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Chapter 5 Transportation and its infrastructure

Contents

EXECUTIVE SUMMARY

Status and Trends

Current transportation activity is overwhelmingly driven by internal combustion engines powered by petroleum fuels (96% of total transport energy use). As a consequence, transport energy use and carbon dioxide emissions closely track each other, and both will track the growth of transportation activity, mediated by changes in efficiency or shifts to less carbon-intensive fuels. In the developed world, transport activity and transport GHG emissions currently are increasing at 1-2% per year. In the developing world, the rapidly increasing motorization of transport is expanding human mobility and increasing transport GHG emissions at a much faster rate, generally between 3 and 5% per year.

In the year 2000, the transport sector used 77 EJ of energy and produced 24% of world energy-related GHG emissions. Passenger transport currently accounts for 65% of total transport energy consumption and GHG emissions while freight movement comprises the remaining 35%. .

The motorization of transport in the developing world is well underway and expected to grow rapidly in the coming decades. Transport energy use in the developing world increased at a much faster rate (2.6 %) than that (2.1%) in developed world and is projected to grow from 32% now to 46% of world transport energy use by 2030. Such rapid motorization has created severe congestion and air quality problems in the large cities of the developing world. The transport priorities of developing countries will therefore focus on economic development, congestion mitigation and environmental quality.

It is not clear that oil from conventional sources can continue to supply the energy needs of the world's growing transport system. There is no shortage of alternative fossil energy feedstocks, ranging from coal to oil sands and shale oil, and possibly natural gas . A transition to these feedstocks would significantly increase transportation's GHG emission, unless the carbon emissions were sequestered. Alternatively, greatly increased energy efficiency could postpone the transition, and greatly increased use of biofuels and energy carriers such as electricity or hydrogen, produced from low or zero carbon sources, could direct the transport sector towards a low-carbon future.

Mitigation Technologies

Significant developments in mitigation technologies since the TAR include the initial market success of hybrid vehicle technology, the development of clean diesel technology, and the institution of significant research, development and demonstration programs around the globe for hydrogen-powered fuel cell vehicles. In addition, numerous opportunities for improvement of conventional technologies still exist, and biofuels continue to be important in certain markets and hold much greater potential for the future.

Efficient Technologies and Alternative Fuels

Full hybridization of a light-duty vehicle can increase fuel economy by 40%, and can yield substantial improvements to urban buses and delivery vehicles. Direct injection, turbo-charged diesel engines capable of meeting Euro4 or Tier 2 emissions standards can deliver about 30% greater fuel economy (on a volumetric basis) than a conventional gasoline engine, and a 20% reduction in carbon emissions (though emissions of fine particles will be a concern unless adequate filtering devices are used). A combination of other technologies, including materials substitution, reduced aerodynamic drag, reduced rolling resistance, reduced engine friction and pumping losses, etc., when combined with hybrid or diesel technologies could create the potential to increase the fuel economy significantly.

The preference of the market for power and size, as well as for features such as air conditioning and four wheel drive, has consumed much of the potential for GHG mitigation achieved over the past two decades.

Since the TAR, governments and industry have made very substantial investments in research and development of hydrogen-powered fuel cell vehicles. The future technological, economic and market potentials of hydrogen vehicles remain uncertain. Significant technological advances are needed in fuel cell stack cost, hydrogen storage, and hydrogen production from low- or zero-carbon sources. The GHG mitigation potential of hydrogen fuel cell vehicles depends strongly on the energy efficiency of the vehicle system and the fuel-cycle pathway by which the hydrogen is produced. Well-to-wheel carbon emissions could be reduced by 50-60% versus a conventional gasoline powered vehicle – and considerably more if the carbon emissions from hydrogen production are sequestered. In the long-run, if hydrogen could be produced economically from biomass, solar, wind, or nuclear energy, well-to-wheel carbon emissions could be nearly eliminated.

Over the next 30-50 years the market potential, as well as the GHG mitigation impacts of biofuels will depend strongly on the feedstocks and the processes employed. Ethanol is the most widely used biofuel at the present time. Ethanol from sugar cane is both more economical and has lower fuel cycle GHG emissions than ethanol produced from corn. It appears unlikely that biofuels produced by fermentation and distillation could displace more than 10% of road transport energy. Achieving this level could reduce road transport carbon emissions by 2-5% on a well-to-wheel basis.

Biofuels may also be made from the ligno-cellulosic components of plants, as well as from biological wastes. With these feedstocks, the potential for biomass fuels could increase to as much as 20% by 2030, achieving a 16% reduction in road transport carbon emissions.

Air, marine, rail

The dependence of air travel on kerosine appears likely to continue for some decades. Energy efficiency gains will continue, however, as a result of continuous improvements in aerodynamics, weight reduction and fuel efficient aircraft engines, and through enhancements in air traffic management technologies which, if implemented, could produce up to 10% fuel efficiency improvements. Aircraft operational improvements might offer up to 5% fuel efficiency improvements, and by optimising flight procedures. The blended wing body, a concept with a greater promise of carbon emission reduction, still faces challenges of costs of production, as well as market acceptance. Considering all sources, a 20% improvement in aircraft efficiency of new planes over 1997 levels is expected by 2015, with a cumulative 30-50% improvement likely by 2050. Such improvements will not be sufficient to keep carbon emissions from global air travel from increasing significantly.

From the study of the International Maritime Organization (IMO) it was found that a combination of technical measures could reduce carbon emissions by -30% in ships. The short-term potential for operational measures ranged from 1-40%, depending on a variety of factors related to the current operation of the vessels. The study estimated a total reduction potential for the world fleet of about 18% by 2010 and 28% by 2020. This is not expected to be sufficient to offset the growth in shipping activity over the same period.

The main opportunities for mitigating GHG emissions associated with high-speed passenger rail travel are improving aerodynamics, introducing regenerative braking and on-board energy storage and, of course, mitigating the GHG emissions from electricity generation.

Operating Practices
Global trends in the modal distribution of both passenger and freight transport have generally favored motorized over non-motorized modes and faster, flexible, energy intensive motorized modes. On the passenger side, these trends reflect increasing incomes and, as a consequence, the value of travelers' time. On the freight side, trends reflect increasingly interdependent and integrated production activities and the minimization of inventories. In general, passenger transport by private automobile uses several times the energy required for bus or rail transport. The question of how much transport can be shifted to less energy intensive modes is highly dependent on local conditions.
However, there is significant worldwide mitigation potential if public transport and NMT share loss is reversed. Recent scenario study estimated that a 5% increase in Bus Rapid Transit (BRT) mode share against a 1% mode share decrease of private automobiles, taxis and walking, plus a 2% share decrease of mini-buses can reduce CO_2 emissions by 4% at an estimated cost of 66 USD/tonCO_2, in typical Latin American cities.

Policies and Measures
Surface Transport
Most industrialized nations have set fuel economy standards for new light-duty vehicles (LDVs). China has now established a system of weight-based fuel economy regulations. The universality of the use of regulatory policy to address light-duty fuel economy appears to acknowledge a nearly universal failure of the market to achieve high fuel economy levels regardless of the widely varying cost of fuel. Fuel economy standards have been universally effective in raising new vehicle fuel economy, increasing on-road fleet average fuel economy, and restraining increases in fuel use and carbon emissions. A key feature of fuel economy standards is that they direct the trade-off of potential fuel economy gains versus increased vehicle performance and weight in favour of the fuel economy gains.

Aviation
An EU study found that charges of € 30 per tonne-CO_2 and € 3.6 per tonne-NOx would reduce CO_2 emissions in EU airspace by 9%; about half of the reduction would be due to technical and operational changes, the other half to reduced air travel. An ICAO(International Civil Aviation Organization) study concluded that a charge of $0.5/kg-jet fuel (€ 123 per tonne- CO_2)could reduce

CO_2 emissions by 18%, three quarters of which would be due to reduced air travel. An additional analysis by ICAO indicated that if aviation were to participate in an open emissions trading system, total air transport activity would be reduced by only 1%, because aviation would purchase the vast majority of the credits it would need.

Transport Sector Mitigation Potential

There are various possible mitigation technologies and measures for the transport sector.
For road transport, these include fuel efficient technologies such as diesels, hybridization and fuel cell, coupled with improvements in vehicle use and use of low carbon fuels such as biofuels.
Many studies indicated that substantial reductions in transport GHG emissions could be achieved at negative or minimal costs, although these studies generally used optimistic assumptions about future technology costs and/or did not consider tradeoffs between vehicle efficiency and other (valued) vehicle characteristics. Assessment of economic potential and also market potential will decrease the estimates of mitigation potential substantially.
In the developing countries where rapid motorization is essentially inevitable, managing this motorization with strong public transportation and integration of transit with efficient land use, continued support of bicycle transport, encouragement of mini cars, and incentives for efficient transport technology and alternative fuels are important components of a strategy to reduce GHG emissions. However, GHG emissions from transport will grow regardless of strategy, at least until there are sufficient breakthroughs in carbon-neutral fuels to allow their use worldwide and in huge quantities.

Long-term Outlook

As economies grow, people tend to use more energy-intensive modes of travel. Therefore, energy consumption of the transport sector will continue to increase in the future without radical changes in transport technologies. Based on the analysis of WBCSD(2004), over the next 25 years total energy use in the transport sector is likely to increase at an average rate of 1.7%/year if current transport patterns persist.

The expected energy consumption growth of air travel is highest (2.6%) and that of LDVs is considerably more modest, though still quite significant(1.5%). However, by 2050, almost 40% of total energy will be consumed by LDVs, with all road transport accounting for more than 70% of all the transport energy use. 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, which is almost three times higher than the present level. Nearly all of this increase will be in the developing world.
This assessment makes it evident that even if implemented worldwide, diesels and hybrid ICEs fueled with conventional gasoline and diesel fuel, or fuel cells fueled by with natural gas-derived hydrogen without carbon sequestration, can no more than slow the growth in road transport CO_2 emissions during the period 2000-2050. Only the use of carbon-neutral hydrogen in fuel cells and advanced biofuels in ICE-powered vehicles can largely or totally offset the growth in CO_2 emissions produced by the growth in road travel during this period.
Questions on technical feasibility must still be answered. The introduction and widespread use of hydrogen fuel cell vehicles, for example, requires overcoming many major obstacles, such as huge reductions in the costs of fuel cells, breakthroughs in onboard hydrogen storage, and major advances in hydrogen production.

Among the other transport modes, commercial aircraft present a particular challenge. The efficiency of aircraft engines is increasing, improved aerodynamics and the use of lightweight materials on aircraft, and the enhancements in air traffic management and aircraft operations are expected to continue to be important sources of greater energy efficiency in commercial aviation. Even so, the rate of demand growth projected for this form of mobility is so great that even with these improvements, both energy use and GHG emissions are projected to increase faster than in any other transport modes.

5.1 Introduction

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

Since transportation relies on oil for virtually all its fuel, and accounts for almost half of world oil consumption, the future will be challenging times for the transport sector. In this chapter, we assess existing and future options and potentials to reduce greenhouse gases (GHG).

It is crucial for policymakers to recognize that GHG emissions reductions will not be viewed as the critical issue in transportation during the coming decades. In developing countries especially, demand for private vehicles is increasing rapidly whereas transportation infrastructure – including both road networks and public transit networks – lags well behind. The result is growing congestion and air pollution,[1] and sharp increases in traffic accidents. Further, the predominant reliance on private vehicles for passenger travel is creating substantial societal strains as economically disadvantaged populations are left out of the rapid growth in mobility. In most countries, therefore, concerns about transportation will focus on these local effects, and the global warming issue in transportation must be addressed in the context of sustainable development.

5.2 Current Status[2] and Future Trends

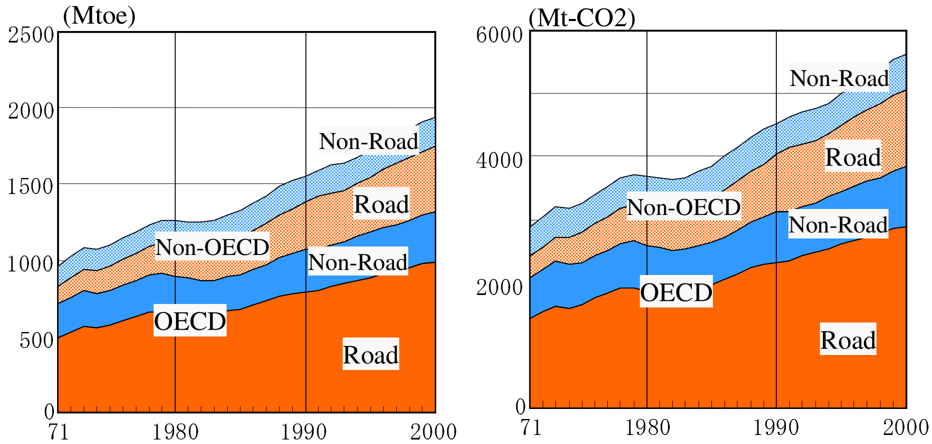
5.2.1 Overview

The current level of transportation activity in the world closely tracks economic development – wealthy nations have high levels of transportation activity not only because they can afford to, but also because transportation is a key engine of wealth, providing the means to trade and to specialize. Consequently, growing globalization and the further economic growth of the developing world is inextricably linked to growing transportation activity – the two go hand in hand. Where transportation activity is high, personal travel has increasingly moved towards the fastest modes, especially automobiles and, for longer distances, airplanes, and this pattern appears to be occurring in developing nations, as well. However, other modes, e.g. rail and inland waterways for freight, bus transit, bicycles, etc., play an important though varying role in most nations, and the intensity and efficiency of travel also varies among regions of similar income levels because of differences in fuel taxation, infrastructure choices, land use controls, and other factors. One factor is essentially constant, however – current motorized transportation activity is overwhelmingly driven by internal combustion engines powered by petroleum-based fuels, and these fuels have similar-enough carbon contents that transport energy use and carbon emissions track each other fairly closely (see Figure

[1] Although congestion and air pollution also are found in developed countries, they are exacerbated by developing country conditions.
[2] The primary source for the "current status" part of this discussion is Massachusetts Institute of Technology and Charles River Associates Incorporated, *Mobility 2001*, World Business Council for Sustainable Development, 2002 .

5.1). Consequently, the growing transportation demand that will inevitably accompany further globalization and economic growth will lead to higher energy use and carbon emissions unless there are dramatic increases in efficiency and/or shifts toward non-carbon fuels. There exist a variety of existing and potential means to accomplish changes in the current direction – fuels from biomass, technologies that yield greater efficiency, promotion of less travel-intensive urban forms, and so forth – though none appears to be a single "grand solution."

Energy Consumption and CO2 Emission in Transport Sector



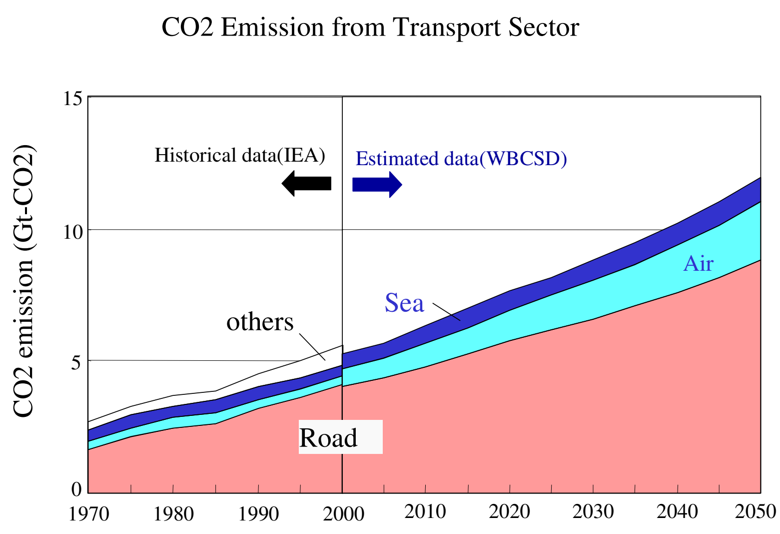


Fig.5.1 *Energy consumption and* CO_2 *emission in transport sector.*

5.2.2 Transport Today

The transportation sector plays a crucial and growing role in world energy use and emissions of greenhouse gases. In 2000, the transport sector was responsible for about 21-28% of world energy and energy-related greenhouse gas emissions.[3] It is also noted that the growth rate of energy consumption in transport sector during 1990-2002, is highest among all the end-use sectors. Of a total of 77 EJ of total transport energy use, road vehicles account for more than three-quarters, with light-duty vehicles and freight trucks having the lion's share (see Table 1). And virtually all (96%) of transport energy comes from oil-based fuels, largely diesel (23.6 EJ, or about 31% of total energy) and gasoline (36.4 EJ, 47%). One consequence of this dependence, coupled with the only moderate differences in carbon content of the various oil-based fuels, is that the CO_2 emissions from the different sectors are roughly proportional to their energy use.

***Table 5.1**. 2000 World Transport Energy Use, by mode (exajoules)*

LDVs	34.20	
2-wheelers	1.20	
Heavy freight trucks	12.48	
Medium freight trucks	6.77	
Buses	4.76	
Rail	1.19	
Air	8.95	
Shipping	7.32	
Total	76.87	*Source*: IEA/SMP Model

A number of forces have shaped our current transportation system, and these forces will continue to play a crucial role in the future. Economic development and transportation are inextricably linked – it is not just that development can drive transport demand, but that the availability of transport drives development by allowing trade and specialization. Industrialization and growing specialization have created the need for large shipments of goods and materials over substantial distances; accelerating globalization has greatly increased these flows, and regional and world trade are major drivers of transport. Urbanization has been extremely rapid in the past century, and fully 75% of people living in the industrialized world and 40% in the developing world now live in urban areas. Also, cities have gotten larger, with 19 cities now having a population over 10 million. A parallel trend has been the decentralization of cities – they have spread out faster than they have grown in population, with rapid growth in suburban areas and the rise of "edge cities" in the outer suburbs. This decentralization has created both a growing demand for travel and an urban pattern that is not easily served by public transport. The result has been a rapid increase in personal vehicles – not only cars but also 2-wheelers – and a declining share of transit. Further, the lower-density development and the greater distances needed to access jobs and services has seen the decline of walking, and bicycling as a share of total travel.

Another crucial aspect of our transportation system is that much of the world is not yet motorized because of its extreme poverty, and another large part of the world is only at the early stages of motorization. The majority of the world's population does not have access to personal vehicles, and many do not even have access to motorized public transport services of any sort. Thirty-three percent of China's population and 75% of Ethiopia's still do not have access to all-weather transport. Walking more than 10 km/day each way to farms, schools, and clinics is not unusual in rural areas of the developing world, particularly Sub-Saharan Africa, but also in parts of Asia and Latin America. Commuting by public transport is very costly for the urban poor, taking, for example, 14% of the income of the poor in Manila compared with 7% of the income of the non-

[3] Data are imprecise. Fulton and Eads (2004) cite 6.3 gigatonnes of CO_2-equivalent emissions on a well-to-wheels basis, out of a world total of 22.6 gigatonnes; IEA (2004) cites 4762 Mt CO_2 from transport oil use out of 23,116 MtCO_2 total energy-related CO_2, or 20.6% for 2002.

poor (The World Bank, 1996). If and when these areas develop and their population's incomes rise, the prospects for a vast expansion of motorization, fossil fuel use, and greenhouse gas emissions are dramatic. And these prospects are exacerbated by the evidence that the most attractive form of transportation for most people as their incomes rise is the motorized personal vehicle, which is seen as a status symbol as well as providing the most flexibility, freedom, and usually shorter travel times. Further aggravating the energy use and environmental concerns of the expansion of motorization is the large-scale importation of used vehicles into the developing world. Although the increased travel will be a crucial part of a huge increase in well-being for the inhabitants of these areas, a critical goal will be to minimize the negative environmental aspects of this increase.

Worldwide travel studies have shown that the average time budget for travel is roughly constant worldwide, with the relative speed of travel determining distances traveled yearly (Schafer, 2000). As incomes have risen, travellers have shifted to faster – and more energy-intensive – modes, from walking and bicycling to transit to automobiles, and to airplanes for longer trips. And as income and travel have risen, the percentage of trips made by automobile has risen with them. Auto travel now accounts for less than 10% of total trips in the developing world, but 50% in Western Europe, and 90% in the United States. The world auto fleet has grown with exceptional rapidity – between 1950 and 1997, the fleet increased from about 50 million vehicles to 580 million vehicles, five times faster than the growth in population. In China, for example, vehicle sales (not including scooters, motorcycles, and locally-manufactured rural vehicles) have increased extremely rapidly, from 700,000 in 2001 to 1.1 million in 2002 to 1.7 million in 2003. 2-wheeled scooters and motorcycles have also played an important role in the developing world and in warmer parts of Europe, with a current world fleet of a few hundred million vehicles.
Other modes also play a crucial role in personal travel. Non-motorized transport continues to dominate the developing world. Even in Latin America and Central and Eastern Europe, walking accounts for 20 to 40% of all trips in many cities. And bicycles continue to play a major role in some cities and countries, e.g. New Delhi, China, Vietnam.

Public transit continues to play a crucial transportation role in urban areas. Buses, though declining in importance in the industrialized world, are increasing their role elsewhere, up to 45% of trips in some areas. Paratransit – primarily minibus jitneys run by private operators -- has been rapidly taking market share from the formal public-sector bus systems in many areas, now accounting for 40% of trips in Caracas and Bogota, and up to 65% in Manila and other Southeast Asian cities. Fixed rail transit systems are generally found only in the largest, densest cities of the industrialized world and a few of the upper-tier developing world cities, and even in these cities they are rarely the dominant mode.

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

Industrialization and globalization has also driven freight transport, which now consumes 35% of all transport energy, or 27 exajoules (out of 77 total). Although freight transport is considerably more conscious of energy efficiency considerations than is passenger travel because of pressure on shippers to cut costs, there is a countervailing pressure to increase speeds and reliability. The result has been that, although the energy-efficiency of specific modes has been increasing, there has been an ongoing movement to the faster and more energy-intensive modes. Consequently, rail and domestic waterways' shares of total freight movement have been declining, highway's share has been increasing, and air freight, though it remains a small share, has been growing rapidly. Some breakdowns:

- Urban freight is dominated by trucks of all sizes
- Regional freight is dominated by large trucks, with bulk commodities carried by rail and pipelines, and some water transport
- National or continental freight is carried by a combination of large trucks on higher speed roads, rail, and ship
- International freight is dominated by ocean shipping, which accounts for 6% of total freight energy use. The bulk of international freight is carried aboard extremely large ships carrying bulk dry cargo (e.g., iron ore), container freight or fuel and chemicals (tankers).

There is considerable variation in freight transport around the world, depending on geography, available infrastructure, and economic development. The United States' freight transport system, which has the highest total traffic in the world, is one in which all modes participate substantially. Russia's freight system, in contrast, is dominated by rail and pipelines, whereas Europe's freight systems are dominated by trucking with a market share of 72% (tkm) in EU-25 countries, and only a 16.4% market share to rail despite its extensive network.[4] China's freight system uses rail as its largest carrier, with substantial contributions from trucks and shipping.

Box 5.1 Non- CO_2 impacts

When considering the mitigation potential for the transport sector, it is important to understand the effects that it has on climate change. Whilst the principal greenhouse gas emitted is CO_2, other pollutants and effects may be important and control/mitigation of these may have either technological or operational tradeoffs. The principal effects of the three main sectors (surface vehicular transport, shipping, aviation) as mediated through various emissions and environmental effects, and their mitigation potential for current technologies are summarized in Table 5.2.

Individual sectors have not been studied, with the exception of aviation, in great detail. Whilst surface vehicular transport has a large fraction of global emissions of CO_2, its radiative forcing (RF) impact is little studied. Vehicle emissions of NO_x, VOcs and CO contribute to the formation of tropospheric O_3, a powerful GHG. Shipping has a variety of associated emissions, similar in many respects to surface vehicular transportation. One of shipping's unique features is the potential enhancement of low-level clouds which has a negative RF effect. The potential coverage of these clouds and its associated RF is poorly studied but one study estimates a negative forcing of 0.110 W m^{-2} (Capaldo *et al*., 1999), which is potentially much larger than its positive forcing from CO_2 and it is *possible* that the overall forcing from shipping may be negative, although this requires more study. However, a distinction should be drawn between RF and an actual climate effect in terms of global temperature change or sea-level rise; the latter being much more complicated to estimate.

Non- CO_2 emissions (CH4 and N2O) from road transport in major Annex I parties are listed in UNFCC GHG inventory data. The refrigerant banks and emission trend of F-gasses from air-conditioning are reported in the recent IPCC special report on Safeguarding the Ozone Layer and the Global Climate System (IPCC, 2005). Since the rapid switch from CFC-12 to HFC-134a, which has a much lower GWP index is taking place, total amount of F-gasses is increasing due to the increase in vehicles with air-conditioning, but

[4] This rather small share is the result of priority given to passenger transport and market fragmentation between rival national rail systems.

total emission in CO_2 equivalent is decreasing and forcasted to continue to decrease. Using the recent ADME data (2006) on F-gas emissions, the shares of emissions from transport sectors for CO_2, CH_4, N_2 and F-gasses are

US	88.4	0.2	2.	8.9	
JP	96.0	0.1	2.5	1.4	
EU	95.3	0.3	2.8	1.7	(%).

It can be seen that non- CO_2 emissions from transport sector is not so large, but we can not neglect those. Also we should consider the additional energy consumption for air-conditioning, too. Although this depends strongly on the climate conditions, it is reported to be 2.5-7.5% of vehicle energy consumption (IPCC, 2005)

Aviation has a significantly greater climate impact in terms of radiative forcing than its CO_2 emission alone. This has been estimated for 1992 and a range of 2050 scenarios by IPCC (1999) and updated for 2000 by Sausen *et al*. (2005) using more recent scientific knowledge and data. Aviation emissions impact radiative forcing in positive (warming) and negative (cooling) ways as follows: CO_2 (+25.3 mW m^{-2}); O_3 production from NO_x emissions (+21.9 mW m^{-2}); ambient CH_4 reduction as a result of NO_x emissions (-10.4 mW m^{-2}); H_2O (+2.0 mW m^{-2}); sulphate particles (-3.5 mW m^{-2}); soot particles (+2.5 mW m^{-2}); contrails (+10.0 mW m^{-2}); cirrus cloud enhancement (10 – 80 mW m^{-2}). These effects result in a total aviation radiative forcing for 2000 of 47.8 mW m^{-2}, excluding cirrus cloud enhancement, for which, no best estimate could be made (as was the case for IPCC, 1999). The total radiative effect from aviation in terms of its radiative forcing index (RFI) which is the sum of forcings divided by the CO_2 forcing, is 1.9 (excluding cirrus) or, approximately 2% of total anthropogenic forcing for 2000.

Table 5.2. *Overview of impacts of present-day transportation sectors on climate change through radiative forcing (RF) and potential mitigation measures*

	Surface transportation (vehicular)		**Shipping**		**Aviation**	
Forcing (derivative)	Forcing (+/-) mW m^{-2}	Technological mitigation measures	Forcing (+/-) mW m^{-2}	Technological mitigation measures	Forcing (+/-)[a] mW m^{-2}	Technological mitigation measures
CO_2	+ve	fuel efficiency	34.3 [b]	fuel efficiency, ship modifications	25.3	fuel efficiency
NO_x (O_3)	51[c]	combustion technology, catalysts	29[d]	combustion technology, catalysts	23	combustion technology
SO_4 particles (direct effect)	-ve	fuel S content	-20[e]	fuel S content	-3.5	fuel S content
Black Carbon particles	64 – 160[f]	combustion technology, particle traps	+ve	combustion technology	2.5	combustion technology
Water vapour	negligible	–	negligible	–	2.0 (but potentially larger for supersonics)	fuel efficiency
Linear contrails	–	–	–	–	10	operational measures
Enhanced cloudiness	unknown	combustion technology, particle traps	-110[g]	combustion technology, fuel S content	30[h] 0 – 26[i]	operational measures
CH_4[k]	-ve (indirect)	combustion technology, catalysts	-20 (indirect)[l]	combustion technology, catalysts	-10.4 (indirect)	–
VOCs (O_3)	+ve (indirect)	combustion technology, catalysts	+ve (indirect)	combustion technology, catalysts	+ve (indirect) but negligible	combustion technology
CO (O_3)	+ve (indirect)	combustion technology, catalysts	+ve (indirect)	combustion technology, catalysts	+ve (indirect) but negligible	combustion technology

[a] Aviation RFs taken from recent reanalysis of Sausen et al. (2005), excepting enhanced cloudiness
[b] Eyring et al. (2005 in prep.)
[c] Niemeyer et al. (2005?)
[d] Calculated from 0.7 DU tropospheric czone column chnage from Endresesen et al. (2003) and 0.042 W/m^{-2}/DU (IPCC, 2001)
[e] Endresen et al. (2003)
[f] Schultz et al. (2004)
[g] Capaldo et al. (1999)
[h] Stordal et al. (2005)
[i] Minnis et al. (2004)
[k] CH_4 has complex impacts: it is a direct GHG (+ve RF); ambient CH_4 is destroyed by tropospheric chemistry and NO_x emissions (indirect –ve RF); it contributes through tropospheric chemistry to O_3 formation
[l] Endresen et al. (2003)

5.2.3 Transportation in the Future

There seems little doubt that, short of a collapse of the current trend of growing industrialization and rising world incomes, transportation demand will continue to grow at a rapid pace for the foreseeable future. The shape of that demand and the means by which it will be satisfied depend on several factors, however.

First, it is not clear that oil can continue to be the dominant feedstock of transport fuels that it has been for a century. There is an ongoing debate about the date when conventional oil production will peak and begin turning downwards, with many arguing that this will occur within the next few decades (though others, including some of the major multi-national oil companies, strongly oppose this view). There is no shortage of alternatives to conventional oil, beginning with liquid fuels from so-called unconventional oil (heavy oil, oil sands), manufactured from natural gas or coal, or produced from biomass. Other alternatives include gaseous fuels (natural gas, hydrogen) and electricity (if battery development is greatly successful). However, all of these alternatives are costly, and most will increase greenhouse gas emissions significantly without carbon sequestration.

Second, the growth rate and shape of economic development, the primary driver of transport demand, is uncertain. If China and India as well as their Asian neighbors continue to rapidly industrialize, and if Latin America and Africa fulfill much of their economic potential, transport demand will grow with extreme rapidity over the next several decades. Although it is implausible that demand will *not* grow substantially, its growth could be slowed considerably if economic development is disrupted;the range of prospects for future transport demand is quite wide.

Third, transportation technology has been evolving rapidly, and the efficiency of the different modes and vehicle choices as well as their cost and thus desirability (and likely market share) will be strongly affected by technology developments in the future. For example, although hybrid electric drivetrains have made a strong early showing in the Japanese and U.S. markets, their ultimate degree of market penetration will depend strongly on further (and uncertain) cost reductions and other factors – and the future efficiency of the auto fleets in these countries will reflect this. Similar uncertainty surrounds the migration to other markets of technologies with substantial penetration in limited markets, e.g. light-duty diesel in Europe and alcohol fuels in Brazil.

Fourth, as incomes in the developing nations grow, transportation infrastructure will grow rapidly. Current trends point towards growing dependence on private cars, but other alternatives exist (as demonstrated by cities such as Curitaibo). Also, as seen in Figure 5.2, the intensity of car ownership varies widely around the world even when differences in income are accounted for, so different countries have made very different choices as they have developed. The future choices made by both governments and travelers will have huge implications for future transport energy demand and CO_2 emissions in these countries.

Vehicle Ownership rate vs GDP per capita

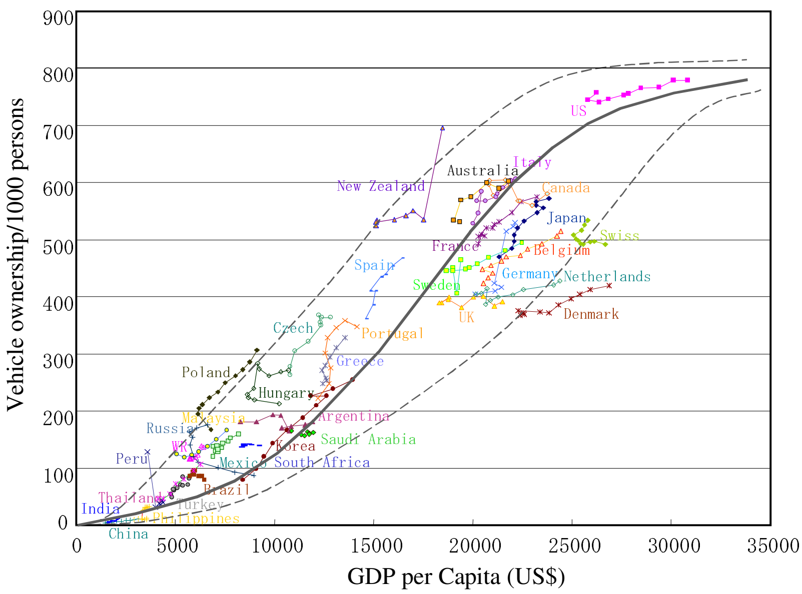


***Figure 5.2:** Vehicle Ownership as a Function of Per Capita Income*

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

Two widely-cited projections of world transportation energy use are the Reference Cases in the ongoing world energy forecasts of the United States Energy Information Administration (International Energy Outlook 2005; EIA, 2005) and the International Energy Agency (World Energy Outlook 2004; IEA, 2004a); a recent study by the World Business Council on Sustainable Development, *Mobility 2030*, also developed a projection of world transportation energy use. Because the WBCSD forecast was undertaken by IEA personnel (IEA/SMP, 2004), the IEO 2004 and Mobility 2030 forecasts are quite similar.

A key conclusion of these projections is that unless there is a shift away from current patterns of energy consumption, world transportation energy use will grow robustly over the next few decades, at a rate slightly over 2% per year. This means that transportation energy use in 2030 will be about 80% higher than in 2002. Almost all of this new consumption is expected to be in petroleum fuels, which the forecasts project will remain at over 95% of transport fuel use over the period. And because oil will remain the feedstock for the great majority of transport energy, CO_2 emissions will grow essentially in lockstep with energy consumption.

It is important to note that the three cited projections all assume that world oil supplies will be sufficient to allow the large projected increases in oil demand, in other words that concerns about the peaking of world conventional oil production turn out to be incorrect, and that world economies continue to grow without significant disruptions.

Another important conclusion is that there will be a significant regional shift in transport energy consumption, with the emerging economies gaining significantly in share (see figure 5.3). For example, EIA's International Energy Outlook 2005 projects a robust 3.6%/year growth rate for these economies (the IEA projects the same growth rate), especially in China, India, Thailand, and Indonesia. The emerging economies' share of world transportation energy use would grow from 31% in 2002 to 43% in 2025 if these rates are realized. In China, the number of cars has been growing at an astounding rate of 20%/year, and personal travel has increased by a factor of five over the past 20 years. At its projected 6% rate of growth, China's transportation energy use would nearly quadruple between 2002 and 2025, from 4.1 quadrillion Btu in 2002 to 15.5 quadrillion Btu in 2025. China's neighbor India's transportation energy is projected to grow at 4.7%/year during this time period, and countries such as Thailand, Indonesia, Malaysia, Singapore, Taiwan, and Hong Kong will see growth rates above 3%/year. Similarly, the Middle East, Africa, and Central and South America will see transportation energy growth rates at or near 3%/year.

