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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 the growth of transportation activity. In the developed world, transport activity and carbon emissions continue to increase at 1-2% per year as these economies expand. In the developing world, the rapidly increasing motorization of transport is expanding human mobility and increasing transport GHG emissions at a much faster rate. Motor vehicle travel now comprises 10% of total passenger kilometers in the developing world, 50% in Western Europe and 90% in the United States. As incomes grow and the value of travelers' time increases, travelers are expected to choose faster modes of transport, shifting from non-motorized to automotive, to air and high-speed rail. Increasing speed has generally led to greater energy intensity and higher GHG emissions.

In the year 2000, the transport sector used 77 exajoules of energy and produced 28% of world energy-related GHG emissions (6.3 gigatonnes of CO_2-equivalent on a well-to-wheels basis). Passenger transport currently accounts for 65% (50 exajoules) of total transport energy consumption and GHG emissions while freight movement comprises the remaining 35% (27 exajoules) (table E-1, which is identical to table 1).

It is not clear that conventional oil can continue to supply the energy needs of the world's growing transport system. There is a growing consensus that conventional oil production will peak sometime in the next several decades. What replaces oil as the predominant source of energy for transport will have enormous implications for the sector's future GHG emissions. There are no shortage of alternative fossil energy feedstocks, ranging from coal to oil sands and shale oil, and possibly natural gas. A transition to alternative fossil energy resources would significantly increase transportation's GHG emission, unless the addition 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 could direct the transport sector towards a low-carbon future.

Analytical Approach

The analytical approach for assessing the GHG mitigation potential for transport relies on three key methodologies: 1) life-cycle analysis (LCA), 2) assessment of technological, economic and market potential of individual technologies, measures and policies and, 3) integrated assessment to take account of synergies across strategies, account for the joint impacts of policies and the technologies and practices they are intended to foster, to account for interactions with the global economy.

Life-cycle analysis/Rebound effects

Life-cycle analysis (LCA) has become the standard for evaluating the potential for alternative fuels and energy efficient transportation technologies to reduce GHG emissions. Referred to in the fuels area as "well-to-wheels" analysis, LCA attempts to capture the comprehensive impacts of fuel choices on GHG emissions by accounting for significant emissions in the chain of activities from resource extraction to tailpipe exhaust.

When considering energy efficiency improvements to transportation vehicles, LCA recognizes the GHG emissions generated producing the materials of which the vehicle is comprised, its manufacture and its end-of-life disposal, as well as its lifetime of use. A complete assessment of energy efficiency impacts also recognizes the potential for "rebound" effects, the tendency for energy-using activity to increase when energy efficiency improvements reduce the cost of energy per unit of activity. However, when energy efficiency improvements increase capital cost, the offsetting impact on activity must also be considered.

The LCA method has its limitations, however. Boundary issues, where to stop calculating impacts, invariably arise. Not only are there often difficulties in obtaining data on GHG emissions for all processes, but associated processes are also subject to technological and behavioral change. In a GHG-constrained world, the GHG emissions of upstream and downstream processes will not remain constant. Predicting how these processes may change over time in a manner consistent with changes in the technology at issue is an important but unresolved aspect of LCA.

Specific mitigation potential

Technologies, operating practices, policies, and even behaviors have technical, economic and market mitigation potentials. For fuels and technologies, technical potential can be defined relative to established performance standards, such as the EU, Japanese or U.S. test cycles for motor vehicles. Economic potential can then be assessed based on cost-energy savings trade-off analysis. Market potential assessment requires consideration of a broader range of attributes of interest to consumers, as well as compatibility with codes and standards. At each step, the maximum theoretical mitigation potential can be reduced. Technical potential for operating practices, policies and behaviors are more difficult to isolate from economic and market potential, and are usually derived from case studies or modeling analyses. Uncertainty is a key factor at all stages of assessment, from technology performance and cost to market acceptance.

Integration

Integration of the specific mitigation potentials of technologies, operating practices, policies and behaviors into sector-wide and global mitigation potential requires taking account of synergies and systemic interactions. At the most basic level, mitigation actions applied to the same source of GHG emissions have a multiplicative rather than an additive synergy that must be taken account of: e.g., two strategies individually capable of reducing GHG emissions from passenger cars by 10% taken together achieve a 19% not a 20% reduction. Similarly, policies that can reduce vehicle travel by 10%, would achieve only a 5% mitigation if vehicle emissions were reduced by 50% by technological means. Accurately accounting for such interactions is essential for calculating sectoral mitigation potentials. Double counting must be avoided in assessing the mitigating impacts of policies, like fuel economy standards, that induce the adoption of GHG-reducing technologies.

Mitigation potential is estimated with reference to a baseline projection of GHG emissions. This implies that either the mitigation options considered are not used in the baseline projection or that their degree of market up-take is known. Only one global, bottom-up assessment of transport sector

GHG mitigation has been identified, and even that study considered only road transport. This leaves three alternatives, rely on the one available assessment or compare mitigation potential to an artificial "frozen technology/policy" scenario, or estimate the level of mitigation inherent in available GHG scenarios.

This chapter's analytical framework stops at the point where the transport sector's mitigation potential has been identified. Ideally, one would combine the mitigation actions and potentials for all sectors and estimate a new global mitigation scenario, taking into account the interactions among sectors. Such an analysis is beyond the scope of this chapter.

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

Over the next 30-50 years the market potential, as well as the GHG mitigation impacts of biofuels will depend strongly on the feedstocks from which they are made and the processes employed to make them. Ethanol is the most widely used biofuel at the present time. In Brazil, ethanol is made from sugar cane by fermentation and distillation. The same processes are used in North America to produce ethanol from corn. Ethanol from sugar cane is both more economical and has lower GHG emissions than ethanol produced from corn. In North America and Europe, ethanol is often blended with gasoline at levels of 5-10%, while in Brazil ethanol is used in up to near-neat concentrations. Chiefly due to the small fraction of the total chemical energy in biomass utilized by these processes and the large energy inputs to their production, 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.

In the near future, biofuels may be made from the ligno-cellulosic components of plants, as well as from biological wastes, with conversion either by enzymatic processes or by gasification and synthesis. Because these processes utilize a far higher percentage of the chemical energy in biomass, either pathway should both lower the costs and greatly reduce the net GHG emissions from biofuels. As a result, the potential for biomass fuels to displace fossil fuels in road transport could increase to as much as 20% by 2030, achieving a 16% reduction in road transport carbon emissions (IEA, report). By 2050, biofuels produced by advanced methods might displace half of total transport energy use by 2050 with a consequent reduction of 35% in well-to-wheel carbon emissions.

The market success of hybrids and "clean diesels" are noteworthy developments in the energy efficiency of road vehicles since the TAR. Since the commercial introduction of the Prius in 1998, learning and technological innovation have significantly decreased the costs and improved the performance of key hybrid system components, including batteries, motors and controllers. Further advances are expected. Full hybridization of a light-duty vehicle can increase fuel economy by 40%. Direct injection, turbo-charged diesel engines capable of meeting Euro4 or Tier 2 emissions standards can deliver about 30% greater fuel economy (per volume) than a conventional gasoline engine. Given the higher carbon content of diesel fuel, however, the reduction in carbon emissions is only about 20%. 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 create the potential to approximately double the fuel economy of new light-duty vehicles by 2030, thereby roughly halving vehicular carbon emissions.

A critical threat to all these fuel economy technologies is that they can be used either to increase fuel economy and reduce carbon emissions or to increase vehicle power and size. The preference of the market for power and size has consumed much of the potential for GHG mitigation offered by technological advances achieved over the past two decades. If this trend continues, it will significantly diminish the GHG mitigation potential of the advanced technologies described above.

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. With a 50% vehicle efficiency and hydrogen produced from natural gas with a conversion efficiency of 60%, well-to-wheel carbon emissions could be reduced by 50-60% versus a conventional gasoline powered vehicle. If the hydrogen were produced by electrolysis in the US, where coal currently accounts for more than half of primary energy used in electricity generation, carbon emissions would actually increase by 25%. 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.

Air, marine, rail

The dependence of air travel on fossil fuels appears likely to continue indefinitely. Energy efficiency gains will continue, however, as a result of continuous improvements in aerodynamics, weight reduction and fuel efficient aircraft engines. The blended wing body, a concept that promises up to a 50% fuel burn, and therefore aircraft carbon emission reduction, still faces challenges of costs of design, development and production, as well as market acceptance. Considering all sources, a 20% improvement in aircraft efficiency over 2000 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.

Since the TAR, the International Maritime Organization (IMO) has published a significant assessment of options for mitigation GHG emissions from the shipping industry. The study found that a combination of technical measures could reduce carbon emissions by 4-20% in older ships and 5-30% in new 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 and Behavior

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: 3-4 times as much in the EU, 2-6 times as much in Japan. The question of how much transport can be shifted to less energy intensive modes is highly dependent on local conditions. Existing studies indicate that increasing the price of carbon fuels by 10% could increase use of public transport by 1-3%. The ability to shift travel to non-motorized modes strongly depends on the provision of pedestrian and cyclist-friendly infrastructure, as well as on the density and design of land use.

The potential for telecommuting to reduce overall automotive CO_2 emissions has been estimated at approximately 1% under real-world conditions.

Aviation system operations can be optimized for energy use and CO_2 emissions by minimizing taxi time, flying at optimal cruise altitudes, flying minimum distance great-circle routes, and minimizing holding and stacking around airports. The GHG reduction potential of such strategies has been estimated at several 2-3%. More recently, researchers have begun to address the potential to minimize the total climate impact of aircraft operations, including ozone impacts, contrails, and nitrogen oxides emissions.

Policies and Measures

Policies and measures to reduce the transport sector's GHG emissions are intended to function via four basic mechanisms:

1. investing in infrastructure and regulate land use so as to create efficient transport systems;
2. internalizing the external costs of transport so that climate change and other impacts are more appropriately taken account of in market decisions;
3. correcting market failures that result in excessive GHG emissions;
4. influencing consumers and firms to shift their preferences and practices in favor of lower GHG emitting commodities and activities.

Surface Transport

The energy requirements for urban transport are strongly influenced by the density and spatial structure of the built environment, as well as by location, extent and nature of transport infrastructure. Land use and transportation planning policies have important roles in each area.

Most industrialized nations have set fuel economy standards for new light-duty vehicles. In addition to the EU, Japan, United States, Canada, and Australia, China has now established a system of weight-based fuel economy regulations. The forms of standards vary widely, from uniform, mandatory corporate average standards (US), to graduated standards by vehicle weight class (Japan and China), to voluntary industry-wide standards (EU and Canada). 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 acceptable fuel economy levels regardless of the widely varying cost of fuel among these countries. Fuel economy standards have been universally effective in raising new vehicle fuel economy, increasing one-road fleet average fuel economy, and reducing fuel use and carbon emissions. In some countries, fuel economy standards have been strongly opposed by segments of the automotive industry on a variety of grounds ranging from economic efficiency to safety. A key feature of fuel economy standards is that they direct the trade-off of potential fuel economy gains for vehicle performance and increased weight in favor of fuel economy.

Transportation Demand Management (TDM) consists of more than three dozen different strategies whose goal is to improve the performance of road systems by reducing traffic volumes. TDM strategies range from the provision of information to travelers, to traffic restrictions (e.g., freeway ramp metering or high-occupancy vehicle lanes), to improved driving styles. Well designed and capably implemented TDM plans have been demonstrated to achieve vehicle travel reductions exceeding 10% in cities around the world.

Taxes on vehicle purchase, registration, use and motor fuels, as well as road and parking pricing policies are important determinants of vehicle energy use and GHG emissions. They are variously employed by different countries as user fees, to raise general revenue, to partially internalize the external costs of vehicle use or to regulate use of public roads.

The Clean Development Mechanism offers the possibility to obtain funding for transportation projects that mitigate GHG emissions. However, there are significant barriers to the use of the CDM for transport projects including, the interpretation of additionality and the relatively low value of GHG benefits relative to the costs of most transport projects. As of the end of 2004, no transport CDM projects had been approved. It is likely that CDM rules will need to be adapted for the CDM to become a significant policy tool for mitigating transport's GHG emissions.

Aviation and Marine

At the present time the International Civil Aviation Organization (ICAO) has not agreed on what policies to implement to insure the mitigation of GHG emissions from international aviation. However, several studies have estimated the potential impacts of emissions charges or trading systems. An EU study found that charges of € 30 per tonne of CO_2 and € 3.6 per tonne of 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 study concluded that a charge of \$50/kg of jet fuel would 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.

