Mexico City, and Sao Paulo, among others (Kahn, Ribeiro et al, 2007).

In Europe, Japan, and Russia, electricity is a major energy source for rail, while diesel dominates in North America, China, and India (see Figure 9.11). Electric power for rail systems comes from a variety of sources, predominantly from coal. Coal is also directly used as locomotive fuel in some developing countries.

Trains are more efficient when compared with trucks, and the same applies for passenger trips when compared to all other motorized options (Figure 9.12). Efficiency is strongly dependent on the loading factor. Hence, the economic and environmental viability of public transport crucially depends on urban density.

9.2.3 Aviation

Since 1960, passenger air traffic grew 2.4 times faster than the global GDP growth rate, enabling unprecedented global mobility and causing total aircraft GHG emissions to rise (IPCC, 1999). From 1985–2005, total scheduled traffic, measured in terms of tonne-km, grew at an average annual rate of 5.5% (see Table 9.2).

In 2005, over 3940 billion domestic and international passenger-km were logged by the world’s scheduled airlines (Figure 9.13). In the same year, nearly 150 billion t-km of domestic and international freight were transported by scheduled airline services (Figure 9.14). It is estimated that in 2005, the world’s airlines carried over 2.1 billion passengers and some 40 million tonnes (Mt) of freight on scheduled services. During the same year, airlines performed on scheduled services 3940 billion p-km (equivalent to 365 billion t-km), some 150 billion freight t-km and 4.6 billion mail t-km (ICAO, 2007).

Today, international air traffic represents just over 60% of the total scheduled passenger air traffic and about 85% of global freight air traffic (ICAO, 2010). The demand for international flights has increased almost four times from 1985 to 2005, while domestic demand has only doubled (see Figure 9.15). The lower growth of domestic demand when compared to international demand can be attributed to competition with other modes by land.

The regional share of international air passenger traffic changed in the period 1985–2005. Europe, Asia/Pacific, and the Middle East increased their shares in total air passenger-km while North America, Latin America, and Africa have decreased (see Figure 9.15).

The share by region of international freight traffic changed in the period between 1985 and 2005 (see Figure 9.16). Asia/Pacific and the Middle East increased their shares in total freight-t-km considerably. North America did not vary much. Latin America, Africa, and Europe decreased (see Figure 9.17).

Aviation contributes to climate change in a number of different ways, and in more complex ways than most other sectors (IPCC, 1999). Aviation

Table 9.2 | Trends in total scheduled air traffic. World (1975–2005).

Scheduled Services	Average annual growth (%)		
	1975–1985	1985–1995	1995–2005
Passenger-km	7.0	5.1	5.2
Freight tonne-km	7.5	7.6	5.5
Mail tonne-km	4.3	2.5	-1.9
Total tonne-km	7.1	5.8	5.2

Source: ICAO, 2007.

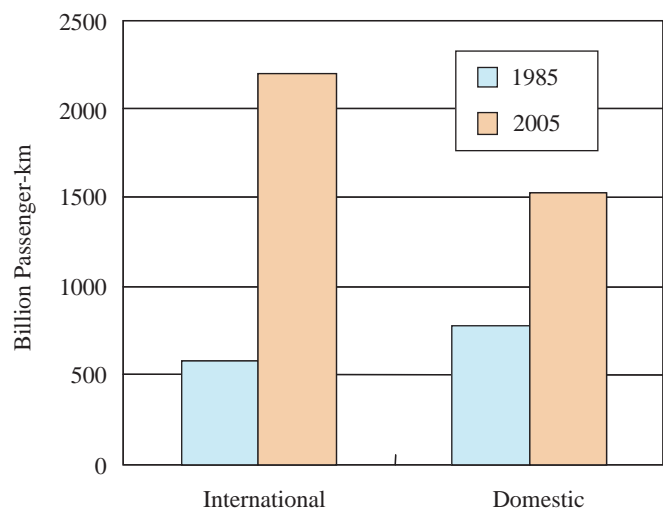


Figure 9.13 | Trends in schedule international and domestic traffic – world (1985–2005). Source: ICAO, 2007. ©ICAO, reproduced with permission.

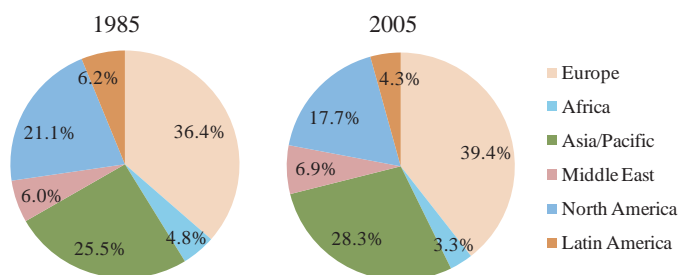


Figure 9.14 | Regional distribution of air passenger transport (p-km). Source: ICAO, 2007. ©ICAO, reproduced with permission.

used 252 Mtoe of energy in 2007, mostly jet fuel, which is around 11% of all transport energy used. International travel accounts for 62% of aviation, and is continuously increasing (IEA, 2009b). The total energy demand is expected to triple to about 750 Mtoe in 2050 in the IEA 2009 baseline scenario (IEA, 2009c). In the same study's high baseline scenario, this reaches nearly 1000 Mtoe (IEA, 2009c). Estimating the impact of aviation's GHG emissions is complicated by a number of uncertainties.

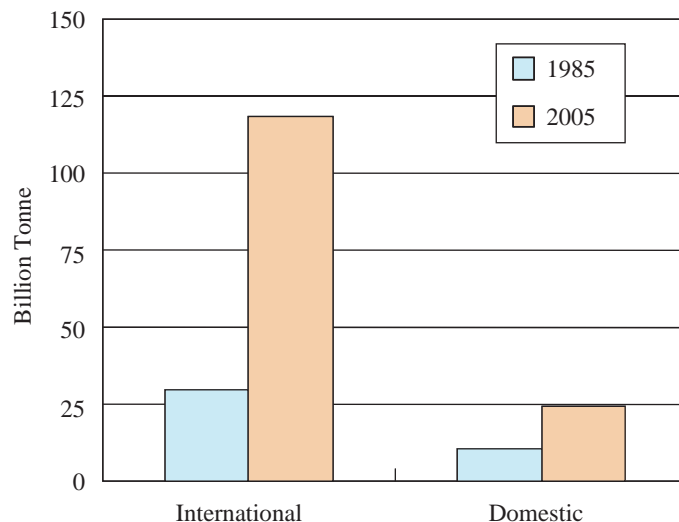


Figure 9.15 | Trends in scheduled international and domestic air freight traffic – world (1985–2005). Source: ICAO, 2007. ©ICAO, reproduced with permission.

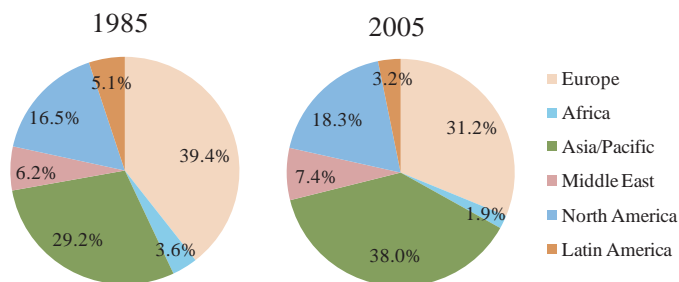


Figure 9.16 | Regional distribution of air transport – freight t-km. Source: ICAO, 2007. ©ICAO, reproduced with permission.

Total aircraft fuel consumption is expected to grow at a rate of 3 and 3.5 %/year, as shown in Figure 9.17. This is far less than the predicted 4.8%/year growth rate in air traffic. During the 37th Session of the Assembly in October 2010, the International Civil Aviation Organization (ICAO) adopted the first globally harmonized Resolution on international aviation and climate change. The resolution was adopted with some States expressing reservations and calling upon the ICAO Council to continue its work on specific aspects of the agreement. The resolution aims to collectively achieve global aspirational goals of improving fuel efficiency by 2% per year and stabilizing CO₂ emissions at 2020 levels. The Assembly also agreed on the guiding principles for market-based measures and decided to explore a global scheme for international aviation. A global CO₂ certification Standard for aircraft is being developed aiming for 2013.

Some measures, such as reducing overall airplane travel volumes, may reduce emissions across the board. But other measures, such as improving aircraft engine efficiencies, may result in trade-offs between different pollutants; for example, a reduction in CO₂ emissions might be

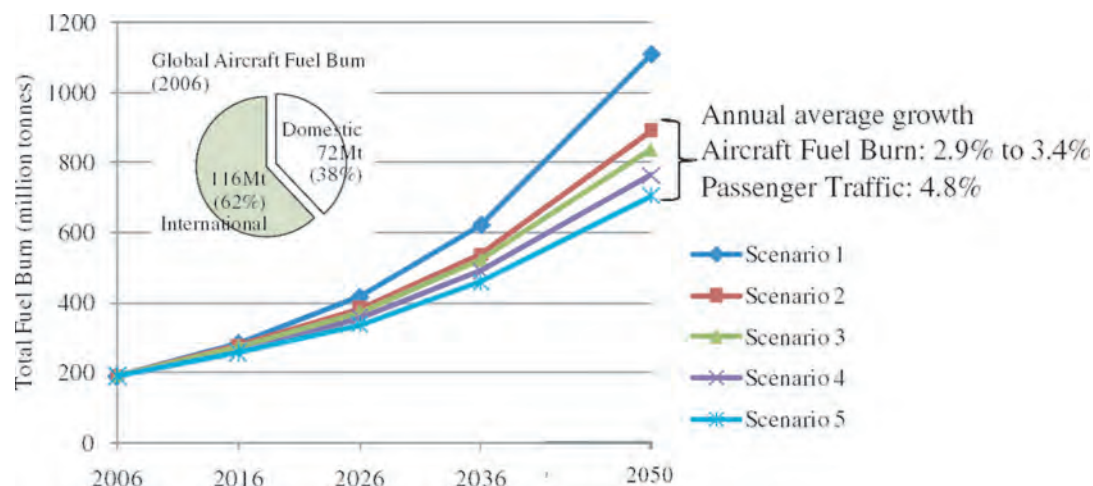


Figure 9.17 | Global aircraft fuel burn, international and domestic traffic combined (2006–2050) (Details of scenario; see Box 9.2). Source: modified from ICAO, 2010.

achieved at the cost of higher NO_x emissions. The levels of scientific understanding of the impacts of each of the contributors to radioactive force from aviation varies, and research is urgently needed to better understand and quantify the potential impacts of aviation emissions and the net effects of various mitigation strategies (IEA, 2009c). Box 9.2 details technology-specific scenarios developed by the ICAO (ICAO, 2010). Policies that also affect total air traffic demand and address air transport externalities are explained in Section 9.6.

9.2.4 Shipping

According to the United Nations Conference on Trade and Development (UNCTAD), more than 80% of global trade by volume is carried by sea (IMO, 2009; UNCTAD, 2010). Throughout the last century, the shipping industry has seen a general trend of increases in total trade volume. Increasing industrialization and the liberalization of national economies have fuelled free trade and a growing

Box 9.2 | The Future of Aviation

The ICAO (2010) estimated average annual passenger traffic growth of between 4.0–5.2 % through 2036. In order to accommodate this growth, the size of the global commercial aircraft fleet would need to grow by nearly 250% by 2036. The complete forecast is presented in the table below.

A range of potential technology and operational scenarios were considered in order to estimate global aviation fuel consumption through 2036, and they were then extrapolated to 2050. Described below as in ICAO (2010), these scenarios include a business-as-usual (BAU) sensitivity case, which was not considered to be likely, given the investments currently being made in operational improvements and the increasingly aggressive levels of operational and technological improvement.

Description of ICAO/CAEP (2010) Future Scenarios

- *Scenario 1 (Sensitivity)*: This scenario includes the operational improvements necessary to maintain current operational efficiency levels, but does not include any technology improvements beyond those available in current (2006) production aircraft.
- *Scenario 2 (Low Aircraft Technology and Moderate Operational Improvement)*: In addition to including improvements associated with migration of the latest operational initiatives, e.g., those planned in NextGen and Single European Sky ATM Research (SESAR) (Scenario 1), this scenario includes fuel burn improvements of 0.96 %/year for all aircraft entering the fleet after 2006 and prior to 2015, and 0.57 %/year for all aircraft entering the fleet beginning in 2015 out to 2036. It also includes additional fleet-wide moderate operational improvements by region.

- *Scenario 3 (Moderate Aircraft Technology and Operational Improvement)*: In addition to including improvements associated with migration of the latest operational initiatives, e.g., those planned in NextGen and SESAR (Scenario 1), this scenario includes fuel burn improvements of 0.96 %/year for all aircraft entering the fleet after 2006 out to 2036, and additional fleet-wide moderate operational improvements by region.
- *Scenario 4 (Advanced Aircraft Technology and Operational Improvement)*: In addition to including improvements associated with migration of the latest operational initiatives, e.g., those planned in NextGen and SESAR (Scenario 1), this scenario includes fuel burn improvements of 1.16 %/year for all aircraft entering the fleet after 2006 out to 2036, and additional fleet-wide advanced operational improvements by region.
- *Scenario 5 (Optimistic Aircraft Technology and Advanced Operational Improvement)*: In addition to including improvements associated with migration of the latest operational initiatives, e.g., those planned in NextGen and SESAR (Scenario 1), this scenario includes an optimistic fuel burn improvement of 1.5 %/year for all aircraft entering the fleet after 2006 out to 2036, and additional fleet-wide advanced operational improvements by region, as shown in Table 9.3 under “upper bound.” This scenario goes beyond the improvements based on industry recommendations.

Table 9.3 | CAEP/8 passenger traffic growth rate forecast – Most Likely, High, and Low Scenarios.

Scenario/Sector	Average annual growth rate of passenger traffic (%)				
	2006–2016	2016–2026	2026–2036	2006–2026	2006–2036
High Scenario (Optimistic)					
International	5.9	5.5	5.0	5.7	5.5
Domestic	5.0	4.7	4.4	4.9	4.7
Global [Int. + Domestic]	5.5	5.2	4.8	5.4	5.2
Most Likely Scenario (Central Forecast)					
International	5.4	5.0	4.6	5.2	5.0
Domestic	4.5	4.3	4.1	4.4	4.3
Global [Int. + Domestic]	5.1	4.8	4.4	4.9	4.8
Low Scenario (Pessimistic)					
International	4.8	4.4	4.0	4.6	4.4
Domestic	3.6	3.2	2.8	3.4	3.2
Global [Int. + Domestic]	4.3	4.0	3.6	4.2	4.0

Source: ICAO, 2010.

The results of this analysis are shown in Figure 9.17, which estimates that global fuel consumption will increase from approximately 200 Mt in 2006 to between 711 and 897 Mt in 2050. This translates to between a 2.9 % and 3.4 % annual average growth rate in fuel consumption over the period. On a per flight basis, efficiency is expected to improve over the period; however, in absolute terms, GHG emissions are expected to rise significantly relative to 2006 emissions. Further, market-based policy instruments may possibly be required to achieve a notable contribution from the aviation sector to achieve 2050 climate mitigation goals (see Section 9.6).

demand for consumer products. In 2006, seaborne trade reached over 48 trillion t-km; this represents an increase of 49% compared to trade in 1996, as shown in Figure 9.18 (Singapore Maritime Careers, 2011)

Also according to the Singapore Maritime Careers (2011), the three main types of goods transported by sea are dry bulk, oil, and containerized cargo. Dry bulk (iron ore, grain, coal, bauxite/alumina, phosphate, etc.) accounted for 38% of the world's seaborne trade in 2006. The

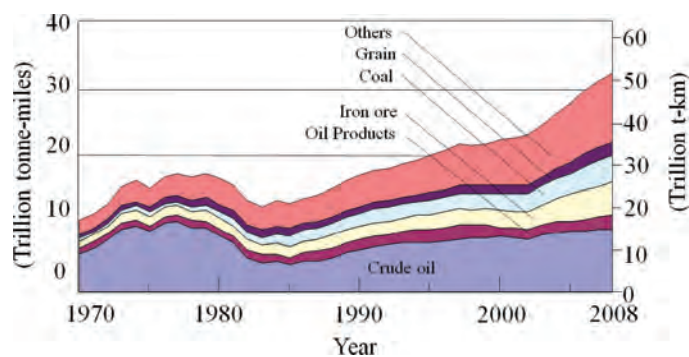


Figure 9.18 | World seaborne trade. Source: based on UNCTAD, 2010.

second largest share of cargo was oil trade, which accounted for 36%, and containerized cargo contributed 15%. These trades are carried by more than 20,000 merchant ships to various ports around the world, leading to a global cargo throughput of 14.8 Gt and container throughput of 440 million twenty-foot equivalent units (TEUs).⁵

Ships transport food (grains, rice, maize, meat, fish, sugar, vegetables, vegetable oils, etc.), and also fertilizers to increase crop productivity), energy (crude oil, refined oil products, ethanol, coal, and gas), raw materials (iron ore, scrap iron, minerals, lumber, wool, rubber, cotton, etc.) and finished products of all sorts. Besides this regular transportation, special ships perform other tasks like offshore service activities, cable laying, pipe laying and dredging, fishing, and exploration and research, among others.

Shipping fuel consumption is mainly residual fuel. Residual fuels are the cheapest fuels with the highest boiling points. They usually contain relatively high amounts of pollutants, in particular sulphur, and they contaminate water and air along coastlines. Estimates for 2007 show total fuel consumption was 333 Mt, as shown in Figure 9.19. The greatest demand for fuel (83%) comes from international routes.

Emissions from fuel in seaborne transport were estimated to amount to 1065 MtCO₂-eq in 2007, more than that of rail and aviation combined. However, black carbon emissions are not measured. Also, this figure does not include hydrofluorocarbon emissions from refrigerating systems and fugitive emissions of CH₄ from oil transport (IMO, 2009). Advances in technology have increased shipping's efficiency. For example, cargo vessels are estimated to emit 2–30 gCO₂/t-km, compared to a range of ca. 200 to 800 gCO₂/t-km for trucks with trailers (IMO, 2009; IEA, 2009d). However, efficiency gains are outweighed by significantly higher increases in overall volume.

⁵ TEU is a unit of cargo capacity used to describe the capacity of container ships and container terminals. It is based on the volume of a 20-foot-long (6.1 m) intermodal container.

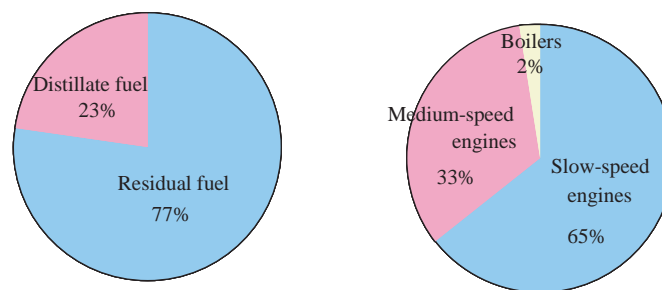


Figure 9.19 | Share of seaborne shipping fuel consumption by fuel type and engines in 2007. Source: data based on IMO, 2009.

Shipping activity is driven by the world economy. Understanding this mechanism for seaborne transport and other shipping activities is vital to estimate future energy demand and emissions from this mode. The huge growth rates of world seaborne trade figures were mostly driven by international trade, and the globalization of supply chains. Shipping is not immune to economic downturns – a notable fall in trade occurred, for example, during the worldwide economic recession of the early 1980s, during the Asian financial crisis of the late 1990s and, more recently, the financial crisis of 2008/2009 led to a small reduction in seaborne transport in 2009 that was already more than compensated for in 2010 (estimate by UNCTAD, 2010).

9.3 Transportation Trends and their Relation to Major Global Issues

Transport has a strong two-way interaction with the major global issues addressed by the Global Energy Assessment: urbanization, equity, climate, energy security, health, and environmental protection. This section explores this interaction, stressing that the results of implementation of transportation policies and investments can be favorable or detrimental to the attainment of goals in any of these areas. Therefore, gaining further understanding of these opportunities, challenges and potential co-benefits is necessary. Goals for sustainable transportation consider reducing the need to travel (to have fewer and shorter trips), encouraging a shift to more energy-efficient and safer modes of travel, and improving the technologies and operations of different transport modes (Banister, 2008; Dalkmann and Sakamoto, 2011). The last five years have seen the emergence of climate concerns as a flag point with the reporting by IPCC on the role of transport in CO₂ emissions (IPCC, 1999; Kahn Ribeiro et al., 2007; Stern, 2007; Bakker and Huizenga, 2010).

The GEA proposes combining the goals regarding global and local issues and those for sustainable transportation into a multi-goal framework approach that highlights normative goals and creates the opportunity of multiple entry points for decision makers (Chapters 2–6). In this way it envisions the synergy of effective action toward selected goals producing a catalyzing effect of change toward a larger systemic transport and energy transformation. The ability to impact

transportation activity and trends is paramount to achieving goals in any of the major global and energy issues that GEA addresses; this requires the assessment of the purpose and goals of specific transport interventions and their impact on larger goals. The methodological approach followed in this assessment begins with a review of the relationship between current transport trends and their impact on major global issues. Understanding the specific terms of this relationship can help to pinpoint the variables that serve to measure progress toward these goals. Transport sustainability is matched in this assessment with goals linking transport, urbanization, and equity, as well as those that link health and environmental protection (e.g., quality of life, reduced air pollution, noise). Climate mitigation focuses on emissions reduction goals, while energy security relates to fossil fuel independence (fuel diversification and net reduction of fossil fuels use for transportation).

Enabling conditions for change include increasing the level of investment, capacity building, technology transfer, institutional building, and general public awareness and education. The assessment of potential approaches at regional, national, and local levels are comprehensive but different approaches are necessary by region and locality, appropriate pricing policies for fuels, vehicles, and congestion will be needed across the globe and are further discussed in Section 9.6.

9.3.1 Economic Growth and Equity

Transportation systems are the backbone of urban social and economic development and are a determinant of the quality of urban life. As global urban populations are rapidly increasing, land-use planning and technologies and practices for smart urban transport become essential for urban development. Technological advances and motorization have brought major improvements in our ability to cover longer distances, become flexible, and make use of available space.

However, in most cities, urban travel and mobility has deteriorated over time. For instance, the yearly delay in urban areas in the United States with more than three million inhabitants has increased from 31 hours per auto commuter in 1982 to 50 hours in 2010 (Schrang et al., 2010). In most cities in developing countries, rapid urbanization and motorization are coupled with the inability of local governments to respond adequately to the demand for growth in infrastructure and public transport services (Vasconcellos, 2001; World Bank, 2008a). Simultaneously, the rate of car ownership growth supersedes the extension of road capacity. The combined rapid population and motorization growth and slower pace of economic development results in urban spatial impoverishment (see Chapter 18), making the provision of an adequate level of safe, reliable, and efficient transport services almost impossible. Further, as vehicle ownership and road use increase, traffic congestion, noise, and air pollution worsen (Vasconcellos, 2010).

Urbanization and urban form, or the spatial shapes of cities, have a complicated and interwoven bidirectional relationship with transportation (Small and Verhoef, 2007). Large-scale urbanization is only feasible with reduced transport costs (Krugman, 1991). Urbanization produces economics of agglomeration, a precondition to global integration. This generally leads to rising incomes and greater service provision, which, in turn, usually increases rates of ownership of motorized forms of transportation. Urban form, on the other hand, determines transportation needs (Næss, 2006). For example, dense cities and mixed land-use patterns create short distance destinations enabling walking and non-motorized transport options, whereas sprawling cities perpetuate dependence on motorized modes. In turn, highway infrastructure and inexpensive cars and fuels contribute to sprawled, auto-oriented urban development (Newman and Kenworthy, 1999; Banister, 2005).⁶

Accessibility is a useful measure to evaluate the quality of urban transport for users. It can be defined as ease of reaching opportunities throughout the urban area, such as jobs, shopping, medical services, and social activities (Cervero, 2005). Poor accessibility, quality of transportation services, and the question of transport service affordability are strong indicators of the links between transportation, urbanization, and social equity. Improving accessibility levels depends upon the urban form, distribution of land uses, transportation infrastructure, and the transport service level measured in travel time. Accessibility can be improved by proximity or mobility. Proximity is a function of urban form and land-use mix (i.e., dense, mixed-use development with a good jobs-housing balance) and mobility is determined by the level of transportation services, system operations, and vehicle performance characteristics within a particular urban area.

Cities with low auto-mobility could have high levels of accessibility due to the proximity of the urban opportunities in the city core if sustainable transport modes are used (Cherry, 2007). Cities with high auto-mobility might have low levels of accessibility due to the distance of decentralized activities in sprawling suburban communities. Lack of job accessibility, especially for vulnerable populations – those with low income, women, the elderly, and persons with disabilities – has been identified as a major contributor to poverty in developing countries and is an essential consideration in the development of any transportation policy (Gwilliam, 2002; Vasconcellos, 2001; 2010).

The provision of sustainable transport services, including low-carbon vehicles, can be hampered by lack of affordability. Affordability of transport means the ability to purchase access to basic goods and activities (e.g., medical care, basic shopping, school, work, other social services and socializing), usually expressed as the percentage of monthly income devoted to transport by poor families compared to a

⁶ For more information on the urban energy system see Chapter 18.

benchmark considered “affordable” for households (Serebrisky, et al, 2009). According to Litman (2007), this benchmark is achieved when households spend less than 20% of their income on transport and less than 45% on transport and housing combined. However, other authors (Serebrisky, et al, 2009) have observed that transport expenditures may be low in poor households due to a suppression of trips or a prevalence of walking and non-motorized modes; therefore subsidies for public transport, a common policy, may not reach the targeted population. These authors consider that the percentage of income used in transport can be seen as a good approximation of the hardship faced by certain population groups and an indication that deeper analyses are necessary.

A more effective use of resources within cities to aid affordability may be investing to increase accessibility improving sidewalks, crossing bridges and other non-motorized infrastructure (Serebrisky, et al, 2009). Urban planners and decision makers can target improving accessibility through integrated transport and urban design favoring mixed use, short distances, and modal integration, and by planning and implementing safe infrastructure for a number of low-cost, low-tech, non-motorized modes of transport (see further discussion in Section 9.6).

Transportation affordability is also affected by the number of vehicles that a household possess, the costs of using each vehicle, indirect costs such as residential parking, and the quality and costs of using alternative modes such as transit, rail, ridesharing, car-sharing, taxi services, cycling, and walking (Litman, 2007). The goal of introducing more efficient vehicles and low-carbon fuel technologies in developing countries will raise other dimensions to the concept of transport affordability at national and regional levels.

Finally, public acceptability is essential to transport sustainability, as it creates the conditions for implementation and improvement. The concept of acceptability will be further elaborated as part of the enabling conditions for sustainable transport implementation in Section 9.6.8. Improving the balance between transportation-urbanization and equity issues requires policies for enhancing the three A’s: accessibility, acceptability, and affordability.

9.3.2 Public Health and Local Ecosystem Impacts

Transportation activity, particularly in cities, has specific impacts on public health and local ecosystems. According to Dora (2011), health risks from transport come from outdoor urban air pollution (1.2 million deaths in 2005), physical inactivity (3.2 million deaths and 19 million healthy life years lost in 2005), traffic injuries (1.3 million deaths in 2005), traffic noise (e.g., stress, memory loss, and analytical impairment), climate change (150,000 deaths), and lack of access to vital goods and services, social networks, equity, and cohesion, which is profound and under-reported.⁷

Road traffic injuries have become a global health and developmental problem (WHO, 2009). Higher road fatalities and air pollution are common in developing countries, while health problems associated with lack of physical activity are more common in industrialized nations. Over 90% of the world’s fatalities on the roads occur in low- and middle-income countries, and almost half of those who die in road traffic crashes are pedestrians, cyclists, or users of motorized two-wheelers. These individuals are collectively known as vulnerable road users, and this proportion is higher in the poorer economies of the world (WHO, 2009). The death rates caused by road traffic accidents have been declining over the last decades in many high-income countries due to the adoption and proper enforcement of traffic laws, as well as persistent allocation of human and financial resources to build up effective and sustainable enforcement activities. However, even in these countries, road traffic injuries remain an important cause of death, injury and disability (WHO, 2009).

Dependence on car mobility and lack of physical activity foster obesity (Woodcock et al., 2009, 2011). The effects of physical inactivity and obesity on population health are more detrimental than those produced by traffic injuries and deaths when comparing the leading causes of death (heart attacks, heart diseases) and Burden of Disease studies by the WHO (WHO, 2009; Dora, 2011). The cost of urban road transport and air pollution on public health can be in the order of 3% of GDP (Creutzig and He, 2009).

Other significant indirect effects on health from transport are related to stress (e.g., noise-induced), which compound the dramatic effects that lack of exercise and car dependence have had in developed countries and result in other potentially debilitating health conditions. Both short- and long-term exposure to air pollution affects human health adversely. Air pollution is caused by emissions from mobile (vehicles) and stationary sources and can have significant local effects during stagnant weather conditions (WHO, 2006; see Box 9.3 and Figure 9.20). Even low concentrations increase the risk of adverse health impacts. The air quality guidelines of the WHO recommend 20 µg/m³ annual mean (indicated in Figure 9.24 by a dashed line), which is exceeded even for most cities in OECD countries. Limit values that are in force in several countries are typically 40–60 µg/m³ (the EU limit value is also indicated in the Figure 9.20 by a dashed line) (WHO, 2006). Air pollutant emissions can be directly linked to the fuel combustion, energy production, and industrial activities taking place in a particular urban environment. However, air pollution is also trans-boundary, as air pollutants can travel considerable distances from their sources.