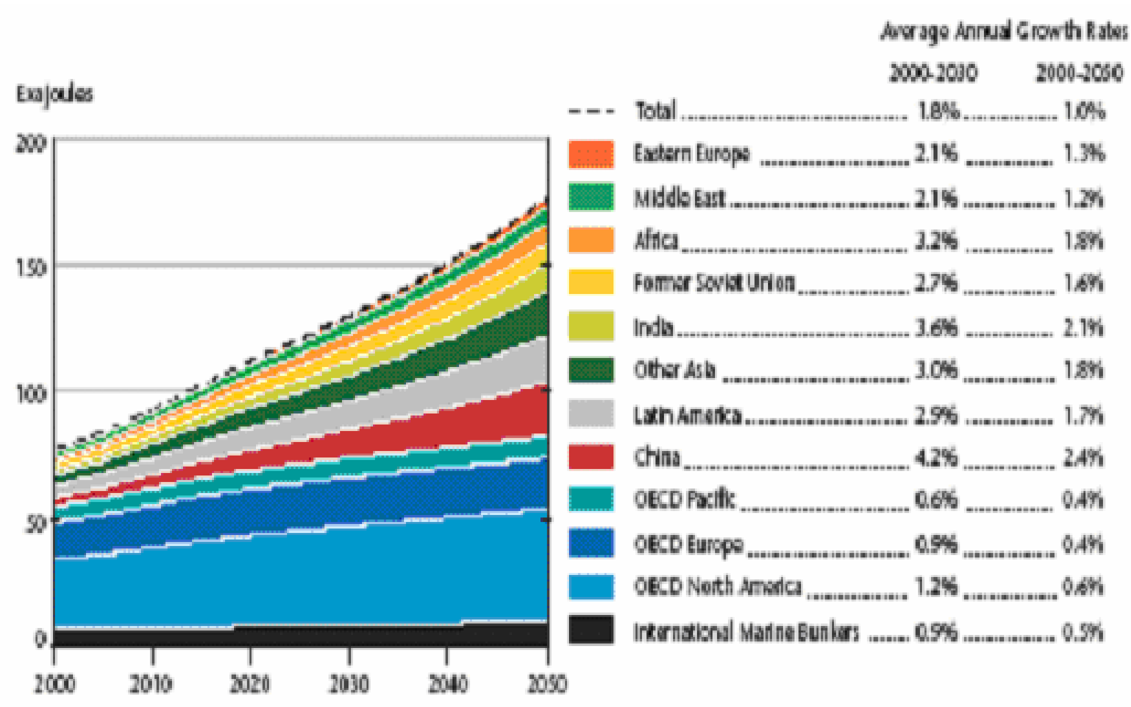


Figure 5.3 *Projection of transport energy consumption by region (WBCSD,2002)*

In contrast, transportation energy use in the mature market economies is projected to grow at a slow rate, averaging 1.2%/year (the IEA forecast for the OECD nations is similar, at 1.3%/yr growth). At these rates, these economies' share of world transportation energy would decline from 62% in 2002 to 51% in 2025. EIA projects transportation energy in the United States to grow at 1.7%/year, with moderate travel growth coupled very modest improvement in efficiency. Western Europe's transport energy is projected to grow at a much slower 0.4%/year, because of high fuel taxes and significant improvements in efficiency (IEA projects a considerably higher 1.4%/yr for OECD Europe). Japan, with an aging population, high taxes, and low birth rates, is projected to grow at only 0.2%/year. These rates would lead to 2002-2025 increases of 46%, 10%, and 5%, respectively.

- The sectors propelling this growth are primarily light-duty vehicles, freight trucks, and air travel. The Mobility 2030 study projects that these three sectors will be responsible for 38, 27, and 23 percent of the total 100 exajoule growth it foresees in the 2000-2050 period.

Aviation

Various estimates of CO_2 emissions from aviation have been made at spot points in time but few efforts have been made to calculate inventories on a consistent basis. Estimates of global aviation CO_2 emissions for 1990 and 2000 using a consistent inventory methodology has recently been made by Lee *et al*. (2005) which increased by a factor of approximately 1.5 from 331 Tg CO_2 yr^{-1} to 480 Tg CO_2 yr^{-1}. Based on an estimated global emission of CO_2 of 6.3 Pg C yr^{-1} for the 1990s (IPCC, 2001), aviation thus represents 2% of anthropogenic CO_2 emissions in 2000.

Aviation emissions are predicted to continue to grow strongly. Industry forecasts suggest that aviation growth will continue to 2025 (the extent of most industry forecasts) with the Airbus Global Market Forecast 2004 (Airbus, 2004), and Boeing Commercial Market Outlook 2005 (Boeing, 2005) giving passenger traffic growth trends of 5.3% and 4.8%, and freight trends at 5.9% and 6.2% respectively) over the next 20 or 25 years. These forecasts, and others, predict a global average of around 5% each year, a trend, with freight traffic growing at a faster rate that passenger traffic. Scenarios of emissions to 2050 were constructed by IPCC (1999) under various technology and GDP assumptions (IS92a, e and c). These emissions were most strongly affected by the GDP assumptions; the two technology scenarios only having a second order effect (see Figure 5.4). More recently, a European project 'CONSAVE 2050' has produced further 2050 scenarios (Berghof *et al*., 2005). The scenarios were more conceptual, envisaging overall controlling factors rather than the IPCC (1999) approach of extrapolating a relationship between revenue passenger kilometres (RPK) and GDP. Nonetheless, three of the four CONSAVE scenarios are claimed to be broadly consistent with IPCC SRES scenarios A1, A2 and B1. The results were not greatly different to those of IPCC (1999) and are given in Figure 5.4.

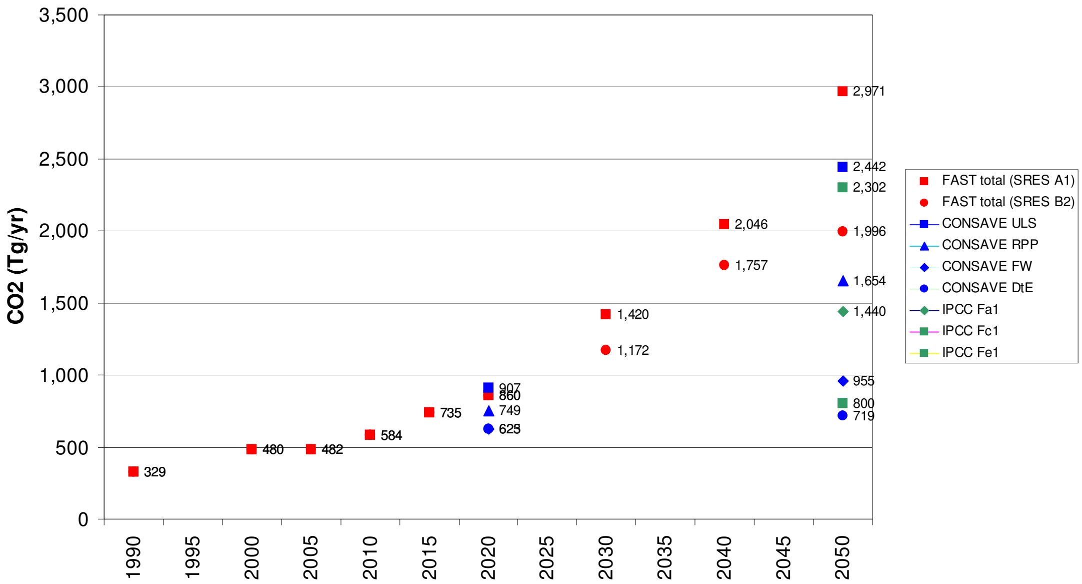


Figure 5.4 *Comparison of calculated global emissions of total aviation CO_2 emissions, 1990 to 2050 with other estimates for 2050.*

The above figure shows the results of a set of calculations of global scheduled aviation emissions from 1990 through to 2050 (Owen and Lee, 2005). Historical data were used for 1990 and 2000, and the forecast years 2005 through to 2020 were constructed using ICAO-FESG forecast statistics of RPK (FESG, 2003) and a scenario methodology applied thereafter according to A1 and B2 GDP assumptions.

Further reduced environmental impact may still be possible through the use of hydrogen as a commercial aircraft fuel, although the additional water vapour this could release into the atmosphere might increase contrail formation and increased cloudiness. However, such developments are unlikely to occur before the latter half of the 21st century.

Long-term trends in shipping emissions

Seagoing shipping has increased in recent decades although fuel usage has previously been estimated using energy statistics (e.g. Olivier *et al*., 1996; Corbett and Fischbeck, 1997; Corbett *et al*., 1999; Endresen *et al*., 2003). More recently, efforts have been committed to constructing inventories using activity-based statistics on shipping movements (Corbett and Köhler, 2003; Eyring *et al*., 2005a). This has resulted in a substantial discrepancy, e.g. Endresen et al. (2003) calculated a global fuel consumption of 144 Tg yr^{-1}, whereas Corbett and Köhler (2003) calculated 289 Tg yr^{-1} and Eyring *et al*. (2003) calculated 280 Tg yr^{-1}. This has prompted debate over inventory methodologies in the literature (Endresen *et al*., 2004; Corbett and Köhler, 2004). Regardless of the absolute magnitude, it is agreed that fuel usage and therefore CO_2 emissions will increase in the future. It is noteworthy that the NO_x emissions estimates also vary strongly between the different estimates and methodologies (Eyring *et al*., 2005a).

Eyring *et al*. (2005a) provided a historical estimation of emissions back to 1950 and a set of projections out to 2050 (Eyring *et al*., 2005b) based upon four traffic demand scenarios corresponding to SRES A1, A2, B1, B2 (GDP) and four technology scenarios which are summarized below in Table 5.3.

Table 5.3 *Summary of shipping technology scenarios of Eyring et al.(2005b)*

Technology scenario 1 (TS1) – 'Clean scenario'	Technology scenario 2 (TS2) – 'Medium scenario'	Technology scenario 3 (TS3) – 'IMO compliant scenario'	Technology scenario 4 (TS4) – 'BAU'
Low S content fuel (1%/0.5%‡), aggressive NO_x reductions	Relatively low S content fuel (1.8%/1.2%), moderate NO_x reduction	High S content fuel (2%/2%), NO_x reductions according to IMO stringency only	High S content fuel (2%/2%), NO_x reductions according to IMO stringency only
Fleet = 75% diesel, 25% alternative plant	Fleet = 75% diesel, 25% alternative plant	Fleet = 75% diesel, 25% alternative plant	Fleet = 100% diesel

‡Note that the fuel S percentages refer to values assumed in (2020/2050)

The resultant range of potential emissions is shown in Figure 5.5.

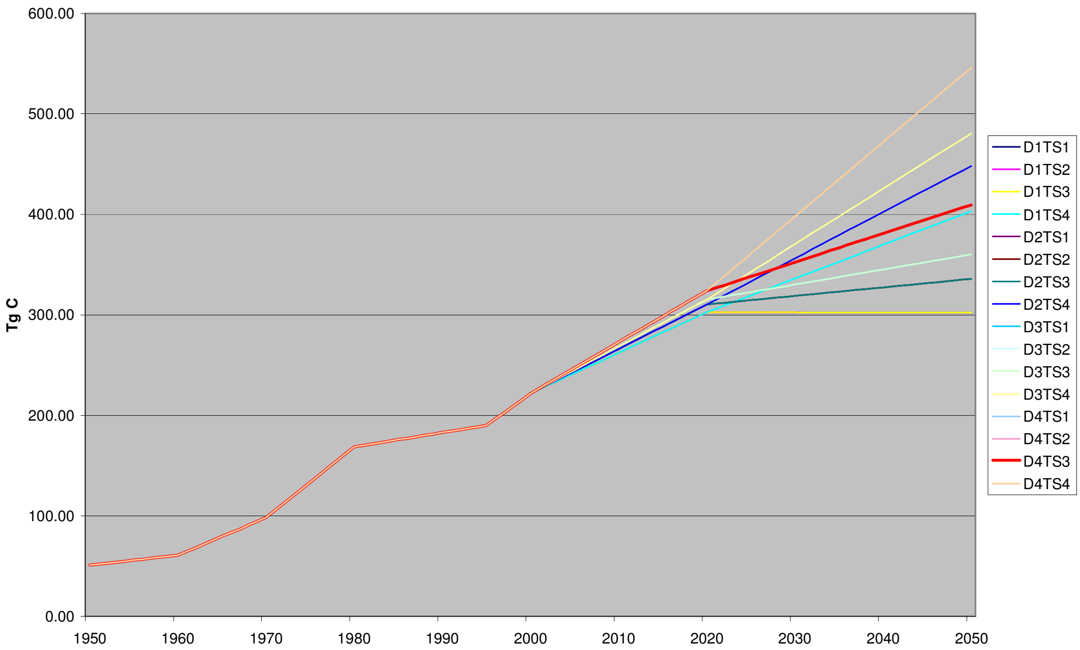


Figure 5.5 *Historical and projected emissions of seagoing shipping, 1990 to 2050 (Tg C yr^{-1}) adapted from Eyring et al. (2005a, b). See Table 5.3 for the explanation of the scenarios.*

5.3 Mitigation Technologies and Practices (operational approach)

All main technologies options were mentioned in TAR, including their evolution. However the report makes clear that the increase in GHG emission in transport sector is almost inevitable, even reducing energy intensities for new transport vehicle. TAR highlighted the main important advances in automotive technology, including hybrids, fuel cells and improvements in fuels, engine controls, and emissions after treatment. Natural gas vehicles were also mentioned as a good possibility for reducing GHG and biofuels could be a good alternative but their costs are still high. For those options a study of life cycle analysis was shown. Despite all of this effort and the increasing price of oil, the report keeps stressing the huge petroleum's share of transport energy use according to the increase of transport activity, result of a continuing increase in demand for mobility of people and goods expected all over the world, specially in developing countries.

5.3.1 Road transport

The GHG emissions/mile of a vehicle can be reduced by three types of measures:

1. Reducing the loads on the vehicle, thus reducing the work needed to move it;
2. Increasing the efficiency of converting the fuel energy to work, by improving drivetrain efficiency and recapturing energy losses; and
3. Changing to a less carbon-intensive fuel.

The loads on the vehicle consist of the force needed to accelerate the vehicle, to overcome inertia; the rolling resistance of the tires; and aerodynamic forces. In urban stop-and-go driving, aerodynamic forces play little role, but rolling resistance and especially inertial forces are critical. In steady highway driving, aerodynamic forces dominate, because these forces increase with the square of velocity; aerodynamic forces at 60 mph are four times the forces at 30 mph. Reducing inertial loads is accomplished by reducing vehicle weight, with improved design and greater use of lightweight materials. Reducing tire losses is accomplished by improving tire design and materials, to reduce the tires' rolling resistance coefficient, as well as by maintaining proper tire pressure; weight reduction also contributes, because tire losses are a linear function of vehicle weight. And reducing aerodynamic forces is accomplished by smoothing vehicle surfaces, reducing the vehicle's cross-section, controlling air flow under the vehicle, and other measures. Measures to reduce the heating and cooling needs of the passengers, for example by changing window glass to reflect incoming solar radiation, are included in the group of measures.

Increasing the efficiency with which the chemical energy in the fuel is transformed into work, to move the vehicle and provide comfort and other services to passengers, will also reduce GHG emissions. This includes measures to improve engine efficiency and the efficiency of the rest of the drivetrain and accessories, including air conditioning and heating. The range of measures here is quite great; for example, engine efficiency can be improved by three different kinds of measures, increasing thermodynamic efficiency, reducing frictional losses, and reducing pumping losses (these losses are the energy needed to pump air and fuel into the cylinders and push out the exhaust), and each kind of measure can be addressed by a great number of design, material, and technology changes. Also, some of the energy used to overcome inertia and accelerate the vehicle – normally lost when the vehicle is slowed, to aerodynamic forces and rolling resistance as well to the mechanical brakes (as heat) – may be recaptured as electrical energy if regenerative braking is available (see the discussion of hybrid electric drivetrains).

Fuel changes can range from the use of alternative liquid fuels, in blends with gasoline and diesel or as "neat fuels" that require minimal or no changes to the vehicle, to a variety of gaseous fuels requiring major changes, to electricity. The liquid fuels include ethanol, biodiesel, and methanol as well as synthetic gasoline and diesel made from natural gas, coal, or other materials. The gaseous fuels include natural gas, propane, dimethyl ether (a diesel substitute), and hydrogen. Electricity can be generated from multiple sources, with a wide range of GHG emission consequences. In evaluating the effects of these fuels on GHG emissions, it is crucial to consider GHG emissions associated with their production and distribution in addition to tailpipe emissions (see the section on Lifecycle Analysis). For example, hydrogen produces no GHG emissions directly from the vehicle, but emissions from production and distribution can be quite high if the hydrogen is produced from fossil fuels (unless the carbon dioxide from the hydrogen production is sequestered).

The sections that follow discuss a number of technology, design, and fuel measures to reduce GHG emissions.

5.3.1.1 Reducing Vehicle Loads

Light Weight Materials

Since 10% weight reduction from a total vehicle weight can improve fuel economy by 4-8% depending vehicle size and whether or not the engine is downsized, the amount of lighter materials in vehicle has been progressively increasing during decades (this is not necessarily for better fuel economy but for increased performance, too). However, the average weight of vehicle was conversely increased by 10-20% in these 10 years (JAMA, 2002; Haight, 2003), which is due to increased concern for safety and customer's desires for greater comfort. There are several ways to reduce vehicle weight; replacement of steel by lighter materials such as Al, Mg and plastics, change from conventional steels to high strength steels (HSS), evolution of design concept and forming technologies.

Steel is still the main material used in vehicles. Aluminum usage has grown to roughly 100kg per average passenger car but these are mainly used in engine, drivetrain and chassis as a form of castings and forgings. One of reasons for the increasing use of aluminum is the superior strength of aluminum; aluminum is twice as strong as steel on the base of per kg, which allows the designer to provide strong, yet lightweight structures.
Usage in body structure is limited but there are a few commercial vehicle made out of all-Al body (ex. Honda NSX, Audi A2) where more than 200kg of Al is used and including the secondary effect such as downsizing engine and suspension, more than 11-13% weight reduction can be achieved. It is shown that up to 300kg of Al can be used in whole vehicle weight of 900kg for the Ford's concept car P2000 (SAE).

Magnesium has a density of 1.7-1.8g/cc (about 1/4 of steel) and a strength similar to steel. Major hurdles for automobile application of magnesium are high cost and several low material performances such as creep strength and contact corrosion susceptibility. At present use of magnesium in vehicle is very limited to only 01-0.3 % of the whole weight. However, its usage in North American-built family vehicles has been expanding by 10 to 14 percent annually in recent years; aluminum by 4 to 6 percent; plastics by 1 to 1.8 percent; and light steels by 3.5 to 4 percent.
Since the production energy of Mg and also Al is very large compared with steel, LCA analysis is important for material selection from the consideration of CO_2 emission reduction. Therefore material recycling becomes an important issue for these metals.

The use of plastics in vehicle has been increasing to about 8 % of total vehicle weight, which corresponds to 100-120kg per vehicle. Growth rate has been decreasing during these several years. This is probably due to the concern for the recycling issue, because most of plastics goes to the automobile shredder residue (ASR) at the end of life.
The FRP(Fiber-reinforced plastic) is now widely used in aviation, but the application to automobiles is limited because of high cost and long processing time. However, the potential of weight reduction is very high to be as much as 60%. Examples of FRP structures manufactured using RTM(resin transfer method) technology are wheel housings or entire floor assemblies. For a compact-size car, this would make it possible to reduce the weight, e.g. for a floor assembly including wheel housings, by 60 % compared to a steel structure. This represents a weight reduction of 22 kg for each car. Research examples of materials in the chassis are leaf or coil springs manufactured from fibre composite plastic. Weight reduction potentials of up to 63 % have been presented in demonstrators using glass and/or carbon fibers (Friedricht 2002).

As mentioned above, steel is major materials comprising about 70% of whole vehicle weight. This portion is continuously decreasing due to an increase in use of light materials but also change from conventional steels to high strength steels(HSS). There are various types of HSS, from relatively low strength grade (around 400MPa) such as solution-hardened and precipitation-hardened HSS to very high strength grade (980-1400MPa) such as TRIP steel and tempered martensite HSS.
At present, average usage per vehicle of HSS is160kg (11% of whole weight) in US and 75kg(7%) in Japan. In the latest Mercedes A-class vehicle, HSS comprises of 67% of body structure weight. International cooperative ULSAB-AVC (UltraLight Steel Auto Body - Advanced Vehicle Concept) project investigated intensive usage of HSS including advanced HSS, and demonstrated that using HSS as much as possible can reduce the whole vehicle weight by 214kg(-19%) and 472kg(-32%) for small and medium passenger cars, respectively. Total usage of HSS in body and closures structures is 280- 330kg, of which over 80% are advanced HSS (Nipon Steel 2002).

Aerodynamics improvement
Although improvements have been made in the aerodynamic performance of highway vehicles over the past decade, substantial additional improvements are possible. Because the aerodynamic force varies with the square of velocity, improvement in aerodynamic performance is most important for vehicles operating in higher-speed environments, e.g. long-distance trucks and light-duty vehicles operating outside of congested urban areas. For example, a 10% reduction in the coefficient of drag (C_D) of a midsize passenger car would yield only about a 1% reduction in average vehicle forces on the U.S. city cycle (with 31.4 kph average speed), whereas the same drag reduction on the U.S. highway cycle, with average speed of 77.2 kph, would yield about a 4% reduction in average forces.[5] These reductions in vehicle forces translate reasonably well into similar reductions in fuel consumption for most vehicles, but variations in engine efficiency with vehicle force may negate some of the benefit from drag reduction unless engine power and gearing are adjusted to take full advantage of the reduction.

For light-duty vehicles, styling and functional requirements (especially for light-duty trucks) may limit the scope of improvement. However, some vehicles introduced within the past 5 years demonstrate that improvement potential still remains for the fleet. The Lexus 430, a conservatively-styled sedan, attains a C_D (coefficient of aerodynamic drag) of 0.26 versus a fleet average of over 0.3 for the U.S. passenger car fleet. Other fleet-leading examples are:
- Toyota Prius, Mercedes E-class sedans, 0.26
- Volkswagen Passat, Mercedes C240, BMW 320i, 0.27 (D. Hermance, Toyota Technical Center, USA, "New Efficiency Baseline Toyota Prius 2004," powerpoint presentation.)

For light trucks, General Motors' 2005 truck fleet has reduced average C_D by 5 to 7% by sealing unnecessary holes in the front of the vehicles, lowering their air dams, smoothing their undersides, and so forth (SAE International, 2004).

The current generation of heavy-duty trucks in the United States has average C_Ds ranging from 0.55 for tractor-trailers to 0.65 for tractor-tandem trailers. These trucks generally have spoilers at the top of their cabs to reduce air drag, but substantial further improvements are available. C_D reductions of about 0.15, or 25% or so (worth about 12% reduced fuel consumption at a steady 65 mph), can be obtained with a package of improved cab shaping, mirror removal, closure of the gap between cab and trailer, and a short boat-tailed rear (Cooper, K.R., "Truck Aerodynamics and Its Future – An Opinion," 8/15/2000 presentation to 21st Century Truck Roadmap Meeting). The U.S. Department of Energy's 2012 research goals for heavy duty trucks (USDOE, 2000)[6] include a 20% reduction (from a 2002 baseline, with C_D of 0.625) in aerodynamic drag for a "class 8" tractor-trailer combination.[7] C_D reductions of 50% and higher, coupled with potential benefits in safety (from better braking and roll and stability control), may be possible with pneumatic (air blowing) devices (Englar, 2001)). A complete package of aerodynamic improvements for a heavy-duty truck, including pneumatic blowing, might save about 15-20% of fuel for trucks operating primarily on uncongested highways, at a cost of about $5,000 in the near-term, with substantial cost reductions possible over time (Vyas, et al, 2002)

The importance of aerodynamic forces at higher speeds implies that reduction of vehicle highway cruising speeds can save fuel, and some nations have used speed limits as fuel conservation measures, e.g. the U.S. during the period following the 1973 oil embargo. U.S. tests of nine

[5] The precise value would depend on the value of the initial C_D as well as other aspects of the car's design.
[6] http://www.eere.energy.gov/vehiclesandfuels/about/partnerships/21centurytruck/21ct_goals.shtml
[7] These are heavy duty highway trucks with separate trailers, but less than 5 axles – the standard long-haul truck in the U.S.

vehicles with model years from 1988 to 1997 demonstrated an average 17.1% fuel economy loss in driving 70 mph vs. 55 mph (Davis, 2001). Recent tests on six contemporary vehicles, including two hybrids, showed similar results – the average fuel economy loss was 26.5% in driving 80 mph vs. 60 mph, and 27.2% in driving 70 mph vs. 50 mph (Duoba, et al, 2005).

5.3.1.2 Improving Drivetrain Efficiency

Advanced Direct Injection Gasoline/ Diesel Engines and transmissions

New engine and transmission technologies have entered the light-duty vehicle fleets of Europe, the U.S., and Japan and could yield substantial reductions in carbon emissions if more widely used.

Direct injection diesel engines yielding about 35% greater fuel economy than conventional gasoline engines are being used in about half the light-duty vehicles being sold in European markets, but are little used in Japan and the U.S. (European taxes on diesel fuel generally are substantially lower than on gasoline, which boosts diesel share). Euro 4 emission standards were enforced in 2005, with Euro 5 (still undefined) to follow around 2009-2010. These standards, plus Tier 2 standards in the U.S., will challenge diesel NOx controls, adding cost and possibly reducing fuel efficiency somewhat. Euro 4/Tier 2 compliant diesels for light-duty vehicles, obtaining 30% better fuel economy than conventional gasoline engines, may cost about $2,000-$3,000 more than gasoline engines (EEA, 2004)

Improvements to gasoline engines include direct injection (Mercedes' M271 turbocharged direct injection engine is estimated to attain 18% reduced fuel consumption, part of which is due to intake valve control and other engine technologies (SAE International, 2003a); cylinder shutoff during low load conditions (Honda Odyssey V6, Chrysler Hemi, GM V8s; SAE International, 2003b), and improved valve timing and lift controls.

Transmissions are also being substantially improved. Mercedes, GM, Ford, Chrysler, Volkswagen, and Audi are introducing advanced 6 and 7 speed automatics in their luxury vehicles (SAE International, 2003b), with strong estimated fuel economy improvements ranging from 4-8% over a 4-speed automatic for the Ford/GM 6-speed to 13% over a manual, plus faster acceleration, for the VW/Audi BorgWarner 6-speed (SAE International, 2003c). If they follow the traditional path for such technology, these transmissions will eventually be rolled into the fleet. Also, continuously variable transmissions (CVTs), which previously had been limited to low power drivetrains, are gradually rising in their power-handling capabilities and are moving into large vehicles.

The best engines currently used in heavy-duty trucks are very efficient, achieving peak efficiencies in the 45-46% range (USDOE, 2000). Although recent advances in engine and drivetrain technology for heavy-duty trucks have focused on emissions reductions, current research programs in the U.S. Department of Energy are aiming at 10-20% improvements in engine efficiency within 10 years (USDOE, 2000), with further improvements of up to 25% foreseen if significant departures from the traditional diesel engine platform can be achieved..

Hybrid Drivetrains

Hybrid-electric drivetrains combine a conventional ICE engine with an electric drivetrain – electric motor/generator and battery (or ultracapacitor) -- in various combinations. In current hybrids, the battery is recharged only by regenerative braking and engine charging, without external charging from the grid. "Plug-in hybrids," which would obtain part of their energy from the electric grid, can be an option but require a larger battery and perhaps a larger motor. Hybrids save energy by:

- Shutting the engine down when the vehicle is stopped (and possibly during braking or coasting);

- Recovering inertia losses by using the motor to brake, and using the electricity generated to recharge the battery
- Using the motor to boost power during acceleration, allowing engine downsizing and improving average engine efficiency
- Using the motor instead of the engine at low load (in some configurations), eliminating engine operation during its lowest efficiency mode
- Allowing the use of a more efficient cycle than the standard Otto cycle (in some hybrids)
- Shifting power steering and other accessories to (more efficient) electric operation.

Since the 1998 introduction of the Toyota Prius hybrid in the Japanese market, hybrid electric drivetrain technology has advanced substantially, expanding its markets, developing in alternative forms that offer different combinations of costs and benefits, and improving component technologies and system designs. Hybrids now range from simple belt-drive alternator-starter systems offering perhaps 7 or 8% fuel economy benefit under U.S. driving tests to "full hybrids" such as the Prius offering perhaps 40-50% fuel economy benefits on these tests[8] (the Prius itself more than doubles the fuel economy average of the combined 2004 model year compact and midsize classes), and considerably more in congested driving conditions (estimated fuel economy benefits are for hybridization only, without added efficiency measures). Hybrid sales have expanded rapidly: in the United States, sales were about 7,800 in 2000 and have risen rapidly, to 83,000 in 2004[9]; worldwide hybrid sales were about 169,000 in 2004.[10]

Improvement of the Prius since its introduction demonstrates how hybrid technology is developing. For example, the power density of Prius's nickel-metal hydride batteries has improved from 600 W/kg in 1998 to 1250 W/kg in 2004, a 108% improvement; similarly, the batteries' specific energy has increased 37% during the same period (EEA, 2004). Higher voltage in the 2004 Prius allows higher motor power with reduced electrical losses, and a new braking-by-wire system maximizes recapture of braking energy. The 1998 Prius compact sedan attained 42 mpg on the U.S. CAFE cycle, with 0-60 mph acceleration time of 14.5 seconds; the 2004 version is larger (midsize) but attains 55 mpg and a 0-60 of 10.5 seconds. Prius-type hybrid systems will add about $4,000 to the price of a mid-size sedan.

The 2005 Honda Accord takes a different design approach but still achieves substantial fuel savings. The system uses a smaller battery and motor than Prius and does not downsize the engine, allowing very high performance; it captures some of the savings Prius obtains from engine downsizing by using cylinder deactivation (shutting down 3 of the engine's 6 cylinders; although cylinder deactivation is available in conventional drivetrains, it is considerably more effective in a hybrid). The hybrid Accord obtains 32.1 mpg vs. 24.3 mpg for the conventional Accord, a 32% fuel economy improvement. The advantage of this type of system is that it avoids the reductions in towing and grade-climbing capability that may be lost with substantial engine downsizing, while providing high acceleration performance that will enhance market acceptance. A system of this type will add about $2,000 to the price of a mid-size sedan.

The attributes of these and other hybrid designs make it clear that hybridization can yield benefits in addition to directly improving fuel efficiency, including (depending on the design) enhanced

[8] Precise values are somewhat controversial because of disagreements about the fuel economy impact of other fuel-saving measures on the vehicles.
[9] R.L. Polk & Co. data, http://www.plk.com/News/LatestNews/news_042505.htm
[10] "Growing Popularity Casts Light on Japan's Hybrid Debate" *Ward's Automotive Reports*, March 21, 2005 for Toyota and Honda, HybridCARS.com website "Hybrid SUVs and Minivans" http://www.hybridcars.com/escape.html for Ford.

performance, less expensive 4-wheel drive systems, ease of introducing electric accessories, e.g. power steering (with added efficiency benefits), provision of electric power for off-vehicle use (e.g., GM Silverado hybrid), and ease of introducing more efficient transmissions such as automated manuals (using the motor to reduce shift shock).

Hybrid drivetrains' strong benefits in congested stop-and-go travel mesh well with some heavier-duty applications, including urban buses and urban delivery vehicles. An initial generation of hybrid buses in New York City obtained about a 10% improvement in fuel economy as well as improved acceleration capacity and substantially reduced emissions (Foyt, 2005); more recently, a different design achieved a 45% fuel economy increase in NYC operation (not including summer, where the increase should be lower) (Chandler et al, 2006). Fedex has claimed a 57% fuel economy improvement for its E700 diesel hybrid delivery vehicles (Green Car Congress, 2004).

Hybrid applications extend to two and three-wheelers, as well, because these often operate in crowded urban areas in stop-and-go operation. Honda has developed a 50cc hybrid scooter prototype that offers about a one-third reduction in fuel use and GHG emissions compared to similar 50cc scooters.[11] However, sales of two and three-wheeled vehicles in most markets are extremely price sensitive, so the extent of any potential market for hybrid technology may be quite limited.

Plug-in hybrids that can travel 20 miles or more on battery power have been recommended as a means of reducing oil use and GHG emissions (Electric Power Research Institute,2001). Their potential to reduce oil use is clear – they can use electricity to "fuel" a substantial portion of miles driven. The U.S. Electric Power Research Institute estimates that 20-mile hybrids can substitute electricity for gasoline for approximately 30-40% of miles driven in the U.S, with hybrids with 60 miles electric range being able to substitute for approximately 63-74%(EPRI, 2001). However, their potential to reduce GHG emissions more than that achieved by current hybrids depends on their sources of electricity. Identification of the source electricity must be done carefully, because it is the marginal change in electricity use caused by the addition of plug-ins to the fleet that should be counted as the source. For regions that rely on relatively low-carbon electricity, e.g. natural gas combined cycle power, GHG reductions will be substantial.

5.3.1.3 Fuel Economy Benefits of Multiple Efficiency Technologies

Several studies have examined the fuel economy benefits of simultaneously applying multiple efficiency technologies to light-duty vehicles. These studies are difficult to compare because they examine various types of vehicles, on different driving cycles, using different technology assumptions, for different time frames. Also, some of the studies do not fully document the details of their technology assumptions.

The Massachusetts Institute of Technology has developed such an assessment for 2020 (MIT, 2000) with documentation of basic efficiency assumptions, e.g. C_D and C_R, indicated engine efficiency, and so forth (Table 5.4) (though with few details about the specific technologies that achieve these values), for a midsize passenger car driving over the official U.S. Environmental Protection Agency driving cycle (Heywood, et al, 2003). There are two levels of technology improvement – "baseline" and "advanced," with the latter level of improvement further subdivided into conventional and hybrid drivetrains.

[11] Honda Worldwide Internet Site, "Honda Develops Hybrid Scooter Prototype," http://world.honda.com/news/2004/2040824_02.html.

Some of the key features of the 2020 vehicles are:

- Vehicle mass is reduced by 15% (baseline) and 22% (advanced), by a combination of greater use of high strength steel, aluminum, and plastics coupled with advanced design;
- Tire rolling resistance coefficient is reduced from the current .009 to .008 (baseline) and .006 (advanced).
- Drag coefficient is reduced to 0.27 (baseline) and 0.22 (advanced). The baseline level is at the level of the best current vehicles, while the advanced level should be readily obtainable for the best vehicles in 2020 but seems quite ambitious for a fleet average.
- Indicated engine efficiency increases to 41% in both baseline and advanced versions. This level of efficiency would likely require direct injection, full valve control (and possibly camless valves), and HCCI operation.

The combined effects of applying this full range of technologies are quite dramatic. From current test values of 30.6 mpg/7.69 l/100km as a 2001 reference, baseline 2020 gasoline vehicles obtain 43.2 mpg/5.44l/100km, advanced gasoline vehicles 49.2 mpg/4.78l/100km, and gasoline hybrids 70.7 mpg/3.33l/100km; advanced diesels obtain 58.1 mpg/4.05l/100km and diesel hybrids 82.5 mpg/2.85l/100km (note that on-road values will be *at least* 15% lower). In comparison, Ricardo Consulting Engineers (Owen and Gordon, 2002) estimate the potential for achieving 92g/km CO_2 emissions, equivalent to 68.6 mpg/3.43l/100km, for an advanced diesel hybrid midsize car *without* substantive non-drivetrain improvements; this probably is a bit more optimistic than the MIT analysis when accounting for the additional effects of reduced vehicle mass, tire rolling resistance, and aerodynamic drag coefficient.

These values should be placed in context. First, the advanced vehicles represent “leading edge” vehicles which must then be introduced more widely into the new vehicle fleet over a number of years, and may take several years (if ever) to represent an “average” vehicle. Second, the estimated fuel economy values are attainable only if trends towards ever-increasing vehicle performance are stifled; this may be difficult to achieve. Third, these advances, though clearly feasible, appear quite optimistic.

Table 5.4: MIT Results for Future Gasoline and Diesel Midsize Cars

	Gasoline				Diesel	
	2001 Reference	2020 Baseline	2020 Advanced	2020 Hybrid	2020 Advanced	2020 Hybrid
Mass (kg)						
Body & Chassis	**930**	**845**	**746**	**750**	**757**	**758**
Propulsion System (3)	**392**	**264**	**252**	**269**	**293**	**297**
Total (Incl. 136 kg payload)	**1458**	**1245**	**1134**	**1155**	**1186**	**1191**
Vehicle Characteristics						
Rolling Res. Coeff	**0.009**	**0.008**	**0.006**	**0.006**	**0.006**	**0.006**
Drag Coeff.	**0.33**	**0.27**	**0.22**	**0.22**	**0.22**	**0.22**
Frontal Area (m^2)	**2.0**	**1.8**	**1.8**	**1.8**	**1.8**	**1.8**
Power for Auxiliaries (W)	**700**	**1000**	**1000**	**1000**	**1000**	**1000**
Engine						
Displacement (L)	**2.50**	**1.79**	**1.65**	**1.11**	**1.75**	**1.16**
Indicated Eff. (%)	**38**	**41**	**41**	**41**	**51**	**51**
Frictional ME Pressure (kPa)	**165**	**124**	**124**	**124**	**153**	**153**
Max. Engine Power (kW)	**110**	**93**	**85**	**58**	**89**	**59**
Max. Motor Power (kW)				**29**		**30**
Use of On-Board Fuel						
Driving Cycle						
US Urban (MJ/km)	**2.82**	**2.00**	**1.78**	**1.20**	**1.53**	**1.03**
US Highway (MJ/km)	**2.06**	**1.45**	**1.25**	**0.91**	**1.04**	**0.78**
US06 (MJ/km)	**2.81**	**1.94**	**1.67**	**1.49**	**1.39**	**1.29**
Combined (MJ/km) (4)	**2.48**	**1.75**	**1.54**	**1.07**	**1.30**	**0.92**
Combined (mpg) (8)	**30.6**	**43.2**	**49.2**	**70.7**	**58.1**	**82.5**
Combined as % Baseline	**141**	**100**	**88**	**61**	**74**	**52**

Notes: (1) 1 liter (0.737 kg) gasoline = 32.2 MJ (LHV)
(2) 1 liter (0.856 kg) diesel = 35.8 MJ (LHV)
(3) Propulsion system mass includes ICE, drive train, motors, battery, fuel (2/3 full), and tank
(4) Combined cycle is 55% urban/45% highway
(5) Fuel cycle energy, MJ per MJ fuel in tank: gasoline 0.21, diesel 0.14
(6) Fuel cycle gC per MJ fuel in tank = gasoline 4.9, diesel 3.3
(7) Vehicle operation gC per MJ burned = gasoline 19.6, diesel 20.8
(8) Gasoline equivalent miles per gallon calculated as equal fuel LHV

5.3.1.4 Alternative Fuels

Biofuels

The term biofuels describes fuel produced from biomass. The biomass can be made up of a great variety of fast growing and undemanding crops. Organic residues such as straw or wood residues can also be used. Biofuels can be used either "pure" or as a blend with standard automotive fuels. Biomass has been a world trend both for the use in transport or in powerplants. There is a large interest in developing biofuels technologies, not only to reduce GHG emission but also to decrease the enormous transport sector dependence on imported oil.