The IMO is investigating measures of ship efficiency, focusing on CO_2 emissions per ton-mile transported. The index could serve as the basis of policies such as incentives or efficiency standards.

Non-climate policies

Many policies not aimed at transport's GHG emissions nevertheless have a significant impact on them. Globally, transport subsidies of various kinds have been estimated at almost 1% of global GDP. Some subsidies, such as of public transport systems, may reduce GHG emissions while others, such as fuel price subsidies in certain countries, undoubtedly increase them. Unfortunately, little is known about the quantitative impacts of transport subsidies on GHG emissions.

Infrastructure

Investments in transport infrastructure have important impacts on the level of transport activity, its modal distribution, and it efficiency. Investments in road systems in developing countries are essential to economic development and will undoubtedly encourage the growth of road transport. At the same time, the efficiency per unit of activity may increase if congestion is decreased. How infrastructure investments are made can have dramatic impacts on the viability of non-motorized transport modes. This could be a potentially important area for in which the CDM, if effectively applied, could have a significant impact on mitigation.

Technology R&D, Transfer and Diffusion

Any private company has no right to press consumers in a particular direction of technology, so companies prepare a wide range of options from which consumers can choose. Although R&D is a key driver for companies to maintain their competitive position through the development and implementation of new technologies and products, investment for R&D is huge and the result of efforts is generally uncertain. In order to facilitate the development of long-term advanced technologies, the role of public funding to their research, development and deployment is very important. Good examples can be found for the development of fuel cell vehicle, including vehicle/fuel technologies and infrastructure development.

Once they succeed to develop new technology, they want to protect that advantage. Such protections are essential to preserve the ongoing ability to innovate through costly R&D. This is a very important point to discuss the technology transfer, especially to developing countries.

The realization of mutual benefit is one of the most important keys to success in technology cooperation and capacity building. Successful partnership is a ‘win-win’ process in which both the overseas partner and the host nation can reap substantial benefits.

Regional Differences

In the developed economies, motorized transport fueled by petroleum (96%) is predominant. Motor vehicle ownership approaches and some cases exceeds one per adult. In the developing world, levels of vehicle ownership are an order of magnitude lower, non-motorized transport plays a significant role, and there is much greater reliance two- and three-wheeled motorized vehicles and public transport.

The motorization of transport in the developing world is well underway and expected to grow rapidly in the coming decades. From 7 million barrels per day oil equivalent in 1990, transport energy use in the developing world increased to 11 mmbd in 1999, and is projected to reach 23 mmbd in 2015, 44% of world transport energy use. 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. While developing economies are expanding infrastructure to provide for greater mobility, they are adopting stricter emissions standards and, in the notable case of China, fuel economy standards to control their economies exploding dependence on imported oil.

Transport Sector Mitigation Potential

There are various possible mitigation technologies and measures for transport sector.
For the road transport, these include the 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. Combination of various powertrain and fuels has been evaluated by well-to-wheels analyses. Further integration of the specific mitigation potentials of technologies, operating practices, and policies was studied by scenario analyses.

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. Assessment of economic potential and also market potential might decrease the whole 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 reduceGHG 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 economy grows, people tend to use more energy-intensive mode of travel. Therefore, energy consumption of the transport sector will continue to increase in the future. Based on the analysis of WBCSD (2004), the total energy use of transport sector increases with an average growth rate of 1.7%/year,

- The growth of air is highest (2.6%) and that of LDVs is not so high (1.5%). However, almost 40% of total energy will be consumed for LDVs in 2050, and the share of road transport will be more than 70% in the transport sector. 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.
- 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 CO2 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 CO2 emissions produced by the growth in road travel during the period 2000-2050.
- 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,suchi 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 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 modes. Additional efficiency improvements may still be possible such as using hydrogen as a commercial aircraft fuel. However, this is unlikely to occur before the latter half of the 21st century.

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 2001).

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).

These days the demand for automobiles increases very rapidly in the cities of developing countries, where infrastructures including road networks and public transportation system are not well developed. So this leads to congestion causing local environmental problems and lots of traffic accidents. Especially in developing countries, the main issue of transportation sector will not be GHG reduction, but the improvement of local environment and safety problem. Therefore, global warming issue should be discussed with sustainable development including the above aspects.

5.2 Current Status[1] 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 the 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. 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 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. 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." And making the issue of growing transportation energy use of increased concern is the likelihood that the world will soon face an important decision point associated with the depletion of conventional oil resources, the peaking and decline of conventional oil production: Will it take the apparent path of least resistance, which would be a growing reliance on unconventional carbon-based fossil resources (heavy oil, oil sands, liquids from natural gas and coal, oil shale) – probably accompanied

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[1] 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 .

by even higher carbon intensity than today's fuels -- or a different path that would focus on lower or zero carbon resources.

5.2.2 Transport Toda

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 28% of world energy-related greenhouse gas emissions – 6.3 gigatonnes of CO_2 -equivalent emissions on a well-to-wheels basis, out of a world total of 22.6 gigatonnes (Fulton and Eads, 2004). Of a total of 77 exajoules of total transport energy use, highway vehicles account for more than three-quarters, with light-duty vehicles and freight trucks having the lion's share (see Table 5.1). And virtually all (96%) of transport energy comes from oil-based fuels, largely diesel (23.6 exajoules, or about 31% of total energy) and gasoline (36.4 exajoules, 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.

[INSERT **Table 5.1.** here]

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 transit. 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 transit services. 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-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. 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, travelers 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(Schafer, 2000). 2-wheeled scooters and motorcycles have also played an important role in the developing world and in warmer parts of Europe, with a current 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 high-speed rail. 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 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 Western Europe's and Japan's freight systems are dominated by trucks, with virtually no freight carried by their extensive rail systems. 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 trade-offs. 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 X

The pollutants and their chemical and physical effects are complex and the subject of more detailed analysis and discussion in the companion Working Group I Fourth Assessment Report of IPCC. However, it is important to realise that the total effect on climate, as assessed using the climate metric 'radiative forcing' (in Watts per square metre) can be a function of positive (warming) and negative (cooling) forcings: moreover, some of these influences may be much larger than the CO_2 forcings.

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 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. The various RF effects from aviation have been the most extensively studied (see IPCC, 1999; Sausen *et al*., 2005) and the single largest influence is potentially enhancement of cirrus clouds, one recent study estimating 0.03 W m^{-2} (range 0.01 to 0.08 W m^{-2}) (Stordal *et al*., 2005).

[INSERT **Table 5.2.** here]

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. There is no shortage of alternatives to 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, especially given prospects for future global terrorism. 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; thus, 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 those fleets 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 1, 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.

[INSERT **Figure 5.1.** here]

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) and the International Energy Agency (World Energy Outlook 2004); 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 IEO2004 and Mobility 2030 forecasts are quite similar.[2]

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.

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 figure2). 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.

[INSERT **Figure 5.2.** here]

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. Some key observations:

- Fuel use from air travel is projected to triple over the period despite strong efficiency gains.
- The majority of light-duty vehicle fuel consumption growth occurs in non-OECD countries, with OECD North America projected to grow by only 1.3%/year, OECD Europe by only 1.0%/year, and OECD Pacific by 2.0%/year, compared to rapid growth in China (6.5%/year), India (5.1%/year), and other Asia (4.0%/year). Latin America, though growing only 2.7%/year,

[2] Note that there are significant differences between the studies in their estimates of *current* transportation energy consumption: 76.5 exajoules in 2002 (WEO2004); 80 exajoules in 2000 (Mobility 2030); to 90 exajoules in 2002 (IEO2005). Part of these differences is likely to be definitional, and part may be from data inadequacy; data on transport energy consumption in many parts of the world, and especially in the developing nations, are quite poor.

begins at a heavier usage rate and its LDV fleet is projected to consume more motor fuel in 2050 than every other region aside from China and OECD North America.

- In 2000, OECD-North America and Europe were even more dominant in heavy freight truck use than in LDVs, accounting for 60% of total world fuel use. By 2050, Mobility 2030 projects them to account for less than 43% of total world fuel use. During this period, China, India, other Asia, and Latin America are projected to grow to 7%, 9%, 15%, and 10% shares of fuel consumption, respectively. Total fuel use from heavy trucks is projected to grow to nearly 30 exajoules by 2050. Total freight activity, in tonne-kilometers/year, is projected to grow by 2.3%/year during 2000-2050.

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 oil production turn out to be incorrect, and that world economies continue to grow without significant disruptions.

Aviation

Aviation has grown strongly over the past few decades, at rates of 3-5% (firm up: IPCC, 1999) per year, globally. Regional growth rates have been even stronger, e.g. in Europe and North America, which combined make up about 80% of global aviation activities. 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.

However, 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.

Aviation emissions are predicted to continue to grow strongly. 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 3). 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 Figure3. Scenarios for international aviation have also been produced by Olsthoorn (2001): however, since domestic emissions (which have historically constituted approximately half of global civil aviation emissions, Lee *et al*., 2005) were not included, it is rather difficult to compare these estimates in an internally consistent manner.

Very few studies have made aviation emission scenarios out to 2100: Vedantham *et al*. (1998) being the notable exception. However, two of the four scenarios of Vedantham *et al*. (1998) were considered "less plausible" by IPCC (1999). In a modelling study of aviation CO_2 and O_3 radiative forcing and consequential temperature response, Sausen and Schumann (1999) extrapolated the IPCC 2050 results to 2100 assuming a growth in emission of 1% per year after 2050, based upon IPCC scenarios Fa1 and Fa2.

[INSERT **Figure 5.3** here]

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.

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 3.

[INSERT **Table 5.3** here]

The resultant range of potential emissions is shown in Figure 4.

[INSERT **Figure 5.4** here]

5.3 Analytical Framework

Although many institutes carried out analytical works on energy projections and GHG emissions, relatively small numbers of studies are available on disaggregated analyses for each end-use sector. Among them, EIA/DOE and IEA produce energy outlook regularly. Projections and scenario analysis can help us to understand the factors that might affect the future of the energy economy. These include uncertain future technological developments, economic growth, government policies and a maze of product introductions and consumer responses that can, over the long run, fundamentally change how and why we use energy. Analysis to tackle these issues must take a long term view - looking ahead at least thirty to fifty years. Unfortunately, analysis of such time frames is an uncertain science. The future is by definition unknown and cannot be predicted (IEA, 2002)

Usually, the way the future is explored is through scenarios. The above definition is in clear contrast with any idea of "prediction", as the future cannot be predicted with certainty. Furthermore, it is radically different from the idea of traditional business forecasting, inasmuch as scenarios present alternative images of the future, rather than merely projecting the trends of the present.

Measuring the potential to mitigate greenhouse gas emissions from the world's transport requires a comparative analysis. Mitigation must be measured relative to some reference path of future transport GHG emissions.

This immediately raises a question on the definition of the reference scenario, i.e., the extent to which the mitigation measures to be evaluated are already incorporated in the reference scenario. Given the relatively high degree of generalization of most global GHG scenario models and the relatively detailed nature of mitigation technologies, policies and measures considered in this chapter, it is not possible to satisfactorily answer the question.

As most of analyses do, the general approach is use of business-as-usual(BAU) scenario: 1. create a BAU scenario reflecting a "best guess" of how the future will evolve; 2. implement all remaining mitigation technologies, policies and measures not included in the BAU scenario and measure their impact. In addition to the fact that, as pointed out above, the extent to which mitigation measures are already reflected in the BAU scenario is generally unknown, this approach has the disadvantage that our best guess of how the future will evolve is certain to be incorrect.

An alternative, feasible method would be to create a "frozen technology"/BAU case from an existing BAU scenario. The "frozen BAU" case would reflect the expected growth in transportation activity but with *no* improvement in technology affecting GHG emissions. This could be done by ex post modification of an existing BAU scenario by inflating energy use and GHG emissions estimates to undo assumed efficiency improvements, and substituting fossil-based hydrocarbon fuels for assumed increases in biofuel use. Mitigation estimates could be made relative to the "frozen BAU" case. The resulting "mitigation" case could then be compared both to the "frozen BAU" and the original "BAU" case, thereby giving some indication of how much mitigation is already incorporated in the BAU case (see Fig.5).

[INSERT **Figure 5.5** here]

GHG emission and mitigation potential could be estimated in a simple manner such as IEA's ASIF approach (IEA, 2002).