A sustainable transport agenda needs to understand transportation as a key component of health in urban development. It thus requires considerable further research, particularly in non-OECD countries where most data or reliable statistics on traffic safety, air pollution, and noise are still lacking (WHO, 2006).

⁷ For more information on energy and health, see Chapter 4.

Box 9.3 | PM₁₀ and PM_{2.5} as Indicators for Suspended Particulate Matter and Typical Values Worldwide

Globally, the most frequently used indicator for suspended particles in the air has been PM₁₀ – particles with an aerodynamic diameter <10 µm, but recent reviews by WHO, the USEPA, and European health agencies have pinpointed PM_{2.5} as a better indicator of health risk as it penetrates more deeply into the respiratory tract. **Studies show correlation of health outcomes with either PM₁₀, PM_{2.5} or both, although PM_{2.5} better represents combustion sources, which are of the greatest concern in this report.** Here we present data for PM₁₀ only; however, since PM_{2.5} is not yet measured routinely in many parts of the world. **PM_{2.5} levels are typically about 10–60% lower than PM₁₀ depending on the location and season, however its temporal and geographical variations are often well correlated with PM₁₀** as shown for example in the recent global modeling study for the Global Burden of Disease project (Brauer et al., 2011).

An overview of typical annual average PM₁₀ concentrations in selected cities around the world is presented in Figure 9.20. The data selected for this presentation demonstrate that the general levels of suspended particles in Asia and Latin America are higher than those in Europe and North America. About 70% of the cities selected from these regions have annual average PM₁₀ concentrations above 50 µg/m³.

In general, the highest concentrations of PM₁₀ were reported in Asia. This region also experiences relatively high background concentrations owing to forest fires and local emissions of particles from use of poor-quality fuels. A well-known springtime meteorological phenomenon throughout East Asia is the Asian Dust cloud, which originates from windblown dust from the deserts of Mongolia and China and adds to the general level of PM in the region.

Chinese cities experience very high airborne particle concentrations due to primary particles emitted from coal and biomass combustion and motor vehicle exhaust, as well as secondary sulphates formed by atmospheric chemical reactions from the sulphur dioxide emitted when coal is burned. Typical annual average PM₁₀ concentrations were reported to be as high as 140 µg/m³ in Beijing. In many areas of the world, massive and prolonged forest fires have caused significant increases in PM concentrations.

For a discussion of air pollution, including particulates, in the GEA pathways, see chapter 17, Section 17.5.2.

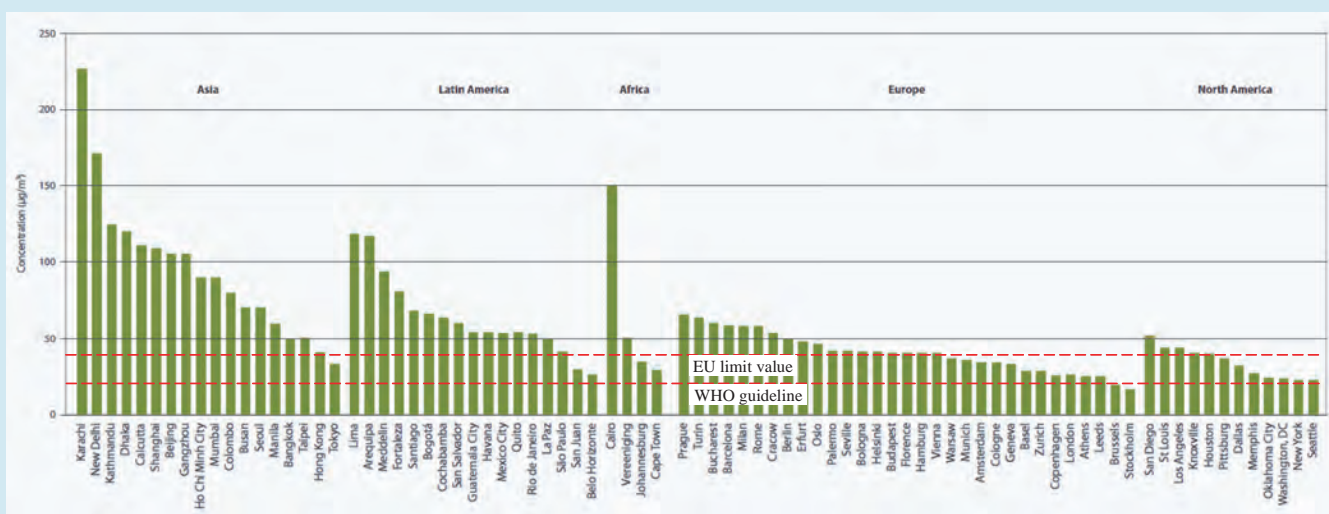


Figure 9.20 | Annual average PM₁₀ concentrations observed in selected cities worldwide. Even low concentrations increase chances of adverse health impact. The air quality guidelines of the WHO recommend 20 µg/m³ annual mean, below levels of even most cities in OECD countries. Source: WHO, 2006.

Source: WHO, 2006; Brauer et al., 2011.

In addition, local and regional pollutants (e.g., acidifying substances, ozone precursors, and particulate matter) damage ecosystems. Releases of oil or chemical substances into the environment by trucks and tankers during routine work or accidents adds to the pollution of soils, rivers, and the sea. The expanse of land area covered by transportation infrastructure excludes it from other uses, cutting through ecosystems and impacting fauna and flora.

9.3.3 Climate Change

The reduction of GHG emissions in all sectors, including transportation, is of paramount importance to reduce the effects of climate change (IPCC, 2007; IEA 2008). While international climate negotiations and treaties (i.e., Kyoto in 1997) were mostly quiet on the transport sector, policy makers at local, national, and regional levels, as well as manufacturers of transport vehicles and systems, have recognized the climate challenge related to transportation.⁸

GHG emissions from transport can be calculated through decomposition of transport demand, energy intensity, and carbon intensity, using a similar approach to the Kaya identity (Creutzig and Edenhofer, 2010; Creutzig et al., 2011a). Transport demand can be divided into activity (trips) and modal share. Energy and carbon intensity are associated with particular modes of travel, as indicated in the ASIF model (Schipper and Marie-Lilliu, 1999).

Of all transport modes, LDVs contribute the highest percentage of GHG emissions (see Figure 9.21), followed by significant contributions by freight trucks, air traffic, and water-borne. Transport activity, and particularly the use of LDVs, generally increases with economic growth; hence the trends indicate increasing emissions if no action is taken. The recent 2008/2009 recession in OECD countries had the effect of reducing the total amount traveled in all transport modes, especially for international shipping; however, overall global transport activity, and hence transport-related emissions, continued increasing.

In terms of GHG intensity, or grams of CO₂ equivalent emitted per unit of freight or passenger transport (tank-to-wheel vehicle emissions during operation), there is a large difference between modes. Rail and shipping are the most efficient modes for both passenger and freight transport (see Figure 9.22).

With respect to CO₂ emissions, IEA estimates that, driven by increases in all modes of travel, but especially in passenger LDVs and aviation, the baseline projection⁹ of GHG emissions in transport increases by nearly 50% by 2030 and 80% by 2050 (IEA 2009; see Figure 9.22). In a high

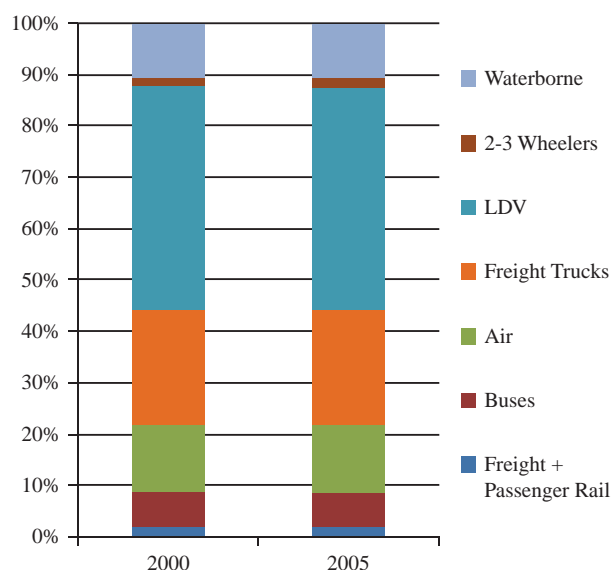


Figure 9.21 | Modal shares in world vehicles in CO₂ emissions (%). Source: based on ITF, 2008.

baseline scenario,¹⁰ it increases by 130%. CO₂-eq emissions increase at even faster rates, due to increased use of high carbon fuels such as coal-to-liquids after 2030. GHG emissions from transport nearly double from about 7.5 Gt in 2006 to about 14 Gt in 2050 in the baseline scenario and to 18 Gt in the high baseline scenario.

Figure 9.23 shows a comparison of CO₂ emissions from various combinations of powertrain and fuel on a well-to-wheels (WTW) basis for LDVs. It is interesting to note that from a climate change mitigation perspective, it may be better to have an internal combustion engine-hybrid electric vehicle (ICE-HEV) than an electric vehicle in areas where the electricity is produced mainly in coal-powered plants. This is an example of why a life-cycle analysis is a crucial approach to inform policymaking.

9.3.4 Energy Security

Transportation demand is expected to grow at a rapid pace for the foreseeable future (IEA, 2009d). However, the way transport needs will be served depends on several factors that are directly related to energy security¹¹.

First, it is in every nation's interest to promote and support transportation activity but as transport is dominated by one feedstock, petroleum, supply disruptions can jeopardize the essential continuity of transport activity (for a further discussion, see Chapters 7 and 17). Second, the primary driver of transport activity is economic

⁸ See also Chapter 3.

⁹ Baseline: follows the IEA World Energy Outlook 2008 Reference Case to 2030 and then extends it to 2050. It reflects current and expected future trends in the absence of new policies. These values represent expert opinions and are subject to high uncertainties.

¹⁰ High baseline: this scenario considers the possibility of higher growth rates in car ownership, aviation, and freight travel over the period to 2050 than occur in the baseline.

¹¹ See also Chapter 5.

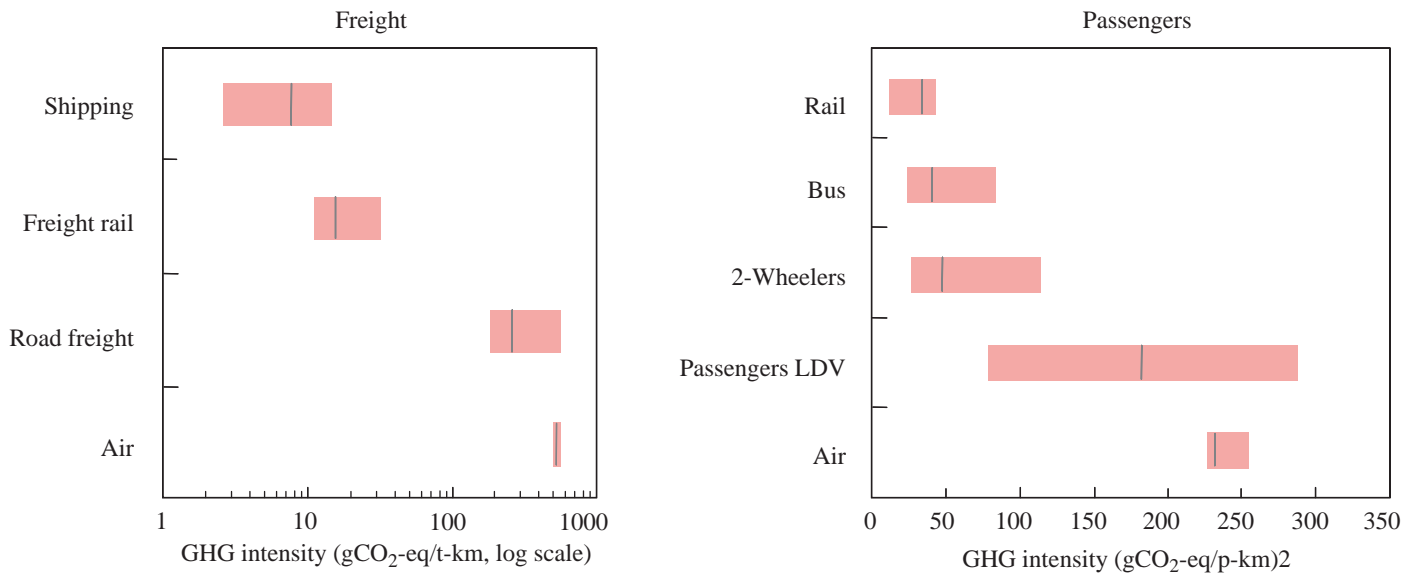


Figure 9.22 | GHG intensity per mode. Source: IEA, 2009c. ©OECD/International Energy Agency 2009.

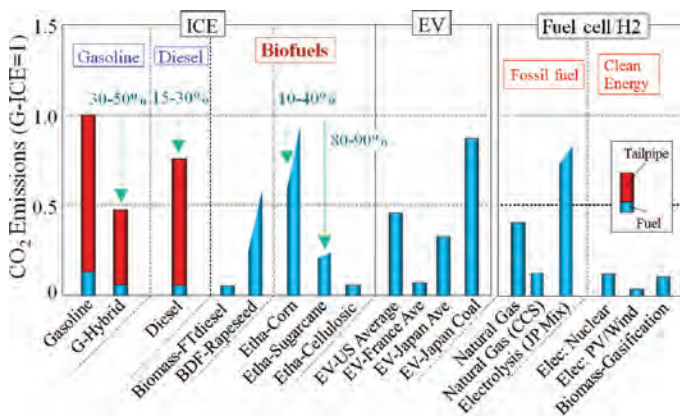


Figure 9.23 | Well-to-Wheel (WTW) CO₂ emissions by vehicle engine type. Arrows indicate the reduction compared with the conventional gasoline vehicles, and the range of data is expressed by slant bars. Source: based on data from Toyota/Mizuho, 2004.

development, as global economic conditions fluctuate and financial capitals move from regions to regions so will the flows of passengers and goods globally. High economic development in industrialized countries, and also in China, India, Brazil guarantees that transport demand levels will remain high. If the rest of Asia, Latin America and Africa fulfill their economic potential, a fast growth of transport demand may take place over the next several decades. Finally, current trends in developing countries point toward an increasing dependence on private cars. This will require substantial increases in petroleum use even when transportation technology, the energy efficiency of different vehicles and fuels, as well as their cost and desirability, is expected to continue improving.

In the aggregate, these trends indicate that energy use in transport will continue to increase and that fossil fuels are expected to continue to be the dominant propulsion source. Nevertheless, countries have choices in policy and infrastructure that may affect the key drivers of energy use and propulsion fuels: transport activity, modal choice, and technologies.

Most projections of transportation energy use and GHG emissions have developed reference cases that project future conditions in the case of governments continuing current policies, which mainly favor automobile use powered by fossil fuels. These reference cases establish a baseline that can be used to compare the implications of different policies and programs.

Widely-cited projections of world transportation energy use include reference cases by the International Energy Agency (IEA, 2008; 2009a; 2009c) and the WBCSD (2004b), whose forecast was undertaken by the IEA.

In contrast with the GEA pathways—which does not include a business as usual (BAU) path, the transportation projections from the mentioned scenario studies include business-as-usual forecasts under the assumptions that world oil supplies will be sufficient to accommodate the large projected increases in oil demand, and that world economies will continue to grow without significant disruptions. Attending to these fundamental assumptions, the BAU scenarios of each of the cited studies forecast robust growth in world transportation energy use over the next few decades, at a rate of around 2%/year. If these projections are correct, it will mean that transportation energy use in 2030 will be about 80% higher than in 2002 (see Figure 9.24 for the most recent estimates available). In addition for these studies, most of the new energy use

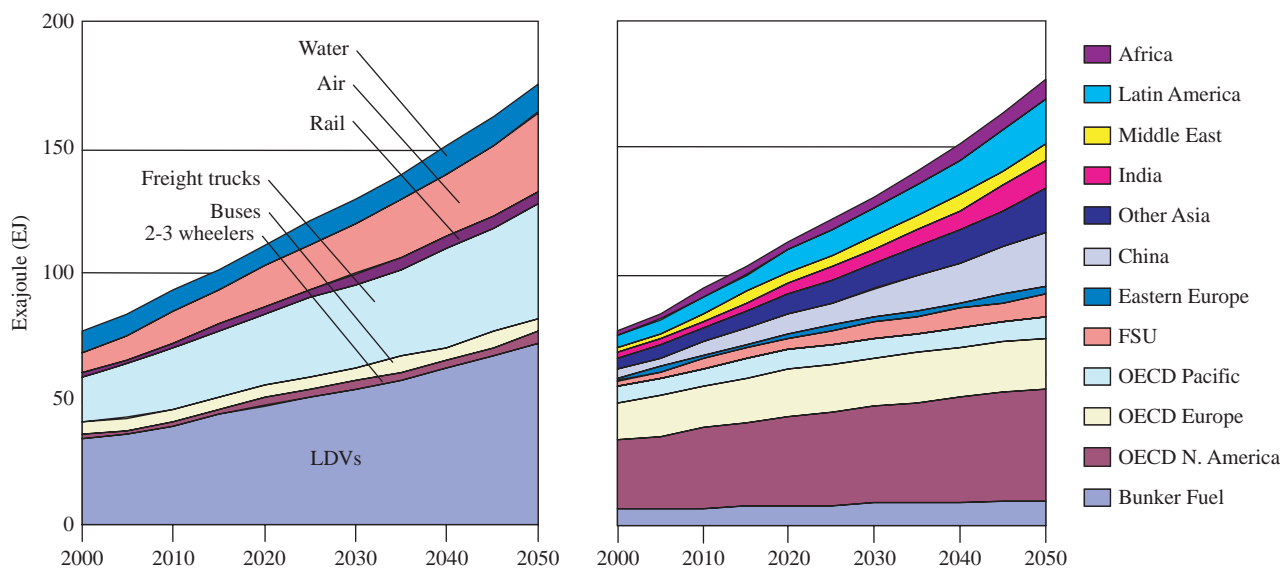


Figure 9.24 | Projection of transport world energy use by mode and region. Source: based on IEA, 2008.

is projected to be in petroleum fuels at 93–95% of transport fuel use over the period (see Figure 9.25). Nevertheless, the BAU scenarios imply increasing prices of oil; and the IEA predicts an average cost above US\$130/barrel in 2030 (IEA, 2010a). All these estimates and assumptions are in danger of encountering further difficulties due to disruptive changes in resource supply (Bundeswehr Transformation Center, 2010), which would amplify energy security concerns. The GEA pathways (discussed in Chapter 17) and the GEA-Transport scenarios in this chapter include assumptions and considerations from a global energy security analysis.

With respect to energy security, it is important to point that the rise of consumption in emerging economies will lead to a shift in transport energy use. For example, in China, where the number of cars is growing at a rate of 20%/year, even under a slower projected growth of 6%/year, China’s transportation energy use would increase by a factor of four between 2002 and 2025, from 4.3 EJ in 2002 to 16.4 EJ. India’s transportation energy use is projected to grow at 4.7%/year during this period, and in countries such as Thailand, Indonesia, Malaysia, and Singapore, growth would be above 3%/year. The same path would be observed in the Middle East, Africa, and Central and South America, with growth rates at or near 3%/year. The current share of non-OECD countries in global transport energy use is 36% and would increase to 46% by 2030 (Kahn Ribeiro et al., 2007).

Developed countries transportation energy use is expected to grow at lower rates of 1.3%/year. This modest figure is attributable to more efficient engines and to the use of alternative fuels as a result of current policies. In North America, growth would be even lower, with a rate of 1%/year due to moderate growth in population and travel but only modest gains in energy efficiency. In Western Europe, transportation energy use would have an increase of 0.6%/year as a consequence of

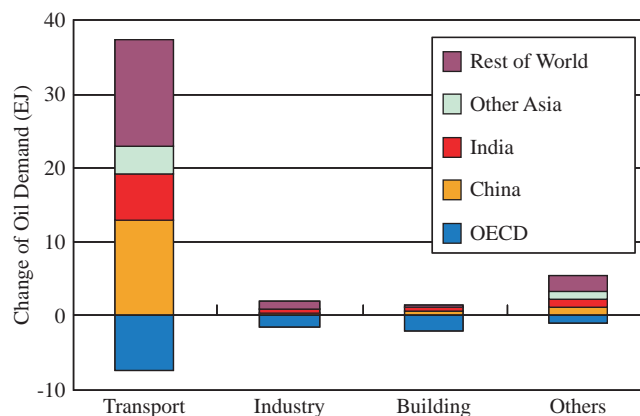


Figure 9.25 | Reference scenario: projected changes in oil demand, 2006–2030. Source: adapted from IEA, 2010a.

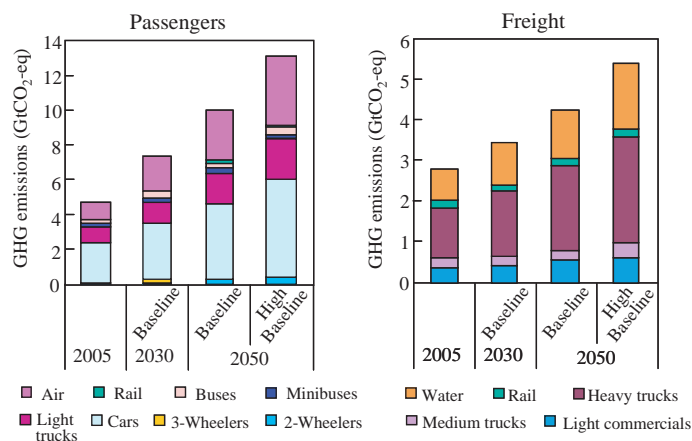


Figure 9.26 | Passenger and freight transport GHG emissions baselines by mode. Source: adapted from IEA, 2009d.

slower population growth, high fuel taxes and improvement in vehicle energy efficiency. Pacific OECD is also expected to grow at a rate of 0.6%/year. In total, developed economies' share of world transportation energy would be reduced from 40% to 31% from 2005 to 2030 (Kahn Ribeiro et al., 2007).

Worldwide expected growth of transport energy use means only that diversification of fuels for transportation is a key component of transport sustainability in terms of energy security. To reduce oil prices, strong policies to reduce demand for fossil fuels are required. IEA (2010a) projects prices in the range of US\$110/oil barrel if new policies are in place and US\$90/oil barrel in 2035 for policies that achieve the goal of keeping carbon concentration in the atmosphere below 450 parts per million (ppm). In the long term, global transportation systems will need to rely on greatly diversified and non-fossil sources of energy. The provision of a high level of transportation services with less dependence on fossil fuel and progressively more reliance on alternative sources of energy (i.e., electricity produced from renewable or non-fossil sources) is feasible worldwide, in combination with the implementation of avoid-shift-improve policies, as indicated by the United Nations Environment Programme (UNEP, 2011).

9.4 Assessing Energy Resources and Technology Options

The need for energy security, avoiding dangerous climate change, and other sustainability concerns, such as better air quality in cities, requires a combined approach (see UNEP, 2011 for more on the avoid-shift-improve framework). This section concentrates on assessing alternative and cleaner fuels and technologies for sustainable transport. Fuels that currently dominate are gasoline and diesel for road transport, electricity for rail, bunker fuels for shipping, and kerosene for air traffic. All modes could benefit from lower carbon technologies, including electric-powered rail, which needs decarbonization of electricity (as discussed in Chapter 11). As road and air are the dominant modes of transport, and are a major source of transport sector GHG emissions, the focus below is on alternative fuels for these modes.

Alternative fuels, including electricity, hydrogen, biofuels, and natural gas, are expected to gain increasing market shares in the coming decades (IEA, 2009d). An important indicator of fuel environmental quality is provided by global warming potential, i.e., GHG content per unit of energy, as estimated by full lifecycle analysis. Crucially, global warming potential can vary enormously for all fuel categories, depending on upstream production process. Hence, electricity, hydrogen, and biofuels constitute low-carbon fuels only if their respective supply chains are low carbon.

Fuel supply chain lifecycle is also important for fossil fuels. For example, upstream emissions of extraction increase significantly for oil tar sands and deep water resources, now entering the market due to increased oil prices (IEA, 2010a). From this perspective, Arabian oil resources perform better than unconventional fossil fuel resources.

Beyond their environmental footprint, novel fuels may have infrastructure constraints, at least initially. While some fuels, such as biofuels and biomethane, can rely on existing distribution infrastructures, electric, hydrogen and hybrid concept cars need completely new or partially new infrastructures. Conversely, from an energy generation standpoint, electric cars can use the capacity existing in current and planned power plants, whereas biofuels and hydrogen would have to scale up production facilities. Building new facilities and approving infrastructure investments necessary to support the market expansion of specific alternative fuels entail making complex decisions. Alternative fuels may function with a certain degree of complementarity, such as when biomass is used to produce electricity. But the most likely case involves trade-offs between alternative sources. Once a decision to create and develop a market for one source is made, it is likely that the chain of decisions and investments will lead to path dependency. Research and development of conventional fuels and powertrains represent sunken investments, as they build on a century of experience, learning curves, and economics of scale. Barriers to the entry of alternative fuels and technologies that hinder their widespread adoption include huge up-front costs for infrastructure and affordable vehicle technologies. This is particularly true for hydrogen, for which investments in infrastructure are considered to be in the range of US\$200–500 billion for its use to be feasible in the United States (Hammerschlag and Mazza, 2005). Another uncertainty regarding future benefits and costs, these investments could constitute another technological lock-in. The issue has a lesser impact for electric cars, as the existing electric grid already provides a crucial part of the infrastructure requirement.

Multiple equilibria, corresponding to different fuels, are possible. Some of them could be far from the global optimum. In fact, several authors indicate that a hydrogen economy could result in a suboptimal equilibrium (Keith and Farrell, 2003; Odgen et al., 2004; Hammerschlag and Mazza, 2005). Taking this into consideration, it is useful to evaluate different fuels based on current knowledge of their respective lifecycle analyses. For more discussion on infrastructures, see Chapter 24.

9.4.1 Alternative Fuels for Road Transportation

9.4.1.1 Natural Gas and Biomethane¹²

Natural gas could rely on the existing internal combustion engine platform of vehicles and existing distribution infrastructures, subject to minor changes. While whole-scale infrastructure investments are not needed, a new pump system for gas fuel is required. Natural gas appears as compressed natural gas (CNG, 200–1500 psi) and liquid natural gas (LNG, liquefied at -160°C). Natural gas and biomethane are methane-based (CH₄) fuels and have about 20% lower carbon content than other fossil-based liquid fuels. As such, they are candidates for lowering the

¹² See also Chapters 12 and 13

carbon intensity of transportation. Natural gas vehicles emit very low levels of particulate matter (PM) – NO_x, and carbon monoxide (CO) – and can reduce carbon emissions by up to 25% for heavy-duty vehicles (US DOE AFAVDC, 2009).

LNG is more than twice as energy dense as CNG, but has only 60% of the energy density of diesel. Vehicle technology, which uses large compressed gas storage tanks and spark ignition ICEs (internal combustion engines), is particularly mature for heavy-duty applications, which are less constrained by the low energy density of natural gas.

Biomethane is a biofuel refined from biogas, a natural byproduct of organic decay. Major sources of biogas include landfills, manure lagoons, and other agricultural systems. For end-use purpose, biomethane can be treated as natural gas. Fuel-graded biomethane can be directly injected into CNG pipelines or liquefied with LNG and be used in all the same applications. Using biomethane provides the opportunity to reduce GHG emissions, especially if it is sequestered from existing facilities such as landfills, manure lagoons, and rice paddies (unsequestered biomethane has 20 times the global warming potential of CO₂). Methane comprises over 10% of all GHG emissions for Annex I countries in terms of CO₂ equivalence, and around 26% for non-Annex I countries (IPCC, 2007). Harnessing and utilizing biogas is a key strategy for reducing these emissions.

9.4.1.2 Biofuels

Biofuels have been seen as a promising way forward to energy security and climate change mitigation. In some world regions, they are also regarded as a new form of revenue for farmers. However, market-mediated deforestation – and other so-called indirect land-use effects – can negate any GHG abatement and add pressure on global food security and biodiversity. The two major biofuel-producing countries are the United States and Brazil; 46% of global production occurs in the United States, 42% in Brazil, 4% in Europe, and 8% in the rest of the world (World Bank, 2008b). The European Union and the United States have ambitious relative or absolute targets for biofuel market shares by 2020 (see Section 9.6). Key questions for biofuels are their climate mitigation potential, and their (indirect) effects on competitive land uses, such as food production and ecosystem functioning (see also Chapter 20).

Biofuels were originally regarded as zero- or low-carbon fuels. This is based on the fact that biofuels release only CO₂ upon combustion that plants previously absorbed from the atmosphere via photosynthesis. However, GHG gases are also emitted during cultivation (by fertilizer and nitrate application) and harvest of the feedstocks, as well as subsequent processing, refining, distribution, or the various transportation requirements throughout the production stages. Moreover, direct and indirect land-use changes associated with growing the feedstock often change the carbon stored above or below ground.