There are two biofuels currently used in the world for transport purposes - ethanol and bio ester.

Today, ethanol is made primarily by the fermentation of sugars produced by plants such as sugar cane, sugar beet and corn. Ethanol is used in large quantities in Brazil, where it is made from sugar cane and the US, where it is made from corn. Ethanol from sugar cane may replace more than 10% of all gasoline used in tropical regions, where it is grown, but ethanol from corn and cereals are less productive and more expensive (Ribeiro & Yones, 2001). Ethanol is blended with gasoline at concentrations of 5-10%, on a volume basis, thereby replacing other oxygenates in North America and Europe. In Brazil ethanol is used in its pure form replacing gasoline. The production of ethanol fuelled cars in Brazil achieved 96% market share in 1985, declining to 0.1% in 1998 due to lack of consumers confidence on reliable ethanol supply. Nevertheless, since 1999 ethanol cars sales retake growth and after 2003 with the introduction of flexfuel cars they took the lead again over gasoline powered cars. In parallel to that, the use of 25% ethanol blended to gasoline has continued without any change since 1990.

The expressive fall in ethanol vehicles share in the total sales of light vehicles in Brazil was due to the fact that ethanol production did not follow the fleet increase, so the country faced a ethanol shortage problem. This led to consumer's lack of confidence in Brazilian ethanol program. Therefore, the sales of ethanol fueled vehicles decreased substantially.

However, since 2003 there are available in the market the so called flexfuel vehicles, which runs either with ethanol or gasoline in any proportion (see Box 5.2). Those vehicles are likely to be as the ethanol fuels cars, since people used mainly pure ethanol when filling the tank due to the price difference between ethanol and gasoline in Brazil, especially in the Southeast region where the ethanol production is concentrated. Another way where ethanol is used in the country is trough a blending with around 25% of ethanol and 75% of gasoline on a volume basis.

Box 5.2: Flexfuel vehicle (FFV)

Nowadays there has been a substantial increase in sales of flexfuel vehicles, especially in Brazil, where there is a large ethanol availability as an automotive fuel. The flexfuel vehicles sales in Brazil represent more than 66% of the market share of light duty vehicles.

The flexfuel vehicle were developed with systems that allow the use of one or more liquid fuels, storage in the same tank. This system is applied to OTTO cycle engines and enables the vehicle to run on gasoline, ethanol or both in a mixture, according to the fuel availability. The combustion control is done through an electronic device which identifies the fuel being used and then adjusts the injection system allowing the running of the engine in the most adequate condition.

One of the greatest advantages of flexfuel vehicles is their flexibility to choose their fuel depending mainly on price. Although vehicle's volumetric consumption of ethanol is around 30% larger than its gasoline consumption, because of ethanol's lower energy density, this difference would be compensated for if the price of gasoline is 30% higher than the price of ethanol. This is the case in several places in Brazil. In Sao Paulo city the difference between gasoline and ethanol prices is about 50%.

Therefore this technology could help to mitigate GHG emission since the flexfuel car owners usually fill their tanks with ethanol with lower GHG emissions.

Table 5.5 shows the energy and GHG impacts of ethanol, pointing out an interesting comparison with gasoline vehicles in terms of km traveled.

Table 5.5: *Energy and GHG Impacts of Ethanol.*

Energy and GHG Impacts of Ethanol:
Estimates from Corn- and Wheat-to-Ethanol Studies

	Feedstock	Ethanol production efficiency (litres/tonne feedstock)	Fuel process energy efficiency (energy in/out)	Well-to-wheels GHG emissions: compared to base (gasoline) vehicle (per km travelled)	
				Fraction of base vehicle	Percent reduction
GM/ANL, 2001	corn-*a*	372.8	0.50	n/a	n/a
GM/ANL, 2001	corn-*b*	417.6	0.55	n/a	n/a
Pimentel, 2001/91	corn	384.8	1.65	1.30	-30%[c]
Levelton, 2000	corn	470.0	0.67	0.62	38%
Wang, 2001a	corn-dry mill	387.7	0.54	0.68	32%
Wang, 2001a	corn-wet mill	372.8	0.57	0.75	25%
Levy, 1993	corn-*a*	367.1	0.85	0.67	33%
Levy, 1993	corn-*b*	366.4	0.95	0.70	30%
Marland, 1991	corn	372.8	0.78	0.79	21%
Levington, 2000	wheat	348.9	0.90	0.71	29%
ETSU, 1996	wheat	346.5	0.98	0.53	47%
European Commission, 1994	wheat	385.4	1.03	0.81	19%
Levy, 1993	wheat-*a*	349.0	0.81	0.68	32%
Levy, 1993	wheat-*b*	348.8	0.81	0.65	35%

Note: Where a range of estimates is reported by a paper, "*a*" and "*b*" are shown in the feedstock column to reflect this.
[c] Negative greenhouse gas reduction estimate connotes an increase. n/a: not available.
Sources: Except for Levelton, 2000, Wang 2001a and GM/ANL 2001, data presented here for these studies are taken from the comparison conducted by CONCAWE, 2002.

Bio esters are produced by a chemical reaction between vegetable oil and alcohol, such as ethanol or methanol. Their properties are close to those of diesel oil, and the two can be mixed similarly to ethanol and gasoline and therefore they all called biodiesel.

Biofuels are an important alternative, especially when considering the potential technological advance in the agriculture and production process leading to a enormous productivity gain and cost decrease. Besides there are also more advanced technologies called - advanced biofuels.

Biochemical and thermochemical conversion technologies can convert CO_2 neutral biomass feedstocks into carbon containing fuels such as biodiesel, di-methyl esters and Fischer-Tropsch liquids as well as to hydrogen. More recently, ethanol has being produced in Canada and Sweden from ligno-cellulosic sources, although still pilot scale experimental plants. The other advantage of using cellulosic crops e.g. grass and trees is that they can be grown in areas unsuitable for grains and other food/feed crops.
There are prospects of commercializing the technology in North America by as early as 2006 (Fulton, 2004). The GHG reduction potential is as high as 90% on a well to wheels basis at a cost

of US$25-50 per tonne of CO_2 for biofuels from sugar cane[12] while ethanol from grain would cost as much as US$500 per tonne of CO_2. The Fischer-Tropsch techniques (BTL- Bio to Liquids) are a promising technology with a cost estimate of US$200 per tonne of CO_2 reaching US$100/t by 2010.

Therefore, the potential for advance biofuels is far greater than that of conventional ethanol and biodiesel, which are already in the market and used in some countries, especially Brazil with ethanol and EU with biodiesel as mentioned before. So, using biomass as a primary energy resource for the production of fuel opens up a new earning potential in agriculture especially in tropical countries with adequate climate and land availability.

The mitigation potential of biofuels varies a lot, depending on the feedstock and the process of obtaining the fuel. Ethanol and biodiesel provide significant reductions in greenhouse gas emissions compared to gasoline and diesel fuel on a "well to wheels" basis. While a range of estimates exists, Figure 5.6 shows that most studies reviewed find significant net reductions in CO_2 equivalent emissions for both types of biofuels. More recent studies tend to make estimates towards the higher reduction end of the range, reflecting efficiency improvements over time in both crop production and ethanol conversion.

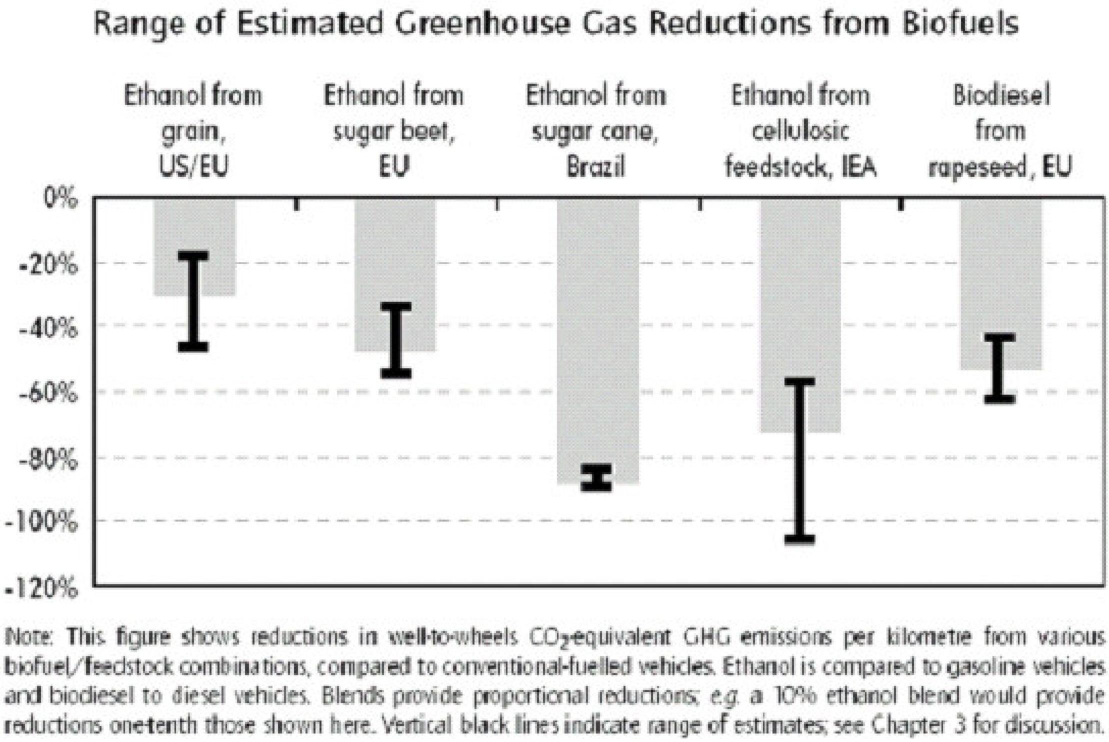


Figure 5.6 *Range of estimated GHG reductions from biofuels (IEA, 2004c)*

Based on known technology and feedstock availability, about 20% of road transport fuel could be derived from very low GHG biofuels by 2030 (Fulton, 2004). If low-GHG biofuels were used in 20% blend in all road transport fuels it would provide an additional 16% reduction in road transport CO_2 and about 12% reduction of all transport CO_2. However, until now essentially all ethanol is being produced from sugarcane and corn, while biodiesel relies essentially in oilseed crops. Up to 2020, the most cost-effective liquid biofuel worldwide is likely to be ethanol produced from sugar

[12] Brazil case.

cane with production taking place in warm climates particularly in developing countries where costs of production are low.

Production costs have dropped somewhat over the past decade and probably will continue to drop in the future. But it does not appear likely that biofuels produces from grain and oil seed feedstock using conventional conversion processes will compete with gasoline and diesel unless world oil prices continue to rises. However the use of lower cost cellulosic feedstock with advanced conversion technologies could eventually lead to the production of a much lower cost ethanol in developed countries (see Fig 5.7).

However, the cost of biofuels can be considerably low in developing countries with sunny, warm climates. In Brazil, feedstock yields of sugar cane per hectare are relatively high; efficient co generation facilities producing both ethanol and electricity have been developed and labour costs are relatively low. Thus the cost of producing ethanol from sugar cane is now close to the Brazilian cost of gasoline on a volumetric basis and is becoming close on a energy basis, depending on the oil price. The economics in other developing countries, such as India, are also becoming increasingly favourable. As production costs continue to drop with each new conversion facility, the long term outlook for production of cane ethanol in developing world appears promising.

Figure 5.8 (IEA,2004c) compares the cost of reducing GHG emissions from several types of ethanol.

As mentioned before, Figure 5.9 shows that ethanol price tends to decline despite some fluctuations. This way, even without possible sales-tax advantages, ethanol is now close to competitive with gasoline on a price-per-unit energy basis at oil prices above $ 25/barrel.

There are prospects to offset significant oil demand using biofuels if the world's potential is exploited to the full and marketed the same way oil is marketed. This can be achieved by encouraging those near-term producing countries that can produce biofuels more cheaply such as Brazil and India. Such an approach is estimated to displace 50-100% of all petroleum by 2050 (Fulton, 2004).

In Africa, biofuels are also receiving significant attention and there is some experience with ethanol-gasoline blending of up to 20%. Ethanol is being produced from sugar cane and there is potential to produce additional ethanol from sweet sorghum, maize, cassava and celluslosic crops as feedstocks. Currently, the structure of the sugar industry dictates the ethanol production technology. Biodiesel production is being considered from jetropha (a drought resistant crop) that can be produced in most parts of Africa (Yamba and Matsika, 2004).
It is estimated that with 10% ethanol-gasoline blending and 20% biodiesel- diesel blending is Southern Africa, a reduction of 2.5 Mt CO_2 and 9.4 Mt CO_2 per annum can be realized.

In short, to illustrate the enormous potential of biofuels, Figure 5.10 shows some main routes to produce biofuels: extraction of vegetable oils, fermentation of sugars to alcohol, gasification and chemical synthetic diesel, biodiesel and bio oil. Such routes should be chosen according to regional differences and their development stages, leading to a more widely use of biofuels in transport.

To conclude, biofuels can play an important role in addressing GHG emissions of transport sector. In the years to come, biofuels can become economically competitive, either through economies of scale, agriculture productivity increase or new technologies. A good example is the use of ethanol in Brazil.

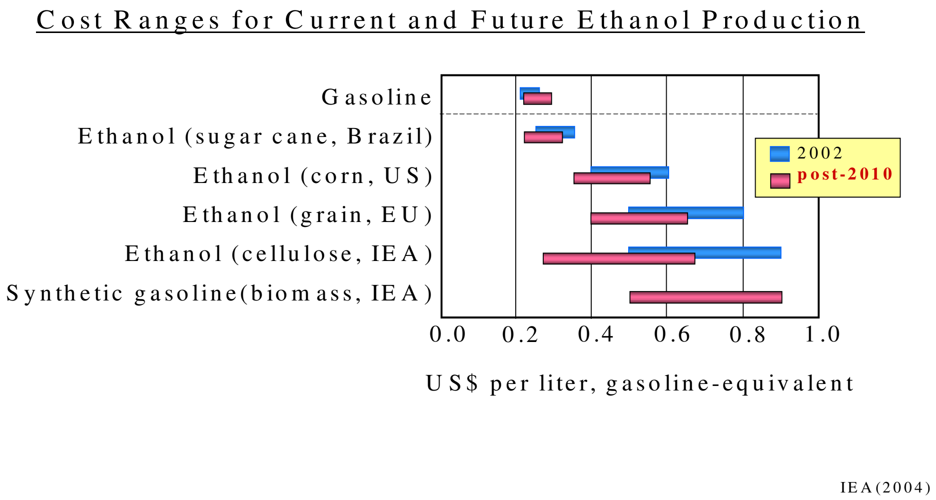


Figure 5.7: *Cost range for current and future (post-2010) ethanol production*

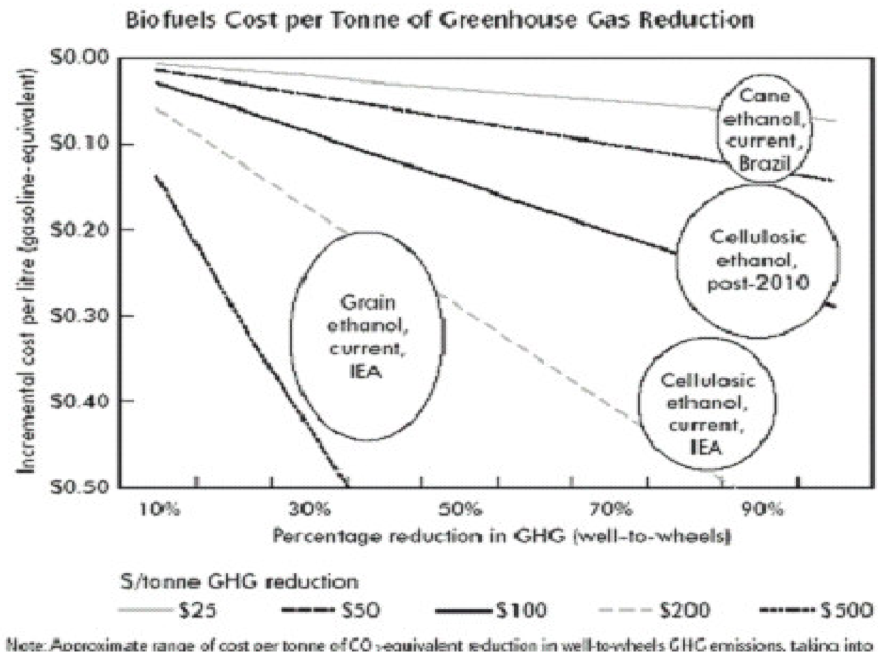


Figure 5.8: *GHG reduction cost for biofuels*

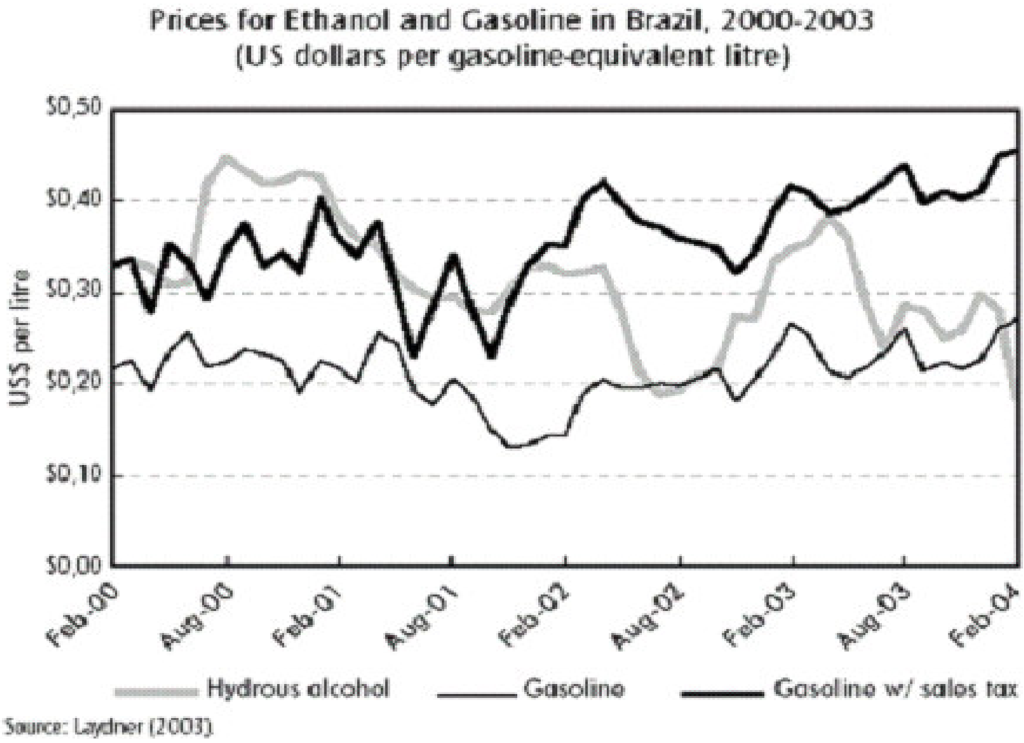


Figure 5.9: *Ethanol and gasoline prices in Brazil*

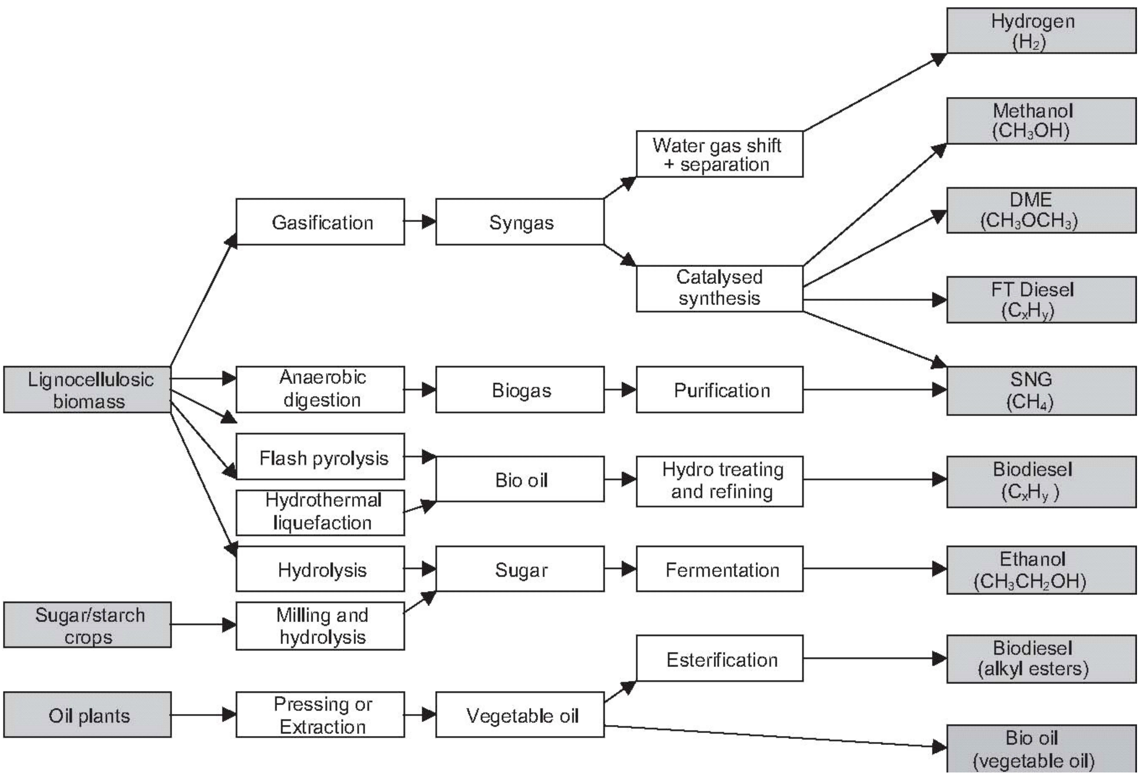


Figure 5.10: *Overview of Conversion Routes from Crops to Biofuels*
(Hamelinck,C.N & Faaij,A.P.C In Energy Policy, 2006)

Natural Gas (CNG/LNG/ GTL)

From natural gas, which is mainly methane (CH4), it is possible to obtain different automotive fuels, such as: CNG (compressed natural gas);synthetic fuel from GTL process *(*"Gas to Liquids"*)* and DME ("Di-Methyl Ether"). The use of natural gas as a feedstock of hydrogen is described in the hydrogen section.

CNG (compressed natural gas) is the only automotive fuel from natural gas that can be used directly in the vehicle, being adequate to spark ignition engines. The vehicles can be dedicated to CNG or can use both CNG and gasoline, using a converted gasoline vehicle and two different tanks. All other fuels derived from natural gas require some chemical processing to convert the gas into other fuels. CNG, as a vehicle fuel has a long history dating back to 1920. With the oil shocks and the possibility of future fuel shortages, there has been much interest in natural gas vehicles. And as awareness surrounding urban and global pollution has grown, interest in CNG has increased even further. CNG is a fuel that, due to its characteristics, burns best in gasoline engines as mentioned before. It has a very high octane rating, about 120, which means that it is advantageous to use in the Otto process. In modern vehicles with exhaust gas after-treatment devices, the emissions from gasoline engines are similar to CNG without cold start. Consequently CNG loses its emission advantages; however, it produces less CO_2 during the burning process in a motor engine. Apart from reducing greenhouse gas emissions, use of CNG can reduce CO by 70%, NOx by 87% compared to combustion of petrol/gasoline. Combined with the energy needed to produce the gas, transport and compress it; emissions will depend on regional circumstances. In Europe, a dedicated CNG vehicles offers up to three per cent GHG benefit over a comparable diesel vehicle, whereas in the US, the nature of the supply chain results in higher CO_2 emissions than diesel. Another characteristic in relation to CNG is that a more complicated storage system is required. As CNG is stored under pressure and has lower energy content as diesel for example, larger and heavier tanks are required for the same range. Thus CNG is more suitable for vehicles which stay within a certain area and do not make long trips.

There were over 1.5 million vehicles running on natural gas worldwide fuelling from over 4 thousand refueling stations in 2001 (Kojima, 2002). The largest NGV market is Argentina (1413664NGVs) followed by Brazil (1000000).[13]

Gas – to – liquids (GTL) processes can produce a range of liquid transportation fuels using Fischer-Tropsch or other conversion technologies. The most likely GTL fuel will be synthetic sulfur-free diesel fuel. GTL processes may be a major source of liquid fuels if conventional oil production cannot keep up with growing demand, but the current processes are relatively inefficient (~70%) and would lead to *increased* GHG emissions unless the CO_2 generated is sequestered.

DME is made from natural gas, but it can also be produced by gasifying biomass. It can be stored in liquid form at a 5-10 bars pressure at normal temperature. This pressure is considerable lower than the one required for the natural gas storage on board of the vehicles (200 bar). A major advantage of DME is its naturally high cetane rating, which means that self ignition will be easier. The high cetane rating makes DME suitable for using in diesel engines, which implies that the higher level of efficiency of the diesel engines compared with the Otto ones is retained when using DME. However, its energy content is lower than in diesel. 1 liter of diesel corresponds to 1.9 liters of DME. DME has attracted much attention recently but it is still at the experimental stage and it still too early to say whether it will be commercially viable. During experiments DME has shown to produce lower emissions of hydrocarbons, nitric oxides and carbon monoxide than diesel and zero

[13] More detailed data, see http://www.iangv.org/content/view/17/35/

emissions of soot[14]. Today there is no developed distribution network for DME, but because of the similarities to LPG the same distribution can also be built up for DME as well.
It has a potential to reduce GHG emissions since it has a lower carbon intensity (15 tC/TJ) than petroleum products (18.9 to 20.2tC/TJ)- IPCC (1996).

Hydrogen/ Fuel Cells and Batteries
During the last decade, fuel cell and fuel cell vehicle (FCV) have been attracting growing attention and made striking progress in related technologies. The drivers for this development are global warming (reduction of CO_2 emission), air quality (zero emission), and energy security (production from a range of sources).
There are several types of FCVs; direct-drive and hybrid powertrain architectures fueled by pure hydrogen, methanol and hydrocarbons (gasoline, naphtha). FCVs with liquid fuels have advantages in terms of fuel storage and infrastructure, but they need on-board fuel reformer (processor) which leads to lower vehicle efficiency (30-50% loss) , longer start-up time, slower response and higher cost. Because of these disadvantages and rapid progress on hydrogen storage tank, main streams are now for pure hydrogen FCVs. This is the biggest change in the field of FCVs since TAR. Another progress since TAR is the world-wide establishment of many demonstration projects.

Since 2000, members of California Fuel Cell Partnership have placed 55 light duty FCVs and 3 FC buses in California, and traveled over 232,000 km on California's roads and highways. In 2002-2003, Japanese automakers got the government certification and started to lease their FCVs in Japan and US, now totaling 17 FCVs.
In Europe, there are several partnership for demonstration such as CUTE(Clean Urban Transport for Europe), CEP (Clean Energy Partnership), and ECTOS(Ecological City Transport System) , using more than 27 buses and 20 passenger cars.

While the future prospects of FCVs is still in dispute, the recent US(NRC/NAE, 2004) and EU(JRC/IPTS,2004) analyses come to the following conculsions.
Although their potential of reduction in GHG emission is very high, there are currently many barriers to be overcome before that potential can be realized in a commercial market.These are

- To develop durable, safe, and environmentally desirable fuel cell systems and hydrogen storage systems and reduce the cost of fuel cell and storage components to be competitive with today's internal combustion engines (ICEs)
- To develop the infrastructure to provide hydrogen for the light-duty-vehicle user.
- To reduce sharply the costs of hydrogen production from renewable energy sources, over a time frame of decades. Or to capture and store ("sequester") the carbon dioxide by-product of hydrogen production from fossil fuels.

And also public acceptance must be secured in order to create demand for this technology.(CaFCP)

As discussed in section 5.3.1.5, the GHG impact of FCVs depends on the hydrogen production paths. Of course these impacts also strongly depend on the technology level of FCV and H_2 production. [At the present (near-future) technology level where the efficiency of FCV can be estimated to be about 50% and hydrogen is produced from natural gas at the efficiency of 60% (well-to-tank base), the well-to-wheel (WTW) CO_2 emission can be reduced by 50-60% compared to current conventional gasoline vehicles. In the future, those efficiencies will increase and the potential of WTW CO_2 reduction can be increased to be close to 70%. If hydrogen is derived from

[14] Kajitani, S., Takeda, M., Hoshimiya, A., Kobori, S. and Kato, M.: The Concept and Experimental Result of DME Engine Operated at Stoichiometric Mixture, presented at International Symposia on Alcohol Fuels (September 26-28, 2005), see http://www.eri.ucr.edu/ISAFXVCD/ISAFXVPP/CnERDEOS.pdf

water by electrolysis using electricity which is produced using renewable energy such as solar and wind, the entire system from fuel production to end use in the vehicle has the potential to be a truly "zero emissions". The same is almost true for hydrogen derived from fossil sources where the CO_2 produced during hydrogen manufacture is captured by sequestration (WBCSD, 2004). On the other hand, if H_2 is produced by electricity in US at present where power generation from coal comprises more than 50%, WTW CO_2 emission increases by about 25% compared with that of conventional gasoline ICE(GM/ANL, 2001).

In order to estimate the real impacts of FCVs on reduction of GHGs, the penetration of FCV into the commercial market should be taken into consideration, which is strongly influenced by the cost of FCV and also H_2. The cost of FCV is estimated to be much higher than the conventional ICE and the retail price of H_2 is 2-7times higher than gasoline. It should be noted that the cost estimate of future technologies is highly challenging and has substantially high uncertainty.

Energy Storage for Future Vehicles

Vehicle electrification requires a more powerful, sophisticated, and reliable energy-storage component than today's lead-acid battery because the batteries of the future will need the power to start the car and also operate powerful by-wire systems, store regenerative braking energy and to operate hybrid vehicles with the demands of increasingly more powerful motor drives. Nickel metal hydride (NiMH) batteries dominate the power-assist hybrid market, and Li ion batteries, dominating the portable battery business are being aggressively developed for automotive applications. The energy density has been increased to 170Wh/kg and 500Wh/L for small-size commercial Li ion batteries (Sanyo, 2005) and 130 Wh/kg and 310Wh/L for large-size EV batteries(Yuasa, 2000). While NiMH has been able to maintain hybrid vehicle high-volume business, Li ion batteries is starting to capture niche market in automotive applications (ex., idle-stop model of Toyota Vitz). The major hurdle left for Li ion batteries is high cost.

The (ultra)capacitor, an intriguing energy storage device offering long-life high-power and good robustness, is being developed as an alternative or supporting energy storage device to a battery. The energy density capabilities of such a device is small and its current cost is quite high. However the prospect for cost reduction and energy enhancement and the possibility of coupling the capacitor with the battery are attracting the attention of energy storage developers and automotive power technologists alike. The energy density of capacitor is now increased up to 15-20Wh/kg (Power System, 2005), which is favorably compared with 40-60Wh/kg of Ni-MH batteries. The cost of these advanced capacitors is in the range of several 10s dollars/Wh, which is about one order higher than that of Li batteries.

5.3.1.5 Technology Assessment (Life Cycle Analysis)

Transportation technologies can be evaluated from the various aspects. Life cycle analysis (LCA) is the most systematic and comprehensive method for the assessment of environmental impacts. In the LCA, various impact analyses are considered, but we focus on the only global warming (GHG reduction).

An LCA has to cope with a number of difficulties mainly related to the non-availability, uncertainty or variability of data. Among them it should be noted that, it is not always clear, where to draw the boundary for the analysis; also there is the problem of treating by-products and their credits.
Also in some cases, LCA data are strongly depend on the region (country).

For a case of automobiles, whole life cycle chain can be divided into the fuel cycle (extraction of crude oil, fuel processing, fuel transportation, fuel use during operation of vehicle), and vehicle cycle (material production, vehicle manufacturing, disposal treatments at the end of life) as shown in Fig 5.11. Recently many studies on this fuel cycle have been reported, especially in the relation with hydrogen production. It should be noted that these fuel cycle (well-to-wheel) analyses cover only fuel cycle part of entire LCA chain.

For a typical internal combustion engine (ICE) vehicle, 70-90% of energy consumption and GHG emission takes place during fuel cycle, as shown in Fig 5.12 (of course, this portion depends on the driving mode and life-cycle driving distance).[15] This indicates that CO_2 reduction measures can be most effective for the fuel cycle, so fuel economy is a very important aspect of vehicle technologies. Vehicle cycle contributes with 10-15% to the overall emissions in conventional cars. Fuel cell and hybrid cars have lower CO_2 emissions than conventional cars, but they 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 unit(Toyota, 2004). More optimistic results on FCV are shown in some analyses such as MIT(Weiss et al., 2003) where they assumed advances in FCV technology closer to the higher targets foreseen by some advocates.

Several detailed studies have been undertaken in recent years on the Well-to-Wheel CO_2 emissions of conventional and alternative fuels and vehicle propulsion concepts. The three typical studies published are shown in Fig 5.14. These are GM/ANL (2001) analysis for North America, EUCAR/CONCAWE/JRC (2004) for Europe and Toyota/Mizuho (2004) for Japan. Major results of analyses are selected and shown in three groups of ICE(Internal combustion engine)/fossil fuel, ICE/Biofuel and FC(Fuel cell). Since the base vehicle for each analysis are different, especially for North America, all the results are normalized by the value of ICE-G (gasoline). As mentioned above, these analyses inherently have a dependency on regions, so some of differences appeared in Fig X2 can be explained by this. For example, results of ICE-gasoline and ICE-D(diesel) reflects the difference of producing region of oil and processing equipments in refinery.

For ICE/Fossil fuel combination, ICE-CNG (compressed natural gas) has 10-20% lower emission than ICE-G because natural gas is lower-carbon fuel and ICE-D (Diesel) has 15-25% lower emission due to high efficiency of engine. The results of hybrids are diverse among the analyses and this is due to the different assumptions of vehicle efficiency and different driving cycle. Since Toyota's data is on the best available vehicle and using Japanese 10-15 driving cycle for the analysis, the average potential of CO_2 reduction can be 20-30%.

For the ICE-Biofuel, the CO_2 reduction potential is very large (55-90%), but the whole impact should be considered with the economic potential, since in many cases except for ethanol in Brazil, production cost is very high and fuel availability is also limited, as discussed before.

For FC/hydrogen, there are many paths for producing hydrogen, as shown in Fig 5.15. Producing hydrogen from natural gas, FC-GH2 (NG) allows to reduce greenhouse gas emissions by 50-60% compared to ICE-G, but this depends on the assumption of FCV efficiency. Since producing liquid (cryogenic) hydrogen, FC-LH2 needs more energy, reduction potential decreases. Producing H_2 by electrolysis of water, FC-G H2 (Elec) uses grid electricity which has different CO_2 emission factors in various regions. In US, coal-fired power generation forms 54% of total generation capacity, which is much higher than the mix in Europe and Japan. At present technology level, only H_2 from fossil fuels is economically viable, as discussed in Section 5.3.1.4. However, FCV is expected to be very clean vehicle, and this can be achieved by sequestering CO_2 produced during H_2 production or making H_2 using renewable energy (see Fig. 5.16).

[15] For other transportation mode such as train and ship, very similar pictures can be seen that the CO2 emission is dominant during operation, as shown in Fig. 5.13 (Aihara et al., 2002; Kameyama et al., 2005). However, the percentage of operation is very sensitive to operation conditions, such as total length and frequency of travel.