The first step is the decomposition of changes in CO_2(GHG) emissions from travel or freight into 4 identities as follows;

$G = Ai * Si * Ii* Fi.$ (1)

where G is the CO_2 (GHG) emission from the particular transport sector, A is total travel or freight activity (in passenger- or tonnes-kilometers), S is the sectoral structure defined by sub-sectoral modal share, and I is the energy intensity (fuel efficiency) of each mode i. The last term, Fi represents the carbon content of fuel j in mode i. Each of these terms responds (at different rates) to different underlying forces (incomes, prices, policies, new technologies, and so forth).

The level of activity (A) is described in term of passenger-kilometers or tonnes-kilometers. In some cases, some further decomposition can be made. For passenger vehicles, this will be decomposed into vehicle-km and load factor (occupancy rate), and vehicle-km will be further decomposed into a number of vehicles and an average mileage per vehicle per year. This decomposition allows the connection with the stock model.

As shown in Fig 1, the car ownership rate is characterized by a S-shaped curve and then car ownership can be estimated by the growth of GDP per capita and population. An example of such projections (IEA/SPM, 2004) is shown in Fig.6 Growth of ownership rates is quite different from region to region.

Vehicle travel is estimated as the product of vehicle stocks and average travel per vehicle. For OECD regions, average travel per vehicle is very stable across time (i.e., increases in car travel track very closely to increases in vehicle stocks). In regions with low travel per vehicle, like India, average travel increases as average speeds increase, which could occur as road infrastructure improves.

The sectoral structure (S) does not comes into calculation directly, but affects strongly an average energy intensity as a whole. Modal split is affected by many factors such as geography, infrastructure, urban planning strategy and so on and also is different between passenger travel and freight transport (Fig 7).

The energy intensity (I) of each transport mode is obtained by dividing the energy consumption of each mode by the activity level. It is expressed in terms of MJ/pass-km for the passenger travel and MJ/tonne-km for the freight transport. In the case of road transport modes (except for buses), the fuel intensity can be more conveniently described in terms of MJ/vehicle-km, which is obtained by simply using the load factor. This vehicle intensity is the one used in the stock model to account for the effect of a policy of improvement of fuel intensity of vehicle.

As already mentioned, a few studies are available for the future projection of transport sector based on the scenario work. IIAS/WEC(1998) have developed several scenarios, which is also used in the recent WEC report(WEC, 2004). Three types of scenarios were used; i.e. high(A type) and low(C type) ranges of growth with middle course (Type B), as shown if Fig 8. This B scenario is compared with reference scenarios of other studies(EIA/DOE, 2005; IEA/SMP, 2004; IEA, 2004 ; EC, 2003) in Fig 8. B scenario is close to those of IEA and IEA/SMP, but DOE's scenario is very close to the high scenario A of IIASA/WEC, and EC's scenario is between scenarios B and C of IIASA/WEC. From these comparisons, it can be seen that mitigation potentials measured from the base of reference scenario will not be consistent among studies.

For making the mitigation scenarios, there are several issues to be mentioned. A key issue in applying mitigation options is to avoid double counting and to take interactions between mitigation actions into account.[3] It may also be desirable to account for a potential rebound effect of increased efficiency, especially in road transport.

[3] Double counting can be controlled by first defining as precisely as possible the modal and submodal activity, energy use, or GHG emissions factors to which a particular mitigation action applies. Second, impacts can be applied multiplicatively to account for first order interactions. For example, two mitigation actions which reduce the en-

Another important question is which mitigation technologies, policies and measures should be implemented? Examples of GHG mitigation costs and mitigation potentials for several vehicle/fuel combinations are shown in Fig. 9. From this type of figure, we can select the certain combinations as target technologies and choose two or more levels of mitigation cost to estimate the mitigation impacts at each level. While this may work well for those technologies whose costs can be estimated with an accuracy of, say +/-25%, other technology costs are more uncertain and the costs (and benefits) of many transport policy decisions (e.g., land use planning, alternative infrastructure investments, etc.) are often very poorly understood. In such cases there may be no better alternative than to use expert judgment to harmonize policies and measures with the more concrete technology mitigation costs.

[INSERT **Figures 5.6, 5.7, 5.8, 5.9** here]

Since projecting long-term energy scenarios involve a large number of assumptions, transparent analyses and comparability among different studies are very important to assess the available data. The present situation is unfortunately far from this requirement.

5.4 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.

Very little was addressed regarding land use planning and shifts to different transport modes, especially because there isn't much information about it. The focus regarding technological and economic potential for transport was fuel economy improvement, especially for light duty vehicles.

5.4.1 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). LCA covers the entire life cycle chain of material and energy flows from the primary extraction of feedstocks and to the end-life of products.

An LCA has to cope with a number of difficulties mainly related to the non-availability, uncertainty or variability of data, such as

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ergy intensity of mode m by 100×x_1% and 100×x_2%, regardless of fuel type, are simultaneously accounted for, as follows;

$$G = A\sum S_f(1-x_1)(1-x_2)I_f G_f \ .$$

- relevant data are uncertain and may vary to some extent, or are not available in some cases,
- most transport fuels have multiple potential feedstocks, refining processes, and distribution options, and the LCA results are highly dependent on the particular feedstock/refining/distribution choices,
- some technologies considered are still under development, so data are subject to large uncertainties inherent in looking ahead for many years,
- 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 example, in the case of electricity, energy sources for power generation are quite different from country to country. Despite the theoretical and practical limitations of an LCA, this is the best method available to assess and compare different energy systems.

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 Fig10. 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 Fig11 (of course, this portion depends on the driving mode and life-cycle driving distance).[4] 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 Figure 13. These are GM/ANL(2001) analysis for North America, EUCAR/CONCAWE/JRC (2003)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 emis-

[4] 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. 12 (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.

sion due to high efficiency of engine. The results of hybrids are diverse among the analyses and this is due to the different assumption 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 later.

For FC/hydrogen, there are many paths for producing hydrogen, as shown in Fig14. 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 H2 by electrolysis of water, FC-GH2(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 H2 from fossil fuels is economically viable, as discussed in Section 5.4.2.1. However, FCV is expected to be very clean vehicle, and this can be achieved by sequestering CO_2 produced during H2 production or making H2 using renewable energy.

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 H2 production is shown in Fig 15 (EC, 2003). 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).

[INSERT **Figures 5.10, 5.11, 5.12, 5.13, 5.14, 5.15** here]

5.4.2 Technologies

5.4.2.1 Road transport

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

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

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. The former include ethanol, biodiesel, and methanol as well as synthetic gasoline and diesel made from natural gas, coal, or other materials. The latter include natural gas, propane, dimethyl ether (a diesel substitute), and hydrogen. 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 previous 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 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. 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). 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.

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

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 main biofuels used in the world for transport purposes - ethanol and bio ester.

Ethanol is made 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. Ethanol is blended with gasoline at concentrations of 5-10% thereby replacing other oxygenates in North America and Europe. In Brazil ethanol is used in its pure form replacing gasoline. The production of ethanol fueled cars achieved 96% market share in 1985, declining to 0.1% in 1998.

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 flex fuel vehicles, which runs either with ethanol or gasoline in any proportion (see Box A). 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.

Box *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 represents more than 30% 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 grates advantages of flexfuel vehicles is their large flexibility to choose the fuel depending mainly on price. Although the consumption of ethanol is around 30% larger than the gasoline consumption, this difference could be compensated if the price of gasoline is higher than 30% of the ethanol price. This happens 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 4 shows the energy and GHG impacts of ethanol, pointing out an interesting comparison with gasoline vehicles in terms of km traveled.

[INSERT **Table 5.4** here]

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.

Producing biofuels from grains and oil seed crops such as being produced in OECD countries is relatively expensive and land intensive. Using this kind of technologies, only 5-10% of conventional fuel displacement can be met taking 20% of cropland in EU and USA by 2020 just to meet biodiesel substitution of 10% in transport sector.

Nevertheless, 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. For this reason the European Directive: 2003/20 has been recently established in order to stimulate the use of biofuel.

The promising technology that can yield significant biofuel production would convert lignocellulosic crops and crop waste into ethanol and biodiesel, and there are prospects of commercializing the technology in North America by as early as 2006 (Fulton, 2004). Biofuels produced through this technology will be competitive with conventional fuels sold at US$30/barrel. The CO_2 reduction will also be competitive with producing biofuels from sugar cane in Brazil since the cellulose and lignin will provide the process energy. 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[5] while ethanol from grain would cost as much as US$500 per tonne of CO_2. The Fischer-Tropsch techniques is a promising technology for such a process with a near term cost of US$200 per tonne of CO_2 reaching US$100/t by 2010. 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.

Therefore, the potential for biofuels is far greater than that of ethanol and biodiesel, which have already been 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 16 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.

[INSERT **Figure 5.16** here]

Basing on the 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 blended up to 20% with conventional fuel to all road transport fuel it would provide an additional 16% reduction in road transport CO_2 and about 12% reduction of al transport CO_2. Up to 2020, the most cost-effective liquid biofuel worldwide is likely to be ethanol produced from sugar cane with production taking place in warm climates particularly in developing countries where costs of production are low.

Regarding to costs, the production cost of ethanol and biodiesel in developed countries is up to three times that gasoline and diesel. 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

[5] Brazil case.

feedstock with advanced conversion technologies could eventually lead to the production of a much lower cost ethanol in developed countries.

However, the cost differs a lot 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 very close to the Brazilian cost of gasoline on a volumetric basis and is becoming close on a energy basis. 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.

[INSERT **Figure 5.17** here]

As mentioned before, Figure 18 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). Other feedstock such as rape seed and soya beans can be used but may not be easily grown in many parts of the continent.

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.

Therefore, considerable cost reductions are possible over the coming decade and beyond, as shown in the "post 2010" section shown in Figure 19.

So, as time goes by, biofuels can become economically competitive, either through economies of scale, agriculture productivity increase or new technologies. A good example in the use of ethanol in Brazil.

[INSERT **Figures 5.18, 5.19** here]

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"*)*; **DME** ("Di-Methyl Ether"); besides **methanol** (CH_3OH).

CNG (compressed natural gas) is the only automotive fuel from natural gás that can be used directly in the vehicle, being adequate to spark ignition engines. The vehicles can be dedicated to CNG or adapted from Otto cycle engines, having two different tanks. All other fuels derived from natural gas requires some kind of process in order 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. Consequently CNG loses its emission advantages, however, it produces less CO_2 during the burning process in a motor engine. Combined with the energy needed to produce the gas, transport and compress it, emissions will depend on regional circumstances. In Europe, CNG offers up to three per cent GHG benefit over diesel, 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 a lower energy content as diesel for example, larger and heavier tanks are required for the same range. Thus CNG is more suitable for vehicles

Methanol is mainly manufactured from natural gas, but biomass can also be gasified to methanol. Actually methanol can be obtained from any carbon source like coal for example, however, due to economic reasons it is normally produced from natural gas. The fuel can be used in its pure form in the engine (100% methanol) or blended to gasoline in different proportions. It is a corrosive, highly toxic product and it is raw material to produce other products such as MTBE, which is used in USA as an oxygenate additive to boost the gasoline octane rating. However, it is now being phased out because of leakage into groundwater. When natural gas is used as raw material, the fuel cycle emissions of carbon dioxide from methanol are approximately the same level as from diesel. Running on methanol gives rise to more hydrocarbons emissions than diesel and in particular emission of formaldehyde, which is poisonous Emissions of nitric oxide, carbon monoxide and particles decreased compared with diesel. Methanol has just like ethanol a high octane rating and hence an Otto engine is preferable

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 gás 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. If DME is produced from biomass, there is no net addition of carbon dioxide to the atmosphere, in case of no fossil fuel is used in its manufacturing and transport chains. If DME is produced from natural gas, the difference compared with diesel will be small. During experiments DME has shown to produce lower emissions of hydrocarbons, nitric oxides and particles than diesel, but somewhat higher emissions of carbon monoxide. 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.

There were over 1.5 million vehicles running on natural gas worldwide fuelling from over 4 thousand refuelling stations in 2001 (Kojima, 2002). The largest NGV market was registered in Argentina followed by Brazil as shown in Table 5.

[INSERT **Table 5.5** here]

Its potential to reduce GHG emissions is in that is has a lower carbon intensity (17.2tC/TJ) than petroleum products (18.9 to 20.2tC/TJ)- IPCC (1996). Apart from reducing greenhouse gas emissions, use of CNG and LNG can reduce CO by 70%, NOx by 87% compared to combustion of petrol/gasoline.