The lifecycle GHG emissions of biofuels have been studied comprehensively, with emphasis usually placed on bioethanol (Quirin et al., 2004; Niven, 2005; Farrell et al., 2006; von Blottnitz and Curran, 2007; see also Chapter 11). The earlier literature suggests that biofuel systems show moderate to strong fossil fuel substitution potential and GHG savings when compared with conventional petroleum-based fuels. GHG savings vary for different biofuel systems, based on differences in growing methods, climate, and feedstock characteristics. Tropical sugar crops, in particular ethanol from Brazilian sugar cane, were shown to be the most productive feedstocks (e.g., Goldemberg, 2009) – a result that is disputed in the more recent literature (Lapola et al., 2010). Second generation biofuels from lignocelluloses are usually suggested to be the most abundant and potentially most sustainable feedstocks (von Blottnitz and Curran, 2007). A number of studies find GHG performance is worse for current biofuels than for fossil fuel systems (Patzek, 2004; Patzek and Pimentel, 2005; Hertel et al., 2010). Some variation is due to model assumptions regarding the system boundaries, the way co-products are accounted for, and the differences in input parameters and secondary data sources used (Farrell et al., 2006). More recently, three crucial qualifications of GHG benefits of biofuels have pointed out that:

- CO₂ emissions from direct and indirect land-use change are often neglected, tend to worsen GHG benefits, and add considerable uncertainties over the net GHG benefits of biofuels (e.g., Searchinger et al., 2008; Creutzig and Kammen, 2009a; Plevin et al., 2010).
- If land-use change is involved, emissions are better accounted for by temporally explicit lifecycle analysis that addresses upfront land-use emissions, long-term GHG savings from biofuels, and potential soil sequestration (O'Hare et al., 2009).
- Nitrous oxide emissions are estimated simplistically in most studies and have high uncertainties, which can have strong negative effects on the GHG emission balance of biofuels. For example, the IPCC default emission factor for nitrous oxides related to biofuels may underestimate emissions by a factor of 3–5 (Crutzen et al., 2008).

Uncertainties are a major issue, in particular with respect to indirect land-use emissions and nitrous oxide emissions. For example, US corn ethanol reduces GHG emissions per kilometer driven by 20% compared to conventional gasoline, as long as land-use change-related emissions are excluded from the calculations. However, once land-use emissions are accounted for, corn ethanol has twice as high lifecycle emissions as gasoline accounted over a 30-year production period (Searchinger et al., 2008). Within a 95% confidence margin, indirect land-use change emissions from US corn ethanol expansion range from 21–142 gCO₂-eq/MJ, i.e., from small, but not negligible, to several times greater than the lifecycle emissions of gasoline (Plevin et al., 2010).

In Europe, there is mainly permanent grassland that could be diverted to biofuel feedstock production. If this conversion takes

place, it may take 20 to 110 years (+/- 50%) to recover the soil carbon through GHG emission savings from using the biofuel grown on the same land (de Santi et al., 2008). The same detailed bottom-up study reveals that emissions from nitrous oxides may vary by a factor of 100 depending on the site-specific conditions, notably soil organic content.

A summary of estimates for a variety of different biofuels is given in Figure 9.27. Note that these estimates are subject to major uncertainties (e.g., Plevin et al., 2010). In summary, indirect land-use change-related emissions can worsen the effect of biofuels significantly. For further discussion of the uncertainty of direct and indirect land-use emissions, see Chapter 11.

The performance of biofuels from different feedstock is very mixed across other environmental impact categories (von Blottnitz and Curran, 2007). Biofuel impact is often more harmful compared to conventional fossil fuels (Quirin et al., 2004). A comprehensive LCA of a broad variety of biofuel feedstocks suggests a trade-off between fewer GHG emissions and higher environmental disadvantages of different kinds compared to conventional petroleum-based fuels (Zah et al., 2007). Biofuels might be a greater overall public health risk than conventional petroleum-based fuels due to ozone effects. For a more comprehensive assessment on issues such as water use and biofuel production, see Chapter 20.

Crucially, agricultural crop production for biofuels competes with food production. The current production of biofuels based on conventional crops – first generation biofuels – has already put pressure on global food prices. While the World Bank estimates that biofuel production has been responsible for roughly 75% of the increase in food prices between 2002 and 2008, the overall literature is ambiguous on the magnitude of the biofuel-induced price hike (see Chapter 20 for a complete discussion). Food price hikes and induced food insecurity have severe consequences for the livelihoods of people in poor countries. The Food and Agricultural Organization of the United Nations (FAO, 2008) suggests that an additional 75 million people were pushed into undernourishment during the global food price crisis in 2007, bringing the total to nearly one billion hungry people in the world. Achieving the aggressive biofuel targets in the United States and Europe could potentially have much larger impacts, which justifies the need for questioning current biofuels strategies.

Second and third generation biofuels have been put forward as biofuels with low lifecycle emissions. Second generation biofuels are derived from non-food crops, and important variants such as cellulosic bioethanol are suggested to have very low lifecycle GHG emissions (Farrell et al., 2006). Third generation biofuels are produced from algae and have much lower land demand. However, more recent studies question the economic viability of second generation biofuels and point out that these biofuels compete with food production, too (Sanderson, 2009). For further discussion, see Chapter 11, Section 11.2.

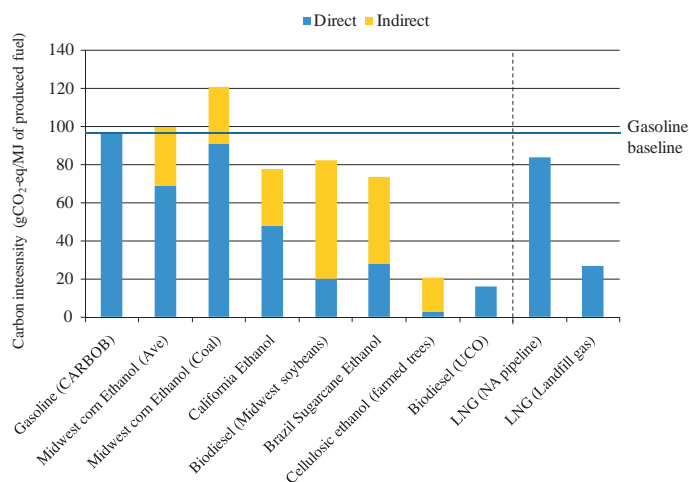


Figure 9.27 | Carbon intensity of different biofuels as compared to gasoline. UCO refers to used cooking oil which is generally assumed to have no indirect effects, and hence, has relatively low carbon intensity. Source: based on CARB, 2009; Creutzig et al., 2011a.

In summary, with a few exceptions¹³ biofuels currently available in the market place have questionable impact on GHG emissions, food security, and other land-related issues, such as deforestation and biodiversity. Large uncertainty on indirect land-use changes and third level impact requires further research. Meanwhile, further large-scale biofuel production must be considered with caution. The accumulation of niche-based solutions, however, may be promising (Tilman et al., 2009). Chapter 11 and 20 suggest that the deployment of advanced biofuels with low GHG footprint is possible and can be recommended if managed in the strict context of sustainable development and if food security remains uncompromised.

9.4.1.3 Electricity and Hydrogen

Electricity and hydrogen as fuels for road transport both represent intermediate energy storage mediums that need to be produced by other sources of energy (e.g., coal, nuclear, or wind in the case of electricity, and natural gas or electricity itself in the case of hydrogen). Hence, they are discussed together. First, common features are presented and both fuels are compared. Then specific issues for each fuel are raised.

The limiting factor for battery electric cars is the total energy that can be delivered and the limited driving range, whereas the constraint for hydrogen fuel cell vehicles is the amount of power they can produce and whether this will be sufficient to meet vehicle acceleration requirements (Eaves and Eaves, 2004). Battery storage has higher WTW efficiency (75–85%) than hydrogen (30–50%) and lesser known variants such as compressed-air storage (<30%) (Schaber et al., 2004; Eaves and Eaves, 2004; Creutzig et al., 2009), translating into the more efficient

¹³ Such as Brazil Sugarcane Ethanol, cellulosic ethanol, Biodiesel from used cooked oil (UCO), and advanced biofuels.

economic and environmental performance of electric cars than hydrogen cars (Hammerschlag and Mazza, 2005). For electric cars, costs scale according to battery capacity. As most trips would be short distances, plug-in hybrid electric vehicles (PHEVs) provide the best cost-benefit ratio in the medium term (APS, 2008). Research and development (R&D) also needs to comprise demand-side technologies, as the current electric grid capacity is sufficient to fuel 20–50% of the European Union or the United States' fleets when demand-side technologies and policies are deployed (Denholm and Short, 2006; Kintner-Meyer et al., 2007; EC DGJRC, 2009).

Electricity

For electric mobility, electricity production and the required vehicle technology and recharging infrastructure need to be assessed. Since electricity generation and its distribution infrastructure are already widely used in most countries, there is no significant barrier to its use for road transport. Efficiency is discussed in Chapter 9, Section 9.3.2. Hence, the focus here is on electricity production. The key factor determining the life-cycle emissions of electric vehicles (EV) is the carbon intensity of the electricity generation.

Renewably produced electricity comprised 18% of global electrical consumption in 2007 and is projected to rise further (EIA, 2010, see also Chapter 11). The difference is mainly due to uncertainty in ambition of global climate change mitigation policies. In 2008, renewables comprised over 50% of all newly added electrical capacity in the United States and Europe combined, or 276.7 GW (Martinot and Sawin, 2009). With the current electricity mix in countries such as the United States and Germany, electric cars can have about the same global warming impact as conventional cars with otherwise the same characteristics (e.g., Creutzig et al., 2009). With an increasing share of renewable energies, the global warming impact of electrics is expected to decrease.

EVs do not necessarily reduce net emissions, but they remove them from inner cities where air pollution has the highest public health impact (i.e., intake fraction is highest). Hence, an electrification of current car fleets would produce public health advantages in most cities.

Electric mobility requires a new infrastructure. Electric vehicles face barriers to market entry, mostly related to range anxiety. The challenges that remain for all-electric vehicles (e.g., BEVs, PHEVs) are technological and logistical.

First, the requirements of fueling infrastructure and capacity of the electric grid to recharge EV batteries are important considerations. The fueling infrastructure for EVs is less costly to deploy than for hydrogen, requiring only recharging stations with conventional outlets connected to the existing electrical grid, which are estimated to cost around US\$2000 per commercial charging station (Morrow et al., 2008). Another option would be to have fueling stations remove depleted batteries from vehicles and provide fully charged batteries to drivers, thereby helping them avoid lengthy recharging times. A study in the United States showed

there is sufficient off-peak electrical capacity to charge 185 million EVs overnight, or 75% of the current US passenger vehicle fleet (Schneider et al., 2008). Policies and smart infrastructures are required to make use of off-peak capacity. While using off-peak electricity will result in overall increased grid efficiencies, it will still result in greater wear and tear of the grid, especially for transformers, resulting in higher maintenance costs (Blumsack et al., 2008).

Second, the batteries themselves are problematic components of EVs. The weight, size, cost, and lifetime of batteries must be optimized to improve the marketability and all-electric range (AER) of EVs. Larger batteries provide longer AERs and weigh from 23 kg (50 lbs) for limited-AER PHEVs to 450 kg (1000 lbs) for highway capable 320 km (200mile) AER BEVs (Shiau et al., 2009). Given the trade-off between battery weight and vehicle fuel efficiency, researchers are trying to reduce battery weight while maintaining desired AER. Most of today's EV models use nickel-metal hydride (NiMH) batteries, but the next generation will use Li-ion batteries, which are more compact and lightweight but also more expensive.

Third, the incremental cost of EVs compared to gasoline ICEs and Gs is significant. In the long term, PHEVs with an AER of 64 km (40 miles) are estimated to be at least US\$11,000 more expensive than gasoline ICE vehicles (Simpson, 2006). The battery is the most expensive component of EVs, with a cost of US\$30,000 or more for BEVs (US BTS 2001). Lower battery costs and higher petroleum costs will make them more competitive, along with other government incentives such as tax rebates and subsidies (Simpson, 2006). When taking into account the fuel cost savings, PHEVs could be up to US\$11,000 cheaper than conventional ICE vehicles over their lifetime. However, the high sticker price for highway capable BEVs, as much as US\$100,000 for some current models, requires substantial reduction before they can be mass-marketed (Tesla Motors, 2009).

Hydrogen

Hydrogen has been used in ICEs of cars, trains, ships, and other applications prior to the 1930s. Hydrogen gas burns cleanly in an ICE with minimal PM, NO_x, and CO₂ emissions. As a second possible technology, hydrogen-fuel cell vehicles emit only water as a byproduct.

Using hydrogen as a transportation fuel enables decentralized fuel production and refueling. Similar to electric vehicles, hydrogen vehicles allow for the displacing of fossil fuels if the hydrogen is produced from renewable energy. Hydrogen vehicles can also act as renewable energy storage devices. As an advantage over electric vehicles, hydrogen has higher energy density, and hence long-range driving is possible. However, WTW efficiency is lower than for electric cars. If not produced by electrolysis where the electricity is provided by renewable energies, hydrogen cars tend to have higher GHG emissions than electric cars.

The largest barrier to hydrogen vehicle use is the present economic infeasibility of mass-marketing the technology. Fuel cells, hydrogen

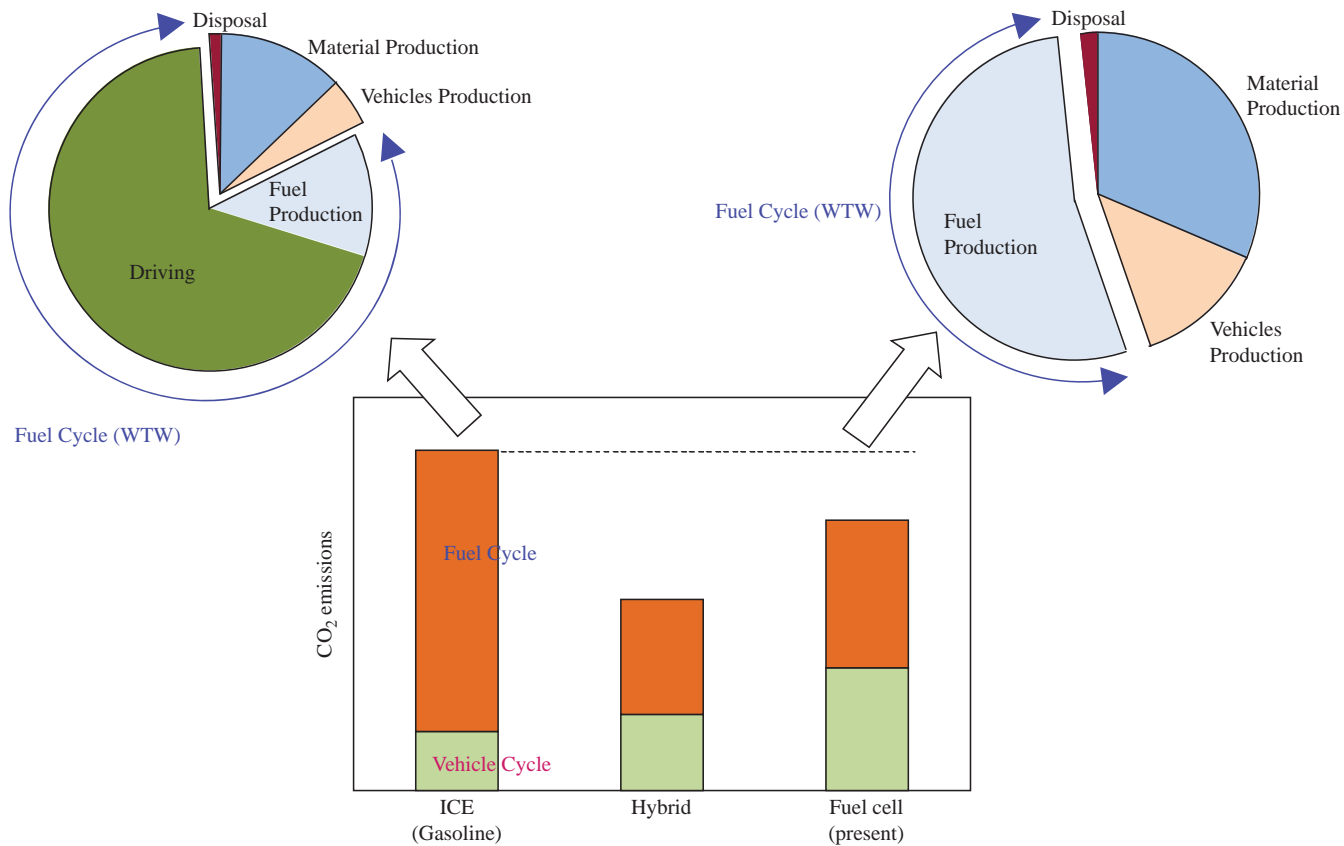


Figure 9.28 | LCA for passenger vehicles. (Pie charts show the details of CO₂ emissions from both fuel and vehicle cycles. Pie chart for HEV is not shown, but general features are between ICE and FCV.) Source: based on Toyota, 2004.

storage devices, fueling infrastructure, and hydrogen production are all currently very costly. Overcoming these kinds of economic and logistical barriers will require substantial political will and public funding into the foreseeable future, another impediment in its own right. However, should hydrogen transportation become economically viable, it provides an opportunity for significantly reducing GHG emissions.

9.4.2 Improving the Efficiency of Road Vehicles

Fuel use is a function of vehicle use (km/yr) and fuel economy (fuel/km). This section addresses potential for improvement for fuel economy.

9.4.2.1 Lifecycle Analysis of Motorized Vehicles

For automobiles, lifecycle analysis can be divided into the two parts; fuel cycle (extraction of crude oil, fuel processing, fuel distribution, and fuel use during vehicle operation) and vehicle cycle (material production, vehicle manufacturing, vehicle distribution, and disposal at the end of life). For a typical ICE vehicle, 70–90% of energy use and GHG emissions take place during the fuel cycle, depending on vehicle efficiency, driving

mode, and lifetime driving distance, as shown in Figure 9.28 (Toyota, 2004).¹⁴ This indicates that the most effective CO₂ reduction measures would target the fuel cycle, making vehicle fuel economy an important aspect of vehicle technologies.

Although the vehicle cycle contributes 10–30% to the overall emissions in conventional cars, fuel cell and hybrid cars have higher levels of vehicle cycle emissions because more energy is needed to make battery, fuel cell stack, and electronic parts, such as motors and power control units (Toyota, 2004).

Recent research has summarized results of fuel cycle analyses (e.g., IPCC, 2007; CARB 2009; Creutzig et al., 2011a), especially in relation to biofuel and hydrogen production. Regional studies of the WTW CO₂ emissions of conventional and alternative fuels and vehicle propulsion concepts include a General Motors/Argonne National Laboratory (GM/ANL, 2005) analysis for North America, EU-CAR/CONCAWE/JRC (2006) for Europe, and Toyota/

¹⁴ For other transportation modes such as train and ship, very similar pictures can be observed where the CO₂ emission is dominant during operation, as shown in Figure 9.33 (Aihara and Tsujimura, 2002; Kameyama et al., 2005). CO₂ emissions during operation are very sensitive to total length, frequency of travel and other operational conditions.

Mizuho (2004) for Japan. These LCAs display small but significant differences for ICE-gasoline and ICE-D (diesel), reflecting the difference in oil producing regions and regional differences in gasoline and diesel fuel requirements and processing equipment in refineries (Khan Ribeiro, et al., 2007).

The WTW CO₂ emissions shown in Figure 9.30 are for the following four groups of vehicle/fuel combinations; ICE/fossil fuel, ICE/CNG, EV, FCVs and a number of hybrids. The full WTW CO₂ emissions depend on not only the drive train efficiency (tank-to-wheel or TTW) but also the emissions during fuel processing (well-to-tank, or WTT). ICE-D has 16–24% lower emissions due to the high efficiency of the diesel engine. The results

for hybrids vary among the analyses due to different assumptions of vehicle efficiency and different driving cycles. Toyota’s analysis of the Prius, using a Japanese 10–15 driving cycle, demonstrates a potential for CO₂ reductions of 30–50% (Khan Ribeiro, et al., 2007).

The lifecycle emissions of ICE vehicles using biofuels and fuel cell vehicles are extremely dependent on the fuel pathways. For ICE-Biofuel, the CO₂ reduction potential is often assumed to be very large (30–90%) (e.g., IPCC, 2007). As the discussion in Section 9.3.1 demonstrated, recent research estimates that current biofuels possibly have a higher global warming potential than gasoline, mostly due to taking indirect land use change into account (see Figure 9.23).

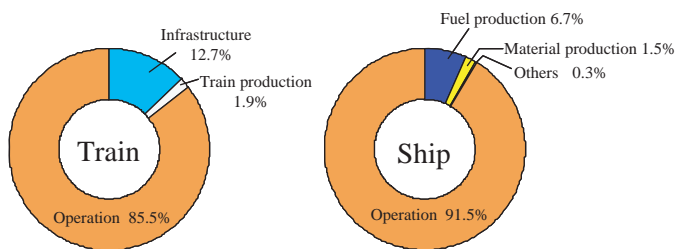


Figure 9.29 | LCA for trains and ships. Source: based on Aihara and Tsujimura, 2002; Kameyama et al., 2005.

The potential of EV is strongly dependent on the CO₂ emission factor of power generation. In regions where coal-fired plants dominate, switching to EV increases CO₂ emissions. The GHG reduction potential for natural gas-sourced hydrogen FCV is moderate, but lifecycle emissions could be dramatically reduced by using CCS (carbon capture and storage) technology during H₂ production. Using renewable energy such as C-neutral biomass as a feedstock or electricity from renewables as an energy source also will yield very low emissions (Khan Ribeiro, et al., 2007).



Figure 9.30 | Relative amount of energy required for different supply chains (the shaded area corresponds to the energy remaining at the wheel) and well-to-wheel GHG emission for various powertrain/fuel combinations. Source: based on Creutzig et al., 2011a.

9.4.2.2 Fuel Economy: Minimizing Energy Losses

There are significant opportunities to improve energy efficiency of road transport. Only about 20% of the energy from the fuel put into passenger vehicles gets used to operate the vehicle. The rest of the energy is lost in the engine and drive train and during idling (OTA, 1995; US DOE, 2010) as seen in Figure 9.31.

There is great potential to improve vehicle energy efficiency through improvements in vehicle technology. Fuel use of road transportation can be reduced by increasing the conversion efficiency of the fuel energy to work by improving drivetrain efficiency and recapturing energy losses; and reducing vehicle loads such as weight, rolling, air resistance, and accessory loads, thus reducing the work needed to operate it.

Engine losses

In gasoline-powered vehicles, more than 60% of the fuel energy is lost in the engine due to engine friction, pumping air into and out of the engine, and wasted heat. These losses can be reduced by advanced engine technologies such as variable valve timing and lift, turbocharging, direct fuel injection, and cylinder deactivation. Also, diesel engines have about 15–25% higher efficiency than gasoline engines. As will be discussed later, fuel cell vehicles and electric vehicles are future options for substantial improvement in powertrain efficiency.

Idling losses

During urban driving, idling at stop lights or in traffic causes significant energy loss. These losses can be reduced by automatically turning the engine off when the vehicle comes to a stop and restarting it instantaneously when the accelerator is pressed. This is a standard technology in current hybrid vehicles.

Drivetrain losses

Energy is also lost in the drivetrain and it is improved by technologies such as automated manual transmission and continuously variable transmission.

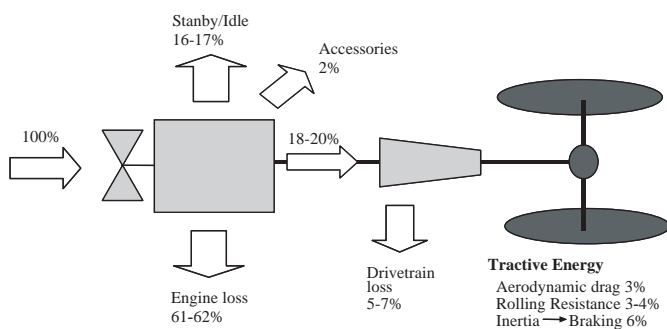


Figure 9.31 | Energy use in a typical gasoline passenger vehicle (mid-size, urban driving mode). Source: based on Kobayashi et al., 2009.

9.4.2.3 Fuel Economy: Reducing Vehicle Loads and Weight

Rolling resistance

Rolling resistance is the resistive forces between the tires and the road, and is directly proportional to weight. It amounts to up to about 30% of total tractive force. It can be reduced by tire design (tread and shoulder designs) and tire materials, and redesigning wheel bearings and seals. For passenger cars, a 5–7% reduction in rolling resistance leads to a 1% improvement of fuel efficiency. However, there are trade-off such as traction, durability, and noise.

Aerodynamic drag

About 30% of total tractive forces is lost by aerodynamic drag, and it become higher during fast highway driving, since drag is directly proportional to the square of speed. Drag forces are reduced by reducing the frontal area of the vehicle, smoothing out body surfaces and adjusting the body's basic shape and so on.

Accessories

Accessories such as air conditioning, power steering, windshield wipers, and audio systems use energy generated from the engine. This becomes substantial in battery-powered vehicles during hot or cold weather.

Braking losses

Upon braking, kinetic energy of vehicles is lost. The regenerative braking system can capture the energy as electricity or a kinetic force.

Vehicle weight

Energy to overcome the vehicle's inertia is directly related to its weight. The less a vehicle weighs, the less energy required to start and drive it. Weight can be reduced by lightweight materials and vehicle design. Lightweight materials in BEVs can increase the driving range – one of the crucial constraints of electric vehicles. For example, carbon fiber materials will be used for BMW's 2013 Mega City Vehicle, but with a penalty of cost.

9.4.2.4 Vehicle Efficiency through Hybrid Technology and Alternative Fuel Engines

Hybrid drivetrains

Typical hybrid-electric drive trains is a combination of a fuel-driven power source, such as a conventional internal combustion engine with an electric drivetrain – electric motor/generator and battery (or ultracapacitor) – in various combinations. In most current hybrids, the battery is recharged only by regenerative braking and engine charging, without external charging system from the grid. Since the 1997 introduction of the Toyota Prius hybrid in the Japanese market, hybrid electric drivetrain technology has advanced substantially. The markets for hybrid vehicles have expanded, presently providing a variety of improved systems in alternative forms and different combinations of costs and benefits.

Hybrid systems now cover a range of technologies from simple belt-drive alternator-starter systems, offering perhaps 7–8% fuel economy benefit under US driving conditions, to “full hybrids” such as the Prius, offering up to perhaps 40–50% fuel economy benefits (IPCC, 2007). Hybrids recover the kinetic energy by regenerative braking system and also save energy by idle-stop, therefore they can improve fuel efficiency in congested urban driving conditions. This might be particularly useful for taxis and vehicles dedicated to urban use as well as for some heavier-duty applications, including urban buses and urban delivery vehicles (IPCC, 2007). FedEx has claimed a 57% fuel economy improvement for its E700 diesel hybrid delivery vehicles (FedEx, 2004). Hybrid sales have expanded rapidly. In the United States, sales were about 7,800 in 2000 but rose to 350,000 in 2007. Worldwide cumulative Prius sales alone hit 500,000 by the end of April 2006, 1,000,000 by the end of April 2008, and 2,000,000 by the end of September 2010.

Plug-in hybrids, or PHEVs, are conventional hybrids with a capability of charging from the grid, and can be seen as a merging of hybrid electric and battery electric vehicles. PHEVs get some of their energy from the electricity grid. Plug-in hybrid technology could be useful for both LDVs and for a variety of medium-duty vehicles, including urban buses and delivery vehicles. Substantial market success of PHEV technology is, however, likely to depend strongly on further battery development, in particular on reducing battery cost and specific energy, as well as increasing battery lifetimes.

By using electricity to “fuel” a substantial portion of distance driven the potential of PHEVs to reduce oil use is clear (IPCC, 2007). The US Electric Power Research Institute (EPRI, 2001) estimates that 30 km hybrids (those that have the capability to operate up to 30 km solely on electricity from the battery) can substitute electricity for gasoline for approximately 30–40% of miles distance driven in the United States. With larger batteries and motors, the vehicles could replace even more mileage. However, their potential to reduce GHG emissions compared with more than that achieved by current hybrids depends on their sources of electricity. For regions that rely on relatively low-carbon electricity for off-peak power, e.g., natural gas combined cycle power, GHG reductions over the PHEV’s lifecycle will be substantial. In contrast, PHEVs in areas that rely on coal-fired power could have increased lifecycle carbon emissions. In the long-term perspectives, transition to a low-carbon electricity sector could allow PHEVs to play a major role in reducing transport sector GHG emissions (IPCC, 2007). Technically, the development of high-performance batteries for PHEVs remains a big challenge.

Hydrogen/fuel cells

During the last decade, FCVs have attracted growing attention and made significant technological progress. Hydrogen fuel cells decouple carbon from power generation and emit only water vapor. Growing urban air pollution, climate impacts and energy security and the potential to provide new desirable attributes for vehicles (low noise, new designs) are main drivers for development of FCVs. Hydrogen can be produced from a wide range of sources including fossil, nuclear and renewable. However, the chicken-and-egg challenge to provide vehicles

and required infrastructure at the same time is more pronounced for hydrogen vehicles than it is for electric vehicles, reducing the short-term likelihood of large-scale deployment. However, a study about the US Hydrogen Initiative states that hydrogen can be produced in a “distributed” fashion at the refueling station by reforming natural gas and renewable fuels like ethanol utilizing existing delivery infrastructure to meet initial lower volume needs with the least capital investments, therefore fuel reformers would not require a substantial hydrogen transport and delivery infrastructure (Chalk, et al., 2008). While production is workable, hydrogen must be compressed, stored and dispensed at refueling stations or stationary power facilities. The same study considers that “hydrogen costs and availability and fuel-cell durability and cost are still formidable challenges to be solved” (Chalk, et al., 2008). Although there are several types of FCVs, such as direct-drive and hybrid powertrain architectures and fuelled by pure hydrogen, methanol, and hydrocarbons (gasoline, naphtha), nearly all auto manufacturers are now focused on the pure hydrogen FCV. Significant technological progress has been made for these several years, including improved fuel cell efficiency and durability, cold start (sub-freezing) operation, increased range of operation, and dramatically reduced costs. (Although FCV drive train costs remain at least an order of magnitude greater than ICE drivetrain costs).