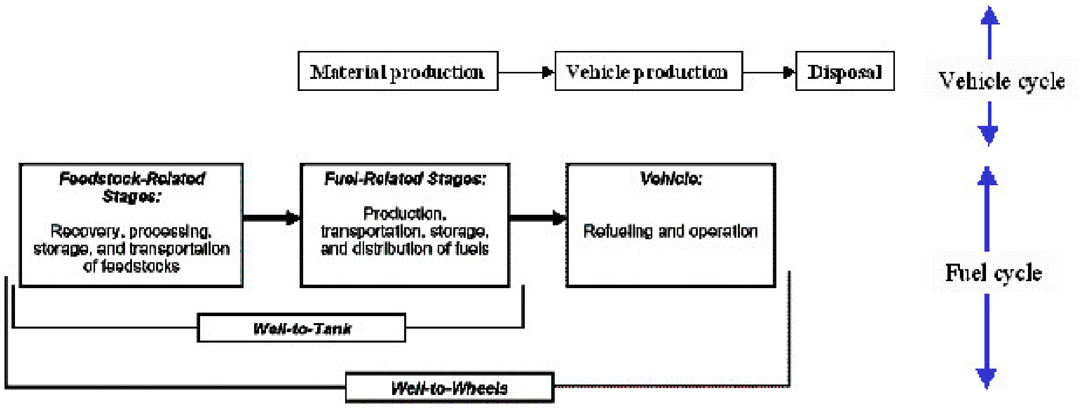


Figure 5.11: *Vehicle cycle and fuel cycle for LCA analysis*

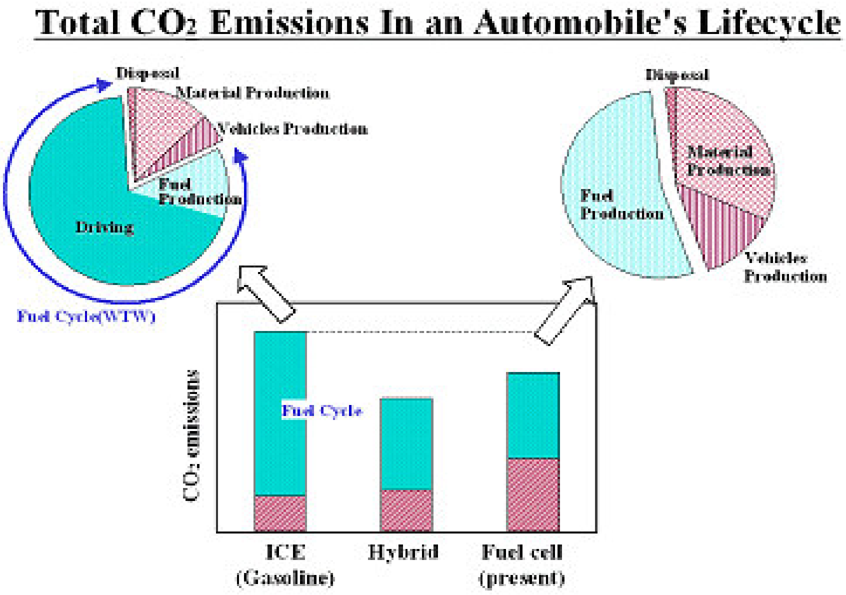


Figure5.12: *LCA analysis of CO_2 emission for various automobiles*

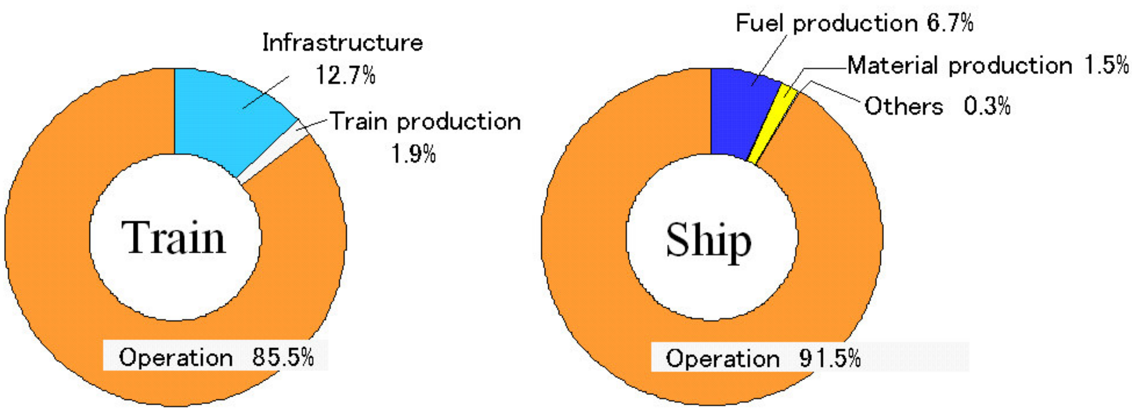


Figure 5.13: *LCA analysis for train and ship*

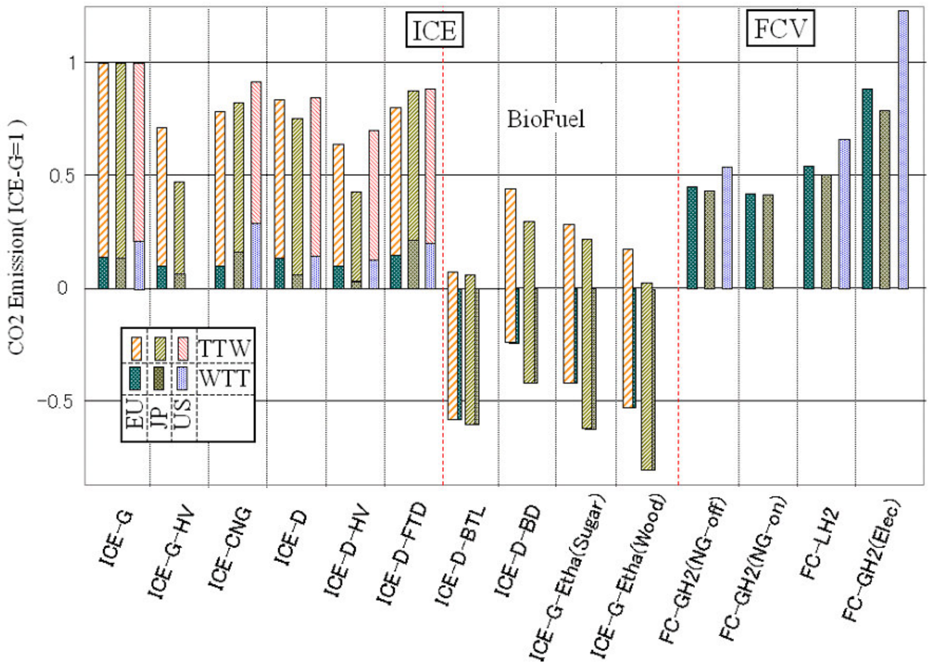


Figure 5.14: *Comparison of three studies on well-to-wheel analyses (see text for an explanation of the legend)*

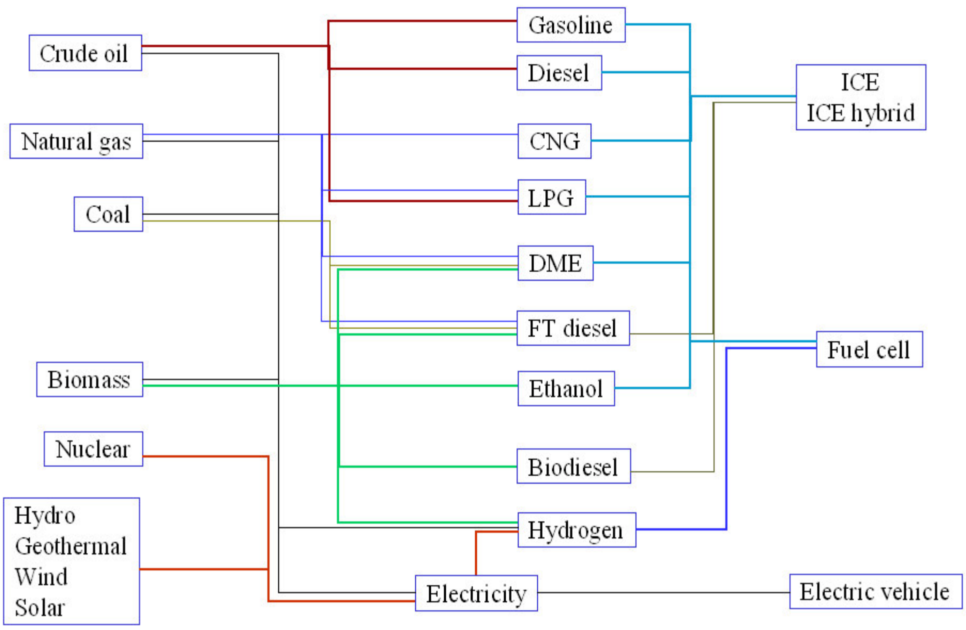


Figure 5.15*:* *Hydrogen production pathways*

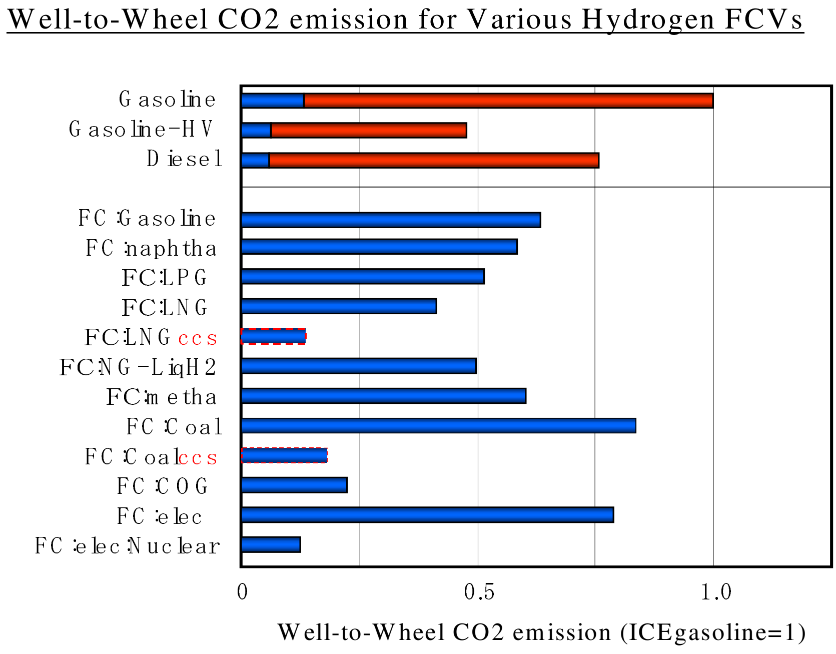


Figure 5.16: *Well-to-Wheel CO_2 emission for Various Hydrogen FCVs*

The CO_2 reduction potential itself can be assessed by LCA or well-to-wheel analysis. But as already mentioned above, the whole impact should be assessed including economic and technical feasibility and fuel availability. Estimating the possible cost of vehicles and fuels is an extremely challenging exercise. A very wide range of estimates exists concerning what these costs might be, especially for hydrogen produced using processes that are not available commercially at the present time (WBCSD, 2004). An example of cost estimates for H_2 production is shown in Fig 5.17 (EC, 2003b). The hydrogen supply costs are strongly influenced by the necessary infrastructure investment, the energy cost and the utilization rate of filling station. The supply cost of hydrogen at the station excluding tax lies in a range between 22 and 66 €/GJ (0.7 and 2.1 € per liter gasoline equivalent) which is roughly two to seven times more than the corresponding value (0.3€ per liter gasoline equivalent) for gasoline (also excluding tax) today. Very similar results are also reported in NRC/NAE report(2004).

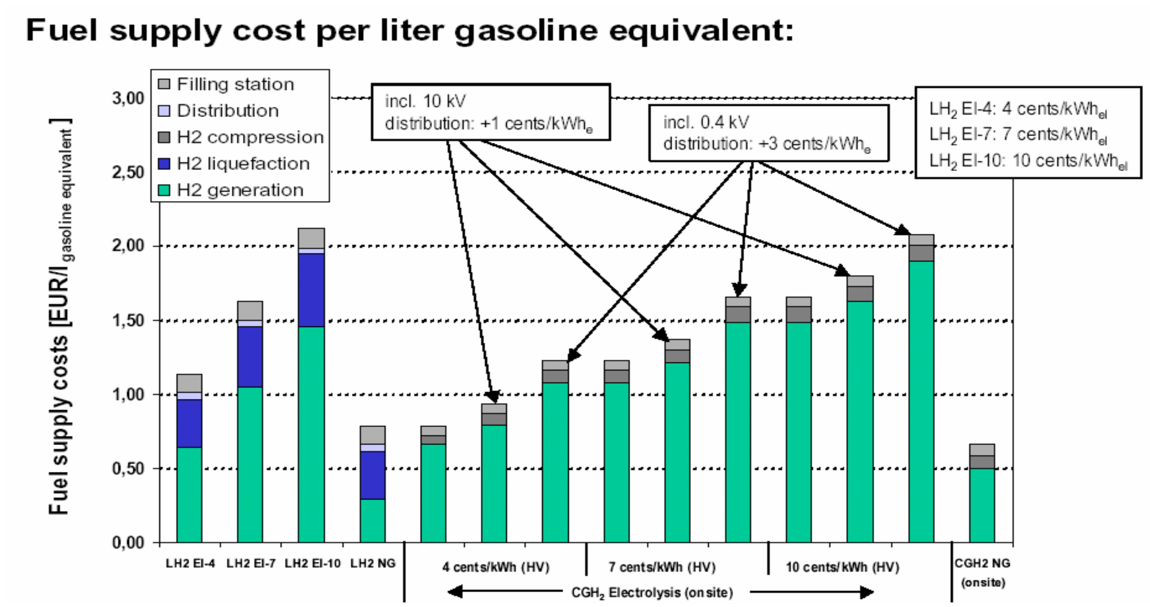


Figure 5.17: *Hydrogen supply cost*

5.3.2 Rail

Railway transportation is widely used in many countries in the world. Its main roles are high speed passenger transportation between remote cities, high density commuter transportation in the city and freight transportation. It is in a tough competition with other transportation modes, such as air, ship, trucks and private vehicles. Major drivers of R&D's are high speed, comfortability, cost cutting, better safety and better punctuality. Among these R&D's, some topics related to CO_2 reduction will be described in the following.

1. Reducing running resistance
   As for high speed trains, such as Japanese Shinkansen, French TGV and German ICE, aerodynamic resistance constitutes almost all of running resistance. It is important to reduce this resistance for energy consumption and CO_2 emission. It is reported that latest series 700 Shinkansen reduced 31 % of a aerodynamic resistance compared with series 0 (first generation Shinkansen).
   Aerodynamic resistance is determined by the shape of the train. Therefore, many researches have been carried out to find optimum shape by using computer simulation and wind tunnel.
2. Reducing train weight
   Reduction of train weight is a effective way to reduce energy consumption and CO_2 emission especially for commuter trains. Stainless steal carbody, aluminum carbody, simple structure bogie and lighter propulsion equipments are good examples.
3. Usage of a regenerative brake
   A regenerative brake is a recent popular topic for hybrid automobile, while it has been used in railways for three decades. In case of railways, an electric energy generated by braking a train is used through a catenary for powering other trains. This brings less energy consumption and CO_2 emission.
4. Usage of energy storage device
   A regenerative braking energy can not be effectively used when there is no train running near a braking train. Recently researches of energy storage device on board or on the ground are progressing in various countries. Lithium ion battery, electric double-layer capacity and flywheel are candidates for such energy storage devices.
5. Higher efficiency propulsion system

Using chopper control or inverter control instead of rheostatic control brings less energy consumption and CO_2 emission. In Japan, it was reported in 1993 that a new type commuter train using stainless still carbody, inverter control and regenerative brake consume only 47% of a electric energy compared with an old type train using steel carbody, rheostatic control and rheostatic braking. Examples of recent researches can be seen for superconducting on-board transformer and permanent magnet synchronous traction motor.

5.3.3 Aviation

Civil aviation is one of the world's fastest growing transport means (contaction and Convergence, UK Carbon Emissions and the Implications for UK air Traffic, Tyndall Centre, 2006)
Estimates from the EC Aero2k project suggest that in 2002 civil aviation scheduled passenger, charter and freight flights consumed approximately 156 million tons of fuel globally (Aero2K 2004). Aviation traffic growth trends from Airbus and UK Department of Trade and Industry, adopted by Aero2k for an aviation emissions forecast inventory, suggest that by 2025 traffic will have increased by a factor of 2.6 and this could increase fuel burn by a factor of 2.1 (Aero2K 2004).

The emissions produced by the turbofan engines fitted to the majority of the civil aviation fleet are carbon dioxide (CO_2), nitrogen oxides (NO_x), water vapour (H_2O), carbon monoxide (CO), hydrocarbons (HC), sulphur oxides (SO_x) from the small amount of sulphur contained in the fuel, soot and particulates. The CO_2 and H_2O are produced in direct proportion the amount of fuel consumed, but the NO_x production (the oxidisation of atmospheric nitrogen) depends in part on the quality of the combustion process – higher temperatures and longer combustor residence times will produce more NO_x. Engine developments require a balancing of the emissions produced to both satisfy operational need (fuel efficiency) and regulatory need (NO_x, CO, Smoke and HC). This emissions performance "see-saw" requires design compromises along with the need to consider safety, reliability, cost, and noise as major design considerations. On the other hand, developments that reduce weight, reduce aerodynamic drag or improve the operation of the aircraft can offer all-round benefits.

The global environmental consequence of civil aviation's fuel consumption is the climate forcing from the pollutants produced, primarily carbon dioxide (CO_2), and from the ozone generated from NO_x emissions. These are estimated to be approximately 492 million tonnes of CO_2 and 2.06 million tonnes of NO_x for the base year, increasing to 1029 and 3.31 million tonnes respectively for the Aero2k 2025 forecast. The environmental effects of aviation activity will not be limited to the climate forcing caused by CO_2 and NO_x, but will also include the (thus far unquantified) effects of contrail and cirrus cloud production, soot, etc. The environmental effects of these emissions will be dealt with in other parts of the report. Some of these emissions will also affect local air quality at and around airports, but this is beyond the scope of this report.

Aviation is a technology-intensive industry and projections of aviation emissions to 2025 should assume and reflect a trend in technology development. The trend for the figures given above has been derived from a regulatory-driven technology scenario that has targeted NO_x emissions reduction along with the need for increasing fuel efficiency for civil aviation. Fuel efficiency is a primary consideration for the operators of modern aircraft, as fuel currently represents significant proportion of total operating costs for modern aircraft at around 22% in 2005 (ref. IATA, estimated value) as a global value, but there will be differences for the different sectors of the aviation market. Technology developments, particularly within the engine, that target fuel efficiency invariably have a "knock-on" deleterious effect on other pollutants produced by the engine, and especially NO_x.

Aviation's perceived global environmental impact is now a strong driver of technology for the industry. In the 1960s the local impact of NO_x, CO, HC and smoke emissions promoted the introduction of regulatory standards for these emissions by the International Civil Aviation Organisation, ICAO. The relatively recent concerns over aviation's contribution to global climate change has redirected the environmental focus, but the current emissions certification regime has not changed.

Certification standards for the other pollutants contribute to the fuel efficiency challenge for current engine technologies. Emissions - and noise - regulatory compliance hinders the quest for improved fuel efficiency, and is most difficult for those engines having the highest pressure ratios – the higher the PR the higher the temperature of the air used for combustion in the engine. In these cases the margin of compliance at NO_x certification testing is in the order of only 10%. Increasing an engine's pressure ratio is one of the options engine manufacturers have to improve engine efficiency, and higher pressure ratios are likely to be a continuing trend in engine development. NO_x certification standards could hinder what might be achieved in this regard, unless revolutionary NO_x control techniques become developed to a flight worthy standard.

There are no fuel efficiency certification standards for civil aviation: market forces provide the only driver. New technology is developed not only to be introduced into new engines, but also, where possible, to be incorporated into engines in current production. Engine manufacturers must ensure emissions performance of their products comply with regulatory standards, as well as ensuing their products have acceptable fuel consumption, and the tradeoff between fuel consumption and the performance of the other emissions creates a significant technology challenge.

Aviation's dependence on fossil fuels is likely to continue for the foreseeable future. This will demand a continuing trend of fuel efficiency improvements for the aviation industry and, over the long term future; civil aviation will require the application of possibly revolutionary technology concepts in order to produce significant or substantial reductions in fuel burn and associated emissions. CO_2 emissions are related directly to fuel burn, and fuel burn reduction will need to be addressed through aerodynamic improvements, weight reductions and fuel efficient aircraft engines. For the airframe, laminar flow technology (reduced airframe drag through control of the boundary layer) is likely to provide the greatest aerodynamic potential. This technology extends the smooth boundary layer of undisturbed air flow over the aerodynamic structure, in some cases requiring artificial means to promote laminar flow beyond its natural extent by suction of the disturbed flow through the aerodynamic surface. Whilst such systems have been the subject of research work in recent times, they are still far from a flightworthy application. Novel aircraft concepts such as blended wing bodies or high aspect ratio/low sweep configuration aircraft designs might accomplish major fuel savings during operation. The blended wing body (flying wing) is not a new concept, but whilst this in theory holds the prospect of significant fuel burn reductions (estimates suggest more than 20%) compared with an equivalent sized conventional aircraft, its development for the future is hampered by costs of design, development and production, and market acceptability.

As mentioned above one of the more serious problems for engine, and in particular combustor, designers is that of the trade-off of emissions performance for the pollutants produced by an engine. In addition, a further practicality is the need to balance not only emissions trade-offs, but the inevitable trade-off between emissions and noise performance from the engine and aircraft. Engineering is the science of practical compromise, and the following "carpet plot" illustrates, for one particular engine and airframe combination, the practical considerations which the engine designer is required to balance in order to produce a commercially viable product. The chart shows the relationship between NO_x emissions, fuel burn and noise emissions, and it clearly demonstrates that the engine may be optimised for minimum NO_x emissions, at which design point the engine will burn more fuel than it might otherwise have done. A similar design compromise affects noise.

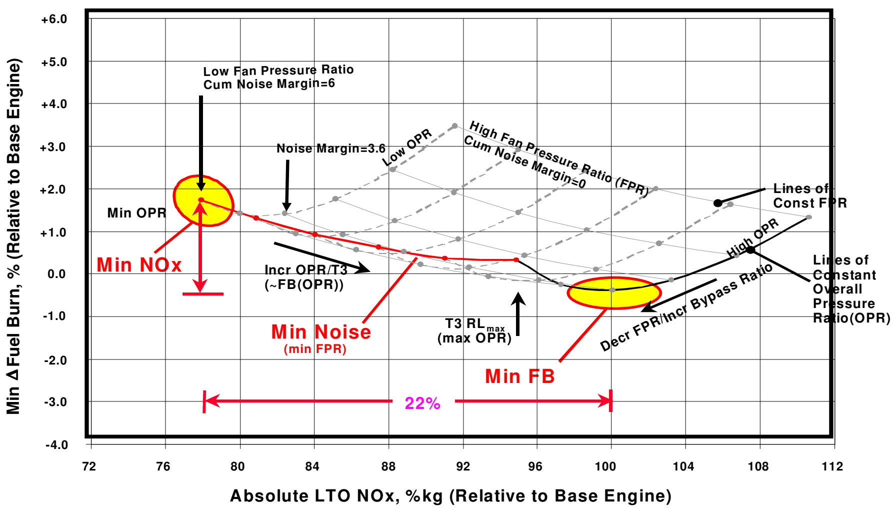


Figure 5.18: *Relationship between NO_x emission, fuel and noise*

Aircraft Developments

Fuel efficiency improvements are available through improvements to the airframe, as well as the engine. The most common configuration for modern civil jet aircraft has low-mounted swept wings and is powered by turbo fan engines mounted beneath the wings. Most aircraft designs feature two or four engines, and these designs now form the industry standard for commercial civil aircraft. Such sub-sonic aircraft being produced today are about 70% more fuel efficient per passenger kilometre than 40 years ago (see section 6.1 of summary for policy makers IPCC report "Aviation and the Global Atmosphere"): "The majority of this gain has been achieved through engine improvements and the remainder from airframe design improvements. A 20% improvement in fuel efficiency is projected by 2015 and a 40% to 50% improvement by 2050 relative to aircraft produced today(1997)". The 70% efficiency gain ignores the pre-jet piston-engined aircraft fleet, the most developed of which had fuel efficiencies approaching those of today's jet aircraft, but these early aircraft lacked the efficiency associated with the speed of the modern jet, and their reliability. It is arguable that the current aircraft configuration, being a highly evolved design, has relatively limited scope for further improvement, although the model is still being evolved. Lightweight composite materials for the majority of the aircraft structure are beginning to appear and promise significant weight and concomitant fuel burn benefits. But some industry experts believe that a new aircraft configuration might be necessary to realise a step change in aircraft fuel efficiency.

In 2001 the Greener by Design (GbD) technology sub-group produced a report entitled "The Technology Challenge" at which it considered, *inter alia*, a range of possible future technologies for the long term development of the aviation industry, and their possible environmental benefits. Among the issues considered was the possible development of an alternative aircraft configuration, the blended wing body and the laminar flying wing. The study concluded that these two concepts could offer significant fuel burn (and CO_2) reduction potential compared with an equivalent payload conventional aircraft design. Other studies ("The Blended Wing Body Aircraft", Leifur T. Leifsson and William H. Mason, Virginia Polytechnic Institute and State University Blacksburg, VA, USA) have suggested similar results. The advantage of such designs arise from the improved aerodynamic efficiency of combining wing and fuselage, as this eliminates the conventional fuselage and tail surfaces, and thereby reduces their wetted area and associated friction drag. It was estimated that, for a typical BWB configuration, the expected L/D of such a configuration would be around 15% higher than that of the equivalent conventional aircraft. In addition, take-off weight would be reduced, relative to a conventional aircraft for the same payload range and cruise speed. Additional developments, especially that of the introduction of laminar flow across the flying wing's surface, was also estimated to produce significantly reduced drag and therefore consequent improvements in fuel burn (CO_2 reduction) and a final variant that of a laminar flying wing powered by an unducted fan engine, produced yet more benefits. All these technologies could be realised during the next 50 years, and several are already technically viable, if not commercially acceptable. Indeed, it is the commercial viability of radical new concepts that may be the most significant barrier to market acceptability for such technological improvements. Table 5.6 summarises the fuel efficiency of these future designs relative to a baseline conventional swept wing aircraft, and shows the significant benefits to be obtained in fuel consumption alone.

Table 5.6: *Aircraft designs fuel efficiencies*

Configuration	Empty Tonne	Payload Tonne	Fuel Tonne	Max TOW Tonne
Baseline	236	86	178	500
BWB	207	86	137	430
Laminar Flying Wing	226	86	83	395
LFW with UDF	219	86	72	377

The GbD report suggested that through technological and operational advances civil aviation has the potential to reduce its impact on climate substantially. Reduction in both NO_X and CO_2 emission could be achieved by advances in airframe and propulsion systems which reduce fuel burn. In propulsion, the open rotor offers significant reductions in fuel burn, particularly for short- and medium-haul operations, since approximately half the world's aviation fuel is burned on flights of 2,500km or less, but rotor noise from such devices will need to be controlled within acceptable (regulatory) limits. In airframe technology, weight reduction through increased used of advanced structural composites, and drag reduction, particularly through the application of laminar flow control, hold out the promise of further significant fuel burn reductions, as well as the flying wing or blended wing-body configuration as described above.

In summary, the GbD report suggests that aviation's environmental impact, in terms of its contribution to global climate change, could be reduced by influencing priorities in design. NO_x emissions could be reduced by reducing engine pressure ratio; ozone generation by NO_x can be reduced by optimising designs to cruise at lower altitudes. In both cases, the result would be an increase in fuel burn, and this would increase CO_2 emissions and operating cost, but the environmental trade (NO_x vs. CO_2) might be environmentally beneficial. Contrail and cirrus formation, and ozone creation, can also be reduced by operational measures which increase fuel burn (such as flying at lower altitudes or routing around areas of the atmosphere that will produce contrails).

Large Aircraft

The development and use of larger aircraft has been a feature of aviation development over its existence. During the jet age, beginning with aircraft capable of carrying little more than 100 people, the technology has advanced to a level at which aircraft can now carry 600 people and more, and fly huge distances that at the onset of civil aviation were unthinkable. The use of larger aircraft improves the cost efficiency of the vehicle. Larger aircraft (the Boeing 747 provides the paradigm in this regard) allows more fare-paying passengers to be carried without a proportionate fuel consumption effect. One advantage of such economy of operation is a reduced fare for passengers. In terms of cost per passenger kilometre flown, such vehicles represent an improvement in aircraft efficiency, but the extent to which this trend will continue for the future is uncertain: the market has yet to decide on the largest acceptable size.

Bio-fuels for aviation

The UK project "The Potential for Renewable Energy Sources in Aviation ("Presav")" (2003) studied the options for potential renewable fuels for civil aviation. The study examined the fuels and energy sources from bio diesel, ethanol, methanol, Fischer-Tropsch synthetic kerosene, nuclear, liquefied hydrogen (H_2) and liquefied bio-methane. Of these, methanol, ethanol and bio-methane, along with nuclear energy, were considered to be inherently unsuitable for civil aviation. Of the remainder, bio-diesel was regarded as a potential kerosene extender, although further research was required in order to understand its cold weather performance (wax solidification) although these were not seen to be insuperable for the future. Fischer-Tropsch kerosene could be used in current jet fuel, although it was suggested that a fuel additive might be required due to the fuel's low sulphur and aromatic content. It was noted that the South African "SASOL" already had a certification for a jet fuel blend of up to 50% coal-derived FT kerosene and 50% conventional kerosene. For hydrogen, the report noted the changes required to jet engines to limit their production of NOx, a greenhouse gas precursor, as hydrogen may be unsuitable for low NOx combustors in modern engines. The changes to the airframe designs that might be necessary to carry sufficient volumes of liquefied hydrogen fuel would be a far greater challenge as other studies have suggested.

It should be noted that current Jet-A kerosine fuel used in commercial aircraft must meet a very comprehensive specification. This includes freezing point and flash point requirements that can be met by synthetic kerosine, but may prove to be significant challenges for some potential alternative fuels.

Cryoplane

There have been several studies on the use of hydrogen as an alternative fuel for aviation. In 2004 the EC published a report entitled "Liquid Hydrogen Fuelled Aircraft - Systems Analysis" of a project co-ordinated by Airbus Deutschland GmbH. Leaving aside the issues related to production of hydrogen and the infrastructure necessary to deliver such fuel to airports and aircraft, the study determined that whilst the technology to develop aeroengines to run on hydrogen was available, a significant development would be necessary for these technologies to be made applicable to aviation operation. Using conventional aircraft designs, modified to accommodate the tankerage necessary for hydrogen fuels, would be possible, but the increased drag due to the hydrogen storage fuselage volume would increase the energy consumption of the aircraft by between 9% and 14%, the weight of the aircraft structure might increase by around 23% as a result, and the maximum take-off weight, dependent on aircraft size, would vary between +4.4% to -14.8% dependent on the aircraft configuration and mission. As a result of this, the study reported that the operating costs for such aircraft would increase by between 4 and 5%, this caused by fuel use only.

However, the study recognised that the use of renewable energy would obviate the environmental effect. The primary environmental benefit from the use of hydrogen fuel would be the prevention of CO_2 emissions during aircraft operation. Hydrogen fuelled engines would, however, produce around 2.6 times more water vapour than through the use of kerosene, and H_20 is a greenhouse gas. However, the H_20 would remain in the atmosphere for only about 6 months, whereas the CO_2 would remain for around 100 years. The report summarised that hydrogen could be a suitable alternative fuel for future aviation, but a significant amount of R&D work would be necessary to provide the suitable hardware in terms of airframe and engines. The earliest implementation of this technology could be expected to be around 15-20 years, provided that research work was pursued at an appropriate level. The operating cost of hydrogen aircraft remain unattractive under today's conditions, with kerosene being cheaper than hydrogen as a fuel.

Supersonic Aircraft

There is continuing commercial interest in developing a modern supersonic fleet. Such aircraft, should they be introduced, are likely to take the form of relatively small supersonic jets, possibly capable of carrying up to around twenty passengers, their size and design reflecting the potential market and the need to minimize sonic boom - the size of the sonic boom is proportional to aircraft weight. Such aircraft, if to be commercially viable, will need the capability to operate supersonically overland, and it is for this reason that the supersonic boom "footprint" must be minimized. The acceptability of sonic boom level over populated areas has yet to be determined, but in the event such acceptability can be defined and agreed the aerospace industries believe that a small fleet of supersonic business jets might be commercially viable.

In terms of environmental performance, a supersonic aircraft, due to its high speed, will require more thrust than a subsonic aircraft of equivalent size, and this will increase CO_2 emissions per passenger mile. NO_x emissions performance will depend upon engine combustor design, but it is not improbable that combustion technology will be able to produce a design that can conform to current NO_x emissions certification standards. But as the IPCC special report on aviation pointed out, the emissions of water vapour that supersonic aircraft produce in the stratosphere where they cruise can have a significant global warming effect. A supersonic aircraft is unlikely to equal the environmental performance of an equivalent subsonic aircraft given the fuel burn disadvantage and the water vapour issue, and the acceptability of sonic booms over populated areas has yet to be determined. Small supersonic aircraft may become part of the civil fleet in the future, but they are unlikely to be operated as conventional scheduled civil transport aircraft as their cost of operation may limit their use to the relatively small and wealthy business and corporate sectors. The size of such a fleet might therefore be relatively small.

5.3.4 Shipping (Technical and operational measures)

In the past few years, the International Maritime Organization (IMO) has started research and discussions on the mitigation of greenhouse gas emissions by the shipping industry. The main objective of a study carried out by Marintek (2000) for IMO was to examine the potential for reducing GHG emissions through a variety of technical, operational and market-based approaches. Regarding the short-term potential of technical measures to reduce CO_2 emissions, the study found that the potential in new ships was 5-30% and 4-20% in old ships. These reductions could be achieved by applying current energy-saving technologies vis-à-vis hydrodynamics (hull and propeller) and machinery on new and existing ships.

The vast majority of marine propulsion and auxiliary plants onboard ocean-going ships are diesel engines. In terms of the maximum installed engine output of all civilian ships above 100 gross tons (GT), 96% of this energy is produced by diesel power. These engines typically have lifetimes of 30 years or more (Eyring, et al., 2005). It will therefore be a long time before technical measures can be implemented in the fleet on any significant scale. This implies that operational emission abatement

measures on *existing* ships, such as speed reduction, load optimization, maintenance, fleetplanning, etc., should play an important role if policy is to be effective before 2020.
Marintek (2000) estimates the short-term potential of operational measures at 1-40%. These CO_2 reductions could in particular be achieved by fleet optimization and routing and speed reduction. A general quantification of the potential is uncertain and varying across segments of shipping. There are e.g. large variations in utilization of the ship across different segments of shipping, and the operational aspects of shipping are not transparent.

The long-term reduction potential, assuming implementation of technical or operational measures, was estimated for the major fuel consuming segments[16]of the world fleet as specific case studies (Marintek, 2000). The result of this analysis was that the estimated CO_2 emission reduction potential of the world fleet would be 17.6% in 2010 and 28.2% in 2020. Even though this potential is significant, it was noted that this would not be sufficient to compensate for the effects of projected fleet growth (at 3% per annum growth[17]: a 36% increase in CO_2 emissions in 2010, 72% in 2020). Speed reduction was found to offer the greatest potential for reduction, followed by implementation of new and improved technology. Speed reduction is probably only economically feasible if policy incentives, such as CO_2 trading or emissions charges are introduced.

A significant shift from primarily diesel-only fleet to a fleet that uses alternative fuels and energy sources until 2020 cannot be expected, as most of the promising alternative techniques are not yet tested to an extent that they can compete with diesel engines (Eyring, et al., 2005). Furthermore, the availability of alternative fuels is currently limited and time is needed to establish the infrastructure for alternative fuels. For this reasons, in the short term switching to alternative fuels provides a limited potential in general, but a significant potential for segments where switch from diesel to natural gas is possible (Skjølsvik, 2005). Switch from diesel to natural gas as fuel has a 20% reduction potential and is being pursued as a measure in Norway for inland ferries and offshore supply vessels operating on the Norwegian Continental Shelf. The main obstacle to the increased utilization of natural gas is the access to LNG (Liquefied Natural Gas) and the technology's level of costs compared to traditional ship solutions based on traditional fuel (Skjølsvik, 2005). A co-benefit of a switch from diesel to natural gas is that it also reduces emissions of SOx and NOx which contribute to local air pollution in the vicinity of ports.

For the long-term (2050), however, the economical CO_2 reduction potential might be large. E.g. a combination of solar panels and sails is possible. The use of large sail for super tankers is currently being tested in Germany and looks promising. The introduction of hydrogen-propelled ships and the use of fuel cell power at least for the Auxiliary engines seem to be a possibility as well. For larger vessels the power demands for fuel cells for a capable and reliable fuel-cells-based ship propulsion system is still a very long way into the future, but might be possible in 2050 (Eyring et al., 2005).
In the framework of the FCSHIP project of the European Commission, Altmann et al. (2004) concluded that fuel cells offer the potential for significant environmental improvements both in terms of air quality and climate protection. Local pollutant emissions and greenhouse gas emissions can be eliminated almost entirely over the full life cycle using renewable primary energies. The direct use of natural gas in high temperature fuel cells employed in large ships and the use of natural gas derived hydrogen in fuel cells installed in small ships allows for a greenhouse gas emission reduction of 20%-40%.

[16] In fact four segments covering 80% of the fuel consumption were assessed: tank, bulk, container and general cargo ships
[17] In line with the 3%-plus average annual growth over the past 20 years.