By using a reformer, natural gas is also being utilized as a feedstock to hydrogen in the fuel cell technology, which is a promising technology to achieve a very low or near zero GHG emissions by 2050. However, this low GHG emission is only feasible if the reformer uses carbon sequestration technology. If natural gas is to be used as a reformer at central plants, with hydrogen shipped to retail stations, costs could eventually drop to near parity with those of gasoline. What is increasingly becoming attractive is using natural gas as a hydrogen reformer with carbon sequestration (Fulton, 2004).

Hybrids

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
- Using 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[6] (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

[6] Precise values are somewhat controversial because of disagreements about the fuel economy impact of other fuel-saving measures on the vehicles.

United States, sales were about 7,800 in 2000 and have risen rapidly, to 83,000 in 2004[7]; worldwide hybrid sales were about 169,000 in 2004.[8]

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 (Energy and Environmental Analysis, Inc, *Analysis of the Cost and Performance of Hybrid and Diesel Drivetrains*, draft, November 2004, prepared for USDOE and NRCanada). 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 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. Some hybrid buses have attained 20-30% fuel economy improvements in city conditions[9] as well as improved acceleration capacity and substantially reduced emissions. Fedex has claimed a 57% fuel economy improvement for its E700 diesel hybrid delivery vehicles (http://www.greencarcongress.com/2004/10/fedex_hybrid_up.html).

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

7 R.L. Polk & Co. data, http://www.plk.com/News/LatestNews/news_042505.htm

8 "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.

9 Although light-duty gasoline hybrids can do considerably better than this in stop-and-go traffic, conventional buses have relatively low-power diesel engines, so that some hybrid benefits – downsized engine, elimination of idle fuel use, improved average engine efficiency – are greatly reduced in this application.

50cc scooters.[10] 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(National Committee on Energy Policy, 2004; 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.

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 and slower response. Because of these disadvantages and rapid progress on hydrogen storage tank, main streams are now for pure hydrogen FCVs.

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.

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

- 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 5.4.1, 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 H2 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%, the well-to-wheel (WTW) CO_2 emission can be reduced by 50-60% compared to 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 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 of hydrogen derived from fossil sources where the CO_2 produced during hydrogen manufacture is captured by sequestration (WBCSD, 2004). On the other hand, if H2 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 H2. The cost of FCV is estimated to be much higher than the conventional ICE and the retail price of H2 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.

Advanced Direct Injection Gasoline/ Diesel Engines and transmissions

New engine and transmission technologies are beginning to enter the light-duty vehicle fleets of Europe, the U.S., and Japan and could yield substantial reductions in carbon emissions if 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 will be 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 (Energy and Environmental Analysis, Inc, *Analysis of the Cost and Performance of Hybrid and Diesel Drivetrains*, draft, November 2004, prepared for USDOE and NRCanada).

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, "Engine Strategies and Engineering," AEI Jan 2003); cylinder shutoff during low load conditions (Honda Odyssey V6, Chrysler Hemi, GM V8s; "A Powerful Mix," AEI May 2003 for GM and Chrysler), 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 ("A Powerful Mix," AEI May 2003), 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 ("A Different Automatic," AEI July 2003). 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.

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. 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 and more power.

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 materials used in commercial vehicle. 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 fibbers (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 19.5 MPH average speed), whereas the same drag reduction on the U.S. highway cycle, with average speed of 48 MPH, would yield about a 4% reduction in average forces.[11] 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 CD by 5 to 7% by sealing unnecessary holes in the front of the vehicles, lowering their air dams, smoothing their undersides, and so forth (“Trucks Get Aerodynamic Touch,” Automotive Engineering International, July 2004).

The current generation of heavy-duty trucks in the United States has average CDs 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. CD 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[12] include a 20% reduction (from a 2002 baseline, with CD of 0.625) in aerodynamic drag for a “class 8” tractor-trailer combination.13 CD 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, R.J., “Advanced Aerodynamic Devices to Improve the Performance, Economics, Handling and Safety of Heavy Vehicles,” SAE paper 2001-01-2072, 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, A., Saricks, C., and Stodolsky, F., The Potential Effect of Future Energy-Efficiency and Emissions-Improving Technologies on Fuel Consumption of Heavy Trucks, Argonne National Laboratory report ANL/ESD/02-4, August 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 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 hy-

[11] The precise value would depend on the value of the initial C_D as well as other aspects of the car’s design.

[12] http://www.eere.energy.gov/vehiclesandfuels/about/partnerships/21centurytruck/21ct_goals.shtml

[13] These are heavy duty highway trucks with separate trailers, but less than 5 axles – the standard long-haul truck in the U.S.

brids, 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).

5.4.2.2 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.

5.4.2.3 Aviation (Peter Newton / Ron)

The primary energy source for civil aviation is kerosene. Estimates suggest that in 2002 the civil aviation scheduled passenger, charter and freight flights consumed approximately 150 million tons of fuel globally. (Ref: Aero2K 2004). For this traffic, estimates suggest that by 2025 this fuel burn is likely to increase by a factor of over 3 (Ref: Aero2K 2004). The environmental consequences of civil aviation's global fuel consumption results from the pollutants produced, primarily carbon dioxide (CO_2) and NO_x emissions, which are estimated to be approximately 2 million tonnes and 3.16 million tonnes respectively for the base year. The environmental impact will not be limited purely to 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 (true?).

Civil aviation is one of the world's fastest growing transport means. Growth trends are covered in Section 5.2.2, and these may be used to provide estimates of the future emissions burden from civil aviation. Possible scenarios are used for this purpose (see Section5.2.3) and these rely on a range of assumptions to describe a plausible development future for the industry, compatible with other global projections for fuel consumption patterns, wealth availability and social trends, etc.

(The following must reflect the proposals from the Scenarios Group, and I have used information from the AERO2k model for the time being)

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 significant consideration for the operators of modern aircraft, as fuel currently represents up to 15% of direct operating costs for modern aircraft. Technology developments, particularly within the engine, that target fuel efficiency invariably have a "knock-on" effect on other pollutants produced by the engine, and especially NO_x. Technology development within aeroengines requires a balancing of the emissions produced to both satisfy operational need (fuel efficiency) and regulatory need (NOx, CO, Smoke and HC). This emissions performance see-saw requires design compromises.

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. Laminar flow technology is likely to provide the greatest aerodynamic potential, but such developments will necessitate the development of active systems to take full advantage. Whilst such systems have been the subject of research work in recent times, they are still far from flight worthy application. In addition, novel aircraft concepts such as blended wing bodies or high aspect ratio/low sweep configuration aircraft designs will be needed in order to 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 up to a 50% fuel burn reduction compared with an equivalent sized conventional aircraft (ref.???), its development for the future is hampered by market acceptability, and costs of design, development and production.

Concern over the growing impact of aviation on local and global air quality has led aircraft engine and airframe manufacturers to work in close harmony with government research agencies to develop the new technologies needed to mitigate the impacts of aviation on the environment. The United States, through NASA, and the European Commission, through the research DG, have funded programmes to develop technologies to reduce gaseous emissions from aircraft engines (CO, UHC, NO_x) and improve engine operating efficiencies and aircraft aerodynamics and performance to reduce fuel burn and the production of global warming gas, CO_2. (*Need to reword the preceding text).*

Aviation's environmental impact is now a strong driver of technology for the industry. The impact of NOx emissions, formerly on local air quality, but in more recent times on global climate change has resulted in emissions regulations the adequacy of which is reviewed regularly. Engine manufacturers must address NO_x emissions performance to ensure their products comply with regulatory standards, as well as ensuing their products have an acceptable fuel consumption. New technology is developed not only to be introduced into new engines, but also where possible, to be incorporated into current production. Whilst aircraft operators will demand the best fuel burn possible from aircraft, the need for engine manufacturers to target NO_x has arguably reduced the fuel burn improvements that might have been possible through engine technology.

There are no fuel efficiency standards for civil aviation: market forces provide the only driver. Other pollutants are regulated however, and in particular compliance with NO_x certification standards contributes to the fuel efficiency challenge for the current engine technologies. Regulatory compliance will hinder the quest for improved fuel efficiency, and will be most difficult for those engines having the highest pressure ratios (PR40 or greater) and in these cases the margin of compliance at NO_x certification testing is in the order of only 10%. Increasing pressure ratio is one of the routes engine manufacturers may take to improve engine efficiency, and higher pressure ratios are likely to be a continuing trend in engine development. NO_x certification standards will be a barrier to what might be achieved in this regard, unless revolutionary NO_x control techniques become developed to a flight worthy standard.

Aircraft engine combustor technology has been categorised into a series of "generations". These new technologies hold the prospect of improved emissions control and therefore should allow greater fuel efficiencies to be offered. These are described as follows:

- Generation 3 technology: Best Practice single annular combustor technology, which continue to be develop to improve engine NO_x emissions beyond those levels that are currently achieved today. Single annular non-staged technology will be limited due to the trade-offs that exist between high power NO_x emissions and emissions of CO and UHC at low power. Current developments are targeted at fuel injection improvements combustor stoichiometries and combustor residence times.

- Generation 4: characterised by a staged combustion system, a successful commercial example being the CFM56 double annular combustor engine series. This technology has not been wholly successful at higher operating pressure ratios due to combustor cooling problems.

- Generation 5: a fuel staging technology similar to Generation 4 technology, but using fully lean fuel injection for the main zone of the combustor to improve NO_x emissions. Commonly referred to as lean pre-mixed, or lean direct injection, developments are being pursued under the project names "ANTLE" and "TAPS" combustors. Some problems with the trade-off between NO_x emissions and CO and UHC have been noted, along with additional combustion noise. This technology is regarded as a <u>revolutionary</u> combustion technology as it does not rely wholly on the evolution of existing combustor designs.

- Generation 6: referred to as "lean pre-mixed pre-vaporised combustion", this technology in theory can produce very low levels of NO_x emissions, but suffers technical difficulties from auto ignition and flashback in the pre-mixing stage of the combustor. Combustion noise can also be a problem at high pressure ratios. This technology, if successful, could allow significant improvements in fuel efficiency, by allowing much more effective control of NO_x emissions than currently achieved by conventional technologies.

- Generation 7: any alternative technology not covered by the above. Examples might be the use of water injection, treatment of exhaust gases downstream of the combustor, and the use of alternative fuels.

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" *(need reference and permission from GE?)* illustrates, for one particular engine type, 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 is clearly demonstrated 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 do at a given engine condition. The same is true about noise.

Aircraft Developments

Fuel efficiency improvements are available through improvements to the airframe, as well as the engine. The most common configuration for modern aircraft has low swept wings and is powered by turbo fan engines mounted beneath the wings. Most aircraft designs feature two or four engines, and such designs now form the industry standard for such aircraft. Sub-sonic aircraft being produced today are about 70% more fuel efficient per passenger kilometre than 40 years ago (Ref para 6.1 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" (ref ?) It is arguable that the current aircraft configuration, being a highly evolved design, has relatively limited scope for further improvement, and 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 technology sub-group produced a report entitled "The Technology Challenge" (ref. ?) 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. Along the issues considered, was the possible development of a new 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. The advantages 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. Similar contemporary studies confirmed this figure. 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.

[INSERT **Table 5.6.** here]

The "Greener by Design" group in the UK has considered the possibilities technological developments to improve aviation's environmental performance over the long term. Its recent report (Title, ref.?) examined the environmental impact of civil aircraft operations from gate to gate. It reviewed current understanding of the three main impacts – noise, air pollution around airports and impact on climate – and assesses the potential for mitigating them by advances in technology and changes in design priorities and operating procedures. It also considered possible future research, technology demonstration and design studies and priorities.

The report is the output from the Science and Technology Sub-Group of Air Travel-Greener by Design. It was given the particular remit of making recommendations to an industry/government forum on future research priorities for the UK. An important issue considered was that between public perception and objective evaluation of environmental impact. The UK Department for Transport (DfT) and the Treasury (HMT) have assessed the external costs of UK civil aviation (ref.?), putting the cost of impact on climate at some 6 to 12 times that of air pollution around airports and more than 50 times that of noise. This is roughly in inverse proportion to public perception, as measured by letters of complaint. Consequently, whilst impact on climate is arguably the most important issue in the long term, public concerns about noise and local air quality are likely to continue to inhibit growth in air travel and to require the attention of the operators, the manufacturers and the research community.