A recent US National Research Council assessment (NRC, 2008) concludes:

- Concentrated efforts by private companies, together with governments around the world, have resulted in significant progress toward a commercially viable hydrogen fuel cell vehicle.
- Fuel cell costs have been reduced significantly over the past 4–5 years. Costs projected for high-volume (500,000 units/year) automotive fuel cell production are approximately US\$100/kW for relatively proven technologies and US\$67/kW for newer laboratory-based technologies.
- A significant market transition to FCVs could start around 2015 if supported by strong government policies to drive early growth.

The GHG reduction potential of FCVs strongly depends on the hydrogen production pathways and the efficiency of vehicles. At the present technology level, with FCV TTW efficiency of about 60%, and where hydrogen can be produced from natural gas at 60–80% efficiency, WTW CO₂ emissions can be reduced by 40–65% compared to current conventional gasoline vehicles. In the future, if hydrogen is produced by water electrolysis using renewable electricity such as solar and wind, or nuclear energy, the entire system from fuel production to end-use in the vehicle has the potential to be a true zero emissions system. The same is almost true for hydrogen derived from fossil sources with CCS system, in which as much as 90% of the CO₂ produced during hydrogen manufacture is captured and stored.

Table 9.4 | Increase of fuel efficiency due to various vehicle technologies.

Engine Technologies	Increase (%)	Transmission Technologies	Increase (%)
Variable Valve Timing & Lift	1–9	Continuously Variable Transmissions (CVT)	3–8
Cylinder Deactivation	7–7.5	Automated Manual Transmissions (AMT)	7–9
Turbochargers	2–7.5		
Idle Stop	0.5–8		
Direct Fuel Injection	3–15	Others	Increase (%)
Reduce Engine Friction	2–6	Weight+Drag+Time	7–18
Variable Compression Ratio	10	Accessories	2–3

Source: Kobayashi et al., 2009.

Electric vehicles

Battery-powered electric vehicles operating today are powered by electricity acquired from the grid and stored on board in batteries. Electric vehicles have high efficiencies of more than 90%, but the big challenges are left to be overcome; short driving range and short battery life. Although the potential for CO₂ reduction strongly depends on the power mix, WTW CO₂ emission can be reduced by more than 50% compared to a conventional gasoline ICE (JHFC, 2006).

Vehicle electrification requires a more powerful, sophisticated, and reliable energy-storage component than lead-acid batteries. NiMH batteries currently dominate the hybrid market and Li ion batteries are expected to replace the market. The energy density has been increased to 170 Wh/kg and 500 Wh/L for small-size commercial Li ion batteries and 130 Wh/kg and 310 Wh/L for large-size EV batteries. The major hurdle left for Li ion batteries is high cost (IPCC, 2007).

Ultracapacitors offer long life and high power but have low energy density and a high current cost. The energy density of ultracapacitors has increased to 15–20 Wh/kg (Power System, 2005), compared with 40–60 Wh/kg for Ni-MH batteries. The cost of these advanced capacitors is in the range of several 10s of dollars/Wh, about one order of magnitude higher than Li batteries (IPCC, 2007).

9.4.2.5 Quantifying the Efficiency Improvement of Technologies

Table 9.4 summarizes the impact of vehicle technologies on vehicle fuel efficiency (Kobayashi et al., 2009). Most of these technologies are already commercially utilized, and the range of improvement by the use of these technologies is still relatively large. There are some trade-offs, such as emission control and safety issues. Employment of these technologies in new vehicles leads to an increase of vehicle production costs, although part (and, in some cases, all) of this cost increment is offset by fuel savings. Car manufacturers will select unique packages of technologies, based on the level of improvement required, economy viewpoint, and also their expertise.

Table 9.5 | Projections of vehicle efficiency improvement (%) relative to the base gasoline vehicle.

	2010	2020	2030–35	2050
Gasoline (G)	6–15	29	37–53	28–45
Diesel (D)	15–29	48	46–60	32–47
Hybrid -G	17–57	57	64–69	40–52
Hybrid -D	36–59	63	72	40–55
Fuel Cell	53–58	71–74	63	
Fuel Cell – Hybrid	52–73	76–78		
Electric Vehicle	82		80	
Ref #	1–4	5	6–8	9

Source: (1) Wurster, 2002; (2) GM/ANL, 2005; (3) EU CAR/CONCAWE/JRC, 2006; (4) JHFC, 2006; (5) Heywood and Weiss, 2003; (6) Bodek and Heywood, 2008; (7) Cheah et al., 2007; (8) Kromer and Heywood, 2008; (9) IEA, 2008.

Based on these technology developments, vehicle efficiency presented here is estimated along the timeline from 2010–2050 (Kobayashi et al., 2009). Since base vehicles, and assumptions about the employment of technologies and their effectiveness are different, the range of estimates among the studies are rather large, and the estimates of MIT (Ref. No. 5–8 in Table 9.7) are in the higher range compared with others. This is partly due to a more optimistic view, but also due to the fact that the potentials for improvement of vehicle efficiency in the US market is larger. As can be seen in Table 9.5, baseline gasoline ICE vehicles with conventional drivetrains could be continuously improved up to 2050, and achieve close to a 50% increase in fuel efficiency with advanced technologies. At the same time, diesel ICEs will gain higher efficiency, but their margin over gasoline vehicles will shrink (Kobayashi et al., 2009).

Several technical hurdles remain to be overcome for wide marketplace acceptance of hybrids, fuel cells, and electric vehicles. As mentioned above, the cost increase due to new technology is very important when gauging potential market penetration (Kobayashi et al., 2009). As in the case of efficiency improvement, there are large differences among studies. In particular, cost estimates for HEVs in EUCAR/CONCAWE/JRC (2004) are significantly higher than other studies. This may be explained by their assumption of very high HEV battery requirement with 6kWh, which allows the 20 km of full EV operation.

In Figure 9.32, most of the data lies below US\$6000. Calculating how many years customers need to pay off the increment of vehicle price by saving the fuel cost provides some implication for the market (Kobayashi et al., 2009). Starting with a typical situation in the United States, that a vehicle has a fuel efficiency of 10 km/L (24 MPG) and travels 19,000 km (12,000 miles) yearly, results in an annual fuel consumption of 1900 L (500 gallons). If fuel costs US\$0.80/l (US\$3/gallon), the annual fuel cost is US\$1500. If the fuel efficiency improvement is 50%, customers need 12 years to pay off the price increment. In Japan, where fuel prices are almost twice as high, but distance traveled per year is around 14,000 km, only six years are needed to pay off the price increment. Although this does not necessarily mean that customers will be willing to buy

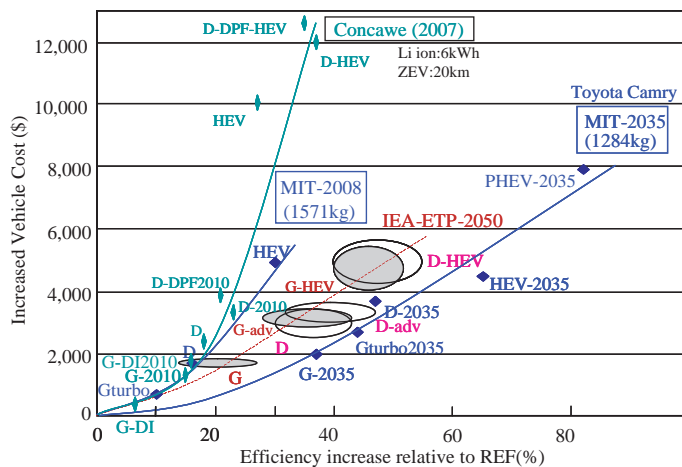


Figure 9.32 | Price increase of vehicle due to efficiency increase. Data for IEA are shown as ellipses indicating the range of data. (G: gasoline, D: diesel, DI: direct-injection, DPF: particulate filter) Source: based on data from EUCAR/CONCAWE/JRC, 2006; Bandivadekar, 2008; IEA, 2008.

the vehicle with such an increased price, this fuel savings/vehicle cost trade-off may be commercially allowable if future consumers are highly concerned about fuel economy.

9.4.3 Aviation

9.4.3.1 Alternative Fuels for Aviation

Sustainable alternative fuels produced from biomass or renewable oils offer the potential to reduce lifecycle GHG emissions from aviation. As these fuels contain significantly lower fuel sulphur, they may also help to reduce emissions of particulate matter and lessen aviation's impact on air quality. Aviation is heavily dependent over the short- and medium-term on drop-in liquid fuels. Sustainable alternative aviation fuels are not available today in significant quantities, and considerable doubts remain on their lifecycle GHG emissions. In fact, the lifecycle GHG emissions of biofuels may be higher than previously estimated when indirect effects are included (see Section 9.3), putting doubts on the straight-forward realization of win-win opportunities.

In the short term,¹⁵ sustainable alternative fuels for aircraft may be available in limited quantities and have a lifecycle CO₂ footprint equal to, or less than, conventional jet fuel. It will be necessary to blend these alternative fuels with conventional jet fuel at up to a maximum of 50% to produce a drop-in fuel. Drop-in jet fuels are completely interchangeable with conventional jet fuel, and so will not require the modification of fuel handling and distribution systems.

In the medium term, it is possible that sustainable alternative fuels for aircraft will be available in much larger quantities. Given sufficient demand or incentive, significant supplies of jet fuel that offer a significant reduction

in lifecycle CO₂ emissions could be available in the mid-term. Significant research and development activities currently underway are expected to lead to a number of commercial scale production facilities. Also, the development of new sustainable alternative fuels for aircraft could be able to reduce costs of fuels to compete with conventional jet fuel in the mid-term.

In the long term, the aviation industry may explore more radical fuels that require redesigned engines and airframes. Fuels such as liquid hydrogen and liquid methane might be used to significantly reduce GHG emissions.

The following goals for alternative fuels are relevant for aviation:

- The US Consortium for Continuous Low Energy, Emissions, and Noise (CLEEN) has set a goal that 20% of jet fuel available for purchase by US commercial airlines and cargo carriers will be alternative fuels by 2016.
- The European Union has established a requirement that lifecycle GHG emission savings from the use of biofuels shall be at least 50% by 2017 and at least 60% by 2018 (however, indirect land-use emissions are not included in this accounting so far, as of April 2011).
- The European Union set a target of 10% use of renewable energy sources in transport by 2020.

Alternative aviation fuels are discussed individually below.

Natural gas and electricity

For ground operations in ground power units (GPUs) and energy backup systems, natural gas and electricity are already being used in some airports, mainly as substitutes for diesel. These measures are for short term implementation. Even though the cost of retrofit or equipment replacement can be expensive, these fuels still may be practicable to use in the aviation industry.

Fuel cells

There are ongoing studies on the use of fuel cells to power small generators and aircraft auxiliary power units when on the ground. The cost of these cells remains very high, and they are seen as a long-term measure for reducing emissions at airports.

Hydrogen

For aircraft operations, the most difficult option from a technological point of view is hydrogen. Great changes in aircraft design will be necessary for using this fuel that releases water vapor and NO_x (which also have radiative forcing) when burned. As it is a radical change of paradigm, this is considered a long-term solution. Since it requires changes in structures for fuel storage and transport, as well as new design technology and aircraft building, the economic impacts must be significant for the aviation industry, and society as a whole, to accept such a radical change.

Synthetic liquid fuel

Synthetic liquid fuels are obtained from different kinds of sources such as coal, natural gas, biomass, oil shale, or tar sand. One problem related to

¹⁵ Short term is approximately 5–10 years; medium term is 11–20 years; long term is over 20 years.

Box 9.4 | Alternative Fuels for Aviation Demonstration Cases

The international aviation industry has successfully demonstrated the technological feasibility of using sustainable alternative jet fuel blends in flight tests without affecting safety. The following test flights using alternative aviation fuels have been conducted during the past two years, which supported the approval of the ASTM D-7566 Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons, the first new jet fuel specification in more than 20 years.

Examples of aviation alternative fuel demonstrations:

- Airbus flew its A380 test aircraft with one of its four engines running on a 40% blend of Gas-To-Liquid (GTL) fuel with conventional jet fuel on 1 February 2008.
- Virgin Atlantic flew a Boeing 747–400 on 23 February 2008 with one engine operating on a 20% biofuel mix produced from babassu oil and coconut oil.
- Air New Zealand flew a Boeing 747–400 with one engine on 50% jatropha-derived hydro-treated renewable jet (HRJ) biofuel and 50% kerosene on 30 December 2008.
- Continental Airlines flew a Boeing 737–800 with one engine using 50% jet fuel and 50% algae and jatropha mix on 7 January 2009.
- JAL flew a Boeing 747–300 with 50% HRJ biofuel (derived from camelina, jatropha, and algae) and 50% kerosene mix on 30 January 2009.
- Qatar Airways performed the first revenue flight with alternative fuel on 12 October 2009. An A340–600 flew from London to Doha with its four engines running on a 48.5% blend of GTL with conventional jet fuel.
- KLM flew a Boeing 747–400 using a mix of 50% HRJ biofuel (derived from camelina) and 50% conventional Jet A1 on 23 November 2009.

Source: UNFCCC, 2010.

this type of fuel is its low lubricity due to the absence of sulphur in its composition. A second problem is the high cost of production, because it is still predominantly based on the Fischer and Tropsch process (coal-, gas-, or biomass-to-liquids), which requires an intense use of energy for precursor gasification and CO polymerization in the presence of water. Therefore, synthetic fuels are energy and CO₂ intensive. In spite of that, they are broadly compatible with current fuel systems, can produce a clean burn, and tend to produce less particulate matter. There are little technological barriers towards the introduction of synthetic liquid fuel technology

Biofuels

In the aviation industry, biofuels are seen as the most promising candidate. Biofuels are being tested by several companies. However, biofuels perform unfavorably in terms of global warming potential, as seen from a lifecycle perspective. For lifecycle accounting of biofuels, see Section 9.3.1.1.

There is an important difference between biofuels for road transport and biofuels for aviation. Because aviation fuels must have a high energy density and chemical stability as well as a low freezing point, conventional biofuels are not suitable. Therefore, biofuels for aviation must be drop-in (hydrocarbon) fuels that can be produced by hydro-treating the bio oil, gasification/F-T

process and other new biochemical pathways, such as sugar-to-diesel process. These production processes are still in the R&D phase.

9.4.3.2 Improving Energy Efficiency in Aviation

The aviation sector's efficiency track record is solid. Aircraft being built today are greater than four times more efficient than those built 40 years ago. According to Greener by Design (2011), "fuel efficiency in aviation improved by 70% between 1960 and 2000 – a better record than any other transport mode. Between 1990 and 2000 alone, aviation fuel efficiency improved by 20%. Improvements of an additional 20% are projected by 2015 and 40–50% by 2050, relative to today's aircraft. Current research programs have goals of reducing landing and take-off NO_x emissions by up to 70% over today's regulatory standards, while also improving fuel consumption by 8–10% over the most recent production engines by about 2010."

ICAO's Assembly Resolution A37–19 is aimed at improving the outlook for aviation's future climate footprint. The resolution recognizes the potential of technological and operational improvements,

market-based measures, and the use of sustainable alternative fuels to reduce aviation's climate impact. The resolution aims to collectively achieve global aspirational goals of improving fuel efficiency by 2% per year and stabilizing CO₂ emissions at 2020 levels. However, with respect to projected growth rate in aviation (Schäfer et al., 2009), GHG emissions from aviation will challenge ambitious GHG mitigation targets.

ICAO (2009) has identified a basket of measures for addressing GHG emissions from international aviation:

- **Aircraft related technology development (including alternative fuels):** Measures in this category include purchase of new aircraft, retrofitting and upgrade improvements on existing aircraft, new designs in aircraft/engines, fuel efficiency standards, and alternative fuels. Some of these measures have the potential for very high gains in fuel efficiency/emissions reduction, but the costs are likely to be high and there will be a long timeframe for implementation.
- **Improved air traffic management and infrastructure use:** More efficient air traffic management planning, ground operations, terminal operations (departure and arrivals), en route operations, airspace design and usage, and air navigation capabilities. These are measures with the potential for relatively short- to medium-term gains, although the scale of potential relative gains is low to medium. More efficient planning and use of airport capacities, construction of additional runways and enhanced terminal facilities, and clean fuel-operated ground support equipment. These can be implemented in the short to medium term, but potential emission reduction gains are likely to be low. Increased airport capacity may also encourage increased emissions from aircraft unless appropriate actions are taken to address the emissions.
- **More efficient operations:** Measures include minimizing weight, improving load factors, reducing speed, optimizing maintenance schedules, and tailoring aircraft selection to use on particular routes or services. This area is essentially a matter for aircraft operators and can be further incentivized by market-based instruments.

9.4.4 Shipping and Railways

9.4.4.1 Improving Energy Efficiency in Shipping

Giving the global volume of seaborne trade, the shipping industry is increasingly expected to share the burden of reducing global emissions of CO₂. Shipping is already a very efficient form of transport in terms of CO₂ emissions per tonne-km of goods moved. It compares favorably with rail transport, is more efficient than road transport, and is considerably more efficient than air freight (see Figure 9.12). Bunker fuels used in shipping are highly polluting for international seas and coasts and they challenge marine ecological systems.

In the past increases in fuel oil prices have encouraged improvements in ships fuel efficiency. During 2008, many ship operators, particularly of container ships, adopted a policy of "slow steaming," i.e., reducing the speed at which a ship operates. Reduction in a ship's speed from 26 knots to 23 knots can result in a 30% fuel savings.

Marine diesel engines are already highly efficient, operating near the theoretical maximum thermal efficiency. Almost 50% of the energy

Table 9.6 | Potential efficiency improvements from technology/design measures for existing ships (HFO: Heavy Fuel Oil; MDO: Marine Diesel Oil).

Improvement	Potential Fuel Saving (%)
Optimized hull shape	3–5
Propeller maintenance	1–3
Fuel injection improvements	1–2
Fuel switching (HFO to MDO)	4–5
Efficiency rating	3–5
Turbocharger upgrade	5–7
Potential total saving	4–20

Source: IMO, 2008.

Table 9.7 | Potential efficiency improvement from technology/design measures for new builds.

Improvement	Potential Fuel Saving (%)
Optimized hull shape	5–20
Optimized selection of propeller	5–10
Optimized propulsion efficiency	2–12
Fuel switching (HFO to MDO)	4–5
Planting improvements (e.g., waste heat recovery)	4–6
Machine monitoring	0.5–1
Potential total saving	5–30

Source: IMO, 2008.

Table 9.8 | Potential efficiency improvements from operational measures.

Improvement	Potential Fuel Saving (%)
Fleet planning (ship size, type, etc.)	5–40
"Just in time" voyage planning	1–5
Weather routing	2–4
Operating at constant engine speed	0–2
Operating with optimized vessel trim	0–1
Operating with minimum ballast	0–1
Optimizing propeller pitch	0–2
Reduced port time for cargo handling operations	1–5
Reduced time for mooring/anchoring operations	1–2
Potential total saving	1–40

Source: IMO, 2008.

Table 9.9 | Potential efficiency improvements from technological options.

Technology	Time Horizon	General Criteria			Energy Efficiency Potential	
		Barriers	Type of Traction	Market Potential	Single Vehicle (%)	Fleet (%)
Medium-frequency transformer	long-term	medium	Electric – AC	highly uncertain	2–5	1–2
HTSC transformer	long-term	high	electric – AC	highly uncertain	5–10	2–5
Single-axle bogies	mid-term	medium	electric – DC, AC – diesel	medium	5–10	2–5
Bogie fairings	mid-term	low	electric – DC, AC – diesel	medium	5–10	1–2
Common rail	mid-term	low	diesel	medium	> 10	1–2
Double-layer capacitors (storage technology)	mid-term	medium	electric – DC	low	> 10	not applicable
CO ₂ -based demand control for coach ventilation	mid-term	medium	electric – DC, AC – diesel	high	2–5	1–2
Driving advice systems in suburban operation	mid-term	medium	electric – DC, AC – diesel	medium	>10	> 5
Driving advice systems in main line operation	mid-term	medium	electric – DC, AC – diesel	high	5–10	2–5
Optimization of train operation by control center	mid-term	high	electric – DC, AC – diesel	medium	5–10	> 5
Wide-body stock	mid-term	high	electric – DC, AC – diesel	medium	> 10	2–5
Switch-off of traction group	mid-term	medium	electric – DC, AC – diesel	not applicable	2–5	1–2
On-board use of braking energy in diesel-electric stock	mid-term	low	diesel	medium	2–5	1–2
Control of comfort functions in parked trains	mid-term	medium	electric – DC, AC – diesel	high	2–5	2–5
Regenerative braking in DC systems	mid-term	medium	electric – DC	high	5–10	> 5
Modification of target temperature in passenger coaches	short-term	medium	electric – DC, AC – diesel	not applicable	< 2	1–2
Double-decked stock	short-term	high	electric – DC, AC – diesel	high	> 10	> 5
Multiple units vs. loco- hauled trains	short-term	low	electric – DC, AC – diesel	high	5–10	1–2
IGBT	short-term	low	electric – DC, AC – diesel	high	5–10	> 5
Ventilation control (in new stock)	short-term	medium	electric – DC, AC – diesel	high	2–5	–
Regenerative braking in 16.7 Hz, 15 kV systems	short-term	medium	electric – AC	high	5–10	> 5
Energy efficient driving strategies	short-term	medium	electric – DC, AC – diesel	not applicable	5–10	> 5
Energy efficient driving by low-tech measures	short-term	low	electric – DC, AC – diesel	not applicable	5–10	2–5
Re-engining of diesel stock (replacement of engine)	short-term	low	diesel	medium	> 10	–
Regenerative braking in 50 Hz, 25 kV systems	short-term	medium	electric – AC	medium	5–10	> 5
Aluminum car body	short-term	low	electric – DC, AC – diesel	medium	2–5	1–2

Source: UIC, 2011.

in the fuel is converted into mechanical work in a large marine diesel engine. Effective recovery of waste heat from the engine can further raise the efficiency to nearly 55%.

Because there is currently little or no scope for improving the efficiency of the marine diesel engine itself, improvements will have to come from other elements of ship design and operation. The International Maritime Organization (IMO) is currently debating which measures could be introduced to limit or reduce shipping's CO₂ emissions. Measures can be divided into operational measures, i.e., those that deal with how the world fleet is managed and operated, and technology/design measures. The latter can be further subdivided: some measures can be introduced only at the design/building stage for a ship, whereas others can be retrofitted to existing ships. Tables 9.6, 9.7, and 9.8 list some of the measures considered by IMO, giving an indication of what might be achievable.

9.4.4.2 Improving Energy Efficiency in Railways

Rail is more energy efficient than most other transport modes. For example, in Germany, rail-based passenger transport has about one-third of the GHG emissions per passenger of air traffic, and half of car transport (IFEU, 2010). Despite this, enhancement of energy efficiency is an important issue in order for railways to reap cost savings and to enlarge competition advantages, as well as to reduce railway's contributions to climate change.

One key means of improving energy efficiency in railways is to deploy advanced technologies. The International Union of Railways funded a project in which all relevant railway energy-saving technologies have been analyzed and evaluated. These evaluated technologies are summarized in Table 9.9. For electric railways, decarbonization can be achieved by switching from fossil fuels (e.g., coal fired power plants) to renewable energies.

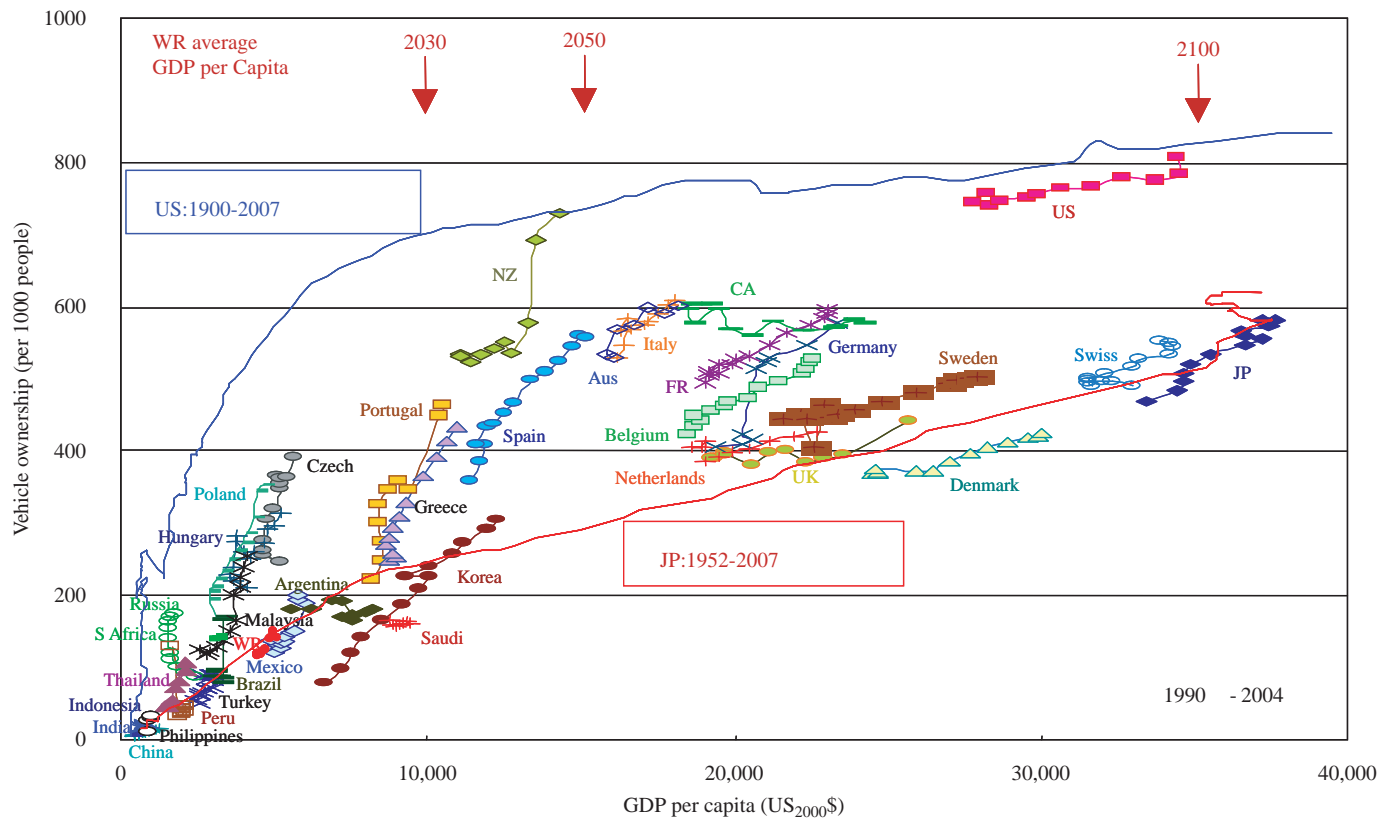


Figure 9.33 | Historical relationship between vehicle ownership and GDP per capita. World average values of GDP per capita are indicated by arrows. Note: plotted years vary by country depending on data availability. Source: based on World Bank, 2010.

9.5 Alternative Images of Future Transport Scenarios

9.5.1 GEA-Transport Model Overview

To conduct projections and policy analysis for GEA-Transport¹⁶, we utilized the IEA’s global transport spreadsheet model, which was developed for the WBCSD’s Sustainable Mobility Project (SMP) (WBCSD, 2004a). The IEA model has the capability of making a scenario through 2050, which was expanded up to 2100 for this GEA transport study, which is a bottom-up model and differs from the one in Chapter 17. The WBCSD/SMP transport spreadsheet model is designed to handle all transport modes and most vehicle types. It produces projections of vehicle stocks, travel, energy use, and other indicators through 2050 for a reference case and for various policy cases and scenarios. It is designed to have some technology-oriented detail and to allow for fairly detailed bottom-up modeling. The model does not include any representation of economic relationships (e.g., elasticities), nor does it track costs. Rather, it is an accounting model, anchored by the ASIF identity:

¹⁶ The GEA-Transport model differs from the GEA model in Chapter 17 in that it is a bottom-up model. The departing approaches resulted in differences that were considered acceptable within the range of allowance.

- Activity (passenger and freight travel)
- Structure (travel shares by mode and vehicle type)
- Intensity (fuel efficiency)
- Fuel type – fuel use by fuel type (and CO₂ emissions per unit fuel use).

For these factors in road transport, vehicle sales and stocks are most important variables to affect the final results. As shown in Figure 9.33, historical vehicle ownership is closely related with growth of income level per capita. Around the threshold of US\$5000/person, vehicle ownership grows very rapidly, but the growth rate for specific regions is quite different and is affected by various factors, such as geographic conditions, infrastructures, policies, and so on.