5.3.5 Operational System / Mitigation Potential Through Practices

Maintenance practices

The most widely used approach to promoting improved vehicle maintenance is a combined mandatory vehicle inspection and maintenance program. Many countries have programs that include testing for emissions, although few appear to directly target fuel economy. Adding tests for fuel economy to such programs could be a low cost method for minimizing fuel use and CO_2 emissions. Repairs to poorly maintained vehicles with high emissions can often, but not always, improve fuel economy. For example, fuel economy will usually improve if a problem resulting in high CO_2 emissions is repaired, but can sometimes worsen if it is related to high hydrocarbon or nitrogen oxide emissions. Inspections and maintenance programs also present an opportunity for adding an element of driver education or awareness of the benefits of fuel efficient driving practices and regular vehicle maintenance, like maintaining proper tire pressure.

Eco driving

Drivers can enhance fuel economy by reducing rates and cycles of deceleration and acceleration, keeping engine revolutions low, shutting off the engine when idling, reducing maximum speeds and maintaining proper tire pressure (IEA, 2001). Results from studies conducted in Europe and the US have suggested possible improvement of 5 to 20 per cent in fuel economy from eco driving training (ECMT/IEA, 2005). Japanese results also showed that training program would possibly improve fuel economy by about 10 per cent if the driver only tried to save energy, and by 10 to 20 per cent if the driver was guided by the audio guidance (ECCJ, 2003). Driver training is cost-effective either through training or technology aids, however, the major problems with a driver-training program were how to motivate drivers to participate in the program, and how to make drivers maintain an efficient driving style long after participating in the program (IEA, 2001). In The Netherlands eco driving training is provided as part of driving school curricula (ECMT/IEA, 2005). Regarding idling stop during red light, the Energy Conservation Center, Japan experimented with a semi-automatic idling stop system, and found that it reduced CO_2 emission by about 13 per cent in urbanized areas and by 6 per cent in all areas (ECCJ, 2003). In the US, a nationwide survey found that, on average, a long-haul truck consumed about 1,600 gallons, or 6,100 litres, per year for idling during driver rest periods, a part of which might have been saved by switching to grid connection and onboard auxiliary power units (Lutsey, N., *et al.*, 2004).

Modal shift

With regard to passenger transport, a reduction in CO_2 emissions by switching from carbon-intensive modes such as cars to carbon-efficient modes such as buses, rails and non-motorized transport (NMT) has been planned and implemented in many countries. The degree of the reduction in CO_2 emissions critically depends on occupancy rates if the alternative is shared transport, and on primary energy sources if the alternative requires an electric power supply. According to the statistics (ORNL, 2006, Kenworthy, J., 2002 cited in Pucher, J., 2004, JMLIT, 2005), the average energy use per passenger kilometer for cars is 2 to 5 times higher than the figures in Western Europe (large cities) for buses or rails, and 3 to 6 times higher in Japan. The average energy use per passenger kilometer for cars in the US is about 15 per cent lower for buses and 17 per cent higher for rails. The fact that buses and rails are not always carbon-efficient modes when then occupancy rate is quite low is manifested in the US. However, if car trips are transferred to buses and rails, these trips are mostly accommodated by increasing the occupancy rate on existing mass transit services. It hardly entails additional emissions, such as the case if bus and rail trips are transferred to cars (Potter, S., 2003, Wee, B.V., *et al.*, 2005).

The question of how many passengers can be transferred from cars to buses and rails if policy measures are taken arises. Compared with the literature on own price (direct) elasticity of car or bus/rail travel demand, the literature on elasticity with respect to other prices (cross price elasticity) is not abundant and likely to vary according to the context (Hensher, D.A., 2001). TRL showed several cross price elasticity estimates with considerable variance in preceding studies (TRL, 2004). Goodwin, P. gave an average cross elasticity of public transport demand with respect to petrol prices of +0.34 (Goodwin, P., 1992). Jong, G.D., *et al.* also gave an average cross elasticity of public transport trips with respect to fuel price and car time of +0.33 and +0.27 in short term and +0.07 and +0.15 in long term (Jong, G.D., *et al.*, 2001).

The literature on actual ridership of new rail passengers that changed from cars is also limited. A monitoring study of Manchester indicated that about 11 per cent of the passengers on the light rail would have otherwise used their cars for their trips (Mackett, R.L., *et al.*, 1998), while a Japanese study of four domestic rails and monorails showed that 10 to 30 per cent of passengers on these modes were diverted from car mode. The majority of the passengers were transferred from alternative bus and rail routes (JMLIT and IHE, 2004). TRL contained international evidence of diversion rates from car to new urban rail ranging from 5 to 30 percent. These diversion rates are partly determined by car mode share so that the rates in the US and Australia are higher than in Europe (Booz Allen Hamilton, 1999 cited in TRL, 2004). It is also known that patronage of metros for cities in developing world has been drawn almost exclusively from existing public transport users or through generation effects (Fouracre, P., *et al.*, 2003).

The development of new rails is an effective measure for diverting car users to carbon-efficient mode while providing existent public transport users with upgraded service. Public transport is also considered favorably from a socially sustainable point of view because it gives higher mobility to the people who do not have access to a car. However, a major hurdle is higher capital and possibly operating cost of the project. During the 1990s, less capital-intensive public transport projects such as light rail transit (LRT) were planned and constructed worldwide. The projects reached ridership target in some European cities and others (Hylen, B., *et al.*, 2002), but less than expected in most US cities (Richmond, J., 2001) where more attention has been paid to bus rapid transit (BRT) recently.

The concept of BRT is not new. Plans and studies for various BRT type alternatives have been prepared since the 1930s, although there has been a greater emphasis on BRT in recent years than ever before (Levinson, *et al.*, 2002). BRT is “a mass transit system using exclusive right of way lanes that mimic the rapidity and performance of metro systems but utilizes bus technology rather than rail vehicle technology” (Wright, 2004). To achieve high level of quality, BRT systems tend to focus on an array of features that enable a city to transform a standard bus service into a mass transit system. These features include (Wright, 2004): exclusive right of way lanes, reformed business and institutional structures, rapid boarding and alighting, free transfers between routes, pre-board fare collection and fare verification, enclosed stations that are safe and comfortable, clear route maps, signage and real-time information displays, modal integration at stations and terminals, clean vehicle technologies and excellence in marketing and customer service. Most BRT systems today are being delivered in the range of US$1–15 million/km, depending upon the capacity requirements and complexity of the project. By contrast, elevated rail systems and underground metro systems can cost from US$50 million to over US$200 million/km (Wright, 2004).

BRT systems now operate in many cities throughout North America; about 20 BRT systems are in service, under construction, or in planning in the United States and Canada (Levinson, *et al.*, 2002).

The projects implemented throughout the United States will be part of a formal data collection and evaluation effort designed to document operational impacts on ridership, travel times, costs, service effectiveness, and customer perception and acceptance (Arrillaga, B., 2002). BRT systems are in service in Europe, Latin America, Australia, New Zealand and Asia. However, it is uncertain if this system can reach the main developing world cities with the same level of quality as Bogota or Curitiba. Jakarta, with kind support of Bogota, opened BRT in 2004 and it reached 49,000 per day ridership, 20 per cent of which had switched from private motorized transport (Ernst, J.P., 2005). Although international support has occurred through the German Overseas Technical Agency (GTZ), the US Agency for International Development (USAID), and The World Bank there has been relatively little project activity to address emissions from the transport sector.

The prospect for the reduction in CO_2 emissions by switching from cars to non-motorized transport (NMT) such as walking and cycling is dependent on local conditions. In The Netherlands, where 47 per cent of trips are made by NMT, the NMT plays a substantial role up to distances of 7.5 kilometers and walking up to 2.5 kilometers (Rietveld, P., 2001). As more than 30 per cent of trips made in cars in Europe cover distances of less than 3 kilometers and 50 per cent are less than 5 kilometers (EC, 1999), NMT can possibly reduce car use in terms of trips and, to a lesser extent, in terms of kilometres. While substitution between NMT, as main transport mode, and public transport is stronger than between NMT and the car is noteworthy, complementarity between NMT, as feeder transport mode, and public transport is also significant. The modal share of bicycle and walking for access mode at the home end of trips by train is about 35 to 40 per cent and 25 per cent respectively in The Netherlands (Rietveld, P., 2001).

Walking and cycling is dependent on local built environment (ECMT, 2004a, Lee, C. *et al.*, 2006). While, in Denmark where modal share of cycling is 18 per cent, the importance of urban planning to ensure journey distances are short is emphasized in guidance on cycling (Page, M., 2005), the provision of better cycling infrastructure such as bike lanes would certainly help (Dill, J., *et al.*, 2003). Also, safety concerns must be eliminated from the viewpoint of social sustainability by traffic engineering and public awareness promotion. NMT users have a much higher risk per trip of being involved in an accident than those using cars, especially in developing countries where most NMT users cannot afford to own a car (Mohan, D., *et al.*, 1999). As of feeder transport mode to public transport, in the UK where over 60 per cent of people live within a 15 minute bicycle ride of a station, convenient, secure bicycle parking at stations and improved bicycle carriage on trains are proposed in addition to the measures mentioned above (ECMT, 2004a).

There is important worldwide mitigation potential if public transport and NMT share loss is reversed. The challenge is to improve public transport systems in order to preserve or augment the market share of low-emitting modes. If public transport gets more passengers, it is possible to increase the frequency of departures, which in turn may attract new passengers and so on (Akerman and Hojer, 2006). Wright and Fulton (2005) estimated that a 5% increase in Bus Rapid Transit (BRT) mode share against a 1% mode share decrease of private automobiles, taxis and walking, plus a 2% share decrease of mini-buses can reduce CO_2 emissions by 4% at an estimated cost of 66 USD/tonCO_2, in typical Latin American cities. A 5 per cent or 4 per cent increase in walking or cycling mode share in the same scenario analysis can also reduce CO_2 emissions by 7 per cent or 4 per cent at an estimated cost of 17 or 15 USD/tonCO_2, respectively. Although the assumptions of a single infrastructure unit cost and its constant impact on modal share in the analysis might be too simple, even shifting relatively small percentages of mode share to public transport or NMT can be worthwhile, because of the relative sensitivity of emission reductions from small changes in motorized mode share. In any case, it is noted that since share of trips by walking, by cycling and by public transport is 50 per cent or higher in European, Asian, African and Latin American cities, even maintaining the current proportion is quite important (Vivier, J., 2001).

Modal shift in freight transportation from trucking to rail, inland waterways and short sea shipping could decrease GNG and other pollutants emissions. Inter-modality promotion, i.e. the combination of these modes with road transport at both ends of the transport chain, would be a way to achieve such a shift. It is part of the EU policy of containing pollution and congestion on the road networks (European Commission, White Paper: European Transport Policy for 2010, 2001). As of now, it is difficult to ascertain the effect of this relatively new policy as its implementation requires many different changes that can only be realised over time, mainly: an improvement of the railways' efficiency through modernization of many equipments, new infrastructures and market liberalization; changes towards more efficient management focusing on users' needs and a better organization of the full transport chains with several modes or operators; standardization of equipments, infrastructures and administrative processes within the EU, plus social cost pricing.

Actually, the Commission's hope was only to maintain the road market share at its level around 2001, rather than at a projected further increased level. At this point, this outcome does not look realistic, as road transport still increases its share as against rail and inland waterways (Eurostat, http://epp.eurostat.cec.eu.int). Nevertheless, in The Netherlands and the United Kingdom, in the forefront of rail liberalisation, the rail market shares have been increasing over the last ten years. On the other hand, in the East European countries, which relied much on rail transports in the past, the institutional changes and modernization presently lead to a rapid increase of road transports. Altogether, the road market share with respect to transported tkm in 2004 is estimated at 44.3 % in EU-25, whereas sea (domestic/intra-EU-25) obtains 39.0% and rail and inland waterways only10.0 and 6.8%, respectively. These numbers can be contrasted with the modes' shares in the US: 31% to trucking, 39.4% to railways and 15.1% to sea and inland waterways in 2003 (see Figure 5.19). Naturally, the modes' performance depends in each region on geographical characteristics and infrastructures. In particular, freight transports by rail are not handicapped in US by the priority given in Europe to passenger rail transport or by electrical catenaries that forbid double stacking of containers. Nevertheless, the contrast between the US and EU figures indicates that there is some hope for better balanced modal shares in Europe, and the fact is that more attention has been given recently to alternative transport solutions by governments, port and maritime operators, as well as industrial and transport firms in view of the road networks increasing congestion and a better understanding of ecological issues.

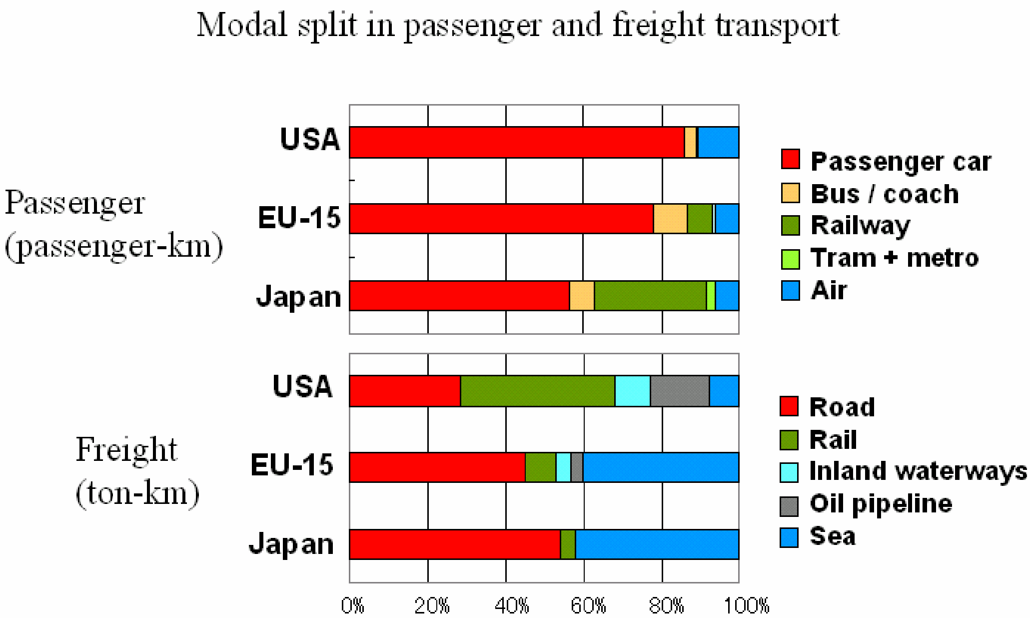


Figure 5.19: *Modal split in passenger and freight transport*

How much could be achieved in the longer run by a voluntary policy of modal shift is subject to controversy, and empirical evidence in the literature is sparse and few, particularly on cross price elasticity. Abdelwahab W.M. (1998), on US survey data, obtained direct price elasticities of demand for rail and trucking transports generally superior to one in absolute value and as high as 2 for some commodities; the estimated cross-price elasticities are of the same magnitude. Beuthe M. et al. (2001) obtained through a spatial network analysis of Belgian freight traffic a full set of demand elasticities: in absolute values, 1.21 for road, 1.25 for rail and 1.72 for inland waterways transports. These are aggregate values over all types of commodities, but there is some dispersion according to the types of commodity. The cross demand elasticities with respect to road cost were rather strong, 2.03 for rail and 1.75 for inland waterways. In a case study on containers' transport, Blauwens et al. (2006) have also shown that the impact on total logistic costs of some trucking cost increase, rail cost decrease and lead time reduction of rail and barge transport could induce significant modal shifts from road transport.

Again, these results indicate that there is some potential for modal shift, provided that adequate service is provided. The quality and convenience of transport services indeed are important factors as shown by W. Abdelwahab (1998), A.V.Deardorff(2005), L.Tavasszy and N. Bruzelius (2005), and also Beuthe M. et al. (2005). Competitive pressures can lead to much improvement on that score, by a better management of operations, vehicle fleet and transport flows, and a focus on customers' demand as to speed, reliability of delivery, and tracking of transports. New and improved infrastructures also can help to improve the services' quality by providing better connection between networks and enlarging links characterized by bottlenecks connection. However, infrastructure projects are often extremely costly, and, in view of the high opportunity cost of funds, rigorous social cost-benefit analysis of projects, including assessment of all externalities, should be realised to validate such projects.

Urban transport planning (system "land use" efficiency/ traffic calming)

Transport planning must face a wider range of political goals than before, including the reduction in CO_2 emission. Even for that single target, it could take a variety of measures and their combinations. The recent literature gave a comprehensive overview of these measures with several case studies (May, A.D. et al., 2003, Litman, T., 2003, Nakamura, H. et al., 2004), though the transferability of the effectiveness should be carefully examined. Since infrastructure investment, provision of alternatives to automobile, pricing and land use planning are set out elsewhere, the rest of the measures are reviewed selectively.

Employer travel plans, originating from a regulation in Southern California that required employers with 100 or more employees to make a travel plan for reducing the number of single occupancy vehicles (Giuliano, G. et al., 1993), were sustained in several countries and regions. The State of Washington in the US kept a state law requiring travel plans in its most urban areas for employers with 100 or more staff. The law reduced the percentage of employees in the targeted organizations who drove to work from 72 to 68 per cent, and affected about 12 per cent of all trips made in the area. In the Netherlands, on average the reduction in single occupant commute trips from a travel plan was about 5 to 15 per cent. In the UK, in very broad terms, the average effectiveness of UK travel plans might be 6 per cent in trips by drive alone to work and 0.74 per cent in the total vehicle-kilometers traveled to work by car. The overall effectiveness was critically dependent on both individual effectiveness and levels of plan take-up (Rye, T., 2002).

Parking supply for employees is so expensive that employers naturally have an incentive to reduce parking demand. The literature found the price elasticity of parking demand for commuting at –0.31 to –0.58 (Deuker, K.J. et al., 1998) and –0.1 to –0.3 (Kuzmyak, R.J. et al., 2003). The State of California enacted legislation that required employers with 50 or more persons who provided parking subsidies to offer employees the option to choose cash in lieu of a leased parking space, in a so-called parking cash-out program. In eight case studies of employers who complied with the cash-out program, the solo driver share fell from 76 per cent before cashing out to 63 per cent after cashing out, leading to the reduction in vehicle-kilometers for commuting by 12 per cent If all the commuters who park free in easily cashed-out parking spaces were offered the cash option in the US, it would reduce 6.3 billion vehicle kilometers traveled per year (Shoup, D.C., 1997).

Reducing car travel or CO_2 emissions by substituting telecommuting for actual commuting has been often cited in the literature, but the empirical results were limited. In the US, a micro-scale study estimated 1.5 per cent of the total workforce telecommuted on any day, eliminating at most 1 per cent of total household vehicle-kilometers traveled (Mokhtarian, P.L., 1998), while a macro-scale study suggested telecommuting reduced annual vehicle kilometers on the order of 0.8 per cent (Choo, S., et al., 2005).

Aviation potential practices

The operational system for aviation is principally governed by air traffic management constraints. If aircraft were to operate optimally, the following constraints would be modified: taxi-time would be minimized; aircraft would fly at their optimum cruising altitude (for load and mission distance); aircraft would fly minimum distance between departure and destination (i.e. great circle distances) but modified to take account of prevailing winds; no holding/stacking would be applied. All these operational constraints would minimize fuel usage, and hence CO_2 emissions.

Another type of operational system/mitigation potential is to consider the total climate impact of aviation. Such studies are in their infancy but were the subject of a major European project 'TRADEOFF'. In this project, different methods were devised to minimize the total radiative forcing impact of aviation; in practice, this implies varying the cruise altitudes as O_3 formation, contrails (and presumably cirrus cloud enhancement) are all sensitive to this parameter. For example, Fichter *et al.* (2005) found in a parametric study that contrail coverage could be reduced by approximately 45% by flying the global fleet 6,000 feet lower but at a fuel penalty of 6% compared with a base case. Williams *et al.* (2003) also found that regional contrail coverage was reduced by flying lower with a penalty on fuel usage. By flying lower, NO_x emissions tend to increase also but the removal rate of NO_x is more efficient at lower altitudes: this, compounded with a lower radiative efficiency of O_3 at lower altitudes meant that flying lower could also imply lower O_3 forcing (Grewe *et al*., 2002). Impacts on cirrus cloud enhancement cannot currently be modelled in the same way, since current estimates of aviation effects on cirrus are rudimentary and based upon statistical analyses of air traffic and satellite data of cloud coverage (Stordal *et al*., 2005) rather than modelling. However, as Fichter *et al*. (2005) note, to a first order, one might expect aviation-induced cirrus cloud to scale with contrails. The overall 'tradeoffs' are rather complex to analyse since CO_2 forcing is long-lasting, being an integral over time. Moreover, the uncertainties on some aviation forcings (notably contrail and cirrus) are still rather high, such that the overall radiative forcing consequences of changing cruise altitudes need to be considered as a time-integrated scenario, which has not yet been done. However, if contrails prove to be worth avoiding, then such drastic action of reducing all aircraft cruising altitudes need not be done, as pointed out by Mannstein *et al*. (2005), since contrails can be rather easily avoided – in principal – by changing one flight level when conditions of ice supersaturation and temperature will tend to contrail formation. However, this more finely-tuned operational change would not necessarily apply to O_3 formation as the magnitude is a continuous process rather than the case of contrails that are either short-lived or persistent. Further intensive research of the impacts is required to determine whether such operational measures can be environmentally beneficial.

ATM (Air Traffic Management) Environmental Benefits

The goal of RVSM is to reduce the vertical separation above flight level (FL) 290 from the current 2000-ft minimum to 1000-ft minimum. This will allow aircraft to safely fly more optimum profiles, gain fuel savings and increase airspace capacity. The process of safely changing this separation standard requires a study to assess the actual performance of airspace users under the current separation (2000-ft) and potential performance under the new standard (1000-ft). In 1988, the ICAO Review of General Concept of Separation Panel (RGCSP) completed this study and concluded that safe implementation of the 1000-ft separation standard was technically feasible

A Eurocontrol study tested the hypothesis that the implementation of RVSM(Reduced Vertical Separation Minimum) would lead to reduced aviation emissions and fuel burn, since the use of RVSM offers the possibility to optimise flight profiles more readily than in the pre-existing ATC regime. RVSM introduces six additional flight levels between FL290 and FL410 for all States involved in the EUR RVSM programme. The study analysed the effect from three days of actual traffic just before implementation of RVSM in the European air traffic control region, with three traffic days immediately after implementation of RVSM. It concluded that the a clear trend of increasing environmental benefit was shown. Total fuel burn, equating to CO_2 and H_20 emissions, was reduced by between 1.6 and 2.3% per year for airlines operating in the European RVSM area. This annual saving in fuel burn translates to around 310,000 tonnes annually, for the year 2003.

Lower Flight Speeds

Speed comes at a cost in terms of fuel burn, although the modern jet aircraft is designed to fly at optimum speeds and altitudes to maximise the efficiencies of their design. Flying slower would be a possibility, but a different engine would be required in order to maximise the efficiencies from such operation. The propfan - this being a conventional gas turbine powering a highly efficient rotating propeller system, as an open rotor or unducted fan - is already an established technology and was developed during the late 1980s in response to a significant increase in fuel cost at the time. The scimitar shaped blades are designed to minimise aerodynamic problems associated with high blade speeds, although one problem created is the noise generated by such devices. The fuel efficiency gains from unducted fans, which essentially function as an ultra high bypass ratio turbofans, are significant, and require the adoption of lower aircraft speeds in order to minimise the helical mach number at the rotating blade tip. Typically the maximum cruise speed would be less than 400 miles per hour, compared with 550mph for conventional jet aircraft. In the event the aero acoustic problem associated with propfans could be overcome, such aircraft might be suitable for short-haul operations where speed has less importance. But there would be the need to influence passenger choice: propeller driven aircraft are often perceived as old fashioned and dangerous, and many passengers are reluctant to use such aircraft.

5.4 Policies and Measures

This section provides policies and measures for the transport sector considering experiences of countries and regions in achieving both energy savings (and hence GHG reduction) and sustainable transport systems. An overall policy consideration at national level and international level is presented in Chapter 13.

The policies and measures that have been considered in this section that are commonly applied for the sector and can be effective are:

- Fiscal measures (Pricing, Taxes and charges; Transport subsidies)
- Regulatory instruments (Traffic management, control and standards)
- Emission Reduction Agreements (Kyoto flexible mechanisms and other initiatives)

This section discusses climate policies related to GHG from international bunkers (aviation and shipping) separately, reflecting the international coordination that is required for effective reduction strategies in these sectors.

5.4.1 Surface transport

5.4.1.1 Urban and transport planning.

Energy use for urban transport is determined by a number of factors, not the least of which is the location of employment and residential locations. Urban planning can have a large impact on transport energy use, while urban transport planning can have an effect on the location of businesses and commerce, and where people choose to live (Karekezi *et al.*, 2003). In recent decades, most cities have been rapidly increasing their dependence on the automobile with a corresponding decrease in the significance of public transport. This has led many cities, in both developed and developing countries, into difficult environmental, social and even economic problems. Urban and transport planning and policy have placed more weights on sustainable development. The policy objectives are often reflected in indicators, such as public transport ridership and non-motorized transport mode use (Miller,1994). All the while cities have been expanding their road infrastructure in an effort to keep a step ahead of traffic growth and congestion or to relieve existing congestion, but with little success (Kenworthy *et al.*, 2002). The limitation of the ‘predict and provide’ approach had repeatedly been discussed during the 1990s (the Royal Commission on Transport and the Environment, 1994, Goodwin, 1999).

Better coordination of land use and transport planning is one of the alternative ways. There are examples of successfully integrated land use and transport planning, such as the Stockholm and the Portland metropolitan area cases (Lundqvist, 2003, Abbott, 2002). They mostly direct denser, more mixed-use and compact land use development coupled with better public transport access in order to minimize auto dependence. Aside from evaluation whether the Portland metropolitan area is winning its war on urban sprawl, an antonym of compact development (Song *et al.*, 2004), the policy has received much controversy especially in the US (Gordon *et al.*, 1997, Ewing, 1997). There are several arguments from that the settlement pattern is largely determined, so changes in land-use are marginal to that there is little evidence that higher densities have much impact on automobile ownership or vehicle kilometres travelled (Richardson *et al.*, 2004). Ewing et al. found that typical elasticity of vehicle miles travelled with respect to local density is -0.05 (Ewing *et al.*, 2001), while Pickrell noted that reduction in auto use become significant only at densities of 10,000 people or more per square mile - densities unlikely observed in US suburbs (Pickrell, 1999), but often reached somewhere else (Newman, *et al.*, 1999). Coordinated transport and land use methods might have greater benefits in the developing world where dense mixed land use is prevailing and car ownership rate is low. Curitiba is a prime example of coordinated citywide transportation and land-use planning (Gilat *et al.* 2003).

Institutionalizing planning systems for the reduction in CO_2 is likely to bring in a significant effect, though it is hard to evaluate quantitatively. Many countries allocate the majority of responsibility for urban and transport policies to regions and municipalities because local governments offer the advantage of exploiting detailed local knowledge. On the other hand, there is growing recognition that National Government's role can be a deterministic factor in bringing about sustainability in urban areas, preventing local government's undesirable efforts to attract business in certain areas by offering derogations to planning requirements. The typical example is proliferation of large out-of-town shopping malls, major generators of traffic. The National Government's roles include establishing a broad, sectorally integrated policy framework for regions and cities to build on, and sending the right messages via targeted policy guidelines/incentives and project financing for sustainable development to regions and cities. Institutional interaction between national and local governments is also important for drawing up common strategies for less sustainable transport in tandem (ECMT, 2002, ECMT, 2004b)

Investment appraisal is an important issue in transport planning and policy. The most widely applied appraisal technique in transport is the cost-benefit analysis (CBA) (Nijkamp *et al.*, 2003). In CBA, the cost of CO_2 emissions can be indirectly included in the vehicle operating cost or directly counted at an estimated price, but some form of robustness testing is useful in the latter case. Alternatively, the amount of CO_2 emissions is listed on an appraisal summary table of Multi Criteria Analysis (MCA) as a part of non-monetized benefits and costs (Mackie *et al.*, 2001, Grant-Muller *et al.*, 2001, Forkenbrock *et al.*, 2001, JSGRIE, 2000). To the extent that the cost of CO_2 emissions has a relatively important weight in these assessments, they may avoid investments in unnecessarily carbon-intensive projects. Strategic CBA can further make transport planning and policy carbon-efficient by extending CBA to cover multi-modal investment alternatives, while Strategic Environmental Assessment (SEA) can accomplish it by including multi-sector elements. (ECMT, 2000, ECMT, 2004b).

5.4.1.2 Transport Demand Management

Transport Demand Management (TDM) consists of measures to improve performance of roads by reducing traffic volumes (Litman, 2003). There are many potential TDM strategies with a variety of impacts. Some improve transportation diversity (the travel options available to users). Others provide incentives for users to reduce driving, changing the frequency, mode, destination, route or timing of their travel. Some reduce the need for physical travel through mobility substitutes or more efficient land use. Some involve policy reforms to correct current distortions in transport planning practices. TDM is particularly appropriate in developing country cities, because of its low costs and multiple benefits. In many cases, effective TDM during early stages of development can avoid problems that would result if communities become too automobile dependent. This can help support a developing country's economic, social and environmental objectives (Gwilliam *et al.*, 2004). (See also 5.7)

TDM includes more than three dozen strategies. The set of strategies to be implemented will vary depending on each country's demographic, geographic and political conditions. TDM strategies can have cumulative and synergetic impacts, so it is important to evaluate a set of TDM programs as a package, rather than as an individual program. Effective strategies usually include a combination of positive incentives to use alternative modes ("carrots" or "sweeteners") and negative incentives to discourage driving ("sticks" or "levelers"). The recent literature gave a comprehensive overview of these programs with several case studies (May et al., 2003, Litman, 2003, WCTRS and ITPS, 2004). Since infrastructure investment, provision of alternatives to automobile, pricing and land use planning are set out elsewhere, the rest of the programs are reviewed selectively.

Employer travel plans, originating from a regulation in Southern California that required employers with 100 or more employees to make a travel plan for reducing the number of single occupancy vehicles (Giuliano *et al.*, 1993), were sustained in several countries and regions. The State of Washington in the US kept a state law requiring travel plans in its most urban areas for employers with 100 or more staff. The law reduced the percentage of employees in the targeted organizations who drove to work from 72 to 68 per cent, and affected about 12 per cent of all trips made in the area. In the Netherlands, on average, the reduction in single occupant commute trips from a travel plan was about 5 to 15 per cent. In the UK, in very broad terms, the average effectiveness of UK travel plans might be 6 per cent in trips by drive alone to work and 0.74 per cent in the total vehicle-kilometers traveled to work by car. The overall effectiveness was critically dependent on both individual effectiveness and levels of plan take-up (Rye, 2002).

Parking supply for employees is so expensive that employers naturally have an incentive to reduce parking demand. The literature found the price elasticity of parking demand for commuting at –0.31 to –0.58 (Deuker *et al.*, 1998) and –0.1 to –0.3 (Kuzmyak *et al.*, 2003). The State of California enacted legislation that required employers with 50 or more persons who provided parking subsidies to offer employees the option to choose cash in lieu of a leased parking space, in a so-called parking cash-out program. In eight case studies of employers who complied with the cash-out program, the solo driver share fell from 76 per cent before cashing out to 63 per cent after cashing out, leading to the reduction in vehicle-kilometers for commuting by 12 per cent If all the commuters who park free in easily cashed-out parking spaces were offered the cash option in the US, it would reduce 6.3 billion vehicle kilometers traveled per year (Shoup, 1997).

Reducing car travel or CO_2 emissions by substituting telecommuting for actual commuting has been often cited in the literature, but the empirical results were limited. In the US, a micro-scale study estimated 1.5 per cent of the total workforce telecommuted on any day, eliminating at most 1 per cent of total household vehicle-kilometres travelled (Mokhtarian, 1998), while a macro-scale study suggested telecommuting reduced annual vehicle kilometres 0 to 2 per cent (Choo *et al.*, 2005).

Reduction of CO_2 emissions by hard measures, such as car restraint, often faces public opposition even when the proposed measures prove effective. Soft measures, such as a provision of information and use of communication strategies and educational techniques (OECD, 2004a) can be used for supporting the promotion of hard measures. Soft measures can also be directly helpful in encouraging a change in personal behaviour leading to an efficient driving style and reduction in the use of the car (Jones, 2004). Well-organized soft measures were found to be effective for reducing car travel while maintaining a low cost. Following travel awareness campaigns in the UK, the concept of Individualized Marketing, a program based on a targeted, personalized, customized marketing approach, was developed and applied in several cities for reducing the use of the car. The program reduced car trips by 14 per cent in an Australian city, 12 per cent in a German city and 13 per cent in a Swedish city. The Travel Blending technique was a similar program based on four special kits for giving travel feedback to the participants. This program reduced vehicle-kilometres traveled by 11 per cent in an Australian city. The monitoring study after the program implementation in Australian cities also showed that the reduction in car travel was maintained (Brog *et al*., 2004, Tayler *et al.,* 2003). Japanese cases of travel feedback programs supported the effectiveness of soft measures for reducing car travel. The summary of the travel feedback programs in residential areas, workplaces and schools indicated that car use was reduced by 12 per cent and CO_2 emissions by 19 per cent. It also implied that the travel feedback programs with a behavioral plan requiring a participant to make a plan for a change showed better results than programs without one (Fujii *et al.,* 2005).

5.4.1.3 Fuel economy standards - road transport

Most industrialized nations now impose fuel economy requirements (or their equivalent in CO_2 emissions requirements) on new light-duty vehicles. The first standards were imposed by the United States in 1975, requiring 27.5 mpg (8.55l/100km) corporate fleet averages for new passenger cars and 20.7 mpg (11.36l/100km) for light trucks (based on tests instituted by the U.S. Environmental Protection Agency, using the "CAFE" driving cycle) by 1985; the passenger car standard remains unchanged, whereas the light truck standard has recently been increased to 22.2 mpg (10.59l/100km) for the 2007 model year. Additional standards include:

- European Union: a 2008 fleetwide requirement[18] of 140 grams CO_2 per kilometre, about 41 mpg (5.74l/100km) of gasoline equivalent, using the New European Driving Cycle (NEDC), based on a Voluntary Agreement between the EU and the European, Korean, and Japanese manufacturers.
- Japan: a 2010 target of about 35.5 mpg (6.6l/100km) for new gasoline passenger vehicles, using the Japan 10/15 driving cycle based on weight-class standards.
- China: fleet targets of about 30.4 mpg (7.7l/100km) by 2005 and 32.5 mpg (7.2l/100km) by 2008 using the NEDC driving cycle, based on weight-class standards that are applied to each new vehicle.
- Australia: a 2010 target for new vehicles of 18% reduction in average fuel consumption relative to the 2002 passenger car fleet, corresponding to 6.8 l/100km, or 34.6 mpg. (DfT, 2003a), based on a voluntary agreement between industry and government.
- The State of California has established greenhouse gas emission standards for new light-duty vehicles designed to reduce per-vehicle emissions by 22% in 2012 and 30% by 2016. Several U.S. states have decided to adopt these standards, as well. At the time of this writing, the U.S. industry was fighting these standards in the courts.

The NEDC and Japan 10.15 driving cycles are slower than the U.S. CAFE cycle, and, for most vehicles (though probably not for hybrids), will yield lower measured fuel economy levels than the CAFE cycle for the same vehicles. Consequently, the EU, Japanese, and Chinese fleets are likely to achieve fuel economies higher than implied by the values above if measured on the U.S. test. A suggested correction factor (for the undiscounted test results) is 1.13 for the EU and China and 1.35

[18] For the entire new light-duty vehicle fleet; there are no specific corporate requirements.

for Japan (An and Sauer, 2004), though these are likely to be at the high end of the possible range of values for such factors.[19] Figure 5.20 shows the "corrected" comparison of standards.