Whilst noise and local air pollution will continue to be constrained by international and local regulation, and limits will continue to be tightened in line with what becomes technically possible, operators and manufacturers will take steps to meet these limits. There are significant research programmes in place to address both challenges. However, the report takes the view that, in the long term, the most serious environmental issue (and threat to the continued growth of air travel) is its impact on climate.

The report suggested that through technological and operational advances civil aviation has the potential to reduce its impact on climate substantially. It will take many years for the more advanced concepts to work their way from the laboratory to the production line but some operational measures may be capable of providing benefits across the whole fleet in a matter of years rather than decades. For example, the report highlights the possibility of substantially reducing the impact of contrails and cirrus cloud to climate change by appropriate air-traffic management.

The report also identifies future developments in engine design with the potential to reduce the emission of nitrogen oxides substantially during take-off and climb and also appreciably in cruise. Further reduction in both NO_X and CO_2 emission can 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 (ref.?), but rotor noise must be brought within acceptable 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. For large aircraft, the flying wing or blended wing-body configuration, possibly with laminar flow control, is potentially a highly fuel-efficient configuration for the future.

Aviation's total environmental impact (define) could be reduced by setting different priorities in design: NO_X emissions can 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, CO_2 emission and operating cost. Contrail and cirrus formation and ozone creation can also be reduced by operational measures which increase fuel burn.

(Relevance here?) Neither design nor operating measures which increase costs are likely to be adopted until there is a regulatory framework or system of environmental charging in place which puts appropriate weight on reducing on impacts other than CO_2 emission. It will be difficult to gain acceptance of any such framework without a more robust understanding than we currently have of the impact on climate of NO_X and of contrails and contrail-derived cirrus. Equally, without this understanding, it is difficult to set priorities for research and forward-looking work in engineering design. For these reasons, the Sub-Group is firmly of the view that there is no higher environmental research priority than the effect of aviation emissions on the atmosphere and on climate.

Large Aircraft

The use of larger aircraft has been a feature of aviation development over its existence. During the jet age, starting off 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, and 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. The latest aircraft type of this genre will be the Airbus A380, which will have around 600 seats and be capable - with reduced seat pitch - of carrying of up to 800 people. In terms of cost per passenger kilometre flown, such vehicles represent an improvement in aviation efficiency, but the extent that this trend will continue for the future is uncertain: the market has yet to decide on the largest acceptable size. Such aircraft facilitate the "hub and spoke" operation, where airlines fly large numbers of passengers between major centres, from which they interline and take ongoing flights in smaller aircraft to their final destinations. Passenger preference is generally for direct "point to point" flights, and this may be for the future the way that many airlines choose to operate. However, for the future it is likely that both models will operate in harmony, maximising both the economies of scale from the "jumbo" aircraft whilst offering the benefits of point-to-point flights where those are economically viable.

Cryoplane

In 2004 the EC published a report entitled "Liquid Hydrogen Fuelled Aircraft - Systems Analysis" of a project co-ordinated by Airbus Deutschland GmbH. The objective of the study was to develop a conceptual basis for applicability, safety, and the full environmental compatibility for a transition from kerosene to hydrogen in aviation. The system analysis covered technical, environmental, societal and strategic aspects of such a radical change of energy source for aviation. 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 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

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. The environmental capability of such aircraft were analysed, and the study recognised that the production of hydrogen would of itself necessitate the production of carbon dioxide, (CO_2) as a by-product.

However, the study recognised that the use of renewable energy would obviate this environmental effect. Moreover, 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 the 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 b e 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 much cheaper than hydrogen as a fuel. The lack of production and delivery infrastructure would also need to be addressed. (Reference "Liquid Hydrogen Fuelled Aircraft - Systems Analysis, Airbus Deutschland GmBH et al 2003).

Bio-fuels for aviation

The UK project "The Potential for Renewable Energy Sources in Aviation" (2003) produced by Imperial College Centre for Energy, Policy and Technology in 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 NO_x, a greenhouse gas precursor, as hydrogen may be unsuitable for low NO_x 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.

These three renewable fuels would be more expensive than the cost of conventional aviation kerosene. In comparative terms, conventional aviation kerosene costs \$4.6 per gigajoule (GJ) whereas the cost of bio diesel, FT kerosene and H_2 would be in the respective ranges of \$33.5 - \$52.6, \$5.8 - \$31.7, \$21.5 - \$53.8 per GJ. The difference in fuel price, along with the need to ensure that any alternative fuel can either be freely mixed with aviation kerosene (to obviate the need for tank and system flushing on re-fuelling) and complies with the current safety and air worthiness regulations that apply to conventional kerosene result in the report's conclusion that for the foreseeable future the use of alternative or renewable fuels would be pursued for other transport modes before being made available for civil aviation.

Alternative CO_2 Mitigation Measures

Today's fleet of aircraft are designed to be operated over a wide range of missions. Typically, a Boeing 747 400 can be operated economically over a range from 1,000 to 8,000 nautical miles. However, in order to accommodate such a wide range of operational distance, and especially in order to be able to fly the extended ranges, modern aircraft designs must compromise performance and capability. For example, in order to fly to 6500 miles the 747 400 is significantly heavier due to its fuel load than might otherwise be necessary. The additional weight of the aircraft (fuel) increases the aircraft's fuel consumption beyond its optimum performance during the take-off and early parts of its flight: its extra weight prevents its operation at the higher altitudes that allow greater fuel efficiency. This is a consequence of having to carry the "extra" fuel to fly the "extra" distance. The figure shows a selective range of modern aircraft, the fuel consumption per available seat kilometres for a range of mission distances. It can be seen that the greatest efficiency for these aircraft occurs around 2500 nautical miles, and the efficient declines thereafter.

5.4.2.4 Shipping (Technical and operational measures)

BOX

Since 1990, the amount of marine bunker fuel sold by Annex I countries has remained fairly constant (8% increase through to 2002), although the share of the EU-25 increased overall by over 32% during that period. The USA, the world's #1 with a share of 16%, showed a decrease of 20%, whereas the Netherlands, #3 with 10%, showed an increase of over 30% (see table 1). However, non-Annex I sales increased by about 60% between 1990 and 2002. Sales by Singapore, #2 with a 13% share in total global sales, increased by about 80%, while sales by South Korea, Hong Kong and the mainland of the People's Republic of China, presently #7, #8 and #10 with a total share of around 10%, doubled or tripled their sales during this period.

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, fleet-planning, 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[14]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[15]: 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 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).

5.4.3 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.

Driving education/ Idling stop

[14] In fact four segments covering 80% of the fuel consumption were assessed: tank, bulk, container and general cargo ships

[15] In line with the 3%-plus average annual growth over the past 20 years.

ECMT showed their estimate of a maximum of 15 per cent reduction by improving driving style (ECMT, 2000). IEA also reported that a driver-training program could improve the driving style for half of the participants such that their average fuel efficiency would increase by 2.5 to 5 per cent per enrolled driver of light vehicles (IEA, 2001). The empirical results showed that the education program could reduce energy consumption by about 10 per cent if the driver only tried to save energy. Moreover, the education could reduce energy consumption by 10 to 20 per cent if the driver were guided by the audio guidance (JECC, 2003). 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). Regarding idling stop, the Japanese Energy Conservation Center experimented with a semi-automatic idling stop system and found that it reduced CO_2 emission by 13.4 per cent in urbanized areas and by 5.8 per cent in all areas (JECC, 2003). In the US, a national survey found that, on average, long-haul trucks consume about 1,600 gal/year for idling with about 10 percent of trucks annually consuming more than 3,400 gal (Lutsey, N., *et al.*, 2004).

Modal split

With regard to passenger transport, a reduction in CO_2 emissions by switching from carbon-intensive modes such as automobiles to carbon-efficient modes such as buses, rails and non-motorized alternatives 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 (Greene, D.L. *et al.*, 2003, Bonnafous, A. *et al.*, 2003, JMLIT, 2004), the average energy use per passenger kilometer for automobile is 3 to 4 times higher than the figures in the EU for buses and rails, respectively, and 2 to 6 times higher in Japan. The figure for automobiles in the US is about 25 per cent lower for buses and 25 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 automobile 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 automobiles (Potter, S., 2003, Wee, B.V., *et al.*, 2005).

The question of how many passengers can be transferred from automobiles to buses and rail if policy measures are taken arises. Compared with the literature on direct price elasticity of automobile or bus/rail travel demand, the literature on cross price elasticity is not abundant and likely to vary according to the context (Hensher, D.A., 2001). Goodwin, P. gave an average cross elasticity of public transport <u>demand</u> 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 about 20 per cent of passengers on these modes were transferred from car mode. The majority of the passengers were transferred from alternative bus and rail routes (JMLIT and IHE, 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 prospect for the reduction in CO_2 emissions by switching from automobiles to non-motorized modes such as walking and cycling is not clear because the length of automobile trips that can possibly be shifted to non-motorized modes is less than about 2 kilometers for walking and 7 kilometers for cycling. In addition, substitution between non-motorized modes and public transport is stronger than between non-motorized modes and the car. The promotion of non-motorized modes does not necessarily lead to less car use and significant reduction in CO_2 emission (Rietveld, P., 2001). It is noted, however, that since proportion of journeys on foot, by bicycle and by public transport is 50 percent or higher in European, Asian, African and Latin American cities, even maintaining the current proportion is quite important (Vivier, J., 2001).

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 (Wachs, M., 1993). 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., 2003).

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*. (2002) 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

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.

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

On January 20, 2005, RVSM was implemented between flight level (FL) 290-410 (inclusive) in the airspace of the lower 48 States of the United States, Alaska, Gulf of Mexico and Atlantic High Offshore Airspace (including Houston and Miami Oceanic airspace) and the San Juan FIR.

The RVSM program enables vertical separation to be reduced between FL 290-410 (inclusive) from 2,000 ft. to 1,000 ft. RVSM was first implemented in North Atlantic Airspace in 1997. It is now implemented in other major airspaces such as Europe, the Pacific Ocean and Australia.

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.

5.5 Policies and Measures

The TAR considered policies and measures in the broader context of national and international market (taxes, tradeable permits, subsidies) and regulatory (standards, product bans, direct government spending including R & D, and voluntary agreements) instruments. These were assessed in the context of environmental effectiveness, cost effectiveness, distribution considerations, administration and political feasibility, government revenues, wider economic effects, effects on changes in attitudes, awareness learning, innovation, technical progress and dissemination of technology.

TAR reported that economic literature concerning the policies focused more on demand for regulation, neglecting the supply side of the political feasibility that is crucial with regard to what policies and measures could be implemented. TAR also pointed out the importance of adequate systems of monitoring and enforcement to ensure effectiveness of the instruments. The concept of a portifolio of instruments was introduced as a means to achieve desired results.

TAR also shows that some tax policies such as road taxes and licenses fees can mean emission reduction in OCDE countries. However, inadequate development and provision of convenient and efficient mass transport systems encourage the use of more energy through use of private vehicles. So, many attempts to encourage a shift in planning provision away from cars, toward public and non motorized transport fail because of the strength of links among transport planners, construction firms and the financing institutions. Therefore, it is the combination of policies and institutional relationships protecting road transport interests that poses the greatest barrier to change, rather than any single type of instrument.

Another important remark that TAR makes is that climate change and energy saving is usually a minor factor in decision and policy in the sector, and mitigation strategies may not be implemented if they seem to reduce the benefits provided by the transport system to individuals and firms.

It is therefore important in AR4 to consider how the desired results of both achieving GHG reduction and sustainable development can be achieved through policies and measures, through considerations on experiences of other countries as presented in the recent literature on the transport sector.

5.5.1 Surface transport (road, rail, inland shipping)

5.5.1.1 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 jobs and residential housing (Karekezi, *et al.*, 2003). Land-use and transport are intertwined and the location of employment in respect to residential areas induces travel demand. Transport also helps develop areas and the indirect benefits of this increased access around stations, public transport lines and stops can be quite substantial (UITP). Both urban and transport have a large impact on transport energy use by affecting 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. 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. J. *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, P., 1999).

Better coordination of land-use and transport planning is one of the alternative ways. Recognizing the importance of land-use planning to transport energy use, the Global Environmental Facility has stated that it is specifically taking a long-term perspective in achieving the associated climate change benefits (GEF, 2001). Alternative transport and land-use planning can be done for the purposes of achieving a less energy-intensive pattern of energy use in the transport sector. Sustainable energy themes are incorporated within urban and regional transport planning, incorporating specific themes (for example, NMT) within urban and transport planning.