As outlined from the long-term historical data for the United States and Japan, this growth pathway is important to determine vehicle stock at a certain economy level. If this growth rate remains at the lower level by some measures in the future, the vehicle stock in developing countries can be kept low compared with those in developed countries.

In the GEA transport model, the future level of vehicle ownership in developing countries is assumed to be lower compared to those for most of

Box 9.5 | Storyline of the Bottom-up Scenarios for Energy and Transport Development

Under the reference scenario, which is produced with the WBCSD/SMP model, energy use of the transport sector increases significantly when it is associated with economic development, especially in developing countries. Car ownership rate, use of more energy-intensive and faster modes of transport, and freight activity increase with an increase in economic level (see Section 9.5 where the transport model is discussed).

At the same time, more efficient powertrain technologies and more efficient operation reduce relative fuel consumption, and more use of low carbon fuel reduces CO₂ emissions from the transport sector. However, as demand increases with economic development, reductions due to technological advancement are offset, leading to an absolute increase in CO₂ emissions from the transport sector.

There are many potential technologies and measures to reduce energy use and CO₂ emissions from the transport sector. CO₂ emissions can be reduced significantly under three CO₂ constraint pathways: GEA-mix, GEA-supply, and GEA-efficiency. In Chapter 17, each pathway has a transport-specific branching point between liquid and advanced transportation fuels. In contrast, the pathways presented in Chapter 9 all assume the introduction of advanced technologies, but with different compositions and to varying degrees.

Under the GEA-mix pathways, the share of biofuels¹⁷ increases in every transport sector using gasoline, diesel and jet fuel, and energy intensity of aviation and shipping are also improved over the reference scenario. While the share of hybrids in passenger and freight vehicles increases, new vehicle types such as electric vehicles and fuel cell vehicles are progressively put into the market. Efficient operation of trucks reduces the fuel consumption of freight transport. The characteristic of this pathway is a balanced use of all possible reduction options.

In the GEA-supply pathways, the negative emission of power generation through CCS, as discussed in Chapter 12, further reduces CO₂ emissions, especially from road transport. The modal shift from personal vehicle to public transport in passenger transport is enhanced by policy measures in both GEA-efficiency and GEA-mix pathways. The efficiency of vehicles is improved progressively toward 2100, but the rate of improvement is highest in the GEA-efficiency set of pathways. At the same time, electric vehicles, including Plug-in HEVs, are aggressively introduced into the market under the GEA-efficiency pathways.

Table 9.10 | Level of importance on each reduction measure for GEA-Transport scenarios.

Scenario		Efficiency	Mix	Supply
LDV	efficiency	***	*	*
	demand	****	**	*
	EV	****	**	*
	FCV	**	***	****
Trucks	efficiency	**	**	**
	demand	***	**	*
	new technology	**	**	**
Aviation	efficiency	**	**	*
	demand	***	**	**
Shipping	efficiency	***	**	**
BF		***	****	***
Electricity	emission factor	**	**	****
Modal shift		***	**	*
notes		FE+Modal shift+Plug-in	BioFuels	FCV/H2+Negative Emission

developed countries. This could be caused by a number of factors, including inhomogeneous structure of countries due to greater urbanization and lower suburbanization, greater income disparities between the wealthy and the poor, and limits on the infrastructure needed to support large numbers of vehicles, as well as future policies to reduce the need for motorized transport. Good examples of the role of policy measures to reduce personal vehicle ownership are discussed in the policy section. Based on GDP per capita, most countries presently classified as developing countries are not classified as developing countries in 2100.

9.5.2 Assumptions

9.5.2.1 Assumptions for Population and GDP

In Figure 9.34, global population reaches 10 billion in 2100, which is close to the level of SRES B2 scenario. Most of the growth occurs in

¹⁷ The values of emission factor for each biofuel are taken from the various studies, such as shown in Figure 9.27.

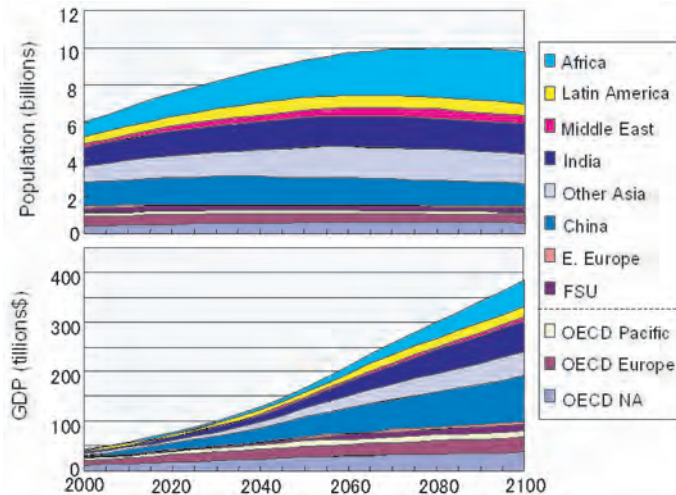


Figure 9.34 | Growth of population and GDP by region.

developing countries. Global GDP grows significantly up to around US\$400 trillion toward the end of the century,¹⁸ and GDP per capita also increases in most developing countries. As GDP is the strongest driver of car ownership, transport activities, and car ownership are expected to increase accordingly (see also Schäfer et al., 2009).

9.5.2.2 Assumptions for Vehicle Stock by Region and Fuel Economy

Three sectors are primarily propelling worldwide transport energy growth: LDVs, freight trucks, and air travel (IPCC, 2007). 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 the number of LDVs will grow to about 1.3 billion by 2030 and to just over 2 billion by 2050, almost three times higher than the present level (see Figure 9.35). Nearly all of this increase will be in the developing world (WBCSD, 2004b).

The present trend reveals a dominance of road transport and private cars, as well as an increase in aviation. As a consequence, it will be hard to curb fuel demand in any scenario timeline. LDVs and OECD countries will continue to dominate transport energy use for a long time, even with the growing participation of developing countries, mainly China.

One important factor affecting levels of car ownership is vehicle life, which determines the rate of replacement of older cars with new ones. As shown in Figure 9.36, the vehicle life is quite different from country to country. In terms of CO₂ reduction, vehicle efficiency is progressively improved, so the total level of CO₂ reduction is not strongly affected by the difference of longer tail at lower survival rate. However, this

18 The assumptions for population and GDP growth are slightly higher than those of Chapter 17, but GDP per capita data, which are only used for the scenario analysis, are consistent with each other.

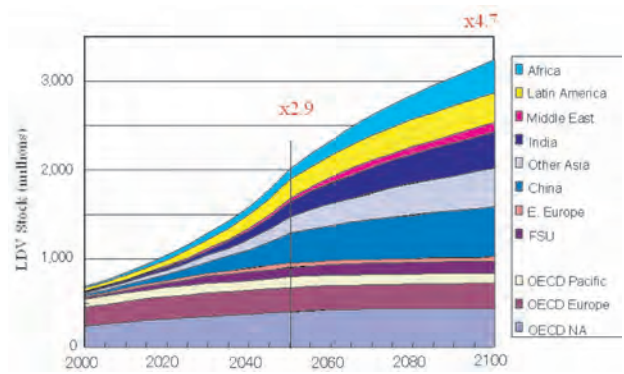


Figure 9.35 | Total stock of LDVs by region. They will grow 2.9, and 4.7 times higher than the present level by 2030, and 2050 respectively. Source: based on WBCSD, 2004b.

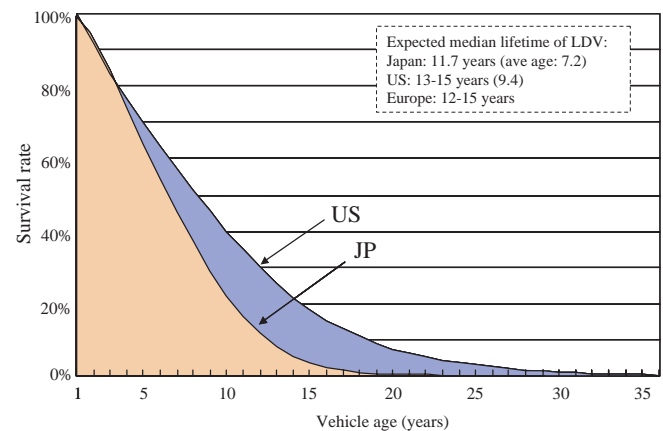


Figure 9.36 | Comparison of survival rate for passenger LDVs. Source: based on ORNL, 2010.

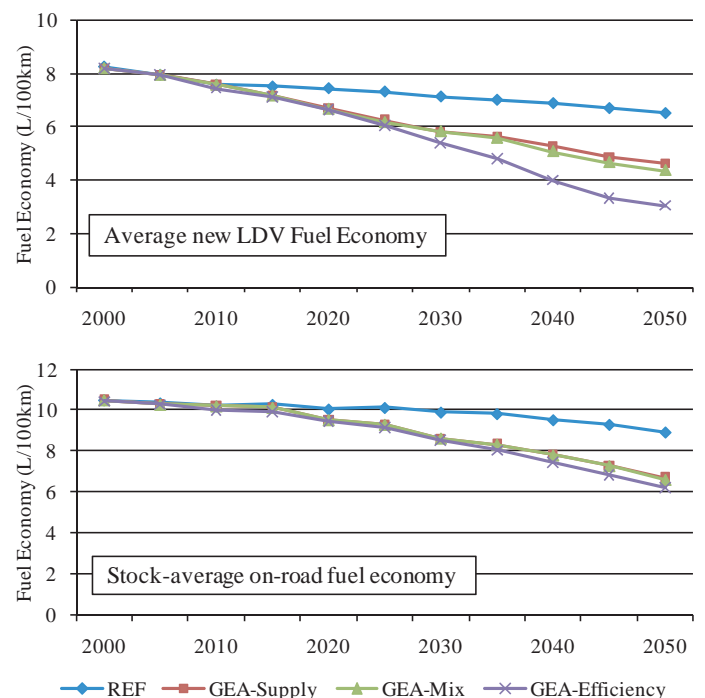


Figure 9.37 | Trend of new vehicle and stock-average on-road fuel economy.

becomes very important when tail pipe emissions are considered. Very few, but very old cars could be responsible for a large part of local air pollution, because these few cars might emit orders of magnitude more pollutants.¹⁹

Figure 9.37 shows the trend of new vehicle and stock-average on-road fuel economy values. Fuel economy values for three GEA scenarios show 40–50% improvement of new car fuel economy over 50 years, while stock-average fuel economy is improved by only 30% or so, because of the delay in replacement by older existing vehicles.

9.5.3 Key Results

9.5.3.1 Fuel Use Projection in the Reference and Pathways to Realize the GEA Scenario²⁰

Along with an increase in population and GDP, as shown in Figure 9.34, vehicle stocks will increase significantly by a factor of 2.9 and 1.6 between 2000/2050 and 2050/2100, respectively, in the reference and GEA-supply scenarios (see Figure 9.35). LDV stocks in 2100 are 4.7 times larger than that in 2000. In 2050, the stocks in Asia are already bigger than that in the United States now, and are almost twice as large as that in all OECD countries in 2100. At the same time, truck stocks increase as fast as those for LDVs. The modal shift from passenger cars to trains will reduce ownership in passenger cars (LDV) by 40% and 20% in 2100, in the GEA-mix and GEA-efficiency pathways, respectively (see Figure 9.38). Truck stocks are reduced by 20% in 2100 in GEA-efficiency pathways due to a modal shift from trucks to freight train.

As the economy and population grow, other subsector activities also increase, as shown in Figures 9.39 and 9.40. Among passenger transport, the growth rate of aviation is largest. Aviation in 2100 is more than ten times larger than in 2000 in the reference scenario²¹ and the GEA-supply and GEA-mix pathways. In the GEA-efficiency pathway, growth rate in aviation is slightly smaller.

In the GEA-efficiency and GEA-mix pathways, passenger train activity grows largely in 2100 because of modal shift from passenger cars. On the other hand, passenger car activity stays almost the same after 2050. In terms of magnitude, the share of LDV and aviation is significant and this is also true in terms of fuel consumption as shown in Figure 9.41.

In order to reduce fuel consumption and CO₂ emissions simultaneously, a variety of options for LDV can lead to the same goal (e.g., Figure 9.23),

19 These high-emitter vehicles were a hot issue in California in the 1990s.

20 See also Chapter 17.

21 Reference scenario is produced based on the WBCSD/SMP model and extended from 2050 to 2100. See Box 9.5.

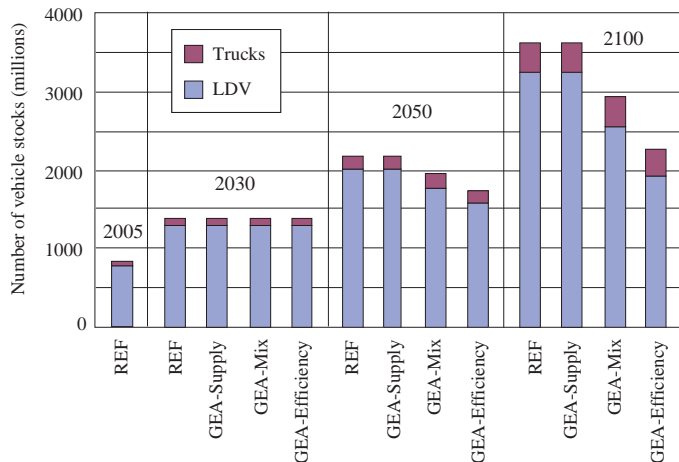


Figure 9.38 | Growth of stocks of LDVs and trucks.

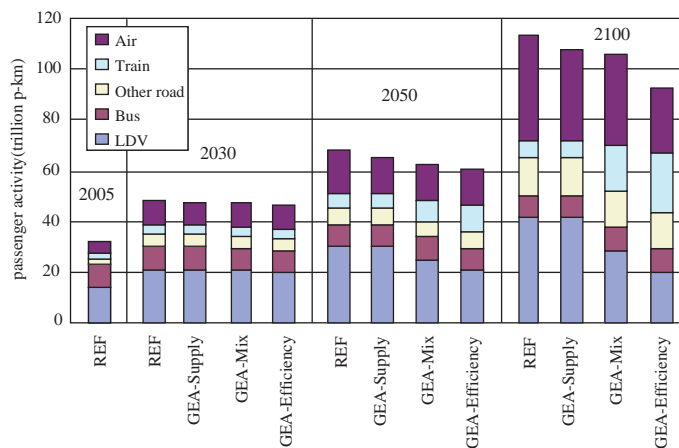


Figure 9.39 | Growth of passenger transport activity.

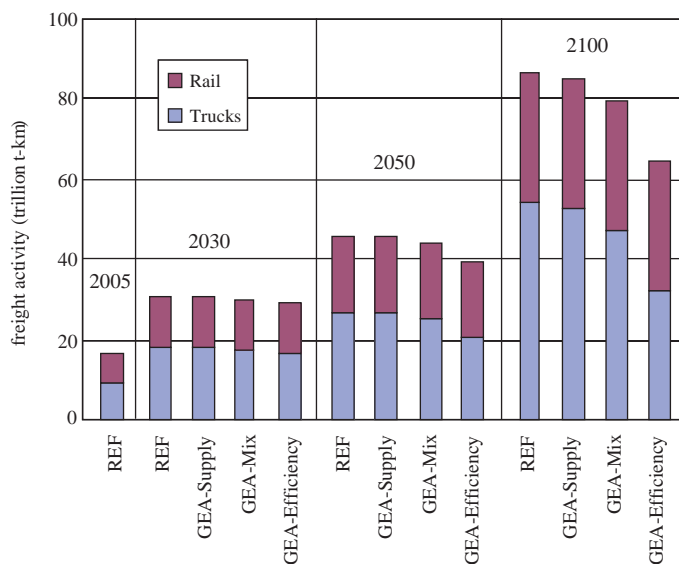


Figure 9.40 | Growth of freight transport activity.

but measures for aviation are limited. The most promising measures are efficiency improvements and biofuel; but there are many issues to overcome to utilize the benefit of biofuels, including the sustainability concern (see Section 9.3.1.1).

In modeling freight transport to project fuel consumption, the starting point was activity data for both trucks and freight trains. But for shipping, the growth rate of fuel consumption is directly projected from the first place of modeling because of its insignificant contribution to overall freight transport.

As shown in Figure 9.40, the growth of truck and freight train activity is significant and their activities in 2100 are four to seven times, and five times larger, than 2000, respectively. In terms of fuel consumption, the share used by trucks is most important, but the actual amount of fuel consumption differs very much depending on the pathways (see Figure 9.41).

In the reference scenario projection, global transportation fuel use increases by a factor of nearly 2.3 between 2000 and 2050 and slows down slightly afterwards, leading to an increase of a factor of around 1.5 between 2050 and 2100 (see Figure 9.42). Use of gasoline, diesel fuel, and jet fuel grows substantially, while other fuels retain a tiny share. Alternative fuels and advanced vehicles do not penetrate significantly in the reference scenario. Total fuel use by mode will grow significantly for all modes but buses, with the biggest growth occurring for LDVs, freight trucks, and air travel. It should be noted that most of the increase in fuel use occurs in developing countries.

Fuel efficiency improvement and introduction of new technologies significantly reduce fuel use by 35%, 40%, and 60% in 2100 for pathways GEA-supply, GEA-mix, and GEA-efficiency, respectively, compared with the reference scenario (see Figure 9.46). Reduction is most prominent in the LDV subsector, while air and trucks remain major players, along with LDVs (see Figures 9.41 and 9.42).

As shown in Figure 9.42, energy use decreases in the order of GEA-supply, GEA-mix, and GEA-efficiency pathways. This is mainly caused by different improvement rates of fuel efficiency and reduction rates of vehicle driving distance per year.

In the reference scenario, conventional fuels make up the major part of fuel consumed. In the GEA pathways, usage of biofuels, especially advanced biofuels, such as cellulosic ethanol and BTL diesel and jet fuel, increase with time. In 2100, the share of biofuels becomes 20–45%, depending on the pathway. Having assumed that advanced biodiesel is widely used in all vehicles with diesel engines, including trucks and buses, the share of advanced biodiesel becomes relatively large compared with that of advanced ethanol in 2100. Preconditions for wide-scale application of advanced biofuels are stringent policy instruments that discriminate against the mostly environmentally

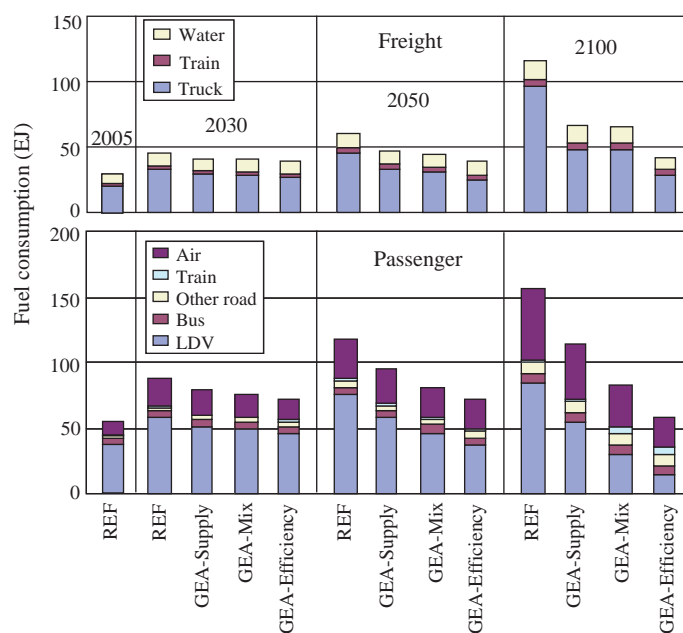


Figure 9.41 | Fuel consumption projection for both passenger and freight transport by mode.

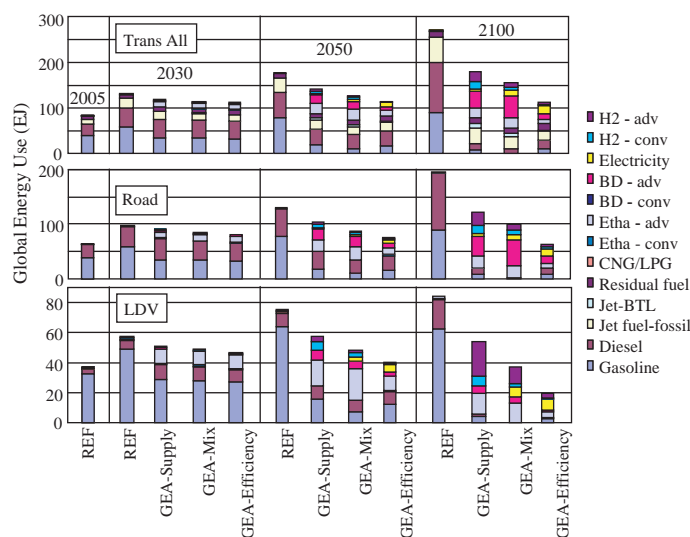


Figure 9.42 | Worldwide transport fuel use for the whole sector, road transport and LDV only by fuel type.

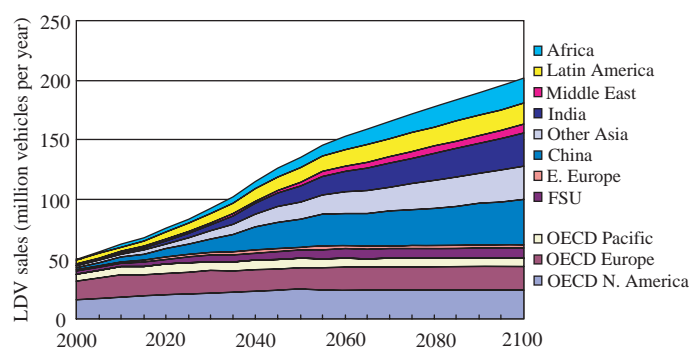


Figure 9.43 | Worldwide LDV sales by region (Reference and GEA-supply pathways).

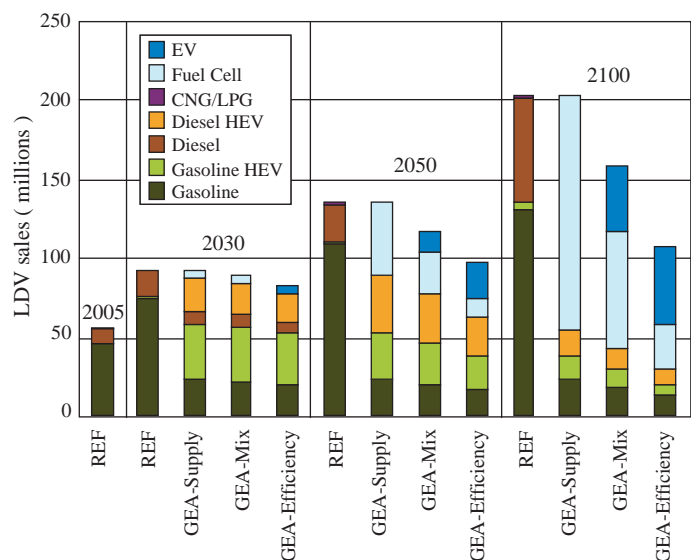


Figure 9.44 | Worldwide LDV sales by vehicle type.

harmful, high-carbon but more price-efficient agrofuels that are currently produced, notably US corn ethanol. Lifecycle analysis of these biofuels is discussed earlier in this chapter, and appropriate policy instruments will be discussed later.

9.5.3.2 Light-Duty Vehicles

In the reference and GEA-supply pathways, new vehicle sales increase by a factor of 2.7 and 1.5 between 2000/2050 and 2050/2100, respectively. Although the new car market in OECD countries is almost saturated, the market in developing countries, especially in Asia (including China and India), will grow significantly (see Figure 9.43).

In the GEA-efficiency and GEA-mix pathways, new car sales decrease significantly because of a modal shift to trains. In 2100, new car sales in the GEA-efficiency and GEA-mix pathways are 44% and 22% lower, respectively, than that for the reference and GEA-supply pathways.

As shown in Figure 9.44, the share of HEVs increases with time, but these are replaced with fuel cell vehicles and electric vehicles in 2050 and 2100. In 2100, the share of FCVs and EVs is around 70%. Since there is a large uncertainty about the evolution of new vehicle technologies, FCV shares over EVs varied significantly among the GEA pathways.

9.5.3.3 CO₂ Projections

Global transport CO₂ emissions from vehicles tank-to-wheel (TTW) are projected to increase by a factor of 2.3, from about 5.4 Gt in 2000 to 12.4 Gt in

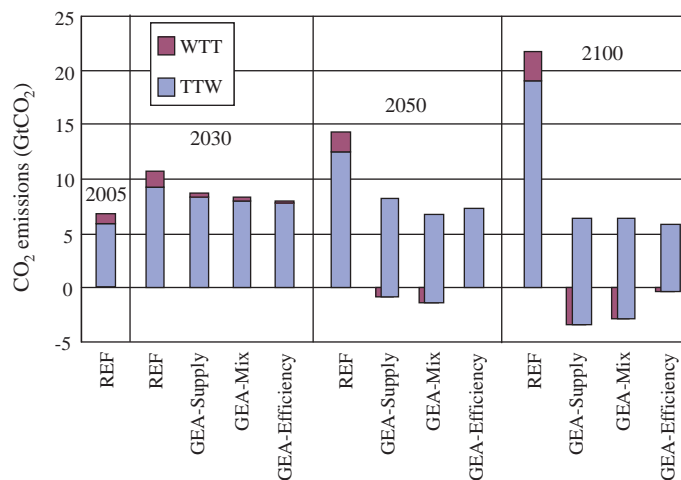


Figure 9.45 | Well-to-wheel CO₂ emissions from transport sector for reference and GEA pathways: tank-to-wheel (TTW), well-to-tank (WTT).

2050 and by 3.5 to 18.9 Gt in 2100 in the reference scenario. Also, like fuel use, the vast majority of CO₂ increase will be in non-OECD (i.e., developing) regions. In the GEA pathways, those emissions are significantly reduced to around 6–7 Gt in 2100. As shown in Figure 9.45, the well-to-wheel (WTT) emissions increase up to 21.6 Gt in 2100 in the reference scenario, but are reduced to 6–7 Gt due to the large use of alternative fuels, such as biofuels, electricity, and hydrogen in the GEA pathways.

As shown in Figure 9.45, the contribution of the TTW and WTT (well-to-tank) component to the reduction of CO₂ emissions is different among the three GEA pathways. In GEA-supply and GEA-mix pathways, the reduction of the WTT component is more important, because the negative emission from power generation, biofuels, and H₂ production is effectively utilized. In the GEA-efficiency pathway, the TTW component contributes more to the reduction of CO₂ emissions through the greater improvement of vehicle fuel efficiency.

Large fuel efficiency improvements and introduction of alternative fuels in LDVs and trucks in the GEA pathways contribute to the greater reduction of CO₂ emissions compared to the reference scenario. In aviation, the large growth of activity offsets CO₂ emission reductions due to efficiency improvement and biofuel use.

Analysis of the contribution of major measures on emission reduction in the LDV subsector is seen in Figure 9.46. It clearly shows that net reduction of CO₂ emissions from the current level can be achieved by the introduction of new technologies, such as EVs and fuel cell (FC) vehicles, although improvement of fuel efficiency in conventional vehicles (FE) and hybrid vehicles (HV) also contribute significantly to the reduction. It should be noted that for market penetration of these new emerging technologies, strong, continuous support from governments is needed from the R&D phase through to the commercialization phase. In the GEA-efficiency and GEA-mix pathways, the contribution of modal shift to trains is also important.