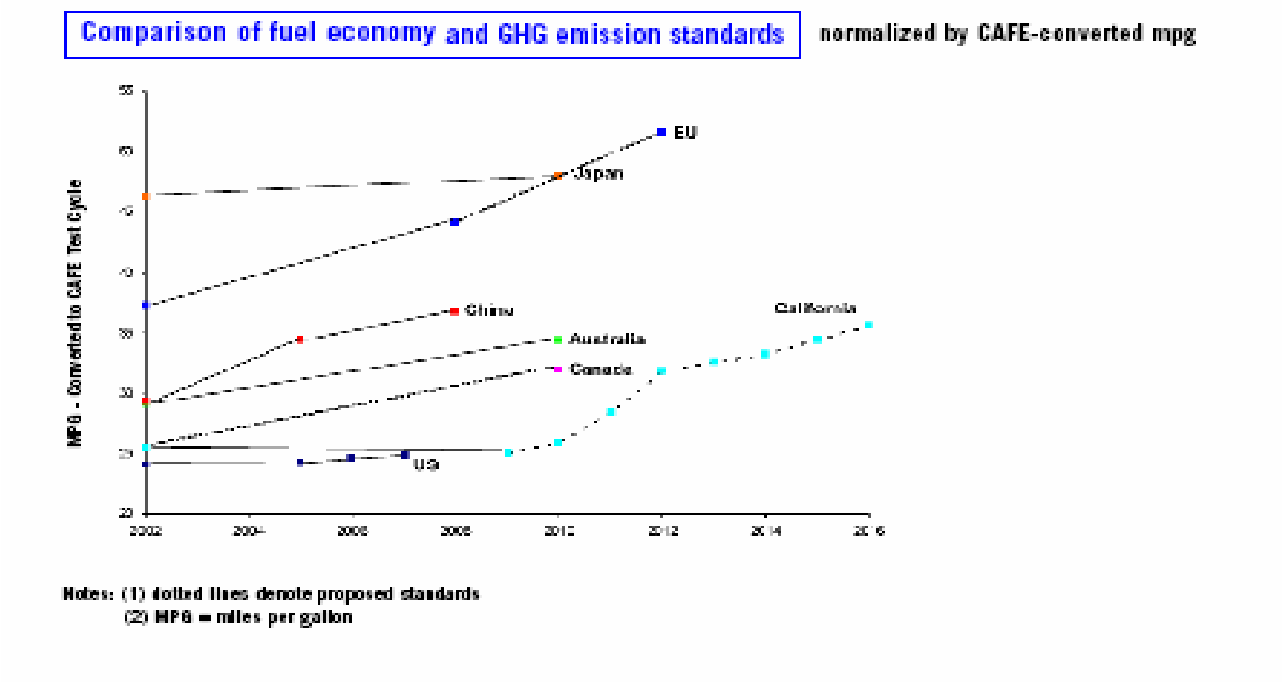


Figure 5.20: *Fuel economy and GHG emission standards*

Recent studies of the costs and fuel savings potential of technology improvements demonstrate considerable opportunity to achieve further fleet fuel economy gains from more stringent standards. For example, the U.S. National Research Council(NRC, 2002) estimates that U.S. light-duty vehicle fuel economy can be increased by 25 to 33% within 15 years with existing technologies that cost less than the value of fuel saved. A study by Ricardo Consulting Engineers for the UK Department for Transport (Owen and Gordon, 2002) develops a step-wise series of improvements in a baseline diesel passenger car that yields a 38% reduction in CO_2 emissions (a 61% increase in fuel economy), to 92 g/km, by 2013 using parallel hybrid technology at an incremental cost of £2,300-£3,100 (with a £15,300 baseline vehicle). Even where fuel savings will outweigh the cost of new technologies, however, the market will not necessarily adopt these technologies by itself (or achieve the maximum fuel economy benefits from the technologies even if they are adopted). Two crucial deterrents are, first, that the buyers of new vehicles tend to consider only the first three years or so of fuel savings (NRC, 2002; Annema, 2001), and second, that vehicle buyers will take some of the benefits of the technologies in higher power and greater size rather than in improved fuel economy. Further, potential benefits for consumers over the vehicle's lifetime generally are small, while risks for producers are high (Greene, D.L., 2005). Also, neither the purchasers of new vehicles nor their manufacturers will take into account the climate effects of the vehicles.

Strong criticisms have been raised about fuel economy standards, particularly concerning adverse safety implications of weight reductions supposedly demanded by higher standards and increased driving caused by the lower fuel costs (per mile or kilometer) associated with higher fuel economy.

[19] These values are derived by simulating U.S. vehicles running on the CAFE, NEDC, and Japan 10.15 cycles and comparing their estimated fuel economies. Because automakers design their vehicles to do well on the cycles on which they will be tested, the U.S. vehicles are likely to do a bit worse on the NEDC and Japan 10.15 cycles than they would have had they been designed for those cycles….exaggerating somewhat the estimated differences between the cycles in their effects on fuel economy.

The safety debate is complex and not easily summarized. Although there is no doubt that adding weight to a vehicle improves its safety in some types of crashes, it does so at the expense of other vehicles; further, heavy light trucks have been shown to be no safer than, and in some cases less safe than lighter passenger cars, primarily because of their high rollover risk (Ross, Patel, and Wenzel, 2006). The U.S. National Highway Traffic Safety Administration has claimed that fleetwide weight reductions *reduce* fleet safety (Kahane, 2003), but this conclusion is strongly disputed (DRI, 2004 NRC, 2002). An important concern with the NHTSA analysis is that it does not separate the effects of vehicle weight and size. In any case, other factors, e.g. overall vehicle design and safety equipment, driver characteristics, road design, speed limits, and alcohol regulation and enforcement play a more significant role in vehicle safety than does average weight.

Some have argued that increases in driving associated with reduced fuel cost per mile will nullify the benefits of fuel economy regulations. Increased driving *is* likely, but it will be modest and decline with higher income and increased motorization. Recent data imply that a driving "rebound" would reduce the greenhouse gas reduction (and reduced oil consumption) benefits from higher standards by about 10% in the United States (Small and Van Dender, 2004) – and less in the future – but more than this in less wealthy and less motorized countries.

In deciding to institute a new fuel economy standard, governments should consider the following:

1. Basing stringency decisions on existing standards elsewhere requires careful consideration of differences between the home market and compared markets in fuel quality and availability; fuel economy testing methods; types of and sizes of vehicles sold; road conditions that may affect the robustness of key technologies; and conditions that may affect the availability of technologies, for example, availability of sophisticated repair facilities.
2. There are a number of different approaches to selecting stringency levels for new standards. Japan selected its weight class standards by examining "top runners" – exemplary vehicles in each weight class that could serve as viable targets for future fleetwide improvements. Another approach is to examine the costs and fuel saving effects of packages of available technologies on several typical vehicles, applying the results to the new vehicle fleet (NRC, 2002). Other analyses have derived cost curves (% increase in fuel economy vs. technology cost) for available technology and applied these to corporate or national fleets (Plotkin, Greene, and Duleep, 2002). These approaches are not technology-forcing, since they focus on technologies that have already entered the fleet in mass-market form. More ambitious standards could demand the introduction of emerging technologies. Selection of the appropriate level of stringency depends, of course, on national goals and concerns. Further, the selection of enforcement deadlines should account for limitations on the speed with which vehicle manufacturers can redesign multiple models and introduce the new models on a schedule that avoids severe economic disruption.
3. The structure of the standard is as important as its level of stringency. Basing target fuel economy on vehicle weight (Japan, China) or engine size (Taiwan, South Korea) will tend to even out the degree of difficulty the standards impose on competing automakers, but will reduce the potential fuel economy gains that can be expected (because weight-based standards eliminate weight reduction and engine-size-based standards eliminate engine downsizing as viable means of achieving the standards). Basing the standard on vehicle wheelbase times track width may provide safety benefits by providing a positive incentive to maintain or increase these attributes. Using a uniform standard for all vehicles or for large classes of vehicles (as in the U.S.) is simple and easy to explain, but creates quite different challenges on different manufacturers depending on the market segments they focus on.

4. Allowing trading of fuel economy "credits" among different vehicles or vehicle categories in an automaker's fleet, or even among competing automakers, will reduce the overall cost of standards without reducing the total societal benefits, but may incur political costs from accusations of allowing companies or individuals to "buy their way out" of efficiency requirements.
5. Alternatives (or additions) to standards are worth investigating. For example, "feebates," which award cash rebates to new vehicles whose fuel economy is above a designated level (often the fleet average) and charge a fee to vehicles with lower fuel economy, may be an effective market-based measure to increase fleet fuel economy. An important advantage of feebates is that they provide a *continuous* incentive to improve fuel economy, because an automaker can always gain a market advantage by introducing vehicles that are more efficient than the current average.

5.4.1.4 Taxation and pricing

Transport pricing is defined as influencing the purchase, the possession or the use of a vehicle. Typically applied to road transport are measures such as fuel pricing and taxation, vehicle license/registration fees, annual circulation taxes, tolls and road charges and parking charges. Table 5.7 presents an overview of examples of taxes and pricing measures that have been applied in some developing and developed countries.

Table 5.7: *Taxes and pricing in the transport sector in developing and developed countries*

Instrument	Developing Countries/EIT	Developed countries
Tax incentives to promote use of Natural gas	Pakistan, Argentina, Colombia, Russia	Italy, Germany, Australia, Ireland, Canada, UK;Belgium
Incentives to promote natural gas vehicles	Malaysia, Egypt	Belgium, UK, USA, Australia, Ireland
Annual Road tax differentiated by vintage	Singapore and India (fixed span and scrapping)	Germany
Emission Trading	Chile	
Congestion Pricing including Area Licensing Scheme; vehicle registration fees; annual circulation tax	Chile; Singapore	Norway; Belgium
Vehicle Taxes based on emissions-tax deductions on cleaner cars e.g. battery operated or alternative fuel vehicles	South Korea	Austria, Britain, Belgium, Germany, Japan, The Netherlands, Sweden
Carbon tax by size of engine	Zimbabwe	
Cross subsidization of cleaner fuels (ethanol blending by gasoline tax-through imposition of lower surcharge or excise duty exemption	India	

Source: Adapted from Pandey and Bhardway (2000), Gupta (1999) and European Natural Gas Vehicle Asociation (2002).

Pricing, taxes and charges, apart from raising revenue for governments, are expected to influence travel demand and hence fuel demand and it is on this basis that GHG reduction can be realized.

Transport pricing can offer important gains in social welfare. For the UK, France and Germany together, (OECD, 2003) estimates net welfare gains to society of optimal charges (set at the marginal social cost level) at over € 20 billion a year.

Although the focus here is on transport pricing options to limit CO_2 emissions, it should be recognized that many projects and policies with that effect are not focused on GHG emissions but rather on other objectives. A pricing policy may well aim simultaneously at reducing local pollution and GHG emissions, accidents, noise and congestion, as well as generating State revenue for enlarging of social welfare and/or infrastructure construction and maintenance. Every benefit with respect to these objectives may then be assessed simultaneously through CBA or MCA; they may be called co-benefits. Governments can take these co-benefits into account when considering the introduction of transport pricing such as for fuel. This is all the more important since a project could be not worth realising if only one particular benefit is considered, whereas it could very well be proved beneficiary when adding all the co-benefits.

Taxes

Empirically, throughout the last 30 years, regions with relatively low fuel prices have low fuel economy (US, Canada, Australia) and regions where relatively high fuel prices apply (due to fuel taxes) have better car fuel economy (Japan and European countries). For example, fuel taxes are about 8 times higher in the UK than in the US, resulting in fuel prices that are about three times higher. UK vehicles are about twice as fuel-efficient; mileage travelled is about 20% lower and vehicle ownership is lower as well. This also results in lower average per capita fuel expenditures. Clearly, automobile use is sensitive to cost differences in the long run (VTPI, 2005). Typically, long run impact of increases in fuel prices on fuel consumption are about 2 to 3 times greater than short run impact (VTPI, 2005). Based on the price elasticities of Goodwin et al. (2004), the reduction on fuel consumption as a result of a permanent increase in the real fuel prices was found to be up to 2.5% in the short term and 6% in the long term (Table 5.8).

Tabele 5.8: *Impact of a permanent increase in real fuel prices by 10%*

	Short run (within 1 year)	Long run (5 years)
Traffic volume	-1%	-3%
Fuel consumption	-2.5%	-6%
Vehicle fuel efficiency	-1.5%	-4%
Vehicle ownership	Less than -1%	-2.5%

Source: Goodwin, P. J. Dargay and M. Hanly, "Elasticities of Road Traffic and Fuel Consumption with respect to price and income: a Review, Transport Reviews, Vol. 24, No. 3, May 2004, pp 275-292.

As an alternative to fuel taxes, registration and circulation taxes can be used to incentivise the purchase (directly) and manufacturing (indirectly) of fuel-efficient cars. This could be done through a revenue neutral fee bate system, where fuel-efficient cars receive a rebate and guzzler cars are faced with an extra fee. There is evidence that incentives given through registration taxes are more effective than incentives given through annual circulation taxes (Annema et al., 2001). Buyers of new cars do not expect to be able to pass on increased registration taxes when selling the vehicle. Due to refunds on registration taxes for cars that were relatively fuel efficient compared to similar sized cars, the percentage of cars sold in the two most fuel efficient classes increased from 0.3% to 3.2% (cars over 20% more fuel efficient than average) and from 9.5% to 16.1% (for cars between 10 and 20% more fuel efficient than average) in the Netherlands (ADAC, 2005). After the abolishment of the refunds, shares decreased again. COWI (2002) modelled the impact on fuel efficiency of reforming current registration and circulation taxes so they would depend fully on the CO_2 emissions of new cars. Calculated reductions percentages varied from 3.3% to 8.5% for 9 European countries, depending on their current tax bases.

Transport Policy (2005) outlines a voluntary agreement with the Swiss government under which the oil industry took responsibility for greenhouse gas emissions from the road transport sector, which they supply with fuel. As of 1 October 2005, Swiss oil importers voluntarily contribute the equivalent of about 5 cents per gallon (approx. $80 million annually) into a climate protection fund that is invested via a non-profit (non-governmental) foundation into climate mitigation projects domestically and abroad (via the emerging carbon market mechanisms of the Kyoto Protocol). Cost savings (compared with an incentive tax) are huge and the private sector is in charge of investing the funds effectively. A similar system in the USA could generate US$ 9 billion in funds annually to incentivize clean, alternative fuels and energy efficient vehicles, which could lower US dependency on foreign fuel sources. This policy is also credible from a sustainable development perspective than the alternative CO_2 tax, since the high CO_2 tax would have led to large-scale shifts in tank tourism -- and bookkeeping GHG reductions for Switzerland -- although the real reductions would have been less than half of the total effect and neighbouring countries would have been left with the excess emissions.

Licensing and parking charges

The most renowned area licensing and parking charges has been applied in Singapore with effective reduction in total vehicular traffic and hence energy (petroleum) demand (Fwa, 2002). Area licensing scheme in Singapore resulted in 1.043 GJ per day energy savings with private vehicular traffic reducing by 75% (Fwa, 2002).

Unfortunately there is currently lack of data on potential GHG savings associated with Policy, institutional and fiscal reforms/measures with respect to transport particularly in other developing countries. General estimates of reduction in use of private vehicle operators resulting from fuel pricing and taxing is 15-20% (World Bank, 2003; Martin et al, 1995).

Table 5.9: *Potential energy and GHG savings from pricing, taxes and charges for the road transport*

Tax/Pricing Measure	**Potential Energy/ GHG Savings or transport improvements)**	**Reference**
Optimal Road Pricing based on congestion charging (London UK)	37% CO2	Maddison et al 1996
Congestion Pricing of the Namsan Tunnels (Seoul S Korea)	34% reduction of peak passenger traffic volume Traffic flow from 20 to 30km/hr	World bank 2002b
Fuel Pricing and Taxation	15-20% for vehicle operators	Martin et al (1995)
Area Licensing Scheme (Singapore)	1.043GJ/day energy savings Vehicular traffic reduced by 50% Private traffic reduced by 75% Travel speed increased 20 to 33 km/hr	FWA, 2002
Urban Gasoline tax (Canada)	1.4 megatonnes by 2010 2.6 megatonnes by 2020	In the case of Canada (Transportation in Canada, 1999- www.tc.gc.ca/pol/en/Report/anre1999/tc9905be.htm

5.4.1.5 Regulatory and operational measures

Although pricing and fiscal instruments are obvious tool for government policy, they are often not very effective as reflected by the potential reduction in fuel savings (IEA, 2003).
Potential effective (and cost effective) non-fiscal measures that can be effective in an oil crisis are regulatory measures such as

- Lower speed limits on motorways
- High occupancy vehicle requirements for certain roads and networks
- Vehicle maintenance requirements
- Odd/Even number plate and other driving restrictions
- Direct traffic restrictions (e.g. non entry into business district)
- Free/expanded urban public transport
- Encouraging alternatives to travel (e.g. greater telecommuting)
- Emergency switching from road to rail freight
- Reducing congestion through removal of night-time/week-end driving bans for freight

IEA (2003) indicates that such measures could contribute to significant oil savings. This is a typical case where a portfolio of measures is applied together and they would work well with adequate systems of monitoring and enforcement.

For the measures to be implemented effectively considerable preparatory work is necessary and Table 5.10 shows examples of what could be done to ensure the measures proposed above can be effective in oil savings.

Table 5.10 : *Preparations required to implement some regulatory measures*

Measures to be implemented	**Preparatory work**
Speed limits	• Install electronic speed limit system • Change the law
Carpool days	• System of finding rides • Car parks • High occupancy car lanes
Energy efficient car and driving choice from home	• On board efficient indicator systems • Driver training • Information on efficient car purchases
Telecommuting days	• Telecommuting programmes and protocols • Practice
Clean car choice	• Public awareness of car consumption
Car free days	• Biking/walking/transit facilities • Home/job commuting reduced

Source: Adapted from IEA, 2003.

The combined effect of these regulatory measures (in addition to blending non-petroleum fuels with gasoline and diesel) is estimated to be a reduction of 15% of daily fuel consumption targeting light duty vehicles.

In OECD countries vehicles consume 10-20% more fuel per km than indicated by their rated efficiency. It is estimated that 5-10% reduction in fuel consumption can be achieved by stronger inspection and vehicle maintenance programmes, adoption of on board technologies, more widespread driver training and better enforcement and control of vehicle speeds.

Vehicle travel demand can be reduced by 10-15% by aggressively combining infrastructure improvements, intelligent transport technologies and systems (e.g. better routing systems and congestion reduction), information systems and better transit systems in addition to road pricing.

5.4.2 International Bunkers

5.4.2.1 Aviation

Up until now the International Civil Aviation Organization (ICAO) has not been able to agree on any action to ensure effective implementation of mitigation policies aiming at reducing greenhouse gas emissions from international aviation. ICAO continues to study the following policy options: voluntary measures, emission-related levies and emission trading.

At its 35th Session in October 2004, the ICAO Assembly decided not to set up an emission trading system for international aviation under their own auspices (ICAO, 2004). Any initiative to implement new policy measures will be left to the states. This implies that Parties to the UNFCCC or regional organizations (e.g. European Union) have to take the initiative. ICAO would only provide guidance.

An important hurdle for the development of mitigation policies, both at global and regional level, is that international aviation (and marine) emissions are not included in the national inventories and hence excluded from the agreed-on targets under the Kyoto Protocol. Most Parties to the UNFCCC do not feel therefore an incentive to develop or actually implement policy measures to mitigate bunker fuel emissions. Another reason for not expecting global action by ICAO, i.e. specific measures to be implemented by all nations, is the reluctance of developing countries to commit themselves to policies before they see clear leadership from industrialized countries.

IPCC (1999), ICAO/FESG (2004a and b), Wit, et al. (2002 and 2005), Cames and Deuber (2004), Arthur Andersen (2001) and others have examined potential economic instruments for mitigating climate effects from aviation.

At the global level no support exists for the introduction of kerosene taxes. The ICAO policy on exemption of aviation fuel from taxation has been called into question in only some, mainly European, states which impose taxes on fuel used by other transport modes and other sources of greenhouse gases. A study by Resource Analysis (1999) shows that introducing a charge or tax on aviation fuel at a *regional* level for international flights would give rise to considerable distortions in competition and may need amendment of bilateral air service agreements. In addition, the effectiveness of a kerosene tax imposed on a regional scale would be reduced as airlines could take 'untaxed' fuel onboard into the taxed area (so-called tankering effect).

Wit and Dings (2002) analyzed the economic and environmental impacts of En-route emission charges for all flights in European Airspace. Using an scenario-based approach and an assumed charge level of € 30 per tonne of CO_2 and € 3.6 per kg of NO_X emitted, the study found a cut in forecast aviation CO_2 emissions in EU airspace of about 10 Megatonnes (9%) in 2010. This result would accrue partly (50%) from technical and operational measures by airlines the other half from reduced air transport demand. The study found also that an en-route emission charge in European airspace designed in a non-discriminative manner, would have no significant impact on competition between European and non-European carriers.

In its report to CAEP/6, the Forecasting and Economic Analysis Support Group (ICAO/FESG, 2004a) considered the potential economic and environmental impacts of various charges and emission trading schemes. For the period 1998-2010, the effects of a global CO_2-charge with a levy level equivalent to 0.02 \$/kg to 0.50 \$/kg jet fuel show a large range of effect on global CO_2 reduction from 1% to 18% respectively. This effect is mainly caused by demand effects (75%). To conduct the analyses the AERO modeling system was used (Pulles, et al., 2002).

As part of the analysis of open emission trading systems for CAEP/6, an impact assessment was made of different emission trading systems identified in ICF *et al.* (2004). The ICAO/FESG report (2004b) showed that under a Cap-and-Trade system for aviation, total air transport demand will be reduced by about 1% compared to a base case scenario (FESG2010). In this calculation, a 2010 target of 95% of the 1990 level was assumed for aviation on routes from and to Annex-I countries and the more developed non-Annex-I countries such as China, Hong Kong, Thailand, Singapore, Korea and Brazil. Furthermore a permit price of US$20 per tonne of CO_2 was assumed. Given the relative high abatement costs in the aviation sector, this scenario would imply that the aviation sector would buy permits from other sectors for about 3.3 billion US$.

Since ICAO has not been able to agree on mitigation policies to reduce greenhouse gas emissions from international aviation bunker fuels, the European Commission decided to prepare climate policies for aviation. On 27th September 2005, the European Commission adopted a Communication that recommends that aviation emissions should be included in the EU Emissions Trading Scheme (EU ETS). The Commission intends to present a legislative proposal towards the end of 2006. The European Commission is aiming at a model for aviation within emission trading in Europe that can be extended or replicated worldwide. In environmental terms, the most effective option is to cover all flights departing from EU airports, as limiting the scope to "intra-EU" flights which both depart and land in the EU, would address less than 40% of the emissions from all flights departing from the EU. 2004 estimates indicate that intra-EU flights emitted around 52 $MtCO_2$ while all departing flights caused 130 $MtCO_2$ (Wit et al., 2005).

Obviously, in deciding on climate policies for aviation, governments outside the EU may consider to set up a national emission trading system for aviation and other sectors that would be linked to the EU Emissions Trading Scheme (EU ETS). In this way a global system can be developed by using a bottom-up approach.

Governments may also consider alternative policy instruments such as fuel taxation for domestic flights. Fuel for domestic flights, which are less vulnerable for economic distortions, is already taxed in countries such as the USA, Japan, India and the Netherlands. In parallel to the introduction of economic instruments such as emission trading, governments could improve air traffic management (see section 5.4.2.3).

Policies to address the full climate impact of aviation

A major difficulty in developing a mitigation policy for the climate impacts of aviation is how to cover non-CO_2 climate impacts, such as the emission of nitrogen oxides (NO_x)and the formation of condensation trails and cirrus clouds. IPCC (1999) estimated these effects to be about 2 to 4 times greater than those of CO_2 alone, even without considering the potential impact of cirrus cloud enhancement. This means the environmental effectiveness of any mitigation policy will depend on the extent to which these non-CO_2 effects are also taken into account.

Governments may consider different approaches to capture non-CO_2 climate impacts from aviation (Wit et al., 2005). A first possible approach is where initially only CO_2 from aviation is included in for example an emission trading system, but flanking instruments are implemented in parallel such as differentiation of airport charges according to NO_x emissions.

Another possible approach is, in case of emission trading for aviation, a requirement to surrender a number of emission permits corresponding to its CO_2 emissions multiplied by a precautionary average factor reflecting the climate impacts of non-CO_2 impacts. It should be emphasised that the metric that is a suitable candidate for incorporating the non-CO_2 climate impacts of aviation in a single metric that can be used as a multiplier requires further development, being fairly theoretical at present. The feasibility of arriving at operational methodologies for addressing the full climate impact of aviation depends not only on improving scientific understanding of non-CO_2 impacts, but also on the potential for measuring or calculating these impacts on individual flights.

5.4.2.2 Shipping

CO_2 emission indexing scheme

The International Maritime Organisation (IMO), a specialized UN agency, has adopted a strategy with regard to policies and measures, focusing mainly on further development of a CO_2 emission indexing scheme for ships[20] and further evaluation of technical, operational and market-based solutions.

The basic idea behind a CO_2 emission index is that it describes the CO_2 efficiency (i.e. the fuel efficiency) of a ship, i.e. the CO_2 emission per tonne cargo per nautical mile. This index could, in the future, assess both the technical features (e.g. hull design) and operational features of the ship (e.g. speed).

In June 2005, at the 53rd session of the Marine Environment Protection Committee of IMO (IMO/MEPC 23/WP11), interim guidelines for voluntary ship CO_2 emission indexing for use in trials were approved. The Interim Guidelines should be used to establish a common approach for trials on voluntary CO_2 emission indexing, which enable shipowners to evaluate the performance of their fleet with regard to CO_2 emissions. The indexing scheme will also provide useful information on a ship's performance with regard to fuel efficiency and may thus be used for benchmarking purposes. The interim guidelines will later be updated, taking into account experience from new trials as reported by industry, organisations and administrations.

A fair number of hurdles have to be overtaken before such a system could become operational. The main bottleneck appears to be that there is major variation in the fuel efficiency of similar ships, which is not yet well understood (Wit et al., 2004). This is illustrated by research by the German delegation of IMO's Working Group on GHG emission reduction (MEPC 51/INF.2, 2003), in which the specific energy efficiency (i.e. a CO_2 emission index) was calculated for a range of container ships, taking into account engine design factors rather than operational data. The results of this study show that there is considerable scatter in the specific engine efficiency of the ships investigated, which could not be properly explained by the deadweight of the ships, year of build, ship speed and several other ship design characteristics. The paper therefore concludes that the design of any CO_2 indexing scheme, and its differentiation according to ship type and characteristics, requires in-depth investigation. Before such a system can be used in an incentive scheme, the reasons for the data scatter need to be understood. This is a prerequisite for reliable prediction of the economic, competitive and environmental effects of any incentive based on this method.

Voluntary use and reporting results of CO_2 Emission Indexing may not directly result in greenhouse gas emission reductions, although it may well raise awareness and trigger certain initial moves towards 'self regulation'. It might also be a first step in the process of designing and implementing some of the other policy options. Reporting of the results of CO_2 emission indexing could thus generate a significant impetus to the further development and implementation of this index, since it would lead to widespread experience with the CO_2 indexing methodology, including reporting procedure and monitoring, for shipping companies as well as for administrations of states.

In the longer term, in order to be more effective, governments may consider to use CO_2 indexing via the following paths:

[20] The basic principle of a CO_2 emission index is that it describes the CO_2 efficiency of a ship, i.e. the CO_2 emission per tonne cargo or passenger per nautical mile.

1. The indexing of ship operational performance is introduced as voluntary measure, and over time developed and adopted as a standard
2. Based on the experience with the standard, the standard will act as a new functional requirement when new buildings are ordered, hence over time the operational index will affect the requirements from ship owners related to the energy efficiency of new ships.
3. Differentiation of en route emission charges or existing port dues on the basis of a CO_2 index performance.
4. To use the CO_2 index of specific ship categories as a baseline in a (voluntary) baseline-and-credit programme.

Economic instruments for international shipping

There are currently only a few cases of counties or ports introducing economic instruments to create incentives to reduce shipping emissions. Examples include environmentally differentiated fairway dues in Sweden, the Green Award scheme in place in 35 ports around the world, the Green Shipping bonus in Hamburg and environmental differentiation of tonnage tax in Norway. None of these incentives are based on GHG emissions, but generally relate to fuel sulphur content, engine emissions (mainly NO_x), ship safety features and management quality.

Harrison et al. (2004) explored the feasibility of a broad range of market-based approaches to regulate atmospheric emissions from seagoing ship in EU sea areas. The study focused primarily on policies to reduce the air pollutants SO2 and NOx, but the approaches adopted may to a certain extent also be applicable to other emissions, including CO_2. According to a follow-up study by Harrison et al. (2005) the main obstacles to a programme of voluntary port dues differentiation are to provide an adequate level of incentive, alleviating ports' competitive concerns, and reconciling differentiation with specially negotiated charges. Swedish experience suggests that when combined with a centrally determined mandatory charging programme, these problems may be surmountable. However, in many cases a voluntary system would not likely be viable, and other approaches to emissions reductions may therefore be required.

An alternative economic instrument, such as a fuel tax is vulnerable to evasion. I.e. ship may avoid the tax by taking fuel on board outside the taxed area. Offshore bunker supply is already common practice to avoid paying port fees or being constrained by loading limits in ports. Thus even a global fuel tax could be hard to implement to avoid evasion, as an authority at the port state level would have to collect the tax (ECON, 2003). A CO_2 based route charge or a (global) sectoral emission trading scheme would overcome this problem if monitoring is based on the carbon content of actual fuel consumption on a single journey. International literature has not analyzed yet the latter two policy options. Governments may therefore consider investigating the feasibility and effectiveness of emission charges and emission trading as policy instruments to reduce GHG emissions from international shipping.

5.4.3 Non Climate Policies

5.4.3.1 Co-benefits and ancillary benefits

The literature uses the term ancillary benefits when focusing primarily on one policy area, and recognizing there may benefits with regard to other policy objectives. One speaks of co-benefits when looking from an integrated perspective. This section focuses on co-benefits and ancillary benefits of transport policies. Chapter 11 provides a general discussion of the benefits and linkages related to air polution policies.

Climate change is a minor factor in decision and policy in the transport sector in most countries. Policies and measures are often primarily intended to achieve energy security and/or sustainable development benefits that include improvements in air pollution, congestion, access to transport facilities and recovery of expenditure on infrastructure development. Achieving GHG reduction is therefore often seen as a co-benefit of policies and measures intended for sustainable transport in the countries.

As mentioned above, several different benefits can result from one particular policy. In the field of transport, local air pollutants and greenhouses gases have a common source in motorized traffic, and the latter may also induce congestion, noise and accidents. Addressing these problems simultaneously, if possible, offers the potential of large cost reductions, as well as reductions of health and ecosystems risks. It should also contribute to a more effective planning of transport, land use and environmental policy (United Nations, 2002; Stead et al. 2004). This suggests that it would be worthwhile to direct some research towards the linkages between these effects.

Model studies indicate a potential saving of up to 40 percent of European air pollution control costs if the changes in the energy systems that are necessary for compliance with the Kyoto protocol were simultaneously implemented (Syri et al., 2001). For China, the costs of a 5–10 percent CO_2 reduction would be compensated by increased health benefits from the accompanying reduction in particulate matter (Aunan et al., 1998). McKinley et al. (2003) analyzed several integrated environmental strategies for Mexico City. They conclude that measures to improve the efficiency of transportation are the key to joint local / global air pollution control in Mexico City. The three measures in this category that were analyzed, taxi fleet renovation, metro expansion and hybrid buses, all have monetized public health benefits that are larger than their costs when the appropriate time horizon is considered.

A simulation of freight traffic over the Belgian network indicated that a policy of internalizing the marginal social costs caused by freight transports would induce a change in the modal shares of trucking, rail and inland waterways transports. Trucking would decrease by 26% and the congestion cost it created by 44%. It was estimated that the total cost of pollution and GHG emissions (together) would decrease by 15,4%, the losses from accidents diminish by 24%, the cost of noise by 20%, and the wear and tear by 27%. At the same time, the total energy consumption by the three modes would decrease by 21% (Beuthe et al., 2002).
Note also a policy of increasing trucks' weight in Sweden and UK that lead to a consolidation of loads that resulted in economic benefits as well as environmental benefits, including a decrease in CO_2 emissions (MacKinnon, 2005).

Obviously, promotion of non-motorized transport (NMT) has large and consistent co-benefits of GHG reduction, air quality, and people health improvement (Mohan and Tiwari, 1999)

In the City of London a congestion charge was introduced in February 2003, to reduce congestion. Simultaneous with the introduction of the charge, investment in public transport increased to provide a good alternative. Since the introduction, congestion in the charging zone has reduced by 30% during the charging hours. The charge has had substantial ancillary benefits with respect to air quality and climate policy. A 18% reduction of traffic in the charging zone has led to estimated reductions in CO_2 emissions of 20%. Primary emissions of NO_x and PM_{10} fell by 16 percent after one year of introduction (Transport for London, 2005).

Under the Integrated Environmental Strategies Program of the US EPA analysis of public health and environmental benefits of integrated strategies for GHG mitigation and local environmental improvement is supported and promoted in developing countries. A mix of measures for Chile has been proposed aimed primarily at local air pollution abatement and energy saving. Measures in the transport sector (CNG buses, hybrid diesel-electric buses and taxi renovation) proved to provide little ancillary benefits in the field of climate policy, see Figure 5.21. Only congestion charges were expected to have substantial ancillary benefits for GHG reduction (Cifuentes et al., 2001, Cifuentes & Jorquera, 2002).

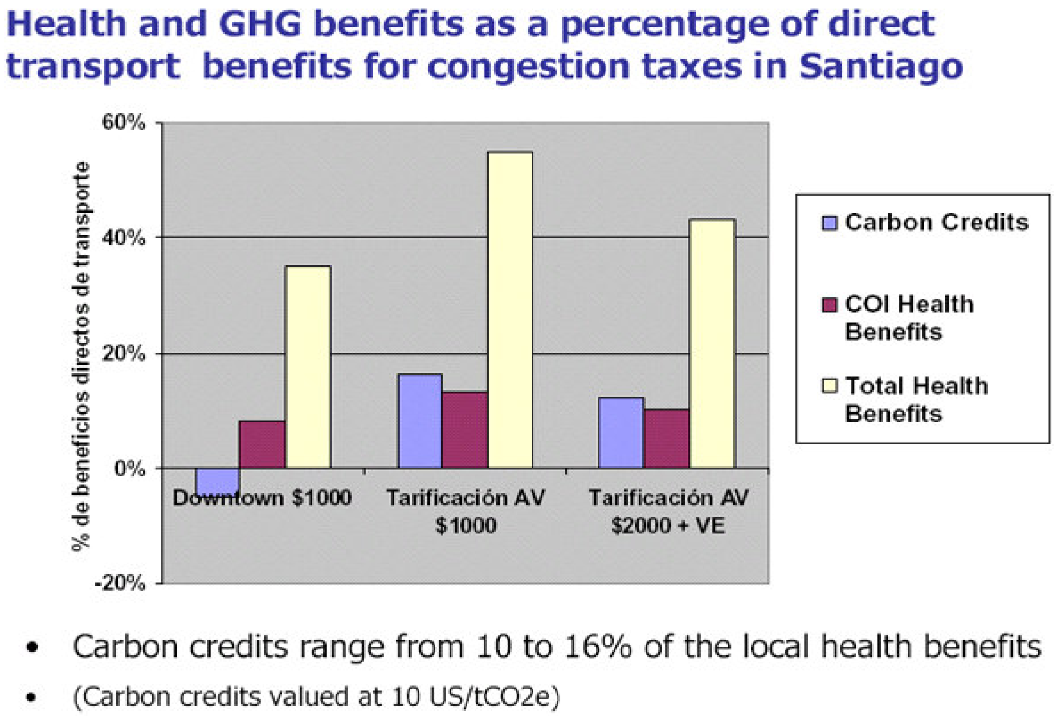


***Figure 5.21**: Co-benefits from different mitigation measures in Santiago de Chile*

While there are many synergies in emission controls for air pollution and climate change, there are also trade-offs. Diesel engines are generally more fuel-efficient than gasoline engines and thus have lower CO_2 emissions, but increase particle emissions. Air quality driven measures, like obligatory particle matter (PM) and NOx filters and in-engine measures, mostly result in higher fuel use and consequently higher GHG emissions.

5.4.3.2 Transport subsidies

Globally, transport subsidies are significant in economic terms. Van Beers and Van den Bergh (2001) estimate that in the mid-1990s, transport subsidies amounted to 225 billion US$, or approximately 0.85% of the world GDP. They estimate that transport subsidies affect over 40% of world trade. In a competitive environment (not necessarily under full competition), subsidies decrease the price of transport. This results in the use of transport above its equilibrium value, and most of the time also results in higher emissions, although this depends on the type of subsidy. Secondly, they decrease the incentive to economise on fuel, either by driving efficiently or by buying a fuel-efficient vehicle.

A quantitative appraisal of the effect of subsidies on greenhouse gas emissions is very complicated (Nash *et al.*, 2002). Not only have shifts between fuels and transport modes to be taken into account, but the relation between transport and the production structure also needs to be analysed. As a result, reliable quantitative assessments are almost non-existent (OECD 2004). Qualitative appraisals are less problematic. Transport subsidies that definitely raise the level of greenhouse gas emissions include subsidies on fossil transport fuels, subsidies on commuting, and subsidies on infrastructure investments.

Many, mostly oil producing, countries provide their inhabitants with transport fuels below the world price. Some countries spend more than 4% of their GDP on transport fuel subsidies (Esfahani 2001). Many European countries and Japan have special fiscal arrangements for commuting expenses. In most of these countries, taxpayers can deduct real expenses or a fixed sum from their income (Bach, 2003). By reducing the incentive to move closer to work, these tax schemes enhance transport use and emissions.

Not all transport subsidies result in higher emissions of greenhouse gasses. Some subsidies stimulate the use of climate-friendly fuels. In many countries, excise duty exemptions on compressed natural or petrol gas and on biofuels exist (e.g. Riedy, 2003). If these subsidies result in a change in the fuel mix, without resulting in more transport movements, they may actually decrease emissions of greenhouse gasses.