There are examples of successfully integrated land-use and transport planning (UITP, 2003), such as the Portland metropolitan area case (see BOX: Oregon case). They mostly direct denser, more mixed-use and compact land-use development 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, Y. *et al.*, 2004), the policy has received much controversy especially in the US (Gordon, P. *et al.*, 1997, Ewing, R., 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, H.W. *et al.*, 2004). Ewing, R. et al. found that typical elasticity of vehicle miles travelled with respect to local density is -0.05 (Ewing, R. *et al.*, 2001), while Pickrell, D. noted that reduction in auto use become significant only at densities of 10,000 people or more per square mile - densities unlikely observed in American suburbs (Pickrell, D., 1999), but often reached somewhere else (Newman, P. *et al.*, 1999)

BOX : Oregon case

In the early 1970's, Oregon State implemented a comprehensive plan to develop the Portland Metropolitan Area. The plan included:

- Control of development areas, in order to control urban sprawl
- Control of the real estate through stringent zoning
- Development of green areas
- Construction of a transit system to support the need for mobility

As a result, Portland built a LRT system to serve its metropolitan area, and started with a high frequency service so its citizens found it an attractive alternative to their cars from the beginning.

Institutionalizing planning systems for the reduction in CO_2 is likely to bring in a significant effect, however, it is hard to evaluate quantitatively. Planning systems for regulating land development processes are found embedded within the structure of government - at both the central and local level. The planning system in the UK is a clear example of “center-local relations” whereby the central government sets the policy ground rules and required resources and local government implements that policy based on those resources. The UK central government produced the 25 Planning Policy Guidance Notes including PPG13 specifically addressing policy issues on transport and land-use (Gillingwater, D. *et al.*, 2003, Curtis, C., 1996). Through the UK statutory Development Plan - development permission system, local government was directed to designate less car-dependent land use within its jurisdiction. An example of “center-local relations” is also found in transport planning. The requirement of annual Local Transport Plans prepared by the UK local governments is to demonstrate that it integrates with the Development Plan (Gillingwater, D. *et al.*, 2003). The requirement of transport plans by the US metropolitan organizations is to conform with state clean air plans, which is also a similar example although its target is local air quality (Howitt, A.M. *et al.*, 1999).

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, P. *et al.*, 2003). In taking into account the cost of CO_2 emissions, CBA avoids investment in unnecessarily carbon-intensive projects. The cost of CO_2 emissions is 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, P. *et al.*, 2001, Grant-Muller, S.M. *et al.*, 2001, Forkenbrock, D.J. *et al.*, 2001, JSGRIE, 2000). 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, 2004).

Transport planning and policy have recently placed more weights on sustainable development, although there is the main concern that the definition of sustainability of a subsystem with relatively strong interactions with other subsystems, such as transport, appears meaningless if such interactions are not taken into account explicitly (Nijkamp, P. *et al.*, 2003). For definitions of sustainable mobility or transport, WBCSD, OECD and some countries use some variation of the Brundtland definition of sustainability (WBCSD, 2004, OECD, 2002, Deakin, E., 2002), while World Bank and others see sustainability as a much broader concept having economic and social as well as environmental dimensions. The policy objectives in transport sector are often reflected in indicators, such as public transport ridership and non-motorized mode use (Miller, D., 2004).

5.5.1.2 Fuel Economy-Road Transport

Most industrialized nations now impose fuel economy requirements (or their equivalent in CO_2 emissions requirements) on their light-duty vehicle fleets. The first standards were imposed by the United States in 1975, requiring 27.5 mpg (11.7 km/l) corporate fleet averages for passenger cars and 20.7 mpg (8.8 km/l) 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 (9.4 km/l) for the 2007 model year. Additional standards include:

- European Union: a 2008 fleetwide requirement16 of 140 grams CO2 per kilometre, about 41 mpg (17.4 km/l) of gasoline equivalent, using the NEDC driving cycle, based on a Voluntary Agreement between the EU and ACEA, the European manufacturers association.
- Japan: a 2010 target of about 35.5 mpg (15.1 km/l) for gasoline passenger vehicles, using the Japan 10/15 driving cycle based on weight-class standards.
- China: fleet targets of about 30.4 mpg (12.9 km/l) by 2005 and 32.5 mpg (13.8 km/l) by 2008 using the NEDC driving cycle, based on weight-class standards that are applied to each vehicle.
- Australia: a 2010 target of 18% reduction in average fuel consumption relative to the 2002 passenger car fleet, corresponding to 16.8 l/100km, or 34.6 mpg. (DfT, 2003), based on a voluntary agreement between industry and government.
- The State of California has established greenhouse gas emission standards for 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 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.[17] Both the EU and Japan are making good progress towards meeting their standards; the Chinese standard was just instituted in 2004.

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

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

[17] 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.

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 (NAS, 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.

The safety debate is complex and not easily summarized. Although there is no doubt that adding weight improves vehicle safety in some types of crashes, it also increases the risk to other vehicles; the net effect on the *fleet* of weight reductions or increases is far less certain. 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 NAS, 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.

5.5.1.3 Transport Demand Management.

Transport Demand Management (TDM) consists of measures to improve performance of roads by reducing traffic volumes (Litman, T., 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.*, 2003). (See also BOX : Asia in 5.8)

TDM includes more than three dozen strategies. The set of strategies to be implemented will vary depending on each country 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, A.D. et al., 2003, Litman, T., 2003, Nakamura, H. et al., 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, 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.*, 2003).

Reduction of CO_2 emissions by hard measures, such as car restraint, often face 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, 2004) can be used for supporting the promotion of hard measures. Soft measures can also be directly helpful in encouraging a change in personal behavior 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-kilometers 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).

5.5.1.4 Taxes and Charges

Studies have shown that it is technically and economically feasible to further improve fuel economy in the short term, using technologies that would not change the size, weight or performance of vehicles. By 2015, fuel economy of light-duty vehicles in the US can be increased by 25 to 33% with existing technologies that cost less than the value of the fuel saved (Greene, D.L. and Schafer, A., 2003, see also (NRC, 2002)[18] and (IEEP/TNO/CAIR, 2005) for results for Europe). In a report for the British Department for Transport (Owen, N.J. and Gordon R.L., 2003) efficiency and costs of different measures for reducing carbon emissions from a midsize diesel reference car were analyzed. Based on the results, it can be concluded (Kageson, P, 2005) that improvements in fuel economy up to one third are socio-economically cost-efficient or close to it in the UK. However, because many technologies show much better cost-effectiveness on a social rather than private basis, government policies are needed to bring these technologies greater use (ECMT/IEA, 2005).

In theory, fuel taxes would be an economically efficient way to increase fuel economy by incentivising technical and operational measures. However, the market for automotive fuel economy does not operate efficiently. Buyers of new cars generally only consider the first three years of fuel savings, and not the fuel savings over the life of the car (NRC, 2003, Annema et al., 2001). Potential benefits for consumers over the car's life time are small, while risks for producers are high (Greene, D.L., 2005). Price decreases due to new technologies may lead to consumers to opt for larger and more comfortable vehicles, annulling potential CO_2 reductions.

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 7 presents an overview of examples of application in developing and developed countries of taxes or pricing that would result in these desired results.

Table 7: taxes and pricing in the transport sector in developing and developed countries

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.

Here the focus is on transport pricing options to limit CO_2 emissions from transport. Ancillary benefits will often occur on other potential policy objectives of transport pricing, such as:

- Recovery of expenditures on infrastructure maintenance and construction
- Congestion reduction
- Improving air quality
- Enlarging social welfare
- Generating revenues that can be used to reduce other distortionary taxes in the economy, which may increase economic efficiency of a country.

Governments should take these possible ancillary benefits into account when considering on the introduction of transport pricing such as fuel 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 is about 20% lower and vehicle own-

[18] Passenger car fuel economy could most likely be increased by 12 (for subcompacts) to 27 percent (for large cars) and light truck fuel economy by 25 (small SUVs) to 42 percent (large SUVs), using technologies that would not change the size, weight, or performance of vehicles.

ership is lower as well. This results in about average per capita fuel expenditures. Clearly, automobile use is sensitive to price (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). (Goodwin, Dargay and Hanly, 2004) made a review of studies on price elasticities. The impacts of a permanent increase in the real price of fuel is depicted in table 5.8.

[INSERT **Table 5.8.** here]

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 feebate 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.

Area licensing and parking charges applied in Singapore were effective in reducing total vehicular traffic and hence energy (petroleum) demand (Fwa, 2002). Area licensing scheme in Singapore resulted in 1.043GJ 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 in developing countries. Relying on developed country information that is derived from different transport characteristics would be unreliable. 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).

ENERGY AND GHG POTENTIAL

The literature gives experiences with regard to potential energy and GHG savings and other transport benefits that could accrue as a result of applying tax and pricing mechanisms (see Table 5.9).

[INSERT **Table 5.9.** here]

5.5.1.5 Emission Trading

The Clean Development Mechanism (CDM) offers the possibility to increase funding for transportation projects; enhance local planning and project evaluation capacity; and expand technology transfer opportunities. However, there are difficult challenges to overcome before these projects become more feasible to undertake. At the end of 2004 none of the nineteen approved baselines and monitoring methodologies for CDM project activities was related with transport sector and only three of almost fifty methodologies under consideration were related with this sector. One methodology was related with fuel-switching project and the other two with biofuel production projects (CDM, 2004).

Three different case studies examined baseline development and questions of additionality, monitoring and data requirements for technological as well as demand-side emission-based reductions in Chile (Browne, 2004):

Bicycle Infrastructure. Two scenarios were examined: an individual bikeway and a comprehensive network.

Bus Technology Switch. Master plan for the Santiago metropolitan zone (Transantiago) includes new requirements for the efficiency of public buses and it assessed the feasibility of employing the CDM to promote additional technology improvements.

Location Efficiency. In Santiago, urban area growth is occurring at a rate 70 per cent faster than population growth. This rapid land conversion has important implications for transportation infrastructure provision and air quality. The "location efficiency" concept rests on the premise that influencing land patterns can produce fundamental changes in individual travel behavior and thereby influence transportation emissions. It assessed the potential for reducing transportation GHGs by changing patterns of urban development.

Despite their emission reduction potential, projects in the transportation sector have been slower to develop than those in other sectors. Those projects that fit within current CDM rules have limited impact on long-term emission trends. Projects that address fundamental structural change (e.g., bus rapid transit and fuel economy standards) offer major GHG reductions but do not fit well into the project based structure of the mechanism. Such projects, especially demand-side initiatives, face significant methodological and financial barriers.

One of the primary challenges with transportation projects under the CDM is additionality. Misinterpretation of additionality rules has the potential to harm the CDM, either by granting credits where business-as-usual activities are presented as projects, or by focussing on overly strict interpretations and making beneficial projects infeasible. A combination of high costs of transportation projects, low prices for CERs and low monetary value of co-benefits makes establishing additionality very challenging for transportation projects.

Development of *baselines and verification* of emission reductions are further stumbling blocks. Baseline scenarios must reflect actual circumstances, (vs. official standards that in many cases are not being met) and should be developed to reflect changes in technology and policy over time. Improvements in data collection; forecasting ability; incorporation of non-motorized trips; and consideration of policy impacts over time can all contribute to stronger methodologies. Robustness must be balanced with practicality and consideration must be given to the multiple co-benefits from transport projects.

As countries work toward reductions for the first commitment period, negotiations commence in 2005 for the next commitment period. Further examination of the architecture post-2012 should take transportation into account and provide greater sustainable development incentives for developing country participation by expanding the scope of the CDM to cover sector-wide or policy-based activities.

A sector-wide structure could incorporate technology standards and may contribute to future additional reductions by non-Annex 1 Parties.

Incorporating the impacts of demand-side measures could potentially be addressed by viewing *de facto* new *policies as projects* under the CDM. As in standard projects, proponents would need to prove that the value of the CER bridged a barrier to the project going forward. While the difficulties of double counting and measurement certainly would need to be addressed, there is considerable opportunity for policies as projects to reduce GHGs in the transportation sector, particularly those related to travel demand.

If an effective scheme is to be implemented, it needs to take account of issues such as the fact that international transport emissions are currently recorded, but not attributed to specific countries (Dobes, 1999).

Just as small scale and renewable projects are recognized for their sustainable development benefits and have received special treatment under the 2001 Marrakech Accords, *alternate methodologies and procedures* could be developed for projects in the transportation sector. Further guidance on additionality requirements for transportation projects could be provided that would facilitate additional project development.
With respect to financial barriers, given the transaction costs involved in tradable permit schemes, it is worth asking whether a carbon tax may be preferable in sectors such as transport. (Dobes, 1999).