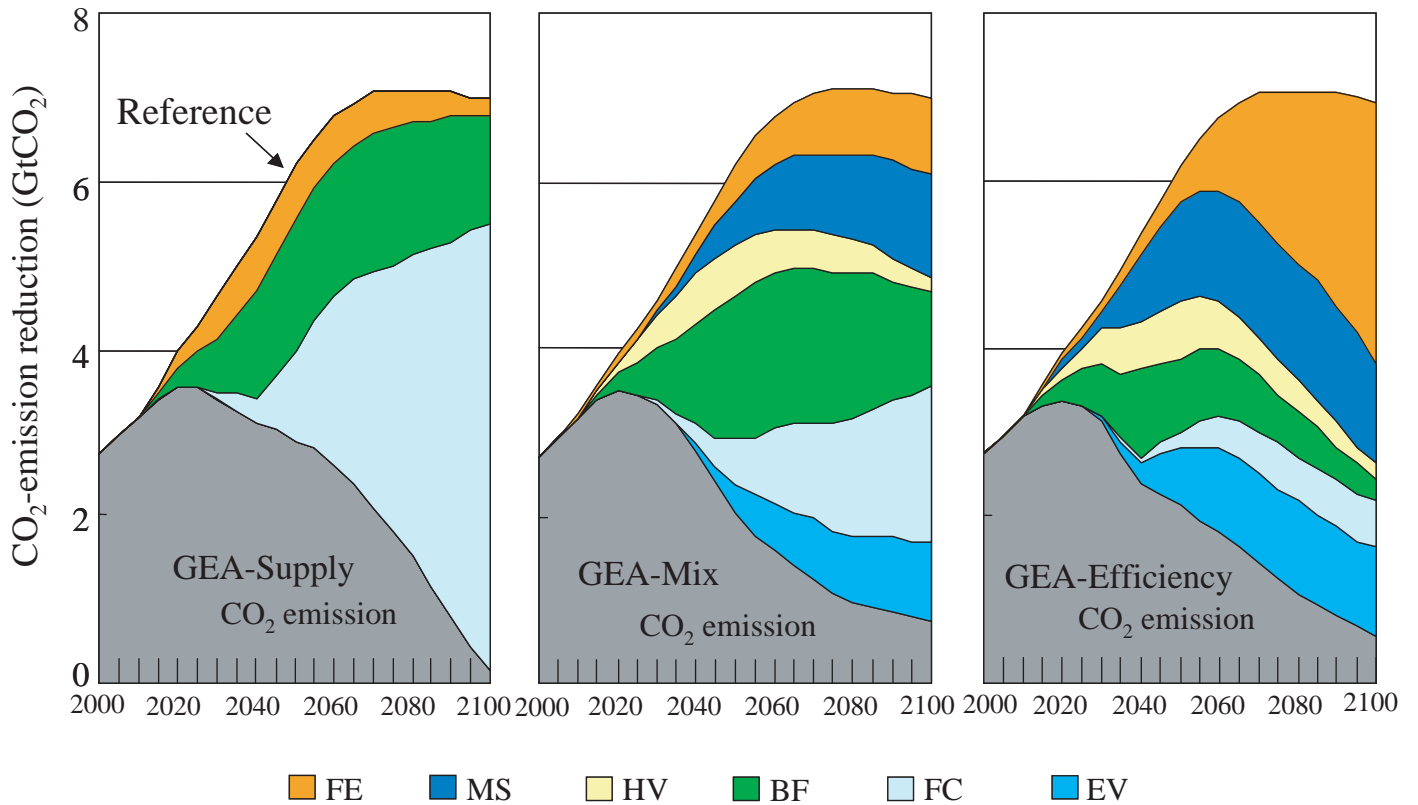


Figure 9.46 | Reduction of well-to-wheel CO₂ emissions for LDVs from reference scenario in GEA (FE: Fuel efficiency, MS: Modal shift, HV: Hybridization, BF: Biofuel, FC: Fuel cell, EV: Electric vehicle).

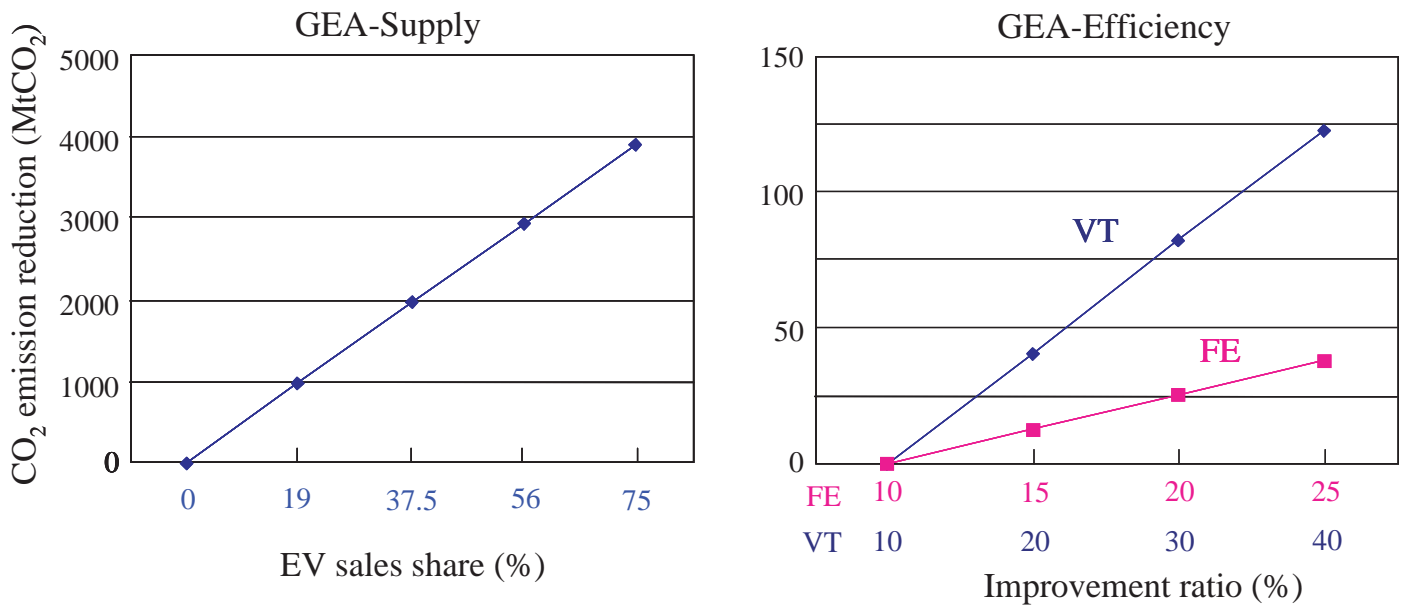


Figure 9.47 | Sensitivity analyses for the EV share in the GEA-supply pathway, and the reduction rate of vehicle driving distance per vehicle (VT) and fuel efficiency (FE) in the GEA-efficiency pathways.

Since perspectives of technology evolution are highly uncertain, especially toward 2100, some sensitivity analyses were performed for the LDV subsector, including the share of EVs, improvement of the fuel consumption rate, or fuel efficiency (FE), and reduction of the vehicle driving distance per vehicle (VT). In the GEA-Efficiency scenario, the share of EV and FCV sales is fixed to be around 75%, and CO₂ emissions from electricity generation factors for FCVs and EVs are nearly zero-emission and negative-emission, respectively. As shown in Figure 9.47, EV share in the GEA-Supply scenario was changed from 0 to 75%; accordingly, FCV share was changed from 75 to 0%. With the increase of EV share, the contribution of reduced emission of electricity generation using fossil fuels becomes larger and CO₂ reduction increases up to 4 Gt, which can be compared with the default emission level of the GEA-supply pathway – about 6 Gt (Figure 9.49).

In the reference scenario, LDV annual VT is assumed to be constant up to 2100, while in the GEA-efficiency scenario, it decreases after 2050 and is 13–17% lower than the reference scenario in 2100. The FE is assumed to be improved 2–3%/year in the reference scenario. In the GEA-efficiency pathway, this is further decreased after 2050 up to 13–17% in 2100, compared with the reference scenario.

The impact of these parameters on the reduction to CO₂ emissions is much smaller than that of the EV share mentioned above. However, this does not mean that the improvement of these parameters is not important, because they strongly affect the total amount of the fuel use in the transport sector. Figure 9.47 shows how a reasonable range of variation of these factors affect the estimated variations quite significantly.

9.5.4 Interpretations of How the Pathways Meet the GEA Goals

Measures to achieve the GEA goals should be distinguished by the time-frame on which one is focusing. Priorities among the many options may change over time. In the short and mid-term, most developing countries will still be in the transition stage of motorization, and available technological measures to meet the goals may be limited. In the long term, some developing countries will be in the middle of motorization, and various advanced technologies, such as advanced biofuels, fuel cell vehicles, and electric vehicles might be widely available in the market.

9.5.4.1 Fuel Efficiency

Improving efficiency is the primary option to reduce energy use and CO₂ emissions simultaneously from now until 2100. Many countries have imposed fuel economy standards. They have shown that these are very effective policy instruments, requiring car manufacturers to make more efficient cars. Additional measures, such as taxes and incentives, are required to encourage customers to buy these more efficient cars.

Fuel efficiency improvement itself is not good enough to reduce tail pipe emissions, such as NO_x, CO, and hydrocarbons. After-treatment devices for exhaust gases are required to significantly reduce pollutants being expelled from the tail pipe, which can be enhanced by emission standards.

9.5.4.2 Modal Shift

Switching passenger transport from LDVs to trains, buses, and non-motorized means can be very effective for reducing energy use. For dispersed suburban living, such as in many parts of the United States, this may not be an easy task. Infrastructure investment, integrated land use and transport planning, and sustainable transport policies are needed to shift personal travel to more energy-efficient modes such as walking, cycling, and public transportation.

A co-benefit of such a modal shift is reduction of traffic volumes, especially in urban areas, which contributes to a reduction in congestion and local air pollution. Since increased traffic volumes correlate to an increase in road traffic fatalities, reducing congestion through a modal shift has another co-benefit of improving road safety.

9.5.4.3 Advanced Biofuels

The merit of biofuels is their additive natures to other improvement measures in conventional vehicles, such as fuel efficiency, and therefore quick effects can be expected. With a careful choice of production pathways, biofuels can reduce CO₂ emissions significantly, as well as some tail pipe emissions.

9.5.4.4 Fuel-Cell Vehicles

FCVs can reduce energy use and drastically reduce emissions with the proper choice of pathways. The biggest barriers to FCV introduction are high costs and infrastructure issues. To build up infrastructure takes a long time and strong government support is needed.

9.5.4.5 Electric Vehicles

Hybrid vehicles and plug-in hybrid electric vehicles offer a cost-effective and smooth transition to electric mobility. PHEV, could expand the sale share to compromise the high cost of batteries. However, since only a small fraction of consumers may accept the limited driving range and high cost of a pure battery electric vehicle, battery electric vehicles may be limited to a small market in urban areas.

One of the major merits of FCVs and EVs is zero emissions from tail pipes. This is especially beneficial in highly-populated urban areas.

However, the GHG reduction potential of electric vehicles depends significantly on the carbon intensity of the electricity generation process. Since hydrogen and electricity can be produced by various energy sources, use of a secondary energy can reduce oil use and increase energy security.

Although advanced technologies have some barriers to overcome, new technologies are needed to reduce CO₂ emissions below the current level (Figure 9.46).

9.6 Policies and Measures to Meet Multiple Goals for Sustainability and toward a Global Energy Transition²²

The transport pathways described in the previous section illustrate alternative paths and aspirations for a progressive transformation of the global transport sector in line with the GEA goals toward attaining a sustainable global energy transition within the next 50 to 100 years. The pathways presented are technologically optimistic but still display insufficient potential to decarbonize the transport sector. GEA emphasizes that the sustainable global energy transition needs to be anchored in socially equitable, environmentally sustainable, and economically effective development goals. The scale and scope of the transition indicates that nothing less than a sustainable systemic change is required. Hence, we also include shifts to non-motorized transport and public transport modes, and integrated land use and transport planning in our analysis of suitable policies towards a desired transition.

The world is now predominantly urban, and most future population increases will be absorbed by urban areas (see Chapter 18). Transport plays a fundamental role in the development and economic prosperity of urban areas because commercial organization, the location of industry, housing, and all other general services are transport dependent. At the present rate of world urbanization, cities will require increased transport services to make accessible the supplies needed for their physical expansion and to support economic development. The challenge of developing sustainable low-carbon transport systems will define the possibility of guaranteeing life in urban places as economically viable, socially constructive, environmentally safe, and, in general, qualitatively enjoyable spatial configurations. Hence, a large part of the policies and measures discussed in this section focus on urban areas.

From a climate change mitigation perspective, one can categorize emissions from transport into carbon intensity of energy, energy intensity of transport, and total transport demand (Schipper and Marie-Lilliu, 1999; Creutzig et al., 2011a). Both the decision to travel or not and the modal choice for this travel affects fuel consumption, and therefore carbon emissions. With a focus on urban road transport, a transition to sustainable transport can follow the “Avoid, Shift, Improve” framework (GTZ, 2007;

Bongardt et al., 2010). This framework considers three major principles under which diverse policy instruments (Planning, Regulatory, Economic, Information, Technological) are grouped interventions to mitigate GHG emissions from transport, assuming different emphases for developed and developing countries (Dalkmann and Brannigan, 2009). “Avoid” and “Shift” influence the level of activity and structural components that link transport to carbon emissions. “Improve” focuses on technological options, not only with respect to climate mitigation but also taking into account local environmental conditions and social concerns.

9.6.1 Reduce the Need to Travel

A transition toward sustainable transport goes beyond technology. In fact, the quality of transport can be improved in a broader sense by a multitude of individual measures and combined policy packages, particularly in urban areas. Reducing or avoiding the need to travel can be achieved through encouragement of greater use of transit systems and non-motorized transport, as well as through increasing urban density, mixed-use urban spaces, and greater emphasis on communications technologies.

While technological pathways and scenarios allow us to envisage large-scale changes that can help decarbonize the transportation sector, measures such as those mentioned above that reduce congestion, air pollution, and motor noise and that increase the accessibility of shopping and local services for pedestrians and cyclists ultimately increase quality of life in a very tangible manner.

9.6.1.1 Enhancing Accessibility

Enhancing accessibility for transport users often reduces overall transport demand in terms of distance while improving the quality of movements. Analysis focuses on aspects of mixed land use and density, modal interconnectedness, and transit-oriented development. The relation between mobility and urban structure is interdependent. While cities generate the transportation systems they require in the development process, mobility demands and transport system responses also shape urban form.

GEA has developed a full module on urbanization and energy use in Chapter 18 that explores the relationships between patterns of spatial, population, and economic growth of cities. It looks at interactions with the patterns generated by urban transport systems, and the resulting effects on total energy use. This section will only focus on general public policies for managing and shaping transport and land use urban activities, and recommend interested readers to take full advantage of the thorough review provided in Chapter 18.

The best opportunities for directing transportation, land-use planning, and urban development toward sustainability may reside in urban

²² See also Chapter 22.

centers of small and medium sizes, where most of the future population and economic growth are expected. Urban populations continue to expand at more than 6%/year in many developing countries. In some of these countries, per capita motor vehicle ownership and use continue to grow by up to 15–20%/year. Sprawling cities make the journey to work excessively long and costly for the very poor. This is overwhelming the operational sustainability of urban transport systems and is one of the causes of social, economic, and environmental imbalances and social inequities. The challenge for towns and cities everywhere is to enhance accessibility and reduce congestion, accidents, and pollution.

Traditional transportation planning developed largely in parallel with a post-WWII explosion of individual motorization in the United States, in an already wealthy society going through a period of sustained economic growth. The initial policy response in the United States, based on a predict-and-provide planning framework, was to accommodate the private car to the maximum extent possible, while retaining public transport modes for the dwindling market of those without cars.

An entirely different strategic approach was taken in the former communist countries, opting for public transport as the primary urban mode and developing cities accordingly. In both these cases, the common element has been the strength of institutions and the importance of public policies for the provision of infrastructure, the supply of services, and, consequently, the modal choices.

9.6.1.2 Enhancing Modal Interconnectedness

Smart Growth (also called New Community Design) is a general term for policies that integrate transportation and land use decisions, as an alternative to urban sprawl. Smart growth and mixed land use is closely related by multimodal interconnectivity. For example, public transit ridership crucially depends on design of pedestrian facilities, enabling smooth and rapid access to stations. Park-and-ride is ambivalent. On the one hand, park-and-ride facilities allow car-dependent commuters to participate in public transit in inner city areas. On the other hand, park-and-ride may encourage further urban sprawl and medium-length commuting to park-and-ride facilities. To increase ridership and improve the economic viability of transit systems, transit stations need to be accompanied with mixed-use development, i.e., including both employment opportunity and housing, and market-rate parking charges (Cervero, 1994). In contrast, large-scale free parking makes the area surrounding transit stations unattractive and increases insecurity. Easy access to car sharing can also have two effects. On the one hand, it can deter car purchase, and by this reduce overall car ownership. On the other hand, it may encourage car driving by those that usually rely exclusively on environmentally friendly modes. However, it is estimated that the overall effect of car sharing is beneficial for mobility and the environment.

9.6.1.3 Enhancing Regional Transit-Oriented Developments

The most consistent approach, which is by now state-of-the-art in progressive cities, is to integrate land use and transportation planning to achieve a low-carbon infrastructure, reduce travel distances and travel time and increase accessibility to jobs, shops, and leisure facilities (Bongardt et al., 2010). The bottom line is that new mixed-use, high density developments must be close to public transit, and vice versa, and that the cost of using a car must be relatively increased in terms of money and time, to avoid high levels of motorization. Transit-oriented developments enable people to access housing, jobs, services by walking, biking, or riding transit, thus avoiding the necessity of driving to meet these needs and increasing the accessibility of goods and services. The case of Curitiba in Brazil offers a good example of how a coherent set of policies linking urban density, and a highly efficient bus rapid transit public transport system can transform a city (Bongardt et al., 2010)

9.6.1.4 Enhancing Mobility Management

Reducing the need to travel by car can be approached by implementing mobility management practices. The goal is to enhance and create transport services that promote a safe interconnection of modes and infrastructure for the use of sustainable modes such as walking, cycling, and public transport. Mobility management is a targeted approach that focuses directly on changing behavior at the individual or group level (e.g., company employees). It requires information, organization, coordination, and effective marketing and promotion to complement traditional traffic system management and infrastructure-orientated transport planning.

Mobility management can be seen as a new way of managing urban transport as a whole. It pulls together traditional approaches with public transport improvements and traffic management measures (including congestion charging and traffic calming). The main aims of mobility management are to:

- improve accessibility for all users and the conditions (social attractiveness, safety, economic efficiency) for an effective use of sustainable travel modes;
- improve the integration of activities and new land uses with sustainable travel modes and services covering the entire urban transport system;
- reduce traffic growth by limiting the number, length, and need for motorized vehicle trips; and
- improve interchange between transport modes and facilitate the interconnection of existing transport networks.

Mobility management has a demand-orientated approach that considers alternative transport modes – public transport, collective transport, car-pooling, cycling, walking, etc. – as “products” that have to be marketed. It works with specific “clients” or “client groups,” defined according to trip nature and purpose (home-school, home-work, shopping, leisure), and ‘traffic generators’ or the sites or activities that attract the traffic (city centers, companies, schools, tourist attractions, events, shopping centers, residential areas, etc.). Because each site is different, mobility management generally works with site-specific mobility plans.















Good marketing is necessary to convey and promote the positive results and benefits on the use of sustainable modes. Changing travel behavior is often associated with restrictions and sacrifices, or with critiques for

placing unfair restrictions on car use. A well-planned mobility management plan ultimately enhances mobility opportunities for everybody, those who accept to shift to alternative modes and those who continue to drive.

9.6.2 Develop Alternatives to Car Use

9.6.2.1 Enhance Public Transportation

Public transportation carries a large proportion of passenger trips in most of the heavily populated urban areas of industrialized and developing regions in the world. Many developing cities, where the modal share for bus transit alone can be in upper range of 65–80%, are

A)								
								
	2 000	9 000	14 000	17 000	19 000	22 000	80 000	
B)	MJ/p-km	1.65-2.45	0.32-0.91*	0.1	0.24*	0.2	0.53-0.65	0.15-0.35
C)	€ p-km infrastructure	2 500-5 000	200-500	50-150	600-500	50-150	2 500-7 000	15 000-60 000
D)	Fuel	Fossil	Fossil	Food	Fossil	Food	Electricity	Electricity

*Lower values correspond to Austrian busses, upper values correspond to diesel busses in Mexico city before introduction of BRT system.

Key:

A) Values are indicative for European and Asian cities and can vary significantly across cities, world regions, and particular situations. For example, BRT capacity can more than double with a second lane. Suburban rails in India can transport up to 100,000 passengers per hour.

B) Energy intensity in MJ per passenger km. SUVs can exceed depicted values for cars. Energy values for bus in the US are generally higher due to low ridership (Chester and Horvath, 2010). While BRT systems have similar energy efficiencies as normal busses, they provide significant systemic energy savings via modal shift, small bus substitution, and reduction in parallel traffic (Schipper et al., 2009). BRT systems can also be converted from oil based fuels to electricity and hydrogen.

C) Estimated infrastructure costs in euros per passenger kilometer are highest for subway systems and heavy rail. Costs for bus system can be significantly lower than for individual motorized transport. Infrastructure costs for non-motorized transport are very cost competitive and can realize significant social benefits.

D) Dominant fuels are given for each mode.

Figure 9.48 | Corridor capacity of different modes of transportation (people/hr on a 3.5 mile-wide lane). Source: Modified from Breithaupt, 2010.

characterized by hundreds of separate bus companies. For example, a single minibus route in Lagos, Nigeria is estimated to be served by 200 mini enterprises (Gwilliam, 2005; Small and Verhoef, 2007). The provision of high-quality public transport connecting urban and suburban centers, with integrated fare systems and efficient intermodal/interface linkages, is paramount to enhancing the public transport services, equal accessibility, and other social aspects related to the provision of equitable services of these transport systems.

Bus Rapid Transit (BRT)

Bus Rapid Transit (BRT) is a high-quality bus-based transit system that delivers fast, comfortable, and cost-effective urban mobility (Wright, 2006). It is one of the most important transportation initiatives today and is increasingly being used by cities looking for cost-effective mass transport solutions.

BRT systems can enhance bus efficiency through segregated bus lanes, designs that make boarding and exiting buses quicker, bus priority at intersections, and effective coordination at stations and terminals. Political backing is a key ingredient for success in all BRT systems (Wright, 2006). However, dedicating road space to exclusive use by public transport can be politically difficult, especially given the relative political strength of private motorists. BRT systems can achieve higher speeds than conventional buses²³ and capacities that equal or exceed rail transit at lower costs as they usually take over an existing road lane (about 35,000 passengers can be carried in each direction; see Figure 9.48) (Hidalgo and Carrigan, 2010; ITDP, 2007). BRT has the flexibility to provide limited stop and express services.

There are currently 47 BRT systems operating worldwide and 16 more under construction. Most systems are in Europe (17, of which 10 are in France), while widely visible systems are in Latin America – in Curitiba, Brazil and Bogota, Colombia (Wright, 2006). By providing high-capacity and high-speed service, BRT systems attract more riders and provide service more efficiently than conventional bus services operating in mixed traffic (ITDP, 2010). BRT systems have achieved a certain amount of success in providing reasonable fare levels without the intervention of operating subsidies. Fares in the range of US\$0.25–0.70 are typical with the subsidy-free systems in Latin America (Hidalgo and Carrigan, 2010).

Not all BRT strategies, technical and operational elements are transferable from one city to another. Availability of institutional, technical and management skills are vital to whether a BRT system will work effectively in its operations (handling of passenger boarding and alighting efficiently, with little delay); system signal prioritization (avoiding disruptions to traffic flow on major cross streets); vehicle designs (affecting system performance, cost, and appearance, both external and internal). These aspects are contributors to the overall success of any BRT system.

²³ Conventional buses usually operate under significant levels of congestion. For example while conventional buses were operating at 10 km/h, the BRT Transmilenio System in Bogota operates at an average commercial speed of 27 km/h (ITDP, 2010)

Light Rail Transit (LRT)

LRT uses electric rail cars operating along a dedicated lane or track, separated from other traffic most typically for density reasons in city centers, or in the case of trams, they often operate in mixed traffic without an exclusive lane. Light rail systems can carry 10–20,000 passengers per hour down one corridor (Wright and Fjellstrom, 2005).

There are currently over 400 light rail systems operating worldwide, of which around 300 are tram systems. Most are in Europe, with a few in developing countries. Advances in electronics, software, and materials are playing a major role in making LRT systems more attractive to operators. This has been a major factor in the expansion of existing systems and the construction of entirely new systems during the past several decades (Wright and Fjellstrom, 2005).

LRT is seen as an extremely diversified mode that can be used for short urban lines, as well as long regional lines with various levels of speed and capacity, using alignments that vary from streets to fully separated tunnels, viaducts, and intercity railway tracks. LRT is also seen as an element of urban economic development; in fact, economic theory suggests that the increased value of land close to LRT is best used to finance public transit. Improvements in track and car design have reduced noise levels to a point where LRT protagonists consider LRT systems quieter than diesel buses (Wright and Fjellstrom, 2005).

Increasingly, BRT is challenging the development of new LRT systems on the grounds of cost. BRT systems are becoming more and more sophisticated and capable of emulating the service levels of LRT at much lower investment and operating costs.

There is considerable debate over the capacity of LRT systems compared with BRT systems. With the use of articulated and bi-articulated buses in Curitiba and Bogota, the capacity of BRT has equaled – and exceeded – that of comparable LRT systems. The development of LRT systems is therefore likely to be limited to cities where tram operations exist, and where they can be cost-effectively upgraded and enhanced.

A negative development limiting applications of LRT has sometimes been over-design. Instead of economical designs that allow for the construction of large networks, a number of projects have been upgraded step by step, resulting in very high costs.

BRT and LRT should be considered as complementary modes. LRT is seen as being suitable for situations demanding heavy passenger volumes, use of tunnels in high-density urban centers, and direct service in pedestrian zones.

Heavy Rail Transit

Heavy rail transit systems comprise Metro and Commuter Rail systems operating in exclusive rights-of-way without grade crossings, with high platform stations.

Metro is the term for mostly underground (subway) heavy rail transit, which are the most expensive form of MRT/km, but have the highest theoretical capacity 50,000 passenger per hour in one direction (even 80,000) (Wright and Fjellstrom, 2005, Salter, et.al, 2011). The option of constructing an underground capital-intensive Metro transport system has been supported by many elected officials and voters with promises that it will help reduce congestion, pollution, transform social culture and even become the gem of a cosmopolitan city (Figueroa, 2010; Global Mass Transit, 2010). This despite evidence of extremely high costs compared to buses and a record of under-predicting the cost on this type of project (Flyvbjerg et al., 2004; Flyvbjerg et al., 2009).

Heavy rail transit systems are primarily found in large, dense cities of the industrialized world. However, there are also quite a few in upper-tier developing world cities, such as Tehran, Mexico City, Guangzhou, and Santiago. Bangkok has a new train system that reaches 60 km/hr, averaging 25–45 km/hr compared with the Bangkok traffic speed of 14 km/hr (Salter, et. al, 2011).

Intraurban – long distance – transport is most efficiently served by railways than it is today when car transport and aviation are the prevalent choices. High-speed railways trips are competitive in time with car and plane trips. Notably in some European countries and Japan, for up to 1000 km (Madrid-Barcelona, Paris-Marseille, Hannover-Munich, Kyoto-Tokyo). China puts efforts into replicating and even superseding this success story. Forty-two high-speed, mass transit train lines have been operationalized in China in the last years. The Chinese bullet train connects Ghangzhou to Wuhan, traveling 1036 km (664 miles) in a little more than three hours. The new superfast trains introduced in China are economically competitive and create economies of large-scale production for another big export industry.

9.6.2.2 Enhance Other Means of Transportation

There are many other alternatives to private car use that can be researched and considered.²⁴

Enhance and Facilitate the Use of Non-Motorized Modes

The vast majority of all trips made daily worldwide are on foot. In the United States, for example, according to the 2001 US National Household Survey, 48% of trips were 3–4 km or less, and 24% were 1.4 km or less. These trips are the most suitable to the use of non-motorized modes. Many people rely on NMT, i.e., trips made on foot or by wheelchair, bicycle, tricycle, skateboard, handcart, cycle rickshaw, or other non-motorized vehicles, to meet their daily transportation and mobility needs. Facilitating the use of NMT is important because they are the least carbon-intensive mode of transport available and have

been shown to have health benefits. Most people worldwide have the potential to use NMT.

The presence of pedestrians and safe cyclists are a commonly-used gauge of a successful, vibrant urban space. Pedestrian environments provide safe and salubrious public spaces where people can meet and interact. Active NMT can be part of the solution to increasing public health and confront obesity concerns, particularly in developed countries.

Planning for NMT extends beyond the physical infrastructure to include psychological factors and institutional stasis hindering the adoption of non-motorized modes, variability in the facility needs of each of mode, safety, equity concerns, and land-use practices conducive to NMT. Below a brief discussion on the ramifications of these concerns, planning strategies applicable to non-motorized vehicles (NMV) and to pedestrians are presented.

Equity

In many places, NMT is viewed as the option of last resort if it is not for recreation. Low-income and transportation-disadvantaged persons (elderly, youth, people with disabilities) often rely and gain independent access to services from improvements on NMT facilities, and so does the community at large. The presence of sidewalks and curb ramps, free from surface irregularities and of adequate width, not only give people with disabilities a way of travelling independently but also benefits all pedestrians. Such infrastructure also benefits parents with prams, tourists with luggage, the old, the young, the pregnant, the visually impaired, wheelchair users, users with crutches, etc. Such universal and equitable access principals promote designs that accommodate the widest range of users possible.

NMT can also provide economic benefits for the poor. For many poor, private vehicle ownership of a bicycle, animal carts, or cycle rickshaws actually indicates a considerable economic achievement or a sign for upward economic mobility.

In urban areas, NMTs are not only relevant for the movement of people, but also for the transport of goods. NMVs such as cycle rickshaws and handcarts are an essential means of transporting people and goods in cities and towns in Asia and Africa. In many African towns, sellers or small-scale service providers use handcarts to transport goods to and from markets. In Asian cities, rickshaws designed for passengers often transport goods. NMT also facilitates indirect economic benefits sparked by the demand for NMTs, spare parts, and services such as repair, vehicle rent, and paid parking.

Safety

Road safety is a critical issue. Increased NMT can beget economic mobility and other equity benefits, but it is irresponsible to promote NMT without addressing various safety concerns associated with these relatively vulnerable road users. The speed and volume of cars, trucks, and buses are particularly threatening to cyclists and pedestrians. Data from several cities shows a “safety in numbers” phenomenon – that increasing the

²⁴ For further references regarding other private providers of public services such as digital hitchhiking, hitchhiking, jitney, share taxis, shuttle services, slugging, taxis, vanpooling, see GTZ, 2002; ITDP, 2010.

number of bicyclists reduces the rate of accidents or injuries of bicyclists (accidents per 1000 bicyclists, for instance). This suggests that without changing the volume of vehicular traffic, introducing more cyclists to the road makes bicycling safer. There are several reasons and theories, including the argument that drivers become more familiar with seeing bikes on the road, and thus come to expect and look for them (Brandt, 2011).