The most heavily subsidised form of transport is probably public transport. In the US, fares only cover 25% of the costs, in Europe 50% (Brueckner, 2004). Although public transport generally emits fewer greenhouse gases per kilometre per passenger, the net effect of these subsidies has not been quantified. It depends on the balance between increased greenhouse gas emissions due to higher demand (due to lower ‘subsidised’ fares) and substitution of relatively less efficient transport modes.

5.5 Infrastructure

The challenge in developing countries is the urgent need to reverse the urban road decay as a result of unclear jurisdiction over road development and maintenance.

In most developing countries NMT is also systematically neglected in urban transport policy, infrastructure development and traffic management. Most cities lack continuous and secure NMT infrastructure. Construction of NMT lanes and pathways that are secure, convenient, well maintained and managed can reduce the number of trips made on motorized vehicles. At introduction of NMT in Bogota, bike trips increased from 0.5% to 4% of total trips and in Netherlands bike usage increased from 40% to 43% (World Bank, 2003). Emission wise NMT assumes 100% energy savings for all the motorized trips substituted.

The need for the expansion of public transport in form of large capacity buses, light rail transit and metro or suburban rail are in demand. The urban rail systems are however prohibitive on account of the high capital and operational costs. The few success stories of Bus Rapid Transit systems (e.g. of Bogotá, Curitiba, Quito and Lima) need to be replicated in other countries (Karekezi et al., 2003). Estimated CO_2 reduction for the Bus Rapid Transit in Bogota was 318 tonnes CO_2 per day in 2001 (Table 5.11).

Improving NMT and bus systems- modes of transport can more directly serve the poor as well as offset high-energy use and emissions associated with private motorized transport. These infrastructural measures (coupled with operational measures) qualify for support under the Global Environmental Facility OP11 (together with Transport and Traffic Management and Land use planning). Improving the efficiency and coverage of public transport is also one of the priorities of the World Bank Urban Transport Strategy and hence can receive support from the Bank.

Table 5.11: *CO2 reduction potential and Cost per tCO2 reduced using public transit policies*

Transport Measure	GHG Reduction Potential %	Cost per tCO2 (US$)
BRT mode share increases from 0 to 5%	3.9	66
BRT mode share increases from 0 to 10%	8.6	59
Walking share increase from 20 to 25%	6.9	17
Bike share increases from 0 to 5%	3.9	15
Bike mode share increases from 1 to 10%	8.4	14
Package (BRT, Pedestrian upgrades, cycle ways)	25.1	30

Source Winkelman, 2006.

Many of the promising transport-technologies that are being proposed as mitigation options are not part of a near term agenda because of lack of infrastructure (apart from their current high cost). Critical to application of low GHG technologies will also be availability of infrastructure e.g. to use natural gas at centralized plants and distribution filling stations will require gas pipelines and storage facilities. Production of biofuels will require transport infrastructure for transporting feedstocks, processing and distribution; a hydrogen economy will require hydrogen production, supply and distribution infrastructure etc.

5.6 Technology research, development /diffusion/ transfer

Any vehicle manufacturers cannot pressure consumers into a particular direction of technology, so companies prepare a wide range of options from which consumers can choose(Sasanouchi,2004). For example, many models for clean fuel vehicles are sold in the market including vehicles fueled with CNG, LPG, ethanol and biodiesel.
Since reduction of GHG emissions and other environment issues are just one consideration in the consumer's choice of vehicles, this approach will be able to meet other customer's needs such as drivability, safety and comfort, and may lead to successful commercialisation of R&D efforts.

R&D is a key driver for companies to maintain their competitive position through the development and implementation of new technologies and products. However, investment for R&D is huge and the result of efforts is generally uncertain whether a company will be successful in developing a new technology.

Flannery(2005) identified several key commercial drivers needed for successful development and commercialisation of innovative technologies for GHG mitigation. Those drivers included performance, cost, consumer acceptance, safety, enabling infrastructure, regulatory compliance and to take account of all associated environmental impacts. An important point he stressed was that the weakest driver or element will determine the strength and hence commercialisation and widespread use of a technology, i.e. failure in any of these dimensions will prevent widespread commercial use. This is exactly applied to the commercialisation of fuel cell vehicles. Not only auto makers but also other all players including governments should participate to enhance the commercialisation of FCVs.
Among them, government role is very important to facilitate the development of innovative technology which will be essential to increase their performance and reduce cost, because auto makers have not enough resources to cover all of wide-range development. Further, development of infrastructure, deregulation for hydrogen handling, and customer education through implementation can be done or initiated by only government. Fortunately, there are R&D projects on FCV supported by public funding in US, EU and Japan. Total of their fund summed up more than $1 billion per year.

There are many factors to facilitate or limit the technology diffusion or transfer. Several transfer paths can be identified; parent company to his affiliates, joint venture between foreign companies and companies of host country, agreement of the non-commercial base cooperation between host country government and foreign countries and so on.
According to Gallagher's analysis for China (2003), U.S. foreign direct investment in the automotive sector did not strongly contribute to improving Chinese technological capabilities because little knowledge was transferred along with the product. This is probably true for all of the Chinese joint ventures with foreign auto companies. The diffusion of good operating practices and management skills can be as significant factor as the technology hardware itself in achieving improved performance.

5.7 Regional Differences

A comparative study of eight Asian cities showed mitigation potential of those measures as well as their marginal abatement cost, reflecting the local circumstances for each city (ARRPEEC-II, 2003). The overall objective of the research is to analyze the technical options for mitigation of GHG and other harmful emissions from the urban transport system. The study covers eight Asian cities, namely Beijing and Hangzhou of China, Bandung and Jakarta of Indonesia, Delhi and Mumbai of India, Manila of the Philippines and Ho Chi Minh City (HCMC) of Vietnam. The projections of the vehicle stocks during 2005-2020 are made using an econometric model relating vehicle stock with GDP and population. Analysis of energy demand and emission levels with different economic growth scenarios are carried out using Long-range Energy Alternative Planning (LEAP) model.
In order to determine the least cost vehicle options, a linear programming (LP) based vehicle-mix model has been developed and used in this study. Table shows the total cumulative CO_2 emissions during 2001-2020 and marginal CO_2 abatement cost (MAC) at selected CO_2 emission reduction targets. Jakarta would have the highest of about 200 million tonnes among the cities under study during 2000-2020 while HCMC would have the lowest total CO_2 emission level (about 5 million tonnes). MAC would be relatively high for Manila (178 US$/tonne of CO_2 at 5 per cent reduction target) and relatively low for HCMC (0.5 US$/tonne of CO_2 at 6 per cent reduction target). The MAC values are relatively low in Beijing, Delhi and Mumbai.

***Table 5.13:** Marginal CO_2 abatement cost at selected emission reduction targets in selected cities, US$/tonne CO_2**

City	Total Comulative CO2 Emission (10^6 tonnes)	Marginal Abatement Cost						
		5%	10%	15%	20%	25%	30%	40%
Bandung	19	121	204	412	132503	NA	NA	NA
Beijing	105	29	33	NA	37	NA	39	253
Delhi	30	35	44	49	66	115	NA	NA
Hangzhou	6	76	89	NA	100	962	NA	NA
Jakarta	200	NA	112	NA	156	NA	269	246215
Manila	182	178	327	528	NA	NA	NA	NA
Mumbai	12	17	NA	19	21	24	47	NA

* The figure for HCMC are 0.1, 0.5, 1.3 and 2.1 US$/tonne of CO2 at 3%, 6%, % and 12% reduction targets respectively.
NA – not available

5.8 Mitigation Potential

As discussed earlier, under "business as usual" conditions with assumed adequate supplies of petroleum, GHG emissions from transportation are expected to grow steadily during the next few decades, yielding about an 80% increase from 2002-2030 or 2.1% per year. This growth will not be evenly distributed; IEA projections of annual CO_2 growth rates for 2002-2030 range from 1.3% for the OECD nations to 3.6% for the developing countries. The potential for reducing this growth will vary widely across countries and regions, as will the appropriate policies and measures that can accomplish such reduction.

Analyses of the potential for reducing emissions of greenhouse gases in the transport sector are largely limited to national or sub-national studies or to examinations of technologies at the vehicle level, for example well-to-wheel analyses of alternative fuels and drivetrains for light-duty vehicles. The TAR presented the results of several studies for the years 2010 and 2020 (Table 3.16 of the TAR), with virtually all limited to single countries or to the EU or OECD. Many of these studies indicated that substantial reductions in transport GHG emissions could be achieved at negative or minimal costs, although these result generally used optimistic assumptions about future technology costs and/or did not consider tradeoffs between vehicle efficiency and other (valued) vehicle characteristics. Studies undertaken since the TAR have tended to reach conclusions generally in agreement with these earlier studies, though recent studies have focused more than the earlier ones on transitions to hydrogen used in fuel cell vehicles.

5.8.1 Worldwide Studies

Two recent worldwide studies – the International Energy Agency's *World Energy Outlook* (IEA, 2004a) and the World Business Council on Sustainable Development's *Mobility 2030* (WBCSD, 2004) – are helpful but limited in scope, with the former focusing on a few relatively modest measures and the latter examining the impact of specified technology penetrations on the road vehicle sector (the study sponsors are primarily oil companies and automobile manufacturers) without regard to either cost or the policies needed to achieve such results. In addition, IEA has developed a simple worldwide scenario for light-duty vehicles that also explores radical reductions in GHG emissions.

World Energy Outlook postulates an "Alternative Scenario" to their Reference Scenario projection described earlier, in which vehicle fuel efficiency is improved, there are increased sales of alternative-fuel vehicles and the fuels themselves, and demand side measures reduce transport demand and encourage a switch to alternative, and less energy intensive transport modes. Some specific examples of technology changes and policy measures are:

- In the United States and Canada, vehicle fuel efficiency is nearly 20% better in 2030 than in the Reference Scenario, and hybrid and fuel-cell powered vehicles make up 15% of the stock of light-duty vehicles in 2030;
- Average fuel efficiency in the developing countries and transition economies are 10-15% higher than in the Reference Scenarios;
- Measures to slow traffic growth and move to more efficient modes reduce road traffic by 5% in the European Union, and 6% in Japan. Similarly, road freight is reduced by 8% in the EU and 10% in Japan.

The net reductions in transport energy consumption and CO_2 emissions in 2030 are 315 Mtoe, or 9.6%, and 997 MtC, or 11.4%, respectively compared to the Reference Scenario. This represents a 2002-2030 reduction in the annual growth rate of energy consumption from 2.1%/yr to 1.3%/yr, a significant accomplishment but one which still allows transport energy to grow by 57% during the period; CO_2 emissions grow a bit less because of the shift to fuels with less carbon intensity, primarily natural gas and biofuels.

IEA has also produced a technology brief that examines a simple scenario for reducing world greenhouse gas emissions from the transport sector (IEA, 2004b). The scenario includes a range of short-term actions, coupled with the development and deployment of fuel-cell vehicles and a low-carbon hydrogen fuel infrastructure. For the long-term actions, deployment of fuel-cell vehicles would aim for a 10% share of light-duty vehicle sales by 2030 and 100% by 2050, with a 75% reduction per-vehicle reduction in GHG emissions by 2050 compared to gasoline vehicles. The short term measures for light-duty vehicles are:

- Improvements in fuel economy of gasoline and diesel vehicles, ranging from 15% (in comparison to the IEA reference case) by 2020 to 35% by 2050.
- Growing penetration of hybrid vehicles, to 50% of sales by 2040.
- Widespread introduction of biofuels, with 50% lower well-to-wheels GHG emissions per kilometre than gasoline, with a 25% penetration by 2050.
- Reduced travel demand, compared to the reference case, of 20% by 2050.

Figure 5.22 shows the light-duty vehicle GHG emissions results of the scenario. The penetration of fuel cell vehicles by itself bring emissions back to their 2000 levels by 2050. Coupled with the nearer-term measures, GHG emissions peak in 2020 and retreat to half of their 2000 level by 2050.

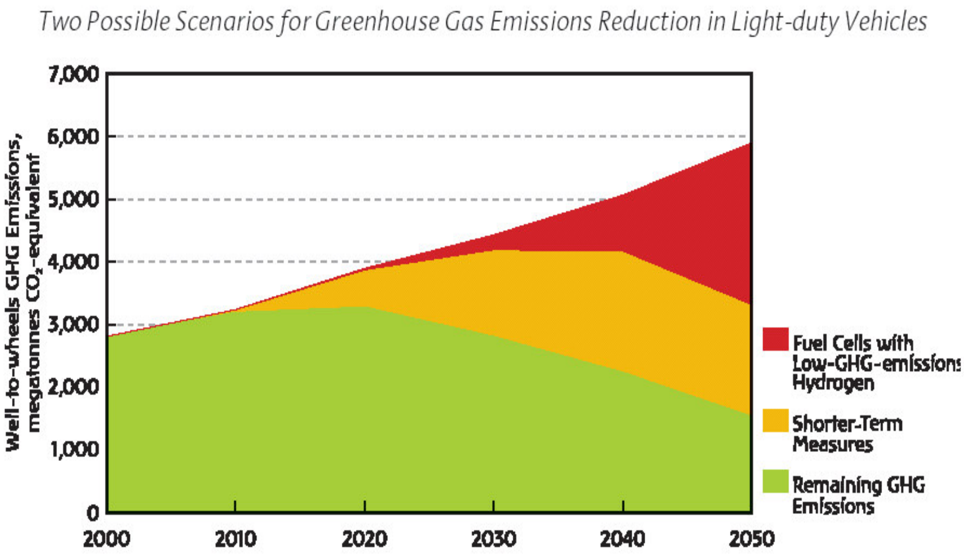


***Figure 5.22**: Two Possible Scenarios for Greenhouse Gas Reductions in Light-Duty Vehicles*
Source: IEA, 2004b

The *Mobility 2030* study examined a scenario postulating very large increases in the penetration of fuel efficient technologies into road vehicles, coupled with improvements in vehicle use, assuming different timeframes for industrialized and developing nations.

The technologies and their fuel consumption and carbon emissions savings referenced to current gasoline ICEs were:

Technology	Carbon reduced/vehicle	
1. Diesels	18%	
2. Hybridization	30%	(36% for diesel hybrids)
3. Biofuels	20-80%	
4. Fuel cells with Fossil hydrogen	45%	
5. Carbon-neutral hydrogen	100%	

Figure 5.23 shows the effect of a scenario postulating the market penetration of all of the technologies as well as an assumed change in consumer preferences for larger vehicles and improved traffic flows. The scenario assumes that diesels make up 45% of light-duty vehicles and medium trucks by 2030; that half of all sales in these vehicle classes are hybrids, also by 2030; that one-third of all motor vehicle liquid fuels are biofuels (mostly advanced) by 2050; that half of LDV and medium truck vehicle sales are fuel cells by 2050, with the hydrogen beginning as fossil-based but gradually moving to 80% carbon neutral by 2050; that better traffic flow and other efficiency measures reduce GHG emissions by 10%; and that the underlying efficiency of light-duty vehicles improves by 0.6%/yr due to steady improvements (e.g., better aerodynamics and tires) and to

reduced consumer preference for size and power. In this scenario, GHG emissions return to their 2000 level by 2050.

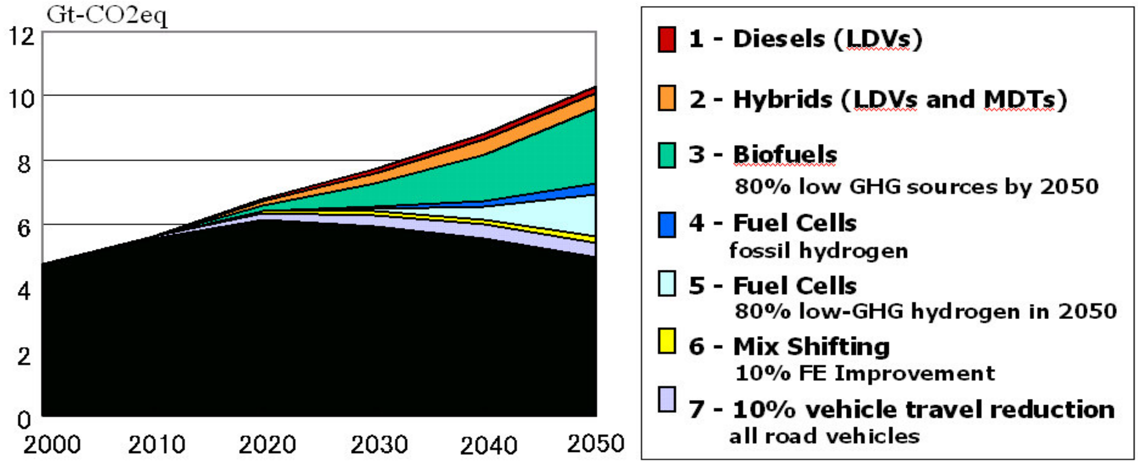


Figure 5.23: *The effect of a scenario postulating the market penetration of all technologies*
Source: WBCSD, 2004.

Mobility 2030's authors make it quite clear that for this "mixed" scenario to be even remotely possible will require overcoming many major obstacles. The introduction and widespread use of hydrogen fuel cell vehicles, for example, requires huge reductions in the costs of fuel cells; breakthroughs in onboard hydrogen storage; major advances in hydrogen production; overcoming the built-in advantages of the current gasoline and diesel fuel infrastructure; demonstration and commercialization of carbon sequestration technologies for fossil-fuel hydrogen production (at least if GHG emission goals are to be reached); and a host of other R&D, engineering, and policy successes.

5.8.2 Well-to-wheels analyses

As noted previously, well-to-wheels analyses measure the energy and emissions effects of technology options over the complete fuel cycle, including effects associated with finding, extracting, refining or transforming, and delivering the fuel to the vehicle. The results of well-to-wheel studies should be interpreted with caution. The various studies often use different baseline vehicles (varying from compact cars to pickup trucks) and base energy consumption values on different driving cycles (the relative advantage of alternative drivetrains is quite cycle-dependent; for example, hybrid-electric drivetrains have a large advantage over conventional drivetrains in slow stop-and-go urban driving conditions, and comparatively little advantage on higher-speed highway cycles). Also, different studies may assume different performance and emission control requirements for the vehicles, which may affect the fuel efficiency of the baseline vehicle as well as the improvement potential of advanced technologies. For vehicles that use electricity or hydrogen, greenhouse gas emissions are critically dependent on how the electricity or hydrogen is produced. Further, many of the technologies examined in available well-to-wheel analyses are at an early stage of development, with considerable uncertainty about their future prospects, costs, and performance.

General Motors and the Argonne National Laboratory (with others) have recently prepared an analysis of the well-to-wheels energy use and GHG emissions of a 2010-model-year full sized GM pickup truck, for the year 2016 (at the truck's assumed mileage midpoint) for a variety of drivetrain and fuel combinations. The assumed driving cycle is the combined 55% city/45% highway cycle used by the U.S. Environmental Protection Agency to evaluate fuel economy and emissions for U.S. light-duty vehicles. Although this vehicle is at the large end of the light-duty vehicle scale, the relative differences among the various drivetrain/fuel combinations should be applicable to most vehicles. The analysis uses the Laboratory's Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model.

Table 5.14 shows the fuel economy results for 20 different drivetrain/fuel combinations for the pickup truck, with a range for each combination showing results assuming different performance levels. The results show that several drivetrain technologies have a large potential to improve drivetrain efficiency, with hydrogen fuel cell technology in a hybrid configuration yielding about a 160% improvement in overall efficiency.

***Table 5.14:** Composite Fuel Economy Results for Various Scenarios*

Propulsion System	Fuel Economy, mpg gasoline-equivalent		
	Worst Case	Best Estimate	Best Case
Gasoline DOD SI CD Baseline	20.2[a]	21.3	22.4
Gasoline DI SI CD	23.2	24.2	25.4
Diesel DI CI CD	25.2	25.8	27.1
E85 DOD SI CD	20.2[a]	21.3	22.4
CNG DOD SI CD	19.9[a]	21.0	22.1
H_2 DOD SI CD	24.3[a]	25.6	26.9
Gasoline DOD SI HEV	24.5	26.5	34.0
Gasoline DI SI HEV	27.0	29.2	33.6
Diesel DI CI HEV	28.5	30.8	39.4
E85 DOD SI HEV	24.5	26.5	34.0
CNG DOD SI HEV	23.5	25.4	32.5
H_2 DOD SI HEV	29.2	31.6	40.5
Gasoline/naphtha FP FCV	25.7	32.2	36.3
Gasoline/naphtha FP FC HEV	29.5	37.5	42.2
MeOH FP FCV	28.1	35.2	39.6
MeOH FP FC HEV	32.7	40.8	45.9
EtOH FP FCV	25.7	32.2	36.3
EtOH FP FC HEV	29.5	37.5	42.2
H_2 FCV	47.6	50.8	54.5
H_2 FC HEV	52.6	56.1	59.8

[a] Engine modeled without DOD for the worst-case scenario.

Source: General Motors, 2005

Abbreviations

DOD	Displacement on demand
SI	Spark ignited
CD	Conventional drivetrain
DI	Direct injection
CI	Compression ignition
E85	85% ethanol/15% gasoline (by volume) fuel
CNG	Compressed natural gas
H_2	Hydrogen
HEV	Hybrid electric vehicle
FP	Fuel processor
FCV	Fuel cell vehicle
MeOH	Methanol
EtOH	Ethanol

Figure 5.24 shows the full well-to-wheels GHG emissions of several drivetrain/fuel combinations examined in the GM study, and explicitly compares those using non-renewable and renewable fuels. The net GHG values show the importance of the "well to tank" portion of the fuel cycle to the emissions results. Hydrogen fuel cell vehicles, in particular, yield well-to-wheels GHG emissions that are extremely dependent on the hydrogen source - with hydrogen from North American gas fields, a fuel cell hybrid vehicle yields less than half the GHG emissions of the baseline gasoline vehicle, but the same vehicle yields *higher* GHG emissions than the baseline vehicle if the hydrogen is obtained from electrolysis using average U.S. electrical power. Renewable fuels may yield even lower net emissions than the natural gas-sourced hydrogen fuel cell vehicle, even in vehicles with conventional drivetrains and spark-ignited engines, but here the key is using cellulosic ethanol or

similar fuels rather than corn-based ethanol. For example, the hydrogen fuel cell vehicle with North American natural gas as the hydrogen source emits 278 g/mi of GHGs (most likely case, station-generated hydrogen) compared to 552 g/mi for a conventional gasoline-powered vehicle. A conventional E85 vehicle fueled by corn-based ethanol emits 451 g/mi – about 20% better than the gasoline vehicle – but the same vehicle fueled by cellulosic ethanol, at 154 g/mi, has GHG emissions more than 70% lower than the gasoline vehicle, and 45% lower than the natural-gas-based FCV. And using cellulosic ethanol in a fuel-processor-equipped FCV yields about *zero* net well-to-wheels GHG emissions. The conclusion to be drawn from this and similar studies is that vehicle technologies have considerable potential to sharply reduce GHG emissions, but shifts to alternative fuels may have wide-ranging effects, from somewhat negative to strongly positive, depending on the details of how the fuel is obtained, processed, and transported.

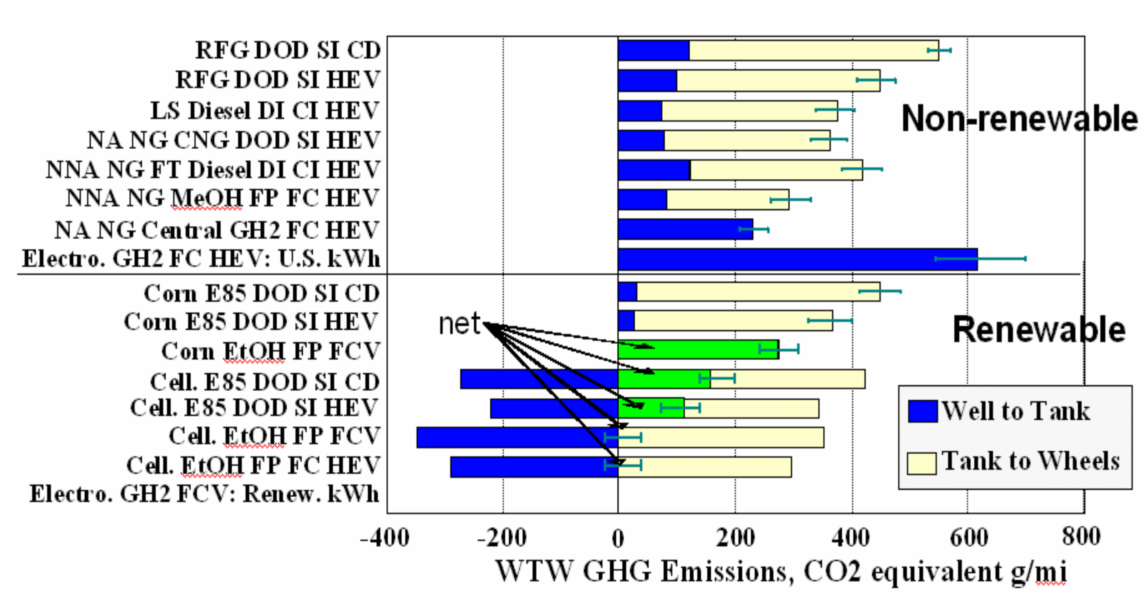


***Figure 5.24**: Well-to-wheel analysis for various combination of powertrain and fuels*
Note: See Table 5.14 for an explanation of the abbreviations

Ricardo Consulting Engineers examined the implications of a technology roadmap to hydrogen vehicles in the United Kingdom, moving from conventional diesel drivetrains to diesel hybrids to various combinations of hydrogen vehicles (Owen and Gordon, 2003). Table 5.15 shows the tank-to-wheels and well-to-wheel values for some of the technologies embedded in "a composite average of current class-leading C/D segment (e.g., Ford Focus, VW Golf)"; the baseline vehicles tank-to-wheel's emissions are 149 g/km. The results for the diesel drivetrains are worth comparing to the GM/Argonne results in Table above. Ricardo found a 38% reduction in CO_2 emissions, to 92 g/km tank to wheels (103 g/km well-to-wheels), for a diesel parallel hybrid vehicle in 2012, from the baseline. This is a 62% improvement in fuel economy, compared to Table 's 19% improvement for a diesel hybrid compared to a diesel conventional drive pickup. The improvement in the Ricardo analysis appears to be solely due to the hybrid drivetrain, so the two analyses seem quite comparable. However, in the Ricardo analysis, the engine is radically downsized, a key component of the improved efficiency. In the GM analysis, the performance requirements for the pickup may have prevented much (if any) engine downsizing (the report does not specify engine size details), which would have limited efficiency gains. The Ricardo value is quite optimistic based on currently available technology (e.g., Prius),[21] and presumably assumes that considerable improvement in hybrid technology will occur during the next 5-7 years.

Table 5.15: *Tank to Wheels and Well to Wheels CO_2 Emissions from Compact Cars With Four Different Powertrains (Owen and Gordon, 2003)*

Technology	**Year**	**CO_2 Tank to Wheels**	**CO_2 Well to Wheels**
Baseline diesel	2004	149 g/km	167 g/km
Mild hybrid	2010	114 g/km	123 g/km
Parallel hybrid (Prius-type)	2012	92 g/km	103 g/km
Hydrogen series hybrid FCV	2030	0 (0.89-1.43 kg/100km H_2)	74-119 g/km

For the hydrogen vehicle, the tank to wheels value for hydrogen consumption is equivalent to about 3.0-4.8 L/100km of diesel fuel, compared to 5.5 L/100km for the current average diesel fuel consumption of the baseline diesel diesel and 3.4 L/100km for the 2012 diesel parallel hybrid. In other words, Ricardo expects the FCV to be more fuel-efficient than a diesel parallel hybrid only when fuel cells become extremely efficient. Note also that the well to wheels value for the FCV is based on producing hydrogen from natural gas, at a well-to-tank efficiency of 66%.

5.8.3 Technical potential in developing nations

There have been few studies of the potential to moderate the expected growth in transportation GHG emissions in developing nations, partly because of a severe lack of reliable data and the very large differences in vehicle mix and travel patterns among varying areas. As discussed earlier, vehicular travel is growing at rapid rates in these countries and typically the growth in private vehicle ownership – both two-wheelers and automobiles – has been particularly rapid. This growth in motorization creates strong pressure for government intervention, but in the developing world it is not GHG emissions that will energize change, but issues such as congestion, degrading air quality, and problems with energy supply (especially oil supply).

An examination of nine cities and countries found that vehicle ownership explained the differences in transportation carbon emissions per capita among them, suggesting that slowing the growth in personal vehicle ownership is a key strategy to slowing growth in such emissions (Sperling and Salon, 2002). Of course, such a strategy is acceptable only if high levels of mobility and accessibility can be provided by alternative means.

Table 5.16 shows the broad average GHG emissions from different vehicles and transport modes in developing countries, indicating that GHG emissions per passenger kilometer are lowest for transit vehicles and two-wheelers. The values also demonstrate the potential of alternative fuels to reduce GHG emissions. There are substantial differences among various nations in emission factors, however, because of varying vehicle characteristics as well as occupancy rates. For example, buses in India and China tend to be more fuel efficient than those in South Africa and the industrialized world, primarily because they have considerably smaller engines (Sperling and Salon, 2002) (and thus accelerate more slowly and have lower top speeds).

[21] Hybrid drivetrains should yield a lower fuel economy improvement in a diesel vehicle than in a gasoline one, because a diesel engine has fewer inefficiencies to reduce – lower idle fuel rate than a gasoline engine, for example, and higher efficiency at part load.

Table 5.16: *GHG Emissions from Vehicles and Transportation Modes in Developing Countries (Source: Sperling and Salon, 2002)*

	Load Factor (average occupancy)	CO_2-Equivalent Emissions Per Passenger-Km (full energy cycle)
Car (gasoline)	2.5	130-170
Car (diesel)	2.5	85-120
Car (natural gas)	2.5	100-135
Car (electric)*	2.0	30-100
Scooter (two-stroke)	1.5	60-90
Scooter (four-stroke)	1.5	40-60
Minibus (gasoline)	12.0	50-70
Minibus (diesel)	12.0	40-60
Bus (diesel)	40.0	20-30
Bus (natural gas)	40.0	25-35
Bus (hydrogen fuel cell)**	40.0	15-25
Rail Transit***	75 percent full	20-50

Note: All numbers in this table are estimates and approximations, and are best treated as illustrative.
*Ranges are due largely to varying mixes of carbon and non-carbon energy sources (ranging from about 20-80 percent coal), and also the assumption
that the battery electric vehicle will tend to be somewhat smaller than conventional cars.
**Hydrogen is assumed to be made from natural gas.
***Assumes heavy urban rail technology ("Metro") powered by electricity generated from a mix of coal, natural gas, and hydropower, with high passenger use (75 percent of seats filled on average).

Figure 5.25 shows the GHG transport emission results, normalized to year 2000 emissions, of four scenario analyses of developing nations and cities: New Delhi, India; Shanghai, China; Chile; and South Africa (Sperling and Salon, 2002). For three of the four cases, the "high" scenarios are "business as usual" scenarios assuming extrapolation of observable and emerging trends with an essentially passive government presence in transport policy. The exception is Shanghai, which is growing and changing so rapidly that "business as usual" has little meaning.

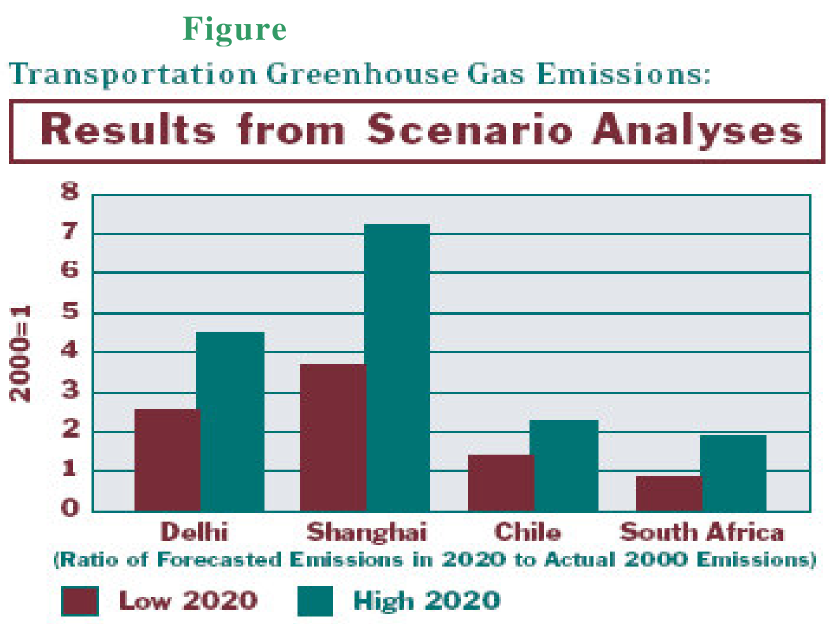


Figure 5.25 *: Projections for transport GHG emissions for some cities of developing countries*

In each of the four case studies, the low scenarios postulate that strong changes in transport and land use policy substantially moderate the growth in GHG emissions expected over the 20 year period and in one case, South Africa, actually reduce emissions. The four low scenarios can be summarized as follows:

A. Delhi (Bose and Sperling, 2001) - The low case yields more than a doubling of GHG emissions, but this is about half of the Business as Usual case. The reduced growth is due to:
   1. Completion of planned busways and rail transit, which currently appears problematic
   2. Land use planning for high density development around rail stations
   3. Network of dedicated bus lanes
   4. Promotion of bicycle use, including purchase subsidies and special lanes
   5. Promotion of car sharing
   6. Major push for more natural gas use in vehicles
   7. Economic restraints on personal vehicles

B. Shanghai (Zhou and Sperling, 2001) - The low case still yields a quadrupling of GHG emissions, compared to a seven-fold increase in the high case. Shanghai has a large portfolio of planned investments, including expansion of a new airport, a new deepwater harbor, 200 kilometers of rapid rail, and lots of new highways. The high case assumes both rapid motorization *and* rapid population increase; the low case assumes stable population. In the high scenario, GHG emissions per passenger kilometer double, whereas they increase by only 10% in the low scenario. Shanghai has made strong attempts to channel development, with coordination of transportation with other land use policies, high taxes on personal vehicles, and execution of a land use/transport plan to build satellite cities with rail transit and highway links to the central city; the high case assumes that these efforts falter, and the auto industry is treated as a prime arena for economic development. The low scenario stresses:
   1. Emphasis on rapid rail system growth
   2. High density development at rail stations
   3. Bicycle promotion with new bike lanes and parking at transit stations
   4. Auto industry focus on minicars and farm cars rather than larger vehicles
   5. Incentives for use of high tech in minicars – electric, hybrid, fuel cell drivetrains
   6. Promotion of car sharing

C. Chile (O'Ryan, et al, 2002) – Chile has already undertaken strong structural changes in its transport sector, so further change may be difficult. In the high case, the share of personal vehicles grows to 39%, from 31% in 2000, with bus and rail losing market share. The low case, by contrast, sees growth to only a 34% share, with a 10% reduction in total passenger kilometers and a 5% reduction in freight ton-miles. The effect on GHG emissions is dramatic; in the 2000-2030 period, emissions increase by only 42% in the low case, versus a 117% increase in the business-as-usual case. The low case includes:
   1. Overall focus on stronger use of market-based policy to insure that vehicle users pay the full costs of driving, internalizing costs of pollution and congestion, through parking surcharges and restrictions, vehicle fees, and road usage fees
   2. Improvements in bus and rail systems
   3. Encouragement of minicars, with lenient usage and parking rules
   4. Strong commitment to alternative fuels, especially natural gas. By 2020, all taxis and 10% of other light and medium vehicles use natural gas; all new buses use hydrogen.
   5. Improvements in bus and rail systems

D. South Africa (Prozzi and Sperling, 2002) – In the business as usual case, transport increases its reliance on old personal cars and minibus jitneys, land use policy remains diffuse, economic development focuses on growth in the auto industry, and reliance on coal-based synfuels continues. There would be a 90% increase in passenger kilometers, and the private vehicle share of travel would increase from 51% to 57%. In the low case, transit share would be 52% in 2020. The net effect of the low case on GHG emissions is a 12 percent decrease from 2000 levels, despite an increase in passenger-kilometers traveled of 54%. Important policies to attain this decrease include:
   1. Land use policies towards more efficient growth patterns
   2. Strong push to improve public transport, including use of busways in dense corridors, provision of new and better buses
   3. Strong government oversight of the minibus jitney industry
   4. Incentives to moderate private car use
   5. Coal-based synfuels shifts to imported natural gas as a feedstock

These case studies, and earlier ones, make it clear that, with rapid motorization essentially inevitable in the developing world, managing this motorization with strong public transportation and integration of transit with efficient land use, continued support of bicycle transport, encouragement of mini cars, and incentives for efficient transport technology and alternative fuels are important components of a strategy to reduce the growth of GHG emissions in the transport sector. It is clear, however, that GHG emissions from transport in the developing world will grow regardless of strategy, at least until there are sufficient breakthroughs in carbon-neutral fuels to allow their use worldwide and in huge quantities.