5.5.2 International Bunkers

5.5.2.1 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 policy options. At its 35th Session in October 2004, the ICAO Assembly adopted, with regard to market-based measures to address aircraft engine emissions the following decisions:

1. **Voluntary measures**: States are encouraged to limit international aviation emissions, in particular through voluntary measures and by making use of guidelines provided by ICAO.
2. **Emission-related levies**: States are urged to refrain from unilateral implementation of greenhouse gas emission charges prior to the next regular session of the Assembly in 2007. In addition, studies on such charges should continue, with the aim of completion by the next regular session of the Assembly in 2007.
3. **Emissions trading**: Further development of an open emissions trading system[19] for international aviation should be continued. This work should focus on two approaches:
   a. ICAO would support the development of a voluntary trading system that interested Contracting States and international organizations might propose.
   b. ICAO would provide guidance for use by Contracting States, as appropriate, to incorporate emissions from international aviation into Contracting States' emissions trading schemes consistent with the UNFCCC process.

Furthermore, the 35th Assembly of ICAO decided not to set up an emission trading system for international aviation under their own auspices (ICAO, 2004). Any initiative to implement new policy

[19] 'Open' emissions trading means that participants in an international aviation trading scheme must be able to buy and/or sell emission allowances and so on outside the aviation sector.

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 reason for the slow 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), CE Delft (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 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).

A study by CE Delft (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 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.

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 preferred 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 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 (ATM). Fuel consumption, for example, can be reduced by minimizing queuing before take-off, using more optimal flight paths and reducing the extent to which aircraft must fly in holding patterns before landing at congested airports. The IPCC Special Report (1999) estimated that improvements in ATM could help to improve overall fuel efficiency by 6-12%. IATA (2005) estimates that eliminating delays in Europe would save 1 $MtCO_2$ per annum.

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. Apart from emitting CO_2, aircraft contribute to climate change through the emission of nitrogen oxides (NO_x), which are particularly effective in forming the greenhouse gas ozone when emitted at cruise altitudes. Aircraft also trigger formation of condensation trails, or contrails, and are suspected of enhancing formation of cirrus clouds, both of which add to the overall global warming effect. 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):

1 **No additional policy in the short and medium term**. As scientific understanding of some of the non-CO_2 climate impacts of aviation is still poor, consideration might be given to limiting initial mitigation policies such as emissions trading to CO_2 and waiting for additional scientific evidence on non-CO_2 impacts before including them in the scheme. In terms of climate impacts, however, open emissions trading involving the aviation sector on the basis of CO_2 emissions alone may undermine the environmental integrity of the entire scheme. Furthermore, focusing solely on CO_2 might provide incentives for airlines to take measures that, while reducing their CO_2 emissions, may well have the negative trade-off of e.g. increasing contrail formation as more modern technology has a higher propensity to cause contrails because of a cooler exhaust.

2 **Flanking instruments**. In this option, other policy measures would be relied on to ensure the environmental integrity of an CO_2 emissions trading system, for example. Basically, the main question to be investigated here is whether flanking instruments would be able to mitigate the

non-CO_2 climate impacts of aviation effectively and possibly more efficiently if these are not covered by, say, an emissions trading system. Potential flanking instruments include:

a Regulations on alternative flight altitudes [e.g. see Fichter *et al.*, 2005] to prevent contrail formation, based on guidance from air traffic control.
b Continued NO_x LTO stringency through ICAO.
c A NO_x cruise certification regime
d Differentiation of airport charges to NOx emissions
e Introduction of NOx emission charge covering the whole flight

3 **CO_2 × multiplier to capture full climate impacts**. An approach in which aviation is required, for example, to surrender a number of emission permits corresponding to its CO_2 emissions multiplied by a factor reflecting the climate impacts of non-CO_2 impacts.

With regard to the third approach, 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.

5.5.2.2 Shipping (policies and measures)

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 53[rd] 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

[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.

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.
- It would provide an extensive database of information on the CO_2 index of a large range of vessels, which can then be analysed and used to either further improve the methodology or develop policy measures aligned with this index.
- It does not alter the competitiveness of the vessels involved in the system and, as the impact of this measure is limited mainly to administrative actions, it will not encourage evasion.
- It could speed up IMO discussions on this topic, as it would promote the use of an indexing method deemed promising by the IMO.

As mentioned above, this option may not significantly reduce CO_2 emissions from international shipping. In the longer term, though, in order to be more effective, governments may consider to use CO_2 indexing via the following paths:
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.
- 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 SO_2 and NO_x, but the approaches adopted may to a certain extent also be applicable to other emissions, including CO_2. Three approaches were identified as most promising in this respect:

1. *Credit programmes* which provide tradable emissions "credits" to sources that voluntarily reduce emissions below their "business as usual" ("BAU") levels. A credit-based programme would allow ship owners to reduce emissions and sell the emission reduction credits either to land-based sources assumed to be subject to a cap-and-trade programme or to the government if a subsidy programme were in effect.
2. *Consortia benchmarking* in which vessels would have the option of joining a "consortium" that would voluntarily commit to achieving an average emissions rate, known as the benchmark.
3. *Environmentally differentiated charges*, involves the differentiation of port dues or other infrastructure-related charges along environmental criteria.

In a follow-up study by Harrison et al. (2005), these economic instruments were assessed in more detail. According to this study 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.

5.5.3 Non Climate Policies

5.5.3.1 Co-benefits

There appear to be different classes of literature regarding the costs and benefits of climate change mitigation related to other policy fields. 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 is about ancillary benefits in the field of climate policy that come about when focusing on other policies in the field of local air quality, congestion reduction, energy security, land use and the provision of public transport.

Several types of linkages can be distinguished between air pollution and climate change: (i) many of the traditional air pollutants and greenhouse gases have common sources, (ii) they interact chemically and physically in the atmosphere, and (iii) they cause a variety of intertwined environmental effects at the local, regional and global scale. Capturing synergies and avoiding trade-offs in addressing the two problems simultaneously offers potentially large cost reductions and reductions of health and ecosystem risks. This justifies reorientation of scientific research in the two areas and incorporation of the linkages between air quality and climate change in policy development (Swart, 2004).

Energy use and agricultural practices are the main sources of both air pollution and climate change. Therefore, specifically in the transportation sector, many measures to cut air pollution also benefit climate through reduction of greenhouse gas emissions and vice versa. Understanding these synergies and addressing local, regional and global objectives simultaneously makes economic sense. 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. Global benefits, due to improved fuel efficiency, are also large. In contrast, they found that traditional "no-regrets" electricity efficiency do provide large GHG emission reductions, but do not provide local benefits to Mexico City because the majority of electricity is produced away from the valley in which Mexico City is located.

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 5.20. Only congestion charges were expected to have substantial ancillary benefits for GHG reduction (Cifuentes et al., 2001, Cifuentes & Jorquera, 2002).

[INSERT **Figure 5.20.** here]

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. CO_2 control strategies that are targeted at single sectors (e.g., the power sector) may shift less cleaner fuels to other sectors where emissions of important air pollutants can be controlled less efficiently (e.g., in the domestic sector). Techniques that reduce nitrogen oxides from vehicles as well as certain ammonia abatement measures related to manure application may increase nitrous oxide emissions (Swart, 2004).

Policy implementation also has trade-offs. International emission trading, joint implementation and the clean development mechanism under the Kyoto Protocol have the potential to reduce the overall costs of targeted greenhouse gas emission reductions. However, they might shift abatement measures and associated co-benefits to other regions, which could have significant effects on the distribution and levels of air pollution (EEA, 2003). In some countries, greenhouse gas trading might even counteract the structural measures in the energy system that are required to achieve the emissions reductions (e.g., of NO*x*) necessary to meet air quality standards.

An economic assessment that considers both aspects in conjunction has the potential to optimize the use of resources and avoid negative side-impacts. Potential implications for the current international policy negotiations vary. Because the optimal policy design for a particular substance depends on a combination of scientific and political concerns (Rypdal et al., 2004). At one end of the spectrum could be a gradual development towards a fully integrated regime, combining an effect-based approach for long-term target setting in both areas with an integrated short-term emissions control strategy based on economic feasibility. At the other end of the spectrum, a more cautious approach would be to routinely address air pollution implications of climate policies and vice versa locally, nationally and internationally.

Especially in low-income countries, accounting for potential synergies of climate change policies and air pollution policies, is very important. Both policies directed at climate change and at air quality are, in most cases, still relatively marginal issues compared to other issues such as poverty eradication, food supply, provision of energy services, employment and transportation (Van Vuuren et al., 2003). It is shown that the mitigation scenarios aimed to stabilize GHG concentrations at 650 and 550 ppmv CO_2-equivalents can also significantly reduce sulphur dioxide and nitrogen oxide emissions.

5.5.3.2 Privatization

In TAR, liberalization and restructuring of energy markets (Section 6.2.1.3) only emphasized experiences in the power sector but no mention on transport impacts.

In the 1980s many countries experimented with privatization of previously publicly-owned transport enterprises and this took the form of either selling state owned companies, contracting out specific services to private vendors, deregulation or attracting private financing for new infrastructure investment (e.g. through BOT, BOOT). The purpose was to enhance operational efficiency, increase investment and releasing government financial debt and hence the need for new taxes and new public spending.

The premise was that competition enhanced by privatization would result in large efficient gains in form of efficient transport services and minimal operational costs including for energy. Well managed competition can result in manageable tariffs even by the poor but poorly managed deregulation as is the case of Lima, Peru can result in increased road congestion and pollution and deteriorating safety and security (Karekezi, Majoro and Johnson, 2003). This is also a phenomenon of privatization in most other developing countries where deregulation has attracted small mini-buses (15-seater) replacing the previously state owned large buses (65-seater). With little enforcement of standards, deregulation of the urban road transport sector in particular has compromised energy intensity per passenger km and has caused congestion and pollution to the cities/towns with implications for increased carbon intensity of providing road transport services.

The analysis done as early as 1993 (Gomez-Ibanez and Meyer, 1993) showed that privatization is not a policy panacea. Prospects were realized in international air transport but with limited success in domestic air transport. Intercity bus privatization looks strong in developing countries. Private toll roads may find success in developing countries. Energy wise toll roads may prohibit unnecessary trips and allow free flow of traffic as the roads are well maintained. Privatization of Intercity passenger rail lines and urban rail transit are likely to fail as they cannot be funded from passenger fares alone and incur large environmental externalities. Nonetheless Mexico, Argentina, the UK and Brazil among others have successfully concessioned national rail networks to the private sector (World Bank, 1998). Port privatization is also gaining momentum with successful examples from Mexico and South Africa.

There is paucity of information that links privatization to GHG reduction.

5.5.3.3 Transport subsidies

There are many different transport subsidies. They can be subdivided into on-budget and off-budget subsidies (Van Beers and De Moor, 2001). The first category appear on the government budget; these subsidies are mainly direct cash transfers. The second category are not visible in the government budget. They may be tax exemptions, public provision below cost, capital cost subsidies or transfers from consumers to producers brought about by regulation. An example of the latter is a statutory obligation to mix petrol fuels with biofuels. Some take a radically different view. They consider any deviation of taxes from the Pigouvian level a subsidy (Nash *et al.*, 2002). In their eyes, every deviation of prices from socially optimal prices can be considered an implicit subsidy or a tax.

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.

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.

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). Fuel subsidies affect emissions on two ways. First, they lower the cost of road transport, thereby increasing transport above the equilibrium in absence of the subsidy. Second, they decrease the incentive to economise on fuel, either by driving efficiently or by buying a fuel-efficient vehicle.

Many European countries and Japan have special fiscal arrangements for commuting expenses. In most of these countries, tax payers 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.

5.6 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 318tonnes CO_2 per day in 2001.

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.

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.

5.7 Technology research, development /diffusion/ transfer

Transport Industry manufactures its products, and influences a significant part of worldwide greenhouse gas (GHG) emissions through emissions generated by use of its products. Therefore, industry decisions on investments, product development, and technological innovation will have an enormous impact on future GHG emissions.

Any private company has no right to press consumers in 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 commercialization 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. 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.
Once they succeed to develop new technology, they want to protect that advantage when they introduce the technology to the market place. Such protections are essential to preserve the ongoing ability to innovate through costly R&D. This is a very important point to discuss the technology transfer, especially to developing countries.