Proper infrastructure for pedestrians and bicyclists is critically important for supporting increased NMT mode share. Sidewalks, pedestrian crossings, and bicycle lanes are only the most basic provisions needed. At a minimum, basic, unobstructed, and safe infrastructure is needed to accommodate and promote NMT. Desirable infrastructure would include secure bicycle parking at transit stations, physically segregated bike paths, bike boxes, dedicated bicycle turning signals, and audible and tactile pedestrian crossing signals. The quality of NMT infrastructure will largely determine the NMT mode share.

The presence of so-called “eyes on the street” NMT tends to increase perceptions of safety and can help pedestrians feel safer on less-frequented streets. Adequate light levels at night are important, particularly for women, to enhance safety. Separate facilities and proper lighting are also essential because NMVs and pedestrians may be difficult for drivers to see, particularly when traffic speeds are moderate or high. A concerted effort to increase safety for NMT users is crucial in its own right, but as an ancillary benefit, an attractive and safe pedestrian environment creates more livable communities.

Overcoming Barriers

Even if safe, extensive, convenient facilities for NMT were available, there remain various psychological, educational, geographic, and institutional barriers.

There is a widespread lack of respect for non-motorized users even in developing countries where NMT are dominant. In general, NMT tends to be stigmatized. Some people consider walking and cycling outdated, unsophisticated, and unexciting compared with motorized modes. Some even consider them as symbols of poverty and failure. These are one of the biggest psychological impediments for a modal shift away from motorized modes (UNEP, 2011; Salter, et al., 2011).

Constraints placed by physical barriers and excessive detours to overcome these barriers also impede use of NMT. In many cities, the environment is seen as unattractive for NMT and pedestrian use due to pollution, traffic volumes, and poor quality walkable areas.

Bicyclists report many reasons why they are encouraged to cycle, chiefly among them are cost-effectiveness, health, status. (Alliance for Biking and Walking, 2010). Potential cycle commuters can be however discouraged by a lack of shower and parking facilities at work. NMVs in general, and bicycles in particular, can be easy to steal. Provision of safe and secure bicycle and other NMV parking, in integration with public transportation stations and stop places are therefore essential ingredients

to promote NMV use. Creation of safe routes and parking facilities and simple education and training for people to gain confidence or road skills to cycle contribute to the widespread adoption of NMT (Alliance for Biking and Walking, 2010). Geography can be a factor that constrains NMV in many places.

There are institutional barriers and lack of technical staff to plan NMT facilities and manage a large increase of their use. It is often difficult to agree on prioritizing and secure funding for infrastructure and non-infrastructure projects for NMT due to finite funds, other transportation priorities, and underestimation of the magnitude of NMT. Travel surveys and traffic counts usually ignore or under-count short trips, non-work travel, travel by children, recreational travel, and non-motorized links. Many conventional user surveys attribute the entire trip to a single mode, regardless of the extent to which additional modes are involved and ignoring the fact that virtually every trip begins and ends with walking.

Increasing Non-motorized Transport Mode Share

There are many specific ways to encourage mode shift from other modes to NMT. A short list of suggestions is presented here modified from (Litman, 2010):²⁵

- Planning for NMT is an important part of transport planning. An integrated transport policy is required that defines the role of NMT and NMVs within the total transport system and in relationship to other modes, such as private cars, public transport, and walking. Action plans need to include measures that will help overcome the barriers to NMT outlined above and better integrate NMT. Policies to encourage NMT usually form part of the mobility management and transport demand management measures.
- Improve pavements (sidewalks, cycle tracks), crossings (crosswalks), paths, and bicycle lanes and correct specific road hazards (sometimes called “spot improvement” programs).
- Improve the management and maintenance of NMT facilities, including reducing conflicts between users and maintaining cleanliness and enhancing safety.
- Accommodate people with disabilities and other special needs (universal design).
- Develop pedestrian-oriented land use and building design (new urbanism or transit-oriented development) and increase road and path connectivity, with special NMT shortcuts, such as paths between cul-de-sacs and mid-block pedestrian links.
- Introduce and maintain NMT related street furniture (e.g., benches) and design features (e.g., human-scale streetlights).

²⁵ For a full overview on walking and cycling encouragement, see Victoria Transport Policy Institute, 2011.

- Use traffic calming, speed reductions, vehicle restrictions, and road space reallocation.
- Introduce safety education, law enforcement, and encouragement programs.
- Integrate NMT and public transport facilities (bike/transit integration).
- Provide adequate and secure bicycle parking and address security concerns of pedestrians and cyclists. Create multi-modal access guides, including maps and other information, on how to walk and cycle to particular destinations.

Municipalities and sustainable transport agents can market and promote activities to provide people with information, skills, and positive examples or role models that will promote the popularity of non-motorized vehicles.

Improve Pedestrian Infrastructure

While all the recommendations above also apply to pedestrians, pedestrians are inherently different from NMVs. Pedestrians generally travel more slowly than any other mode – about 4.5 km/hr. Many people will only walk about one kilometer, leaving pedestrians particularly sensitive to detours, roadway conditions, street aesthetics, and perceptions of street crime.

There are many ways to improve facilities, depending on existing infrastructure for pedestrians. A needs assessment can measure indicators of walkability, including factors such as land use mix, street connectivity, residential density, street and building design, scale and nature of place near homes, retail floor area ration, access to public transport, availability and quality of sidewalks, degree of separation from moving traffic and the degree to which moving traffic constitutes a barrier, pedestrian crossings, accessible and direct routes, and air quality.

Additionally, walkability can be evaluated at various scales (Litman, 2010):

- *Site level*: walkability is affected by the quality of pathways, access to buildings, and related facilities.
- *Street or neighborhood level*: the existence of footpaths (pavements or sidewalks) and pedestrian crossings (crosswalks), as well as roadway conditions (road widths, traffic volumes and speeds).
- *Community level*: accessibility, such as the relative location of common destinations and the quality of connections between them.

9.6.2.3 Enhance use of Telecommuting and Communication Technology

Technological change has fundamentally influenced the function and forms of cities and the way people and goods can travel in the city. The convergence of computing and information communications

technologies allows a user-friendly interface for many actors and transactions, for information, education, business and a wide range of daily life social activities (Banister, et al., 2004). Communication networks and applications can improve mobility systems in several ways for example: by substituting some types of physical movement with Information Technology based solutions (for example: e-health & e-care; e-learning, e-working, e-culture & e-media, e-economy, e-mobility, e-government & e-democracy); by unleashing significant traffic efficiency via urban traffic managing systems that increase logistic opportunities and safety, and by facilitating opportunities to create a better connected and integrated array of public transport services.

There is a potential for telecommuting to substitute some work trips, particularly for jobs in which greater work flexibility is possible or where rules are made more flexible. Access to information and communication technologies may also have a dual effect where readily available information on new and exciting destinations and shopping-related entertainment stimulate travel and limit the scope of the substitution of virtual and physical travel. For the most part a synergistic relationship can be expected. That is, the more one or another form of telecommunication takes place, the more all forms of communication and travel are stimulated, while some types of travel are substituted (Mokhtarian, 1990; Banister, et.al., 2004). The full impacts of this dual relationship are still being determined. Some studies report that there is no clear certainty that activities such as online-shopping can result in environmental gains from a reduction in passenger transport (Cullinane, 2009). Similar evidence can be found regarding the effects on freight transport indicating that “internet shopping requires carriers to deliver goods to end users rather than to intermediaries, resulting in overall growth in direct shipments to customers. Together, these trends have increased the number of shipments, particularly small shipments, that carriers handle, and expanded the number of links in the freight supply chain that are needed to deliver goods to their final destination” (US DOT 2010).

9.6.3 Improve Use of Existing Infrastructure

Road traffic growth outpaces population and economic growth in most urban areas of the world. In developing countries, motorization can be as low as ten cars per thousand people (parts of China, India) and rarely exceeds 200 cars/1000 people, while two-wheeler ownership can be high. Motorization is higher than 600 cars/1000 people in the United States. Even with the current low levels of motorization in many developing countries, major challenges are associated with the unprecedentedly fast pace of urbanization, which imposes a high demand for adequate transport and the provision of other urban services and infrastructure. As more than one-half of the developing world’s population and between one-third and one-half of its poor will be living in cities within the course of one generation, a substantial increase in the demand for energy services can be expected from most urban areas (Gwillian, 2002).

Further construction of major road infrastructure has done little to tame congestion or to reduce overall travel time. High-profile examples in large metropolitan areas of developing countries are Beijing, Bangkok, and Mumbai, where a decade of unprecedented investment in transport transformed an entire urban landscape with congestion becoming ever more problematic.

Institutions and policies that either accommodate the car or favor public transport have not been adequate, which resulting in greater congestion and poor accessibility and mobility. With well-known exceptions like Curitiba, Brazil and Hong Kong, China neither urban nor state-based institutions in developing countries have been strong and/or funded enough to accommodate rapid rates of population and motorization growth, exacerbated by the presence of sharp income inequalities.

The World Bank is actively working to carry out a retrospective/prospective study on urban transport policies and activities and is financially supporting construction of several urban transport systems. In addition, several initiatives of a global scale like the global Transport Knowledge Partnership, the Sustainable Urban Transport Project and the Partnership for Sustainable Low Carbon Transport are providing the best available international experience and expertise to help develop sustainable and efficient transport in developing and transition countries.

9.6.3.1 Parking Management Policies

Every car on the road needs a place to be parked; it is a key issue in almost all urban areas (GTZ, 2009). For an average of 23 hours of the day cars are parked, and if used for all journeys they would need a parking space at both ends of every trip – meaning that many spaces are required for every car. A parked car takes up around eight square meters when parked and often the same again in maneuvering space; this is a huge amount of space in dense urban areas where land is limited and expensive.

In many cities around the world, parking is unregulated, in great supply, and provided free of charge. Abundant parking makes it easier and cheaper to drive, and pandemic parking lots increase the distance between development, making cars more necessary (Shoup, 2005).

While drivers may pay very little to park a car, the actual cost of the parking spaces can be quite high. The cost of surface parking (on street or off-street in parking lots) depends on the price of the land and therefore varies significantly by location. Each space in a parking structure costs at least US\$125/month (Shoup, 2005). Despite the high cost of providing parking spaces, in 1995, 95% of US automobile commuters parked free at work (Shoup, 2005).

Free or heavily subsidized parking reduces the costs borne by drivers, biasing individuals' travel choices toward more driving (Shoup, 2005). Shoup estimates that free parking reduces the cost of automobile commuting in the United States by 71%. Since many commuters base travel choices on the relative direct costs of each mode, charging for parking would make a substantial difference in travel behavior (Small and Vehoef, 2007). Removing subsidies for workplace parking in the United States would be equivalent to increasing the price of gasoline to US\$4.44/ gallon (Shoup, 2005).

An environmental impact report for a new parking structure built at University of California, Los Angeles in 2003 estimated that each parking space would generate 1170 vehicle-km (727 vehicle-miles travelled) per month, and have associated external costs from increased congestion and emissions of nearly US\$117/month (Shoup, 2005). Parking should be priced so that the people utilizing the parking internalize its costs.

On street, curb parking is often similarly underpriced. Where there is a parking meter, the price does not cover the actual costs of the parking. Economic theory says that under-pricing curbside parking creates a shortage. This shortage of curbside parking leads to "cruising" – drivers circling the block in search of available spaces. Studies have demonstrated that in some New York City neighborhoods, 30–45% of traffic is from cruising (Transportation Alternatives, 2006; 2007). A study by Transportation Alternatives (2008) estimated that each year, drivers circling for parking on a 15-block section of Columbus Avenue in New York City's Upper West Side drove 589,000 km (366,000 miles) and emitted 325 tonnes of CO₂.

A GTZ report reviews crucial parking effects and policies worldwide (GTZ, 2009), recommending, among others, the following:

- Recognize the role of parking in creating or limiting car demand in transport policy documents and actions.
- Implement maximum parking standards for new developments, paying careful attention to limit parking provision near public transit.
- Legislation is needed to set a framework for parking charges and fines, and to put liability for any fine with the owner of the car.
- Legislation should give local authorities the power to enforce parking regulations and use the parking revenue to improve a sustainable transport system.
- Manage parking demand by introducing paid parking; consider dynamic parking pricing that varies by time of day and parking availability.
- Parking tariffs should be higher for on-street than off-street, to encourage people to use the latter.

- All changes to parking must be communicated well in advance; a positive approach toward working with the public may increase compliance with parking regulations.

9.6.3.2 Intelligent Traffic/Infrastructure Systems

Traffic management via computerized control of traffic signals and traffic segregation is an important urban transport strategy for increasing the movement of people and goods with higher quality and a safer way as well as to enhance urban environment conditions. Segregation in the form of dedicated bus lanes, bicycle lanes and pedestrians also favors safety and attractiveness of public transport and it contributes even more to a healthy environment and to poverty alleviation.

Traffic management requires expertise and a strong local management agency (with strong regulatory and enforcement capacities) to be implemented, maintained and improved. The lack of these requirements might explain why many cities have not yet introduced such measures or benefited from them. According to the global Transport Knowledge Partnership fragmentation of responsibilities between agencies and lack of inter-agency coordination, coupled with a lack of staff and resources, reduces the effectiveness of many traffic management schemes.”

9.6.3.3 Traffic Calming

Traffic calming strategies aim to reduce the speed and volume of traffic to improve safety for pedestrians and cyclists, as well as to improve environmental conditions. Similar to other sustainable transport policies, this involves more than just physical changes; it represents a process of social change requiring extensive community participation. Traffic calming measures are comprised of volume control measures that reduce through traffic by blocking certain movements and diverting traffic to other streets, as well as speed control measures that slow down traffic by changing vertical or horizontal alignment or narrowing the roadway.

Traffic calming measures range from relatively affordable (simple speed humps) to very expensive (designs that affect drainage patterns, utility pole locations or underground services).

Although largely beneficial, traffic calming measures can have drawbacks. Traffic calming measures such as speed humps or raised crosswalks are unsuitable on bus routes or streets that are used frequently by emergency vehicles. Such measures can cause delays up to 10 seconds per measure. Slow traffic on one street can displace vehicles onto adjacent streets, creating unwanted spillover that impacts inhabitants of neighboring streets. Measures that prohibit through traffic can make it more difficult for residents to reach their homes and for visitors to reach local businesses and institutions.

9.6.4 Policies for Alternative Fuels and Efficient Vehicles

9.6.4.1 New Vehicle and Fuel Economy Standards

Fuel economy standards are an effective and efficient policy instrument to reduce GHG emissions in the road transport sector. Fuel economy standards are mandated in many important world regions in order to curb fuel consumption and GHG emissions in new vehicles (An et al., 2007; IEA, 2009d; Creutzig et al., 2011a). Fuel economy standards, however, do not apply for the used vehicles that are often exported to developing countries. Fuel efficiency standards can also complement price instruments, such as carbon taxes and emission trading, that are not fully effective due to dynamic market failures (see also Plotkin, 2008; Flachsland et al., 2011). The European Union and Japan have the most ambitious fuel efficiency standards, with fleet-averaged targets of around 130 gCO₂-eq/km. Although still to be enforced, the European Union adopted an even more ambitious long-term target of 95 gCO₂-eq/km for 2020. China requires ca. 129 gCO₂-eq/km for new vehicles in 2015. The United States implemented a 153 gCO₂-eq/km target for 2016.

The development of fuel efficiency standards in different world regions is summarized in Figure 9.49. This figure is an update from An et al., (2007) with new significant European Union, US, and Chinese regulations (2007). The data is displayed in MJ/km – a suitable measure of energy efficiency, as it applies to all fuels (including electricity/biofuels) and is irrespective of supply-chain GHG emissions (Creutzig et al., 2011a).

An intensity reduction in terms of lower CO₂-eq/MJ is not necessarily equivalent to an absolute reduction in GHG emissions. Two different rebound effects could compromise the desired outcome. First, car

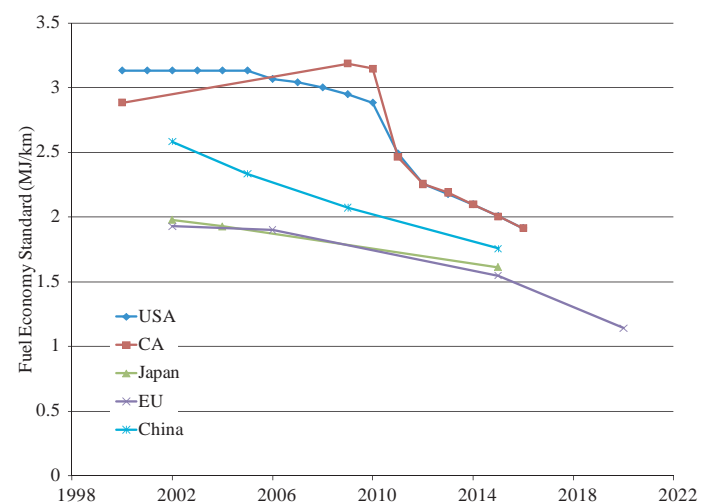


Figure 9.49 | Energy intensity standards of passenger cars extrapolated from current fuel efficiency standards (1 liter gasoline = 32 MJ). Source: An et al., 2007; Creutzig et al., 2011a.

Table 9.11 | Overview of fuel efficiency standards in some world regions.

European Union	CO ₂ emissions	gCO ₂ /km	weight-based fleet standard	NEDC
California	GHG emissions	gCO ₂ -eq/mile	Absolute fleet standard for LDT1/LDT2	FTP 75
United States	Fuel economy and GHG	mpg and gCO ₂ -eq/mile	Footprint-based fleet standards for cars/ light trucks	FTP 75
Japan	Fuel economy	km/l	Weight-based fleet standard	Japan 10–15
China	Fuel economy	l/100km	Weight-based fleet standard	NEDC

Source: Creutzig et al., 2011a.

drivers could use the reduction in marginal cost from lower fuel use to increase total travel distance. Based on a review of 22 studies, Greening et al., (2000) suggest a potential rebound effect in the transport sector of between 10–30%. But they highlight the existence of unmeasured components, such as changes in automotive attributes related to shifts toward increases in weight, horse power, and acceleration of cars purchased. The rebound effect generally decreases with income and level of congestion and increases with fuel costs, suggesting a short- and long-run rebound effect of 4.5% and 22.2%. (Small and Van Dender, 2007; Hymel et al., 2010). The sharp rise in oil prices in 2008 might therefore have led to stronger rebound effects than previously observed. A review suggests that total travel volume in OECD countries started to level off between 2000 and 2010 (Millard-Ball and Schipper, 2011). As another kind of rebound effect, market forces could induce a higher production of fuel efficient cars without inducing a simultaneous reduction in gas guzzlers. Despite moderate rebound effects, total expected GHG abatement by fuel efficiency standards is significant and may be – as part of a broad policy mix – the single most effective climate policy in the transport sector (Creutzig et al., 2011a).

Furthermore, fuel efficiency standards are also considered to be relatively cost effective. Their relative contribution to climate change mitigation corresponds to that of other sectors, and costs are approximately in the same price range (e.g., Blom et al., 2007). One should ask, then, which specific design of fuel efficiency standards is most efficient? For example, some world regions have fleet average requirements (e.g., the European Union), whereas other world regions have targets for each car of a specific weight class (e.g., China; see Table 9.8). Given the same level of overall ambition, the first rule is more cost-efficient, as it gives flexibility to car manufacturers in determining where to invest in fuel efficiency. Effectiveness is not impacted if the fleet average target remains the same. Attribute-based standards redistribute the abatement burden among car manufacturers and consumers, and usually follow political rationale, while decreasing overall efficiency.

The unit of fuel efficiency deserves particular attention. Currently, the most common unit of fuel efficiency is volume per distance or its inverse. With alternative fuels and vehicles taking an increasing share of the market, additional units of fuel efficiency (TTW measures) are suggested to convert to energy or GHG emission per distance, e.g., MJ/km (Creutzig et al., 2011a). This choice of unit would provide a level playing field in a more diverse fuel and vehicle market.

The IEA recommended 25 different efficiency measures, including mandatory fuel economy standards, for LDVs and trucks (IEA, 2008). Four measures are recommended for worldwide implementation:

- Introduce, strengthen, and harmonize, where appropriate, mandatory fuel efficiency standards for LDVs.
- Introduce fuel efficiency standards and related policies, such as labeling and financial incentives, for heavy-duty vehicles.
- Introduce measures that promote proper inflation of tires and adequate tire maintenance and adoption of labeling and other efficient vehicle accessories such as headlights, internal lighting, and air conditioning systems.
- Provide incentives to encourage drivers to adopt safe driving techniques, the promotion of eco-driving, including driver training and deployment of in-car feedback instruments.

9.6.4.2 Used Vehicle Emissions Standards

Imports of used vehicles from developed countries contribute significantly to the vehicle fleet in developing countries. In 2005 alone, Mexico imported 1.3 million vehicles from the United States that were more than 10 years old (Johnson et al., 2009). Strict new vehicle fuel economy standards that increase vehicle prices further encourages the import and sale of older used cars in Mexico and other developing countries. Any fuel economy improvements achieved with new vehicle restrictions could be diminished or negated if older polluting vehicles introduced into the fleet reduce the overall on-road fuel economy.

It is therefore important for any new vehicle fuel economy standards to be accompanied by measures that discourage the purchase and ownership of fuel-inefficient used vehicles, such as inspection and maintenance requirements and border inspection interventions (Johnson et al., 2009).

The World Bank's *Low Carbon Development for Mexico* (Johnson et al., 2009) suggested that border vehicle inspections require imported vehicles to meet minimum environmental standards in order to indirectly regulate the efficiency of used imported vehicles. For instance, vehicles exceeding a certain emissions threshold would be banned from the

country. Similarly, municipal or statewide vehicle inspection programs could restrict vehicle registration or licensing to those vehicles meeting certain tailpipe emissions standards.

9.6.4.3 Reducing the Carbon Intensity of Fuels

Biofuels have been discussed, and partially misunderstood, as low- or zero-carbon sources of energy for transportation, and as a suitable strategy for reducing oil dependency. Hence, the development of biofuels has been supported by a range of policy instruments, including volumetric targets or blending mandates, tax incentives or penalties, preferential government purchasing, government-funded research, development, and deployment (RD&D), and local business incentives for biofuel companies. For example, biodiesel production in Germany jumped with the introduction of a tax break, and slumped again with introduction of a new tax rate.

Another powerful tool that has been introduced into the policy arena over the past decade is renewable fuel mandates. Renewable fuel mandates require fuel producers to produce a pre-defined amount, or share, of biofuels and blend them with gasoline. The mandates aim to reduce the carbon intensity of transportation fuels by entering larger amounts of low-carbon fuels into the market without setting particular intensity targets. Some renewable fuel mandates are non-discriminatory in that they do not differentiate between different types of biofuels. From an environmental perspective, this assumes that any renewable fuel source is less carbon-intensive than conventional gasoline. However, recent evidence shows that this might not be the case (see Crutzen et al., 2008; Searchinger et al., 2008). Discriminatory renewable fuel mandates, on the other hand, apply to only a selection of biofuels or introduce quotas for the least carbon-intensive biofuels.

In its directive on the promotion of the use of energy from renewable sources (EC, 2009a), the European Union mandates 10% renewable fuels used in transportation by 2020. In the United States, the Renewable Fuel Standard 2 (RFS2) program will increase the volume of renewable fuel required to be blended into transportation fuel from 9 billion gallons in 2008 to 36 billion gallons by 2022, corresponding to around 9–13% of total fuels (EPA, 2010a).

However, renewable fuel standards are insufficient for a number of reasons (Creutzig et al., 2011a):

- Only biofuels, and no other alternative fuels, can contribute to achieve this goal. Hence, this is a technology-specific regulation.
- Only some, but not all, biofuels are subject to meeting threshold values. Regulation should be proportional to carbon content to be effective.
- In the current regulation, lifecycle accounting is not accurate as it is performed by relying on hypothetical technologies. It

underestimates indirect land-use emissions and ignores epistemic and highly relevant uncertainties related to land-use change (e.g., Plevin et al., 2010).

A Low Carbon Fuel Standard (LCFS) is different from renewable fuel standards in that it: a) mandates a specific overall decrease in the average carbon intensity of all fuels; and b) accounts for the carbon emissions of each individual fuel, including non-conventional fossil fuels. The primary purpose of a LCFS is to reduce the carbon intensity of fuels for LDVs. As such, a LCFS provides a level playing field across all fuels, rather than mandating specific fuels of the RFS. A LCFS has been implemented in California that requires a 10% reduction in fuel carbon intensity by 2020 (Schwarzenegger, 2007; CARB, 2009). In the European Union the Fuel Quality Directive COM-2007–18 requires a 6% reduction in CO₂-eq of transportation fuels from 2010 to 2020 (EC, 2009a). The US RFS2 indicated threshold values (EPA, 2010a), and a LCFS-like instrument is under discussion in China.

LCFS can remedy some of the insufficiencies in renewable fuel standards. However, a LCFS is also criticized for leakage and shuffling (Stoft, 2009). As an intensity-based instrument, a LCFS suffers from perverse incentives that may, in effect, increase emissions (Holland et al., 2009). Furthermore, the epistemic uncertainty in lifecycle analysis is pervasive, and is not only a matter of research accuracy but is of systemic nature (Plevin et al., 2010). Addressing transport biofuel emissions in a context of a total cap of GHG emissions by introducing fuel and feedstock accounting standards has been suggested to avoid perverse incentives and to decrease the reliance on subjective and unreliable lifecycle accounting to some degree (deCicco, 2009; Creutzig et al., 2011a).

9.6.5 Creating Economic Incentives or Disincentives

Price instruments in transport can cover several purposes. First, price instruments can be understood as user charges to recover investments in infrastructures. Second, price instruments can potentially aim to internalize the huge social costs of transportation (e.g., EEA, 2008b). Third, price instruments have a steering effect, and can reduce or shift demand that produces high social costs. Economic theory predicts that price instruments that address social costs comprehensively are immune to rebound effects. However, if only one category of social costs is priced (e.g., GHG emissions), other social costs of transport will not necessarily improve (e.g., congestion and space consumption of motorized transport in inner cities).

9.6.5.1 Fuel Taxation and Carbon Pricing

In many countries, fuel taxes are an important source of revenue for financing the transport sector. Fuel taxes reclaim the costs of transport infrastructure from road users. As a crude benchmark, US\$0.10/liter may

yield the financial resources necessary to maintain the road system, and an additional US\$0.03–0.05/liter can be a source of finance for urban transport (GTZ, 2009).

Fuel taxes can be evaluated according to four categories of cost recovery and taxation purposes (GTZ, 2009), and countries can be sorted according to these four categories:

- In the first category, fuel prices do not reflect the costs of production and distribution. Some countries, notably Iran and Saudi Arabia, subsidize road users so strongly that not even the costs of oil production and distribution are covered. IEA estimated global fossil fuel consumption subsidies in 2008 alone at about US\$557 billion (IEA, 2010b).²⁶
- The second category recovers road infrastructure costs. Here, the relatively low fuel taxes of the United States are suggested as a conservative benchmark, i.e., the minimum level of fuel taxes to recover road construction and maintenance costs.
- The third category comprises the countries that attempt to internalize the external costs of road transport, i.e., tentatively including issues like consumption of urban space and air pollution.²⁷ Usually, countries that explicitly try to internalize the external costs of road transport have the highest fuel taxes (e.g. European Union countries, Hong Kong).
- In the fourth category, fuel taxes are used as a general source of revenue. Fuel taxes are easier to collect than income taxes or value-added taxes, and can constitute a major source of income for core state functions such as health services and education. This is particularly relevant in countries where tax code enforcement is limited by weak institutional capacity.

Fuel taxation is a straightforward instrument and a good proxy to achieve a number of objectives. However, it is crude with respect to localized externalities, such as congestion and air pollution. Localized road user charges (e.g., congestion charges) can remedy this gap (see below). For the current fleet of vehicles, because GHG emissions are proportional to gasoline and diesel consumption, fuel taxes can address GHG emissions of transport sufficiently accurately. However, with increasing shares of alternative fuels and technologies, fuel supply chains diversify, by this shifting GHG emission upstream in varying supply chains (Creutzig et al, 2011a). GHG emissions of transport are better addressed by upstream emission trading or carbon taxes (Flachsland et al., 2011).

²⁶ www.iea.org/files/energy_subsidies.pdf.

²⁷ Data suggests (e.g., EEA, 2008b) that even the relatively high fuel tax levels in the European Union insufficiently address external costs of road transport. The European Union intends to raise specific road user charges (e.g., EC, 2006).

9.6.5.2 Vehicle Taxation and Subsidies

Vehicle taxation can be used to regulate total car ownership. As most infrastructure and social costs are related to car usage, but not car ownership, vehicle taxation is commonly seen as a sub-optimal price instrument. However, a well designed vehicle tax can successfully mimic non-available first-best pricing instruments (Fullerton and West, 2000). High vehicle taxation limits motor vehicle penetration. For example, Denmark has higher vehicle taxes and lower car ownership than the United States. As another example, cities with dense urban agglomeration, such as Singapore or Shanghai, regulate vehicle ownership by auctioning licenses.