Table 5.17 summaries technical potentials of various mitigation options for transport sector. As mentioned above, there are a few studies dealing with worldwide analysis. In most of these studies, potentials are evaluated based on the top-down scenario analysis. For combination of specific powertrain technologies and fuels, well-to-wheels analyses are used to examine the various supply pathways. Technical potential for operating practices, policies and behaviours are more difficult to isolate from economic and market potential, and are usually derived from case studies or modelling analyses. Uncertainty is a key factor at all stages of assessment, from technology performance and cost to market acceptance.

***Table 5.17**: Summary table of CO_2 mitigation potentials in transport sector taken from several studies.*

Study	Mitigation Measure/Policy	Region	CO2 reduction (%)				CO2 reduction (Mt)				mitigation cost ($/t-CO2)	comments
			2010	2020	2030	2050	2010	2020	2030	2050		
IEA2004	Alternative scenario	World	2.2	6.8	11.4		133	505	997			
		OECD	2	6.9	11.5		77	308	557			
		Developing	2.8	6.8	11.4		49	170	381			
		TransitionE	2.3	6.2	11.2		8	27	59			
IEA2001	Improving Tech for Fuel Economy	OECD		30%	40%							
	Diesel				5-15%							timeframe not clear
	Policy Packages		16%									including transit improvements, parking restrictions and increased prices, and promotion of walking and bicycling
	Policy Packages		>30%									adds significant amounts of low greenhouse-gas alternative fuel (such as cellulosic ethanol) to the fuel economy improvement measures

IEA2002	All scenario included	NA	6.6	14.4			148	358				
	All scenario included	W. Europe	6.6	15.6			76	209				
	All scenario included	JA	8.3	16.1			28	61				
IEA2004	Improving Fuel Economy	World			18%							
	Biofuels				12%							
	FCV with Hydrogen Refuelling				7%							
	COMBINING THESE THREE				30%							
IEA2004	Reduction in fuel use per km	World		15%	25%	35%						Reduction in fuel use per kilometre, gasoline/diesel vehicles (compared with a reference case)
	Blend of biofuels			5%	8%	13%						Blend share in gasoline and diesel fuel of biofuels having 50% lower well-to-wheels GHG emissions per kilometre than gasoline
	Reduction in growth of LDV travel			5%	10%	20%						Reduction in growth of light-duty-vehicle travel(compared with a reference case)

	using hydrogen in vehicle			0%	3%	75%						using hydrogen in vehicle–reduction in well-to-wheels GHG emissions
ECMT												
	Driving training + technical aids(shift indicators, fuel use indicators etc)	EU	5-10%								(-49)-54.5	timeframe not clear
	low rolling-resistance tyres		1-2%								(-327)-(-108)	timeframe not clear
	idle stop/start:Gasoline (dense traffic)		4-8%								(-50)-176	timeframe not clear
	idle stop/start:Diesel (dense traffic)		2-4%								(-18)-474	timeframe not clear
	adaptive cruise control :diesel(light traffic)		15%								(-42)	timeframe not clear
	adaptive cruise control:gasoline(light traffic)		10%								369	timeframe not clear
	All technologies to reduce on-road fuel consumption		>10%									timeframe not clear
EC	voluntary agreement	EU	7.6				75					
	add other operational measures		10.6				105					
	Rolling Resistance (Freight)						10.9				-90	1.25Euro=$

	Variable Valve Lift Timing + Cylinder Deactivation (Passenger carsPetrol)						22.8				23.75	
	Driver Training - (Freight-HDV)						10.9				23.75	
	Petrol to Diesel shift Passenger carsPetrol						7.8				102.5	
	Advanced Gasoline Direct Injection (advanced: "DISC") Passenger carsPetrol						19				115	
	Lightweight structure - Petrol cars Passenger carsPetrol						9.9				271.25	
ACEEE	A scenario	US	9.9	26.3			132	418			(-33.5)-(-27)	moderate tech+2%HEV
	B scenario		11.8	30.6			158	488			(-24)	moderate tech 47%+adv tech 47%+ 6%HEV
	C scenario		13.2	33.4			176	532			(-25)	adv tech +2%HEV
					2035							
MIT2004	baseline	US		3.4	16.8							increase in fuel economy
	medium HEV			5.2	29.9							HEV sale share of 50% in 2035
	composite			14.9	44.4							HEV+VMT constant beyond 2008
	combined policies		2.9-6.2	13.7-23.8	31.9-50.4							Policy measures include CAFÉ, gasoline tax and ethanol (from

												cellulose) content increase.
PEW2003	Efficiency Standards	US		2015								potential in whole transport sector
	Light-duty vehicles			6(9)	18 (31)							
	Heavy Trucks			2(9)	3(20)							
	Commercial Aircraft			1(9)	2(22)							
	Replacement & Alternative Fuels											
	Low-Carbon Replacement Fuels			2(30)	7 (100)							
	Hydrogen Fuel (All LDV fuel)			1(1)	4(6)							
	Pricing Policies											
	Low-carbon fuel subsidy			2(30)	6 (100)							
	Carbon pricing			3(3)	6(6)							
	Variabilization			6(8)	9(12)							
	Behavioral											
	Land Use & Infra-structure			3(5)	5(10)							
	System Efficiency			0(2)	1(5)							
	Climate Change Education			1(1)	2(2)							
	Fuel Economy Information			1(1)	1(2)							

	Total			22	48							
WEC	energy saving due to new technologies	WR		30%		45.55 %						
WBCSD	Road transport	WR										
	WEDGE 1 - Diesels (LDVs)			0.9	2.1	1.8		61	160	181		
	WEDGE 2 - Hybrids (LDVs and MDTs)			2.4	6.1	6.1		161	474	623		
	WEDGE 3 - Biofuels - 80% low GHG sources by 2050			5.7	15.6	29.5		386	1207	3030		
	WEDGE 4 - Fuel Cells - fossil hydrogen			5.9	16.7	32.7		400	1293	3364		
	WEDGE 5 - Fuel Cells - 80% low-GHG hydrogen in 2050			5.9	17.2	45.3		400	1333	4650		
	WEDGE 6 - Mix Shifting 10% FE Improvement			6.7	18.8	47.3		451	1455	4864		
	WEDGE 7 - 10% vehicle travel reduction - all road vehicles			9.4	22.8	51.9		639	1765	5335		

Box 5.3: Sustainable Development impacts of mitigation options and considerations on the link of adaptation with mitigation.

Regarding the potential sustainable development consequences of the mitigation options assessed in this chapter, bio energy (excluding production) is neutral concerning social aspects and uncertain for the economic and environmental aspects. As for energy efficiency the social aspect is neutral, and positive for both economic and environmental aspects. Social and environmental consequences are usually positive compare to uncertain economic impact for public transport. Non-motorized transport and urban planning show positive consequences in all aspects, except for NMT in terms of social aspect, which is uncertain. The vulnerability to climate change of those options are usually very low, however lightweight vehicles might be more vulnerable to high winds and infrastructure in coastal areas might be damaged. No significant impact on GHG emissions due to adaptation is expected.

5.8.4 World Mitigation Costs and Potentials

In this section we provide one estimate for the year 2030 of the overall GHG emissions reduction potential and costs for mitigating world transport GHG emissions, subject to these caveats:

1. The analysis uses a spreadsheet model developed by the IEA for the Mobility 2030 project, and thus uses the IEA's Reference Case.
2. There are large uncertainties about future improvements in performance and reductions in costs for key efficiency technologies, and similar uncertainty in which types of policy measures will prove acceptable and how manufacturers and vehicle purchasers will respond to them. As a result, estimates of future costs and potentials vary widely. The estimates given here assume a substantial level of success in reducing costs and improving performance.
3. The cost estimates are provided in terms of *societal* costs of reductions in GHG emissions, measured in $/tonne of carbon (C) or carbon dioxide (CO_2); the costs are the net of higher vehicle costs minus discounted lifetime fuel savings.. Fuel savings benefits are measured in terms of the untaxed cost of the fuels at the retail level, and future savings are discounted at a low societal rate of 4%/year. These costs are not the same as those that would be faced by consumers, who would face the full taxed costs of fuel, would almost certainly use a higher discount rate, and might value only a few years of fuel savings. Also, they do not include the consumer costs of forgoing further increases in vehicle performance and weight. Over the past few decades, increasing acceleration performance and vehicle weight have stifled increases in fuel economy for light-duty vehicles, and these trends must be stopped if substantial progress is to be made in fleet efficiency. Because consumers value factors such as vehicle performance, stopping these trends will have a cost – but there is little information about its magnitude.
4. The potential improvements in light-duty fuel economy assumed in the analysis are based loosely on the MITs study noted above, but are discounted somewhat from the study results based on our skepticism about the rapidity with which the full benefits can be achieved. Further, fleet penetration of the technology advances are assumed to be delayed by 5 years in developing nations; however, because developing nation fleets are growing rapidly, higher efficiency vehicles, once introduced, may become a large fraction of the total fleet in these nations within a relatively short time. The technology assumptions are as follows:

Midsize Car	MPG (test)	% incr from Ref	Cost %	ΔCost, $
2001 reference	30.6	0	100	0
2020 baseline	43.2	41	105	1000
2020 advanced	45.9	50	109	1800
2020 hybrid	64.3	110	118	3800
2020 diesel	55.1	80	119	3200
2020 dsl hybrid	73.4	140	128	5000

As applied to three key areas, the scenario is:

	% Improvement from 2001 levels		
Region	2015	2020	2025
North America	30%	45%	70%
Europe	20%	30%	55%
Emerging Asia/Pacific	25%	35%	65%

5. In this estimate, hydrogen fuel cell vehicles do not play a significant role, because of the likelihood that such vehicles will not achieve a significant penetration of the World's vehicle fleet by 2030 and because, during a transition to hydrogen, likely early reliance on fossil fuels for hydrogen production would substantially reduce "per vehicle" GHG benefits to be gained. An examination of costs and potentials for a later date, e.g. 2050, could have a very different result.

Table 5.18 shows the light-duty vehicle fuel consumption for the Reference Case and the Efficiency Scenario discussed above. In the Reference Case, LDV fuel consumption increases by nearly 60% by 2030; the Efficiency Case cuts this increase to 21%. For the OECD nations, the Reference Case projects only a 22% increase, primarily because of moderate growth in travel demand, with the Efficiency Scenario actually reducing fuel consumption by 10%. This decrease is overwhelmed by the rapid growth in fleet size and overall travel demand, and the slower uptake of efficiency technologies in the developing nations. Figure 5.26 shows the GHG emissions path for the two scenarios, resulting in a mitigation potential of about 1 $GtCO_2eq$ in 2030.

Table 5.19 show the cost of the reductions in GHG emissions in both $/tonne of CO_2 and $/tonne of carbon for the 2030 new vehicle fleet, assuming oil prices of $30, $40, and $50 over the vehicles' lifetime. Even with assumed substantial cost reductions for efficiency technology, mitigation costs are quite high everywhere but in North America. The lower costs there result primarily from very high levels of vehicle usage and low baseline fuel efficiency, yielding lifetime fuel savings substantially higher than in the rest of the world.

***Table 5.18**: Regional and Worldwide Light-Duty Vehicle Fuel Consumption*

LDV Total Fuel Consumption, Efficiency Case (exajoules)

	2000	2005	2010	2015	2020	2025	2030
OECD North America	17.7	18.5	19.3	19.7	19.3	18.1	16.8
OECD Europe	7.0	7.3	7.6	7.7	7.2	6.6	6.0
OECD Pacific	3.2	3.2	3.2	3.1	2.9	2.6	2.3
FSU	1.2	1.4	1.7	2.0	2.4	2.6	2.7
Eastern Europe	0.7	0.8	0.8	0.9	1.0	1.0	1.0
China	0.7	0.9	1.3	1.8	2.5	3.0	3.5
Other Asia	0.8	0.9	1.1	1.3	1.6	1.8	1.9
India	0.3	0.4	0.5	0.7	0.9	1.0	1.1
Middle East	0.4	0.4	0.5	0.6	0.7	0.8	0.8
Latin America	1.6	1.9	2.3	2.7	3.1	3.2	3.3
Africa	0.8	0.9	1.1	1.4	1.7	2.0	2.2
Total	34.2	36.7	39.4	41.9	43.3	42.6	41.5

LDV Total Fuel Consumption, Reference Case (exajoules)

	2000	2005	2010	2015	2020	2025	2030
OECD North America	17.7	18.5	19.6	20.9	22.1	22.8	23.4
OECD Europe	7.0	7.3	7.6	7.9	7.8	7.6	7.5
OECD Pacific	3.2	3.2	3.2	3.2	3.3	3.2	3.2
FSU	1.2	1.4	1.7	2.1	2.6	2.9	3.3
Eastern Europe	0.7	0.8	0.8	0.9	1.0	1.1	1.2
China	0.7	0.9	1.3	1.9	2.7	3.4	4.4
Other Asia	0.8	0.9	1.1	1.4	1.8	2.1	2.5
India	0.3	0.4	0.5	0.7	1.0	1.2	1.5
Middle East	0.4	0.4	0.5	0.6	0.7	0.8	1.0
Latin America	1.6	1.9	2.3	2.8	3.4	3.7	4.2
Africa	0.8	0.9	1.1	1.4	1.7	2.1	2.4
Total	34.2	36.7	39.9	43.9	48.0	51.1	54.4

***Table 5.19:** Cost of CO_2 Reduction in New 2030 LDVs with revised gasoline cost values*

$/tonneCO2			$/tonneC			
$30/bbl $0.39/L	$40/bbl $0.46/L	$50/bbl $0.53/L	$30/bbl $0.39/L	$40/bbl $0.46/L	$50/bbl $0.53/L	
48	24	-1	176	86	-4	OECD North America
230	206	181	844	754	664	OECD Europe
251	227	202	920	830	740	OECD Pacific
109	85	60	401	311	221	FSU
224	200	175	822	732	642	Eastern Europe
227	202	178	831	741	651	China
230	205	180	841	751	661	Other Asia
333	309	284	1221	1131	1041	India
145	121	96	532	442	352	Middle East
173	149	124	635	545	455	Latin America
211	186	162	772	682	592	Africa
130	105	81	476	386	296	World (sales-weighted average)

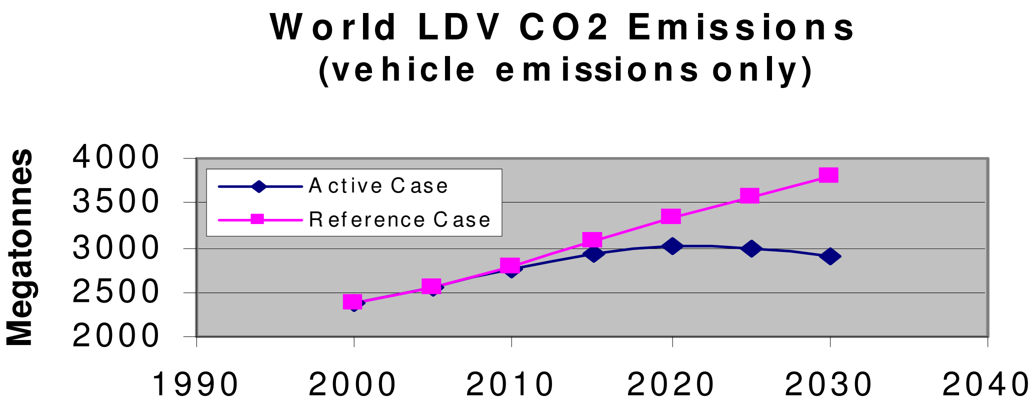


***Figure 5.26:** Light Duty Vehicle CO_2 emissions*

To these can be added the 12% emission reduction of transport CO_2 emission in 2030 achieved by the use of advanced biofuels as mentioned in Section 5.3.1.4, which would give a reduction potential of around 1GtCO_2eq when applied to the IEA-WEO baseline (reference) scenario.

Based on data mentioned in Section 5.3.3 a crude estimate can be made of mitigation potential by aviation. Fuel efficiency improvement (in 2030 ca. 30% improvement of fuel efficiency per passenger kilometre compared to 2000), the flying wing concept (with 50% improvement of fuel efficiency per passenger kilometre) and using biofuels with a blend of 10-50%, could in total contribute to an additional 800 MtCO_2eq based on the IEA-WEO baseline scenario for 2030. However, as no cost information is available, an unknown share of the mitigation potential of aviation may fall in the category of >100 US$/t$CO_2$eq avoided.

5.9 Long term outlook

Mobility is almost universally acknowledged to be one of the most important requisites to achieving improved standards of living. As economy grows, people tends to use more energy-intensive mode of travel. Therefore, energy consumption of the transport sector will continue to increase in the future. According to IEA's WEO2004 (IEA,2004a), energy consumption and CO_2 emission of transport sector will increase almost linearly up to 2030 with an average increase rate of 2.1% per year. This trend is projected to continue up to 2100 by IIASA/WEC(1998) as shown in Fig 5.27. Of course the increase rate strongly depends on the growth of economy and population, which is reflected to the differences between scenarios (A, B, C).
In the following, the future of transport sector will be overviewed, mostly based on the analysis of WBCSD(2004). As shown in Fig. 5.28, the total energy use of transport sector increases with an average growth rate of 1.7%/year, which is slightly lower than the rate projected by IEA(2004). The growth of air is highest (2.6%), followed by 2-3 wheelers (2.1%). Although the growth rate of LDVs is not so high (1.5%), almost 40% of total energy will be consumed for LDVs in 2050, and the share of road transport will be more than 70%. 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, which is almost three times higher than the present level (Fig 5.29). Nearly all of this increase will be in the developing world. If major technology improvement of LDVs will not happen, this leads to large increase of CO_2 emission from LDVs, as shown in Fig 5.30. Again most

of increase will be in the developing countries. The emission of non-OECD countries will become almost 5 times as high as the present level.

The total volume of transport-related GHG emissions is the result of four factors:
***Factor 1** – The amount of energy required by the average vehicle used by each transport mode to perform a given amount of transport activity.*
***Factor 2** – The WTW greenhouse gas emissions generated by the production, distribution, and use of a unit of transport fuel..*
***Factor 3** – The total volume of transport activity.*
***Factor 4** – The modal mix of the total volume of transport activity.*
As discussed in previous section, there are several possible mitigation technologies for LDVs, such as hybrids, fuel cell and biofuels. In considering the impact of these technologies and time period required to have an impact, it is useful to separate the vehicle technologies and fuels into two categories. One category includes vehicle technologies and fuels for which there is some degree of commercial experience somewhere. LDVs using advanced ICE gasoline, advanced ICE diesel and ICE hybrid-electric powertrains are already on the market or are close to being so. "Conventional" biofuels are also in commercial use in several countries. The second category of vehicle technologies and fuels includes more advanced vehicle technologies such as fuel cells and fuels such as carbon neutral hydrogen and advanced biofuels. Their potential to cut transport-related GHGs is beginning to be understood but they are not nearly as close to large- scale commercialization. Questions on technical feasibility must still be answered. The cost of such vehicles and fuels when produced in high volume is also highly speculative.
At first, we will see the extent of impact for each possible technologies on worldwide road transport CO2 emissions. Figure 5.31 shows results for five such technologies – dieselization, hybridization, fuel cells,"carbon neutral" hydrogen, and biofuels. It was assumed that each powertrain technology achieves as close to 100% global sales penetration as possible. It must be noted that these single technology examples are purely hypothetical, since it is highly unlikely for any single technology to achieve 100% penetration. From this single technology assessment, it is evident that even if implemented worldwide, diesels and hybrid ICEs fueled with conventional gasoline and diesel fuel, or fuel cells fueled by with natural gas-derived hydrogen, can no more than slow the growth in road transport CO_2 emissions during the period 2000-2050. Only the use of carbon-neutral hydrogen in fuel cells and advanced biofuels in ICE-powered vehicles can largely or totally offset the growth in CO_2 emissions produced by the growth in road travel during the period 2000-2050. Other recent studies (NRC/NAE, 2004; DfT, 2004; IEA, 2004b) have reached a very similar conclusion, i.e. improved conventional technologies will be an important part of the development, but that fuel switching will be essential.
Since the substantial reduction of CO_2 emissions from road vehicles is likely to require the widespread adoption of several advanced fuel and vehicle technologies, WBCSD/SMP study have examined the combined impact of several actions as an second step of log-term analysis. They have set an illustrative target of reducing annual worldwide CO_2 emissions from road transport by half in 2050. This is equivalent to CO_2 emissions reductions of about 5 gigatonnes from the reference case projects, and returns annual road vehicle CO_2 emissions in 2050 to about their current levels. For illustrative purposes, the CO_2 reduction target is divided into seven "increments." The timing and size of each increment is not fixed and ultimately would be decided subject to sustainability and investment choices at national, regional and global levels. The purpose of the analysis is to illustrate what might be achieved if ambitious changes were made beyond those in the WBCSD/SMP reference case, without any judgment as to the cost or probability of each step being taken. The results are shown in Fig 5.23, confirming the impression conveyed by the single technology analysis, i.e. it would required the widespread adoption of a combination of fuel and vehicle

technologies (plus other factors) to return 2050 CO_2 emissions from road vehicles to their 2000 level.

While LDVs are the world's most numerous motorized transport vehicles, other road vehicles and other transport modes contribute significantly to personal and goods mobility and are an important element in the challenge of making mobility sustainable. Figure 5.32 shows projected reference case WTW CO_2 emissions by mode for the period 2000-2050.
Trucks of various sizes are the principal transporters of freight over land. “Heavy" road vehicles account for a significant share of transport-related energy use, greenhouse gas emissions, and "conventional" emissions (especially NOx and particulates). Increasing attention is being devoted to improving the energy efficiency of the powertrains used in these vehicles, at present mostly diesels and also to reducing their "conventional" emissions. In US, the impact of heavy vehicle idling is discussed with a focus on the heavy duty trucks and locomotives. Idling stop and installation of auxiliary power units(APU) have a significant impact.[22] Efforts are also underway to apply new propulsion system technologies such as hybrids and fuel cells to selected truck and bus types.
Among the other transport modes, commercial aircraft present a particular challenge. The efficiency of aircraft engines is increasing and weight reduction through improved aerodynamics and the use of lightweight materials are expected to continue to be important sources of greater energy efficiency in commercial aircraft. Even so, the rate of demand growth projected for this form of mobility is so great that even with these improvements both energy use and GHG emissions are projected to increase faster than in any other transport sector. Additional efficiency improvements may still be possible. For example, some consideration[23] has been given to using hydrogen as a commercial aircraft fuel. This is unlikely to occur before the latter half of the 21st century.

In road transportation, it appears technically feasible to reduce growth in worldwide GHG emissions significantly by the introduction of advanced powertrains and fuels. At least six possible technologies exist (in addition to improvements in mainstream gasoline engine technology) that appear capable of contributing to stabilization – dieselisation, hybridisation, advanced bio-fuels, fuel cells, carbon-neutral hydrogen, and non-powertrain vehicle efficiency improvements. No single new technology may provide a stabilization solution by 2050. Some of these technologies may not be ready for introduction for several decades. Also, the time required from the introduction of each technology to the deployment with a significant impact on GHG emissions varies widely between 10-50 years. It may be worthwhile to compare the actions taken to reduce GHGs emitted by transport-related activities and actions taken to reduce GHGs impacting other sectors in terms of cost-effectiveness.

[22] See for exapmle, http://www.eere.energy.gov/cleancities/idle/
[23] EU funded CRYOPLANE project. See details: http://europa.eu.int/comm/research/aeronautics/info/news/article_786_en.html

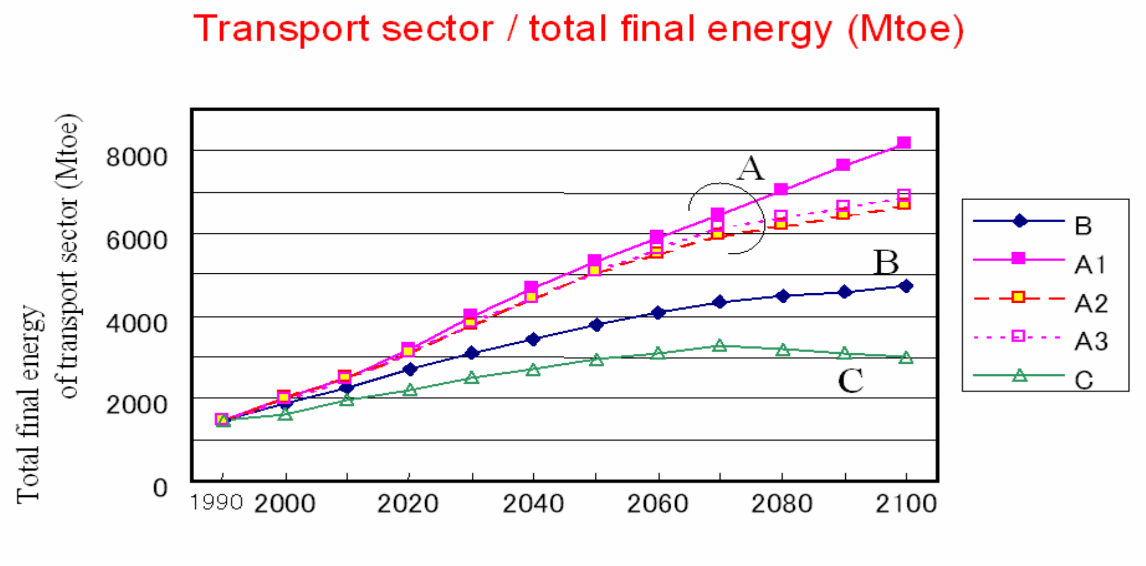


Figure 5.27: *Projections of energy consumption in transport sector*

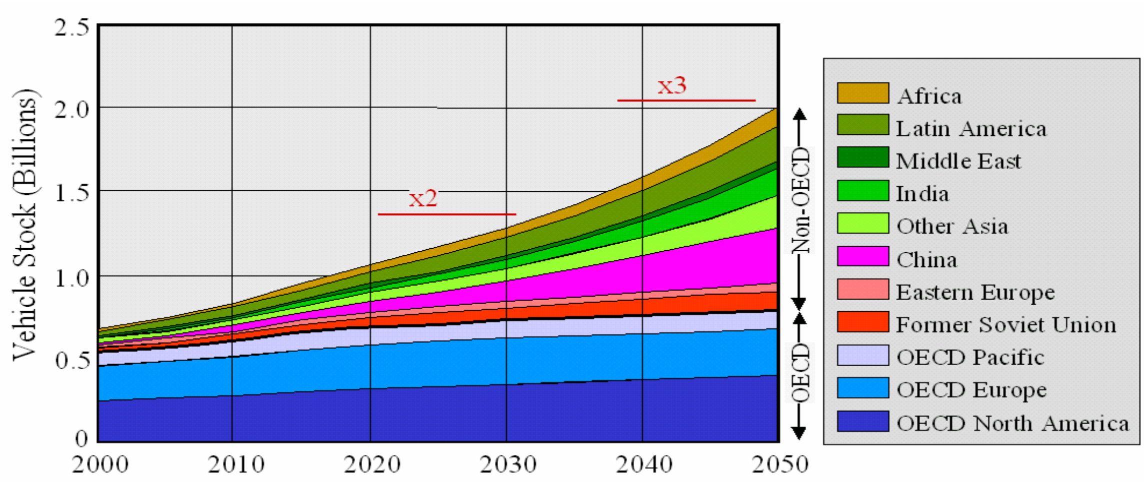
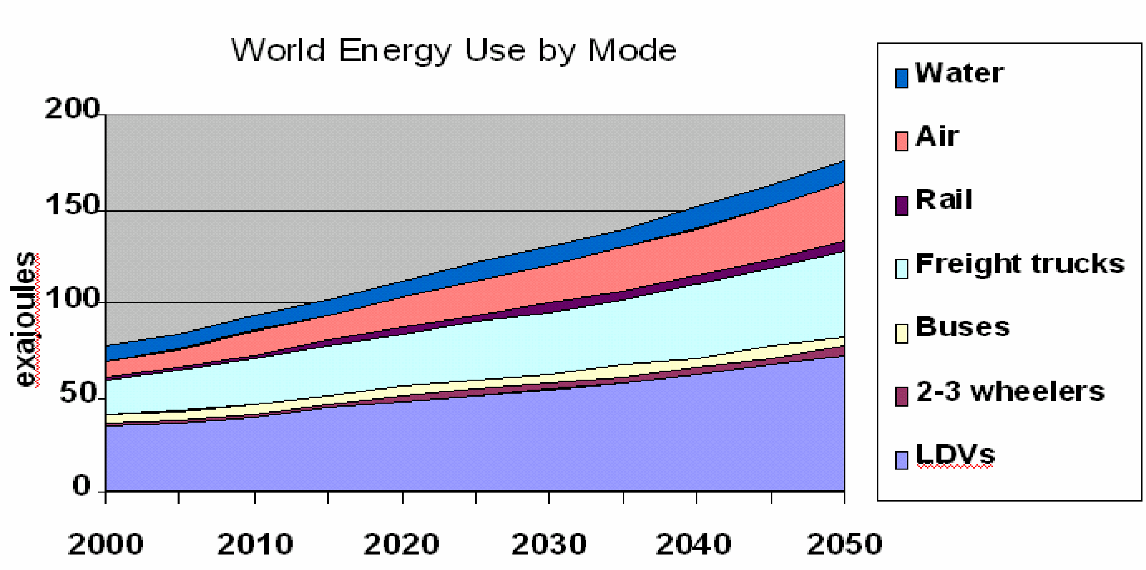


Figure 5.28: *Projection of vehicle stock by region up to 2050*



5 ***Figure 5.29***: *Projection of transport energy consumption by mode*

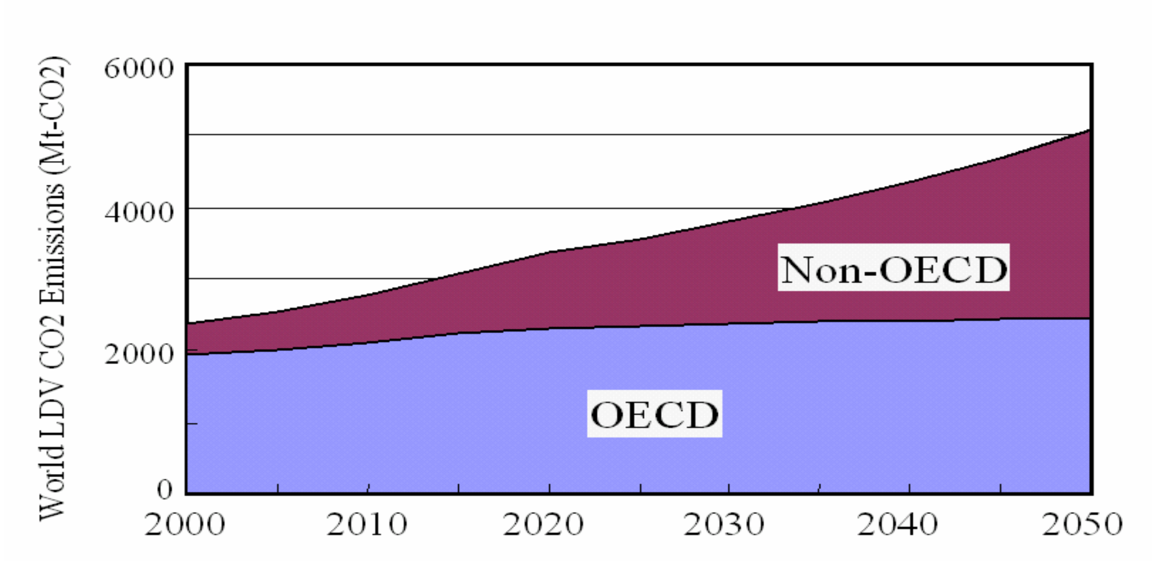


***Figure 5.30**: Projection of LDV CO2 emission for OECD and Non-OECD countries*

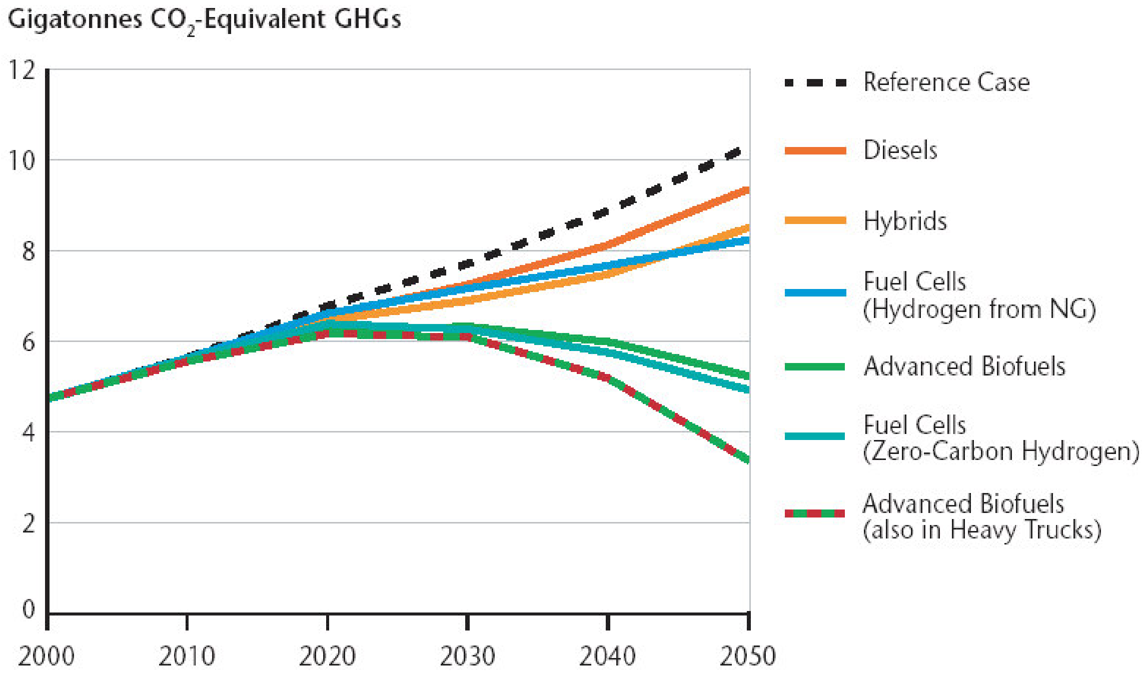


***Figure 5.31**: Single technology scenario for GHG emissions*

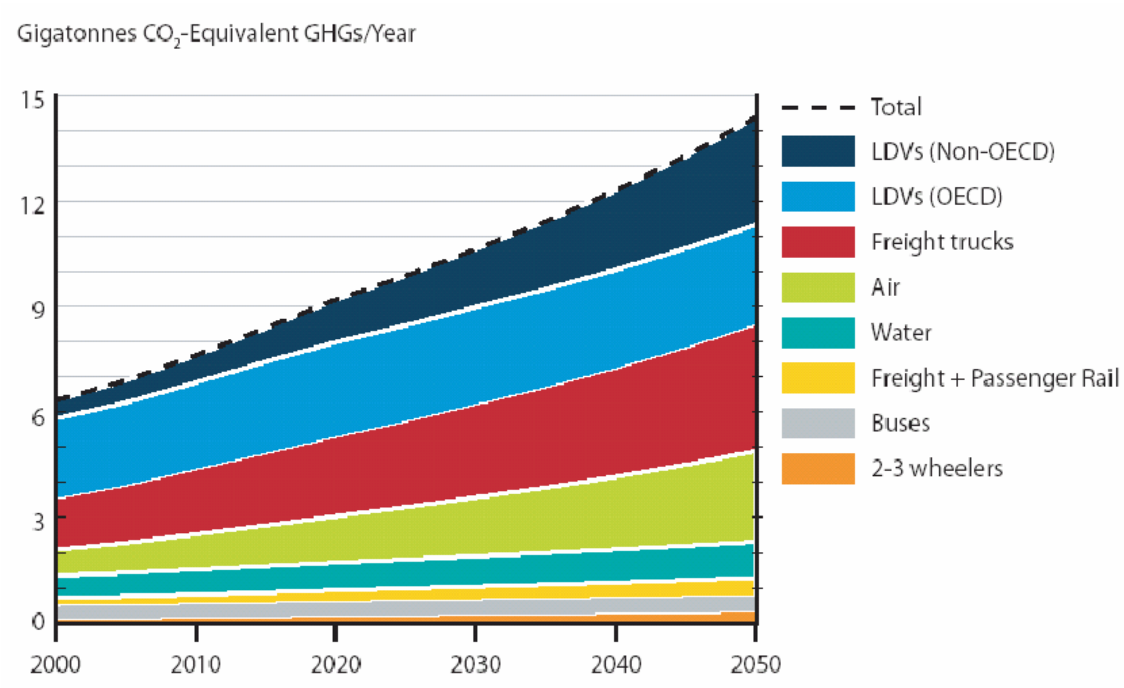


Figure 5.32: *Projection of GHG emissions by mode*

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