Investments over many decades are required even for successful technologies to come into widespread commercial use. Over such long periods many factors will change, including relative prices of input materials and competition from other services and products. Introduction of new technology requires advances in research as a prerequisite, but widespread use requires investment, the introduction of essential infrastructure, and-- above all, consumer acceptance based on economic advantage.

Flannery(2005) identified several key commercial drivers needed for successful development and commercialization 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 commercialization 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 commercialization of fuel cell vehicles.

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.
International technology transfer through foreign direct investment (FDI) can be an effective mechanism for the deployment of cleaner technologies in developing countries.
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.

The likelihood of maximum benefit to all partners will be greatly facilitated if a number of conditions are met (IPIECA, 1999). These include:
- a stable economic system and an attractive investment opportunity for investing partners;
- transparent and equitable legal and financial structure and sound environmental laws;
- realistic expectations from the host country and the communities of the benefits that may result from the partnership;
- a long-term commitment and dedication of resources by all partners;
- a fair distribution of benefits as a goal for all partners;
- industry respect for local culture and values;
- a safe and secure working environment for all employees and contractors; and
- no unnecessary barriers to movement of personnel and materials.

The realization of mutual benefit is one of the most important keys to success in technology cooperation and capacity building. Successful partnership is a 'win-win' process in which both the overseas partner and the host nation can reap substantial benefits.

5.8 Regional Differences

All populations and geographic regions do not participate evenly in the increasing expansion of mobility. Neither in terms of more mobility, nor in more efficient ways. Even within individual countries, the access to mobility enjoyed by citizens of different ages, ethnic backgrounds and incomes vary greatly. Regardless of a country's average income per capita, its wealthy citizens were generally much more mobile than its poor citizens.

The developed world is generally characterized by high incomes, high levels of urbanization, and high mobility, and by population that are both aging and stable. It is also characterized by very high rates of ownership and use of automobiles and other light-duty vehicles. The developing portion of the world is characterized by low but generally rising incomes and by rapidly growing and relatively young populations. The number of vehicles, from bicycles to motorized two-wheelers to cars to trucks and buses, is growing even more rapidly than the populations of many of these areas. Most of these vehicles have no emission controls, and those that do are often poorly maintained. In contrast to the urbanized areas of the developed world, vehicle-related air pollution in the developing world is clearly getting worse. In most of the developed world, the rate of decrease in per-vehicle emissions has been large enough to offset the effects of more traffic.

Reaching the point of almost eliminating "conventional" transport related pollutants has been extremely expensive and it was achieved through the establishment of increasingly/ stringent emissions standards that, in turn, require the installation of increasingly effective pollution control devices on new vehicles. This leads to the need of fuel production which allows these devices to operate properly. In addition, in several developed countries there has been a growing awareness of the importance of eliminating pollutants, so that vehicles do meet the standards when in operation. This was possible due to a number of important technological breakthroughs. Many of these breakthroughs have been made possible by the revolution in microeletronics over the thirty years. This effort has also greatly benefited from collaboration between vehicle manufacturers and fuel processors to better understand the interaction of fuels and engines in generation pollution and how this interaction can be controlled.

However, this is not the reality of developing world. In certain parts of the world, mainly South and East Asia, powered two and three wheeled vehicles constitute a majority of the road vehicle fleet. These vehicles are an essential source of affordable mobility for people in these regions. But at present, they produce a greatly disproportionate share of transport-related conventional emissions. Initial steps are underway to reduce emissions from these vehicles. The most important of these steps is to shift from two-cycle to four-cycle engines. Two-cycle engines are more polluting than four-cycle engines, since oil must be added to the fuel. Some countries already have banned the sale of new two and three wheelers powered by two-cycle engines. This will produce a significant improvement in emissions performance.

A big challenge will be to equip "standard" road vehicles in developing countries with advanced emission control equipment, provide the fuels necessary to enable this equipment to function properly, and assure that vehicles thus equipped and fueled are maintained properly. There are several reasons for that being a challenge, as the average income is lower in developing countries, so the cost of emission control equipment represents a greater financial burden on the vehicle purchaser. Not only that, but a lower income also means that vehicles, once purchased, tend to stay in service much longer. Making the appropriate fuels available is more difficult and more expensive than the "regular" ones. So, the same affordability considerations which delay the introduction of advanced emission control equipment also delay the introduction of these more expensive fuels.

On the other hand, transport related emissions of greenhouse gases is increasing everywhere, since it is heavily dependent on the amount of fuel burned. However carbon emission from transport in developing world is increasing faster and it is projected to equal the developed world by 2015.

An extraordinarily high share of developed world transportation (96%) depends on petroleum based fuels. Developed world transport energy demand accounts for about 65% of total world transportation energy demand. However, transportation services are presenting a rapid rise in developing world's use of energy. Total developing world energy consumption for transport grew from 7 million barrels per day (oil equivalent) in 1990, to 11 million barrels per day in 1999. It is projected to reach 23 million barrels per day in 2015. This means that developing world share of total worldwide transportation energy use rose from 33% in 1990 to 34% in 1999, and is projected to reach 44% in 2015 (EIA,2001).

So, the most probable response to this key concern of GHG emission is increasing substitution of fossil energy by lower carbon intensity alternatives, in particularly renewable. Hydrogen, because of its long term potential for production from renewable sources, appears to be the best long term energy option, even though there is great uncertainty on timing and costs. Most current energy mix forecasts anticipate significant movement over the time span to 2030 and especially significant contribution of hydrogen by 2050. From now to 2030, continued improvement in ICE technologies and the associated cleaner fuels will provide the biggest contribution to reduce GHG emission with respect to powertrains and fuels as well as fuel efficiency programs.

Vehicle fuel efficiency is likely to continue improving in most regions. Voluntary agreements with car manufacturers and standards are expected to lead to improvements in the fuel efficiency of new passenger vehicles of 30% between 2000 and 2030 in the European Union and 20% in Japan, Australia and New Zealand. However, the energy saved will be partially offset by an increase in the total number of kilometers driven. No improvement is expected in United States and Canada, because technical advances in vehicle fuel efficiency will be offset by an increase in car size, weight and the number of appliance in each car. (Energy Outlook, 2003). However, in all regions, hybrids that run on both conventional fuels and electric batteries will gain a foothold in the vehicle fleet, but fuel cell vehicles are not expected to penetrate the fleet to a significant degree before 2030.

However, what may be achievable in the long term will differ from region to region in terms of timescale and cost. For example, in developing countries the key short term objective is to introduce unleaded gasoline and reduce sulphur levels in both gasoline and diesel fuel. Such improvements will enable the introduction of vehicle technology with both improvement fuel efficiency and reduced emissions. “Accordingly”, alternative fuels which require another widespread new infrastructure, for example CNG or LPG, can only play a limited short term role in developing countries and niche markets (e.g. urban fleets) to address local pollution problems.

Therefore, relevance of technology and related times can vary between developed and developing countries. Moreover, the introduction of any new technologies or concepts will only occur if and when the prevailing economic and market conditions are supportive.

The differences among regions are not only those related to fuel and technologies. In the last decades, the developing world faced a huge urbanization. Megacities which are large urban agglomerations sometimes containing tens of millions of people – are springing up throughout the developing world, especially in Asia and Latin America. The opposite phenomenon is the suburbanization of many urban areas in developed world, empting out the centers of many established cities. Those urban phenomena affect the energy spent in transport therefore the GHG emissions. Cities with high density requires a large infrastructure for public transport and inadequate infrastructure seriously impedes sustainable economic and social development, particularly in developing world. Extensive passenger rail network exists only in Asia and Europe, and general roadway provision in the developing countries falls far behind that in the developed world. Problems include lack of capacity and poor connectivity. Infrastructure needs to be provided to accommodate demand growth, especially in developing world.

BOX:Asia

Asia now holds 61 percent of the global population, and its share of the global urban population has risen from 9 percent in 1920 to 48 percent in 2000. This is expected to rise to 53 percent by 2030. Although national trends and figures vary considerably, this pace and scale of urbanization is unprecedented. Whereas London took 130 years to grow from 1 to 8 million people, Bangkok took 45 years, Dhaka 37 years and Seoul only 25 years (UN-HABITAT, 2004). In addition, vehicle registrations are quickly increasing due to the increase in population. The number of motor vehicles is increasing by 15 percent in China, and 10 percent in Korea, Thailand and Taiwan. Since the transportation facility capacity cannot keep up with the pace of motorization, severe congestion emerges in some Asian developing cities even when the vehicle ownership rate is much lower than that in developed cities (Gakenheimer, R., 1999).

What are the implications of large Asian countries becoming motorized? Schipper, et al. found that in their scenario where China’s GDP per capita grew at roughly 6 per cent per annum, the increment of oil for the 100 million cars on the road in 2020 was 2.4 mb/d and about 400 kb/d for India and Indonesia. The likely global oil demand in 2020 was around 100mb/d (Schipper, et al., 2001). The oil demand could be reduced if mitigating measures, such as alternative fuels and modes were taken. 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).

While most Asian cities face rapid motorization and serious congestion, their per capita car use is lower and transit use is higher than American and European cities. Kenworthy, J.R. et al. pointed out that in contrast to city wealth, urban form— in particular higher urban density— was consistently associated with lower levels of car ownership and car use and higher levels of transit use, and that Asian cities had among the highest urban densities in the world (Kenworthy, J.R. et al., 1999). Hong Kong and Singapore are clear examples of less car-dependent cities with high density where a series of measures such as automobile ownership restraint, high quality public transport supply and coordination of transportation and land use planning have long been taken by a powerful government (Cullinane, S., 2002, Willoughby, C., 2001, Cameron, I., et al., 2004). Shanghai is also known for following similar actions of the two leading cities (Sperling, D., 2002).

Technical Options to Mitigate Environmental Emission

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.

[INSERT **Table 5.10.** here]

In 2002, WBCSD released a report, Mobility 2001, in which the main messages regarding regional differences, considering that the current trends continue, and in the absence of policy changes were:
Personal and goods transport activity will grow everywhere, especially in developing countries
Accessibility probably will improve for most people in developed world, but it is hard to see the same improvement in developing world. However, concerns over the equity of accessibility will grow as the conflicting pressures just referred to exacerbate the accessibility problems already being experienced by certain groups in society –e.g., the elderly, the handicapped and the poor.
Transport related GHG emission will grow especially in developing countries and transport related conventional emissions will decline sharply in developed countries over the next decade or two. However they will increase, at least during the next several decades, in many developing countries.
Congestion will increase in all major urbanized areas in both the developed and developing worlds.
Road vehicle related deaths and serious injuries will continue their long term decline in most developed countries. However, they almost certainly will rise in most developing countries, at least during the next couple of decades.
Transport related noise probably will not decrease and transport related material use, land use and energy use will grow.

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

5.9 Mitigation Potential

As discussed earlier, 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.

5.9.1 Worldwide Studies

Two recent worldwide studies – the International Energy Agency's *World Energy Outlook* and the World Business Council on Sustainable Development's *Mobility 2030* – 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 5.21 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.

[INSERT **Figure 5.21.** here]

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 5.22 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.

[INSERT **Table 5.22.** here]

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.

5.9.2 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 5.11 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.

[INSERT **Table 5.11.** here]

Figure 5.23 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.

[INSERT **Figure 5.23.** here]

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 12 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.

[INSERT **Table 5.12.** here]

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. 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%.

5.9.3 Technical potential in developing nations

There have been few studies of the potential to reduce 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

[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.

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).

Table 5.13 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, 2003) (and thus accelerate more slowly and have lower top speeds).

[INSERT **Table 5.13.** here]

Figure 5.24 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.

[INSERT **Figure 5.24.** here]

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. <u>Delhi</u> (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. <u>Shanghai</u> (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 5.14 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 paths. Technical potential for operating practices, policies and behaviors are more difficult to isolate from economic and market potential, and are usually derived from case studies or modeling analyses. Uncertainty is a key factor at all stages of assessment, from technology performance and cost to market acceptance.

[INSERT **Table 5.14.** here]

5.10 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,2004), 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 25. 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. 26, 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 27). 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 28. 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.

[INSERT **Figures 5.25, 5.26, 5.27, 5.28, 5.29, 5.30.** here]

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 car-

bon 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 CO_2 emissions. Figure 29 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 22, 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 30 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 effi-

[22] See for exapmle, http://www.eere.energy.gov/cleancities/idle/

ciency 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.

[23] EU funded CRYOPLANE project. See details: http://europa.eu.int/comm/research/aeronautics/info/news/article_786_en.html

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