9.6.5.3 Road User Charging

Road user charging, or road pricing, means charging for the use of roads in a way that reflects the actual costs of using them, i.e., paying more when roads are congested and less when traffic is light. Congestion charging is a form of demand management that aims to reduce motor vehicle travel, or shift it to the most sustainable modes, for passenger or freight in peak hour traffic in order to reduce congestion, improve travel times, and reduce emissions (Pigou, 1920; Prud'homme and Bojacero, 2005). A city toll would use road pricing in cities not only for reducing congestion, but also to be an efficient measure to account for other externalities, including air pollution, noise pollution, accidents, and GHG emissions (Creutzig and He, 2009). Road pricing works best when applied in parallel with other measures, such as public transport improvements and provisions for cyclists and pedestrians, to support mode shifts. Technically, the joint application of push (pricing) and pull (investments into NMT and public transit) produces synergies via reduced demand elasticities, reduces opportunity costs for car drivers, and increases public welfare gains (Creutzig and He, 2009). Communication and the involvement of key stakeholders are vital to the success of a pricing scheme, and must be consulted effectively to raise the level of awareness and support.

Key examples of road pricing schemes are found in London, Singapore, Milan, and Stockholm. The London Congestion Charging Scheme, in place since 2003, led to a reduction of vehicle-km traveled of about 20%, significant travel time savings, 16% reduction in CO₂ emissions, substantial reduction of air pollution, and altogether higher life quality in London (Transport for London, 2007). The Singapore Area Licensing Scheme, introduced in 1975, is part of a comprehensive policy package that makes Singapore a leading city in urban transportation worldwide. The updated scheme, Singapore Electronic Road Pricing, is adaptive in pricing so that traffic is always fluid, maintaining speeds of 45–65 km/hr on expressways and 20–30 km/hr on arterial roads. The ECO-PASS scheme in Milan, in place since 2008, is relatively young and has better air quality as one of its primary objectives. Money raised will go toward buses, cycle paths, and green vehicles. The Stockholm congestion pricing scheme is particularly interesting for its political implementation. A trial period was

introduced to persuade road users of the congestion relief benefits of this instrument. Following the trial period, in September 2006, a referendum was held in which a majority of voters, comprising city inhabitants but not outer districts, voted in favor of the congestion charging scheme. Carbon dioxide emissions dropped by 10–14%, which is very significant for a single policy instrument. Smaller cities, such as Durham, England and Valetta, Malta, have also had positive experiences with congestion charging.

Both design and distribution effects play a major role in the political success of road pricing and city tolls. A congestion charging scheme in Hong Kong was abandoned partly because people thought their movements might be tracked. Congestion charging is likely to be more accepted if the revenues subsidize alternative modes of transport, including public transit and NMT, and by this reduce opportunity costs for transport users. In contrast to Stockholm, a congestion charge referendum was rejected in Edinburgh. Car users were vehemently opposed and emphasized the costs to them, and neither car users nor public transit users were strong proponents of future benefits (loss aversion). A solid communication strategy with clear objectives was missing. Other crucial success criteria include a single implementation agency and a political champion and figurehead of the process. Design should correspond to the spatial scope of authority and voters. Both consultation and promotion of the project are required and, accordingly, the project must be kept simple (e.g., Gaunt et al., 2006).

9.6.6 Establish Policies Targeting Freight and Long-Distance Transport: Shipping, Trucks, Rail, and Air

Freight transportation continues to show growth rates that mirror development in an economy or exhibit even a slightly faster growth. It is likely that the recent economic downturn will have a short-term impact on the pace of growth, but this will not change the general trend toward long-term growth of freight transport.

9.6.6.1 Heavy-Duty Vehicles

The demand for freight transportation is driven by economic considerations and the development of logistics in the private sector (EEA, 2008b). Road transport dominates the inland freight transport market. Heavy-duty vehicles dominate inland freight transport at the expenses of rail and inland waterway transport, even in countries where a well-developed and extensive rail and water transport network exists, such as in Europe. Policies and measures to reduce the energy use of road freight are therefore focused on the short to medium term.

Three measures with energy saving potential that can also improve the fuel energy efficiency of the road freight sector include: “training of drivers in energy-efficient or eco-driving techniques, allowing larger vehicles, and reducing average driving speed” (McKinsey Global Institute,

2009). Lowering the speed of trucks has to be assessed vis-à-vis overall traffic safety considerations.

Measures such as the internalization of freight transport external costs (i.e., traffic-based air pollution, noise, and congestion), even if not directly aimed at reducing climate emissions, will contribute to that end goal.

A combination of regulatory policies, such as mandated fuel efficiency improvements for trucks, combined with a steadily increasing carbon tax, could achieve significant reductions in energy use per tonne-km of transport. Shifting freight and passenger transport to rail can be encouraged through government support for R&D of new technologies combined with a steadily increasing carbon tax. At present, neither aviation nor international shipping fuel is subject to any tax or regulation and is not subject to any restrictions under the Kyoto Protocol.

9.6.6.2 Rail

Encouraging a modal shift from road freight transport to rail and inland water transport and short-sea shipping are important measures, as the latter are less polluting modes for freight transportation. However, there are limits to how much a rail network can be expanded and this limits the potential for a substantial shift from trucks to rail.

9.6.6.3 Shipping

Inclusion of international transport emissions, or more generally, all sorts of environmental pollution attributable to international shipping, within a global climate policy framework has proven to be difficult, primarily because the responsibility for reducing emissions does not fall directly within the jurisdiction of any single country. Due to the global nature of shipping and aviation, sectoral approaches may be more appropriate for tackling emissions reductions in international transport. In fact, the shipping industry favors a global treatment of GHG emissions to avoid a multitude of regional regulations (UNCTAD, 2010). There are currently two main types of policy for GHG reduction considered by the IMO: market-based instruments and efficiency requirements. Market-based instruments include emissions trading schemes, fuel levies, energy efficiency credit trading schemes, and other hybrid schemes. Regulating emissions from maritime and air transport could potentially generate resources to finance climate change adaptation and mitigation measures in developing countries (Monkelbaan, 2010).

9.6.6.4 Aviation

A wide variety of economic, market-based measures have been identified for the aviation industry to make progress in reducing net emissions.

These include voluntary carbon offsetting, emissions trading schemes, emissions charges, and positive economic incentives.

The most advanced policy is the inclusion of aviation into the European Union emission trading scheme (ETS) (Directive 2008/101/EC; see European Commission, 2006), understood to be the most cost-efficient and environmentally effective option for controlling aviation emissions. Like industries, airlines will receive tradable allowances covering a certain level of CO₂ emissions per year. After each year, airline operators must surrender a number of allowances equal to their actual emissions in that year. From the start of 2012, emissions from all domestic and international flights – from or to anywhere in the world – that arrive at or depart from a European Union airport will be covered by the European Union ETS. The European Union ETS can thus form the basis for global action. Airline operators are expected to buy certificates from non-aviation abatement options. Due to the relatively weak cap of the European Union ETS, expected low carbon prices until 2020, and limited demand price elasticity of passengers, the overall reduction in demand growth and carbon emissions is expected to be insignificant (Anger and Köhler, 2010). Nonetheless, the European Union ETS directs attention to the growing emissions of the aviation sector and is expected to serve as a role model for other countries and world regions considering similar national or regional schemes, and to link these to the European Union scheme over time.

Possible regulatory and other measures include aircraft movement caps/slot management, enhanced weather forecasting, transparent carbon reporting, and education and training programs. Each of these can contribute to an overall action plan by individual Contracting States.

9.6.7 Assessment of Policy Contributions to Meeting the Multiple GEA and Transport Sustainability Goals

No single policy, actor, or technology has the silver bullet for an energy and sustainability transition in transportation. Achieving multiple goals within a relatively limited time frame requires action on all spatial scales in order to address technologies, urban design, and demand management alike. Governments of nations and cities around the world have different reasons for acting on transport energy sustainability. Appropriate policies will vary according to city, country, and circumstances but should be integrated across scales (Corfee-Morlot et al., 2011). The role of government is pivotal for an energy sustainability transition. The GEA approach considers a multiple-goal approach that requires multiple policies to be implemented simultaneously as policy packages.

Forming multi-policy packages as a way to frame transport policy is a strategy that is receiving increasing attention by researchers and policy makers (OPTIC, 2010). The motivation is the realization that traditional approaches based on single-goal policies have limitations when trying to

resolve complex transport problems related to environment and climate. A multi-policy package has been defined as: “a combination of individual policy measures, aimed at addressing one or more policy goals with the objective of improving the impacts of the individual policy measures, minimizing possible negative side effects, and/or facilitating the measure’s implementation and acceptability” (OPTIC, 2010).

Transportation is a sector bound by multiple direction causalities with land use and behavioral parameters that lead to major policy paradoxes. These multi-direction causalities affect transport policy implementation. One crucial example is “induced or latent traffic demand,” in which building new road infrastructures induces additional traffic (e.g., Goodwin, 1996; Cervero, 2008).

The rebound effect states that efficient vehicle technologies make driving cheaper, and hence will increase the amount of driving and the external costs associated with it. The effectiveness of a fuel economy standard in reducing aggregate fuel consumption then is undermined if the rebound effect is large (Small and Van Dender, 2007; Van Dender, 2009). Two arguments contend that while the rebound effect is real, it should not deter advances in energy efficiency. First, trends clearly indicate that people favor a move toward faster modes of travel, and total distance travelled continues to grow globally. Given these preferences, efficiency improvements will mitigate but not limit the rise in fuel use that would be occurring anyway as trends unfold. Improving efficiency is necessary but not sufficient to meet climate, environmental protection, and energy security goals in transport. Second, the demand for driving and the distances driven are increasing because they generate net benefits to the driver, meaning there are benefits and not just external costs that need to be considered. Finally, while better fuel economy does lead to more driving, it appears to increase less when there is congestion, because congestion itself is a deterrent to driving (Van Dender, 2009).

The rebound effect and overall rising demand is difficult to tackle with fuel efficiency regulations and technological improvements alone and requires appropriate and encompassing demand policies, such as pricing, to be in place. In the absence of pricing policies, consumer preferences for faster, heavier, and stronger performance LDVs, induced and latent demand, and the rebound effect will result in total travel demand such that social benefits are heavily outweighed by social costs, such as congestion at the local level and climate change on a global scale. To effectively and efficiently deal with sub-optimally high demand, focused demand management (e.g., based on pricing policies) is a necessary complement to technological advancement.

A qualitative assessment pairs the sustainable goals outlined in this chapter with policies grouped according to the following categories: Planning, Regulatory, Economic, Information, and Technology. The contribution is rated as essential when policy implementation is a step toward the attainment of a particular goal and when this is well documented in the literature. The contribution is rated as uncertain when no conclusive study has proven the effectiveness between policy implementation and the goal. Finally, the

contribution is categorized as complementary when the expected effect can indirectly or in addition to other policies contribute to creating some synergy to the attainment of that goal.

9.6.7.1 Planning Policies (Table 9.12)

- Two essential planning instruments can be adopted in all countries and cities to meet sustainability goals. First, design urban spaces to improve walkability and facilitate the use of non-motorized modes of transportation. This, in addition to parking policies (pricing, location, etc.) and all other policies to reduce car use and accommodate human-powered modes, are policies that serve most goals. Second, increase the speed, frequency, and coverage of public transport to improve the use of public transportation.
- The role of urban densification is essential to improving accessibility to services and jobs, while impact on congestion can be

ambivalent. Increasing density is a planning policy that needs to be seen in a city-wide, or even regional, context when transportation corridors are designed (Cervero, 2008). Density needs to be a complementary policy to other land-use and transport planning policies, such as mixed use zoning, walkability, non-motorized modes, housing policies, etc. (Banister, 2008; Wheeler, 2004).

9.6.7.2 Regulatory Policies (Table 9.13)

- Regulatory policies have a clear role regarding traffic safety, air pollution, noise, climate mitigation, and diversification of energy sources.
- Gaps in regulatory implementation can diminish the effect of otherwise effective instruments. Therefore, capacity for implementation is also essential.

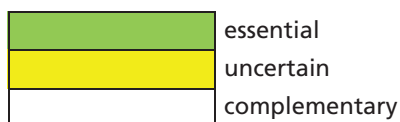
Table 9.12 | Planning policies – potential contribution to attainment of GEA and transport major goals.

GEA Overall Systemic Goals	Multiple Goals and Benefits for a Sustainable Transport System	Policies Aim: Developing Alternatives to Car Use and Reducing Need for Travel										
		Compact, Mixed Use Development	Regional Transit Oriented Development	Urban Design for Walkability	Create safe conditions for use of Non-motorized modes	Create Car-Free Zones. Calming-Parking	Improve Public Transport Access-Reliability	Increase Services of Low-Cost Mass Transit System (BRT)	Management of Urban Traffic System ITS-	Modal Shift Air to Rail long distance	Improve Logistics road freight transport	Shift Inter-city Freight to rail and water transport
Economic Growth, Equity & Urbanization	Functionality, Efficiency	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
	Accessibility	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
	Affordability	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
	Acceptability	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
Health & Environmental Protection	Traffic Safety	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
	Acces of less fit	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
	Human Motion Promotion	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
	Reduce Air Pollution	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
	Reduce Noise	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
Climate	Reduce Congestion	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
	Reduce GHG	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
Energy Security	Diversification Energy sources	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
	Independence from Fossil fuels	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential

	essential
	uncertain
	complementary

Table 9.13 | Regulatory policies – potential contribution to transport and GEA multiple goals.

GEA Overall Systemic Goals	Sustainable Transportation Systems Multiple Goals and Benefits	Aim: Establishing Clear Regulatory Framework								
		Vehicle Standards	Fuel Standards and Mandates	Reduce Travel Speed Limit in Urban Areas	Reduce Travel Speed/Volume of Freight Transport in Urban Areas	Reduce Speed of Airplanes	Reduce Speed of Commercial Maritime Transport	Improved Management Intelligent Transport System	Mandatory Vehicle Inspections	Traffic Safety Regulation
Economic Growth, Equity & Urbanization	Functionality, Efficiency	essential	essential	essential	essential	essential	essential	essential	essential	essential
	Accessibility	uncertain	uncertain	complementary	complementary	complementary	complementary	complementary	complementary	complementary
	Affordability	uncertain	uncertain	complementary	complementary	complementary	complementary	complementary	complementary	complementary
	Acceptability	complementary	complementary	essential	essential	essential	essential	essential	essential	essential
Health & Environmental Protection	Traffic Safety	essential	essential	essential	essential	essential	essential	essential	essential	essential
	Acces of less fit	complementary	complementary	essential	essential	essential	essential	essential	essential	essential
	Human Motion	uncertain	uncertain	complementary	complementary	complementary	complementary	complementary	complementary	complementary
	Reduce Air Pollution	essential	essential	essential	essential	essential	essential	essential	essential	essential
	Reduce Noise	essential	uncertain	essential	essential	essential	complementary	essential	essential	essential
Climate	Reduce Congestion	uncertain	complementary	essential	essential	essential	essential	essential	essential	essential
	Reduce GHG	essential	essential	essential	essential	essential	essential	essential	essential	essential
Energy Security	Diversification Energy sources	complementary	essential	complementary	complementary	essential	complementary	complementary	essential	complementary
	Independence from Fossil fuels	complementary	essential	essential	essential	essential	essential	essential	complementary	essential



- Regulatory policies affecting one transport subsector may have little impact on other subsectors, demonstrating the need for instruments or sets of instruments creating comprehensive coverage.
- Although the impact of regulations on urbanization and equity goals related to transport as they are presented here can be seen as uncertain, the positive benefits of the stringent enforcement of safety, noise, and air pollution rules are without a doubt beneficial to the quality of life in a city for all its inhabitants.

9.6.7.3 Economic Policies (Table 9.14)

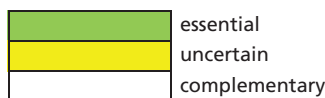
- Pricing policies are essential to address environmental, climate, and energy security goals. They play a complementary role in terms of

sustainability and equity goals. Pricing policies can create incentives for the introduction of new transportation technologies and the use of new infrastructure. Depending on the design and revenue recirculation scheme, they can have regressive or progressive distributional effects.

- Pricing policies are considered in many respects to be more flexible and effective than regulatory and planning instruments, the latter of which are often viewed as “command and control measures.” However, pricing policies may receive little or no acceptability by society and have high political, transaction, implementation, and enforcement costs.
- Economic policies are essential to achieve climate mitigation and diversification of energy sources and have mostly a complementary effect on achieving the other goals.

Table 9.14 | Economic policies – potential contribution to meet transport sustainability and multiple GEA goals.

GEA Overall Systemic Goals	Sustainable Transportation Systems Multiple Goals and Benefits	Aim: Effective Pricing Policies												
		Land Taxation Pricing and Incentives	Vehicles Purchasing Taxes	Alternative Fuel Vehicle Tax Incentive	Vehicle Registration Taxes	Fuel Taxes	Reform of Fuel Subsidies	Distance Based Vehicle Taxation (ldv/trucks)	Congestion Charging (Inner City)	Heavy Goods Vehicles Tolls	Road Pricing (Passenger Vehicles-Inter City)	Road Pricing (Trucks Freight)	Parking Pricing Charges	Feebates for fuel economy standards
Economic Growth, Equity & Urbanization	Functionality, Efficiency	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
	Accessibility	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
	Affordability	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
	Acceptability	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
Health & Environmental Protection	Traffic Safety	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
	Acces of less fit	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
	Human Motion (avoid obesity/heart diseases)	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
	Reduce Air Pollution	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
	Reduce Noise	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
Climate	Reduce GHG	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
	Reduce Fossil Fuel Use	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
Energy Security	Diversification Energy sources	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
	Independence from Fossil fuels	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential



- Road pricing effectiveness depends on the alternatives. If drivers are induced to divert their journeys to non-toll roads, there is only a very localized reduction in air pollution. If trips are taken with other modes of transportation that are more energy efficient, the effects are larger.
- Feebates for fuel economy standards may induce people to drive more (rebound effect), as the marginal cost is cheaper.
- Alternative fuels may not improve air pollution or climate mitigation if they are produced using fossil fuels.

9.6.7.4 Policies to Improve Information (Table 9.15)

Improving information is essential for a low-carbon transition and to contribute to larger goals for transport and urbanization, health, environmental protection, and climate change mitigation (Banister, 2008).

9.6.7.5 Contribution of New/Improved Technologies (Table 9.16)

Measures improving technology and inducing technological shifts contribute to energy security, climate, and environmental goals.

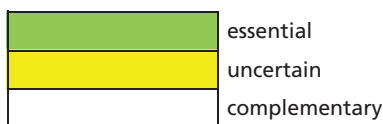
9.6.8 Enabling Conditions to Facilitating a Sustainable, Low-carbon Transition

9.6.8.1 Improving Institutional Capacity

A tension exists between the need for policy and decision makers to commit to a full systemic change and the need to get things done using existing policies, institutions, capacities, and decision-making frameworks. Institutional and human resource capacity is a prerequisite for the implementation of sustainable transport policies. As a rule of thumb, an unregulated transport sector tends to produce a number of inefficient environmental and social externalities. One important factor is

Table 9.15 | Assessment of policies for improving information.

GEA Overall Systemic Goals	Sustainable Transportation Systems Multiple Goals and Benefits	Aim: Improving Information, Inducing Behavioral Change								
		Enhancing Driving Efficiency (LDV Passengers)	Enhancing Driving Efficiency (Trucks)	Traffic Calming Information	Information facilitating Efficient Intermodal Travel	Improve Public Transport Service Information	Improve Information on Safety Rules for Passenger Travel	Information on Safety of Use of Non-Motorized modes	Information on Vehicle Maintenance/Inspections	Encourage use of small efficient LDVs
Economic Growth, Equity & Urbanization	Functionality, Efficiency	Essential	Essential	Uncertain	Essential	Essential	Essential	Essential	Essential	Essential
	Accessibility	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
	Affordability	Uncertain	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
	Acceptability	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
Health & Environmental Protection	Traffic Safety	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
	Acces of less fit	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
	Human Motion	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
	Reduce Air Pollution	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
	Reduce Noise	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
	Reduce Congestion	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
Climate	Reduce GHG	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
Energy Security	Diversification Energy sources	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
	Independence from Fossil fuels	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential



institutional integration and coordination (Banister 1998, 2005; May et al., 2006).

9.6.8.2 Improving Acceptability and Public Information

Sustainable transport is not only characterized by a number of goals or co-benefits, but also by procedures such as participation and open communication. In fact, improving the acceptability of changes of the transport system often is a precondition for successful implementation. Such is its importance, that information itself has been identified as a key component of sustainable transport (Banister, 2008). In Table 9.17 key insights of information for transport transitions are identified.

9.7 Conclusion

Achieving sustainability goals in transport that help induce economic growth, energy security, equitable access and better health, and contribute to poverty alleviation and to meeting low emissions goals, within the limited time frame of a few decades requires transformative actions and political commitment from the local communities to the supra-national and global level. Actions must be taken to change the landscape of cities to favor multiple short-distance destinations, to enhance accessibility by foot and non-motorized modes, and to enhance and extend a variety of smart-integrated public transport services. These kinds of structural and demand-side policies are necessary complements to technological innovation for energy efficiency and alternative fuel deployment.

Table 9.16 | Potential contribution of new/improved technologies to transport and GEA goals.

GEA Overall Systemic Goals	Sustainable Transportation Systems Multiple Goals and Benefits	Improving Efficiency					Widespread Intake and Use of New Vehicles and Fuels											
		Improving Vehicle Efficiency	Improving efficiency of Trucks	Efficiency Technologies Rail	Efficient Technologies for Aviation	Efficient Technologies Shipping	Hybrids gasoline-electric	Hybrids fossil - biofuels	Natural Gas/ Biogas LDV	Electric Plug-in / Battery LDV	Hydrogen LDV	Natural Gas-Biogas Buses	Electric Buses	Hydrogen Buses	Hydrogen Service Vehicles (Industry)	Biofuels Freight (Trucks)	Biofuels in Aviation	Biofuels for Maritime Freight Transport
Economic Growth, Equity & Urbanization	Functionality, Efficiency																	
	Accessibility																	
	Affordability																	
	Acceptability																	
Health & Environmental Protection	Traffic Safety																	
	Acces of less fit																	
	Human Motion Promotion																	
	Reduce Air Pollution																	
	Reduce Noise																	
Climate	Reduce Congestion																	
	Reduce GHG																	
Energy Security	Diversification Energy sources																	
	Independence from Fossil fuels																	

	essential
	uncertain
	complementary

Globally, transportation policy makers, technicians, and manufacturers must purposefully participate in climate change mitigation and actively contribute to reduce energy security concerns. Locally, the livability of human settlements, environmental pollution, health, and spatial equity can be dramatically improved by sustainable transport practices.

Achieving this vital transition requires extensive investment in high-quality public transportation and non-motorized transport that encourages a shift to these modes from private automobiles. There needs to be an overall reduction in VMT, a radical shift in urban development from car-centric to people-centric models that prioritize walkable, dense, mixed-use urban spaces. Also required is the decarbonization of transportation fuels, mainstreaming of near-zero GHG emissions vehicle technologies, such as plug-in hybrid vehicles, full battery electric vehicles, and hydrogen fuel cell vehicles. Altogether, this comprehensive set of policies will affect not only transport use but also societal interaction, e.g., via land-use patterns and personal choices and preferences.

The task of transforming transportation will not be possible without sustained effort and deep involvement over the upcoming years and decades by industry, governments, and consumers (Lutsey and Sperling, 2007). Achieving a multitude of local transitions for sustainable urban

transport is a key challenge as cities for some additional 3 billion urban dwellers will need to be constructed by 2050. As discussed in Chapter 18 most of this urban growth will take place in medium size cities. This represents a window of opportunity to use many of the approaches covered in this Chapter, in particular, for giving a renewed focus on addressing issues of accessibility, density, land use and urban design to favor walking and bicycling, public transport service affordability, local equity and environmental concerns. The future sustainability of cities requires solid policy actions essential to decrease barriers for slow-mode traffic, reduce air pollution and noise nuisances, and to make cities safe and comfortable places for transport and living.

The required planning practices, policies, and technological innovation for this transition cannot be limited to improving the energy efficiency of personal vehicles (LDVs) and fuels. It must aim to upgrade the energy efficiency of all subsectors within all transport systems – including heavy-duty vehicles, buses and trucks, trains, airplanes, ships, agricultural vehicles, and off-road transport – on a scale from the local to the national to the international.

This transformation must embrace a long-term vision. It presents challenges that need to be overcome. Chief among them are societal barriers, limited institutional capacities, and status (e.g., Urry, 2007; Creutzig et al., 2011b). Another challenge is that fuel technologies that may be

Table 9.17 | Key elements for promoting public acceptability for a transport transition.

Information	<ul style="list-style-type: none"> • Education, awareness campaigns, and promotion through media and social pressure are an essential starting point • Explanation of the need for a transition toward sustainable, low-carbon mobility, emphasizing positive economic, social, and health benefits to individuals and businesses
Involvement and communication	<ul style="list-style-type: none"> • The process must be inclusive, with clear aims and an understanding of the consequences by those who the strategy will impact • Design to gain support and understanding, so that stakeholders can buy into proposals • Raise levels of consistency between expectations and outcomes
Packaging	<ul style="list-style-type: none"> • Push and pull policies measures need to be combined in mutually supporting packages • Policies restricting car use or raising its costs should be accompanied by well-publicized programs to improve availability and attractiveness of alternatives to driving alone, including car pooling, public transport, cycling and walking, all financed by dedicated revenues from car pricing measures
Selling the benefits	<ul style="list-style-type: none"> • It is necessary to widely publicize the benefits, even if there are costs, inconvenience, and sacrifice • Car drivers support funding of alternative modes to reduce congestion on the roads they drive on • Overweight or obese individuals would directly benefit from better walking and cycling conditions • Everyone benefits from cleaner air and safer traffic conditions • More walking, cycling, and public transport use would help relieve parking shortages. These are important and direct impacts that all individuals can support
Adopt controversial policies in stages	<ul style="list-style-type: none"> • Support needs to be built up in terms of positive outcomes and measurable improvements in the quality of life • Politics is about reflecting prevailing preferences and also forming opinions • Acceptance of responsibilities and commitment to change through actions is the key to success
Consistency between different measures and policy sectors	<ul style="list-style-type: none"> • Some measures (e.g., pricing) are common to all futures, and such measures need to be implemented now, even though the impacts may not be immediate • Regulations, standards, subsidies, and tax incentives should all be used to encourage manufacturers and other transport suppliers to develop and adopt the most energy-efficient and environmentally friendly technology possible • The precautionary principle should be followed, particularly on the global warming effects of transport emissions, and actions should be consistent over the longer term • Many problems created for the transport system do not emanate from the transport sector, but from other sectors. Thus, a more holistic perspective is needed that integrates decision making across sectors and widens public discourse
Adaptability	<ul style="list-style-type: none"> • Decisions today should not unnecessarily restrict the scope for future decisions, so that the adaptive behavior of individuals and agencies can be assessed • There is no prescription or blueprint for the correct procedures to follow. Each situation requires separate analysis and implementation, including flexibility to change policy measures if intentions and outcomes do not match. Assessment of risk and reversibility are both strong components of sustainable mobility • Adaptability is not an excuse for inaction or weak action. It is an argument for clear decision making and leadership, supported by analysis and monitoring to check the effectiveness of policy action

Source: adapted from Banister, 2008.

best suited to help with the transition are not presently at the commercialization stage. Furthermore, current marginal improvement in technologies can constitute further long-term technological lock-in, and may constitute a barrier for the deployment of transformational technologies.

Transforming transportation toward sustainability requires the implementation of a portfolio or aggregated bundle of policies and hybrids of regulations and market mechanisms directly linked to targets that enhance mobility while protecting the environment. This includes considerations of air pollution, GHG emission reduction, carbon tax policies, quality of accessibility, affordability of urban mobility, safety, and acceptance from urban residents. A transition must build in long-term signals to fuel producers, and needs to incentivize the development and dissemination of new, cleaner, and affordable technologies. To be successful, a transition must be accompanied by the effective communication of sustainable transport goals (Jaccard, 2006). Pioneer regions and cities in sustainable transport can provide

benchmark policies and lower the behavioral barriers in other regions and cities.

It is necessary to immediately start intelligently designing low-carbon transportation systems in developing countries that can also bring co-benefits, such as clean air or a reduction of congestion, that are necessary for sustainable development (Bongardt et al., 2010). Such measures could be supported by international climate mitigation efforts as administered by the UNFCCC, an intervention fostered by the Partnership on Sustainable Low Carbon Transport.

An important near-term approach is to identify strategies for decarbonizing key subsectors like aviation, marine transport, and heavy-duty vehicles. Transport intensity needs to be addressed in all road transport subsectors through urban planning and transportation demand management. The strategy for dealing with automakers is to bring highly efficient, alternative-fuel vehicles to the market with policies that focus on the link between new product commercialization and

the mass dissemination necessary to realize substantial cost reductions from economies of scale and economies of learning (Jaccard, 2006).

Finally, with the multiplicities of sustainable transportation goals and different spatial scales involved, the cost of transforming transportation can vary dramatically across industries, countries, and regions. With

this in mind, it is imperative that local governments gain experience and expertise even before national and global initiatives are in place. Lower-level government policy structures need not preclude – and can even advance – multiple goals toward transforming transportation and sustainability, integrating policy measures across goals while differentiating between geographic settings (Lutsey and Sperling, 2008; Creutzig and Kammen, 2009b).

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