ICTSD Programme on Trade and Environment

Mapping Climate Mitigation Technologies and Associated Goods within the Transport Sector

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Executive Summary

Global climate change is becoming an important force that drives technology development in new directions. The change in technology will have a strong impact on trade due to demand for new technologies and reallocation of technology manufacturing.

The purpose of this study is to present an overview of climate-mitigation technologies and associated goods within the transport sector. The study was commissioned by the International Centre for Trade and Sustainable Development (ICTSD) and looks at all transport modes including road, air, ocean and railway. This study offers a substantial perspective for reduction of greenhouse gas (GHG) emissions, and gives a broad overview of technologies that are commercially available today in both industrialized and developing countries as well as technologies that need 5 to 10 years before commercialization.

In this study, the newly published Intergovernmental Panel Panel on Climate Change (IPCC) Fourth Assessment Report by Working Group III was reviewed on transport technology assessment, which covers a wide range of recent progress and analysis on transport technology and mitigation potential. The IPCC's report is viewed as the most comprehensive assessment on GHG mitigation related research activities, providing a strong basis for the policy making process and supporting further research.

Due to the importance of transport for the environment, energy security and GHG emissions, transport technologies have made rapid progress in recent decades. Many transport technologies are currently commercially available or just have just started to be applied on a more or less commercial base, e.g. in demonstration projects followed by diffusion to the market. Some emerging technologies are still less mature and require perhaps another 5 to 10 years before commercialization (or less than that in case of concerted action by governments and private companies).

Road transport

While road transport is the biggest source of GHG emissions in the transport sector, technology progress in this field is significant. GHG emissions associated with vehicles can be reduced by four types of measures:

1). Reducing the loads (weight, rolling and air resistance and accessory loads) on the vehicle, thus reducing the work needed to operate it;

2). Increasing the efficiency of converting the fuel energy to work, by improving drive train efficiency and recapturing energy losses;

3.) Changing to a less carbon-intensive fuel; and

4). Reducing emissions of non-CO2 GHGs from vehicle exhaust and climate controls.

Railway transport

R&D programmes aimed at CO_2 reduction for trains include:

- Reducing aerodynamic resistance. Aerodynamic resistance is determined by the shape of the train. Therefore, research has been carried out to find the optimum shape by using computer simulation and wind tunnel testing. The latest series 700 Shinkansen train has reduced aerodynamic resistance by 30 percent compared with the first generation Shinkansen.

- Reducing train weight. Aluminium car bodies, lightweight bogies and lighter propulsion equipments are proven weight reduction measures.

- Regenerative braking. For current systems, the electric energy generated by braking is used through a catenary (overhead wire) for powering other trains, reducing energy consumption and CO2 emissions.

- Higher efficiency propulsion system. Recent research on rail propulsion has focused on superconducting on-board transformers and permanent magnet synchronous traction motors.

Apart from the above technologies mainly for electric trains, there are several promising technologies for diesel switchers, including common rail injection systems and hybridization/onboard use of braking energy in diesel-electric vehicles.

Air transport

Fuel efficiency is a major consideration for aircraft operators as fuel currently represents around 20 percent of total operating costs for modern aircraft. Both aircraft and engine manufacturers pursue technological developments to reduce fuel consumption to a practical minimum. There are no fuel efficiency certification standards for civil aviation. Market pressures therefore determine fuel efficiency and CO_2 emissions of aircrafts.

Biofuel is another key option for mitigation in air transport. A potential non-carbon fuel is hydrogen and there have been several studies on its use in aviation.

The introduction of biofuels could mitigate some of aviation’s carbon emissions, if biofuels can be developed to meet the demanding specifications of the aviation industry. Both the costs of such fuels and the emissions from their production process are uncertain at this time.

Shipping

The potential of technical measures to reduce CO_2 emissions was estimated at up to 30 percent in new ships and up to 20 percent 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. These engines typically have service lives of 30 years or more. It will therefore take 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.

In a long-term span, fuel cells could also be used in ships in water transport. 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 capable and reliable fuel-cell-based ship propulsion systems are still a long way into the future, but might be possible in 2050. Fuel cells offer the potential for significant environmental improvements both in air quality and climate protection. Local pollutant emissions and GHG emissions can be eliminated almost entirely over the full life cycle using renewable primary energies.

CHAPTER 1:
An Overview of the Findings on Transport and Climate Change

Findings from the IPCC

The transport sector plays a crucial and growing role in world energy use and GHG emissions. In 2004, transport energy use amounted to 26 percent of the world's total energy use, and the transport sector was responsible for about 23 percent of world energy-related GHG emissions. The 1990 – 2002 growth rate of energy consumption in the transport sector was the highest among all the end-use sectors. Of a total of 77 Exa Joule (EJ) of total transport energy use, road vehicles account for more than three-quarters, with light-duty vehicles and freight trucks having the lion's share. Virtually all (95 percent) of transport energy comes from oil-based fuels, largely diesel (23.6 EJ, or about 31 percent of total energy) and gasoline (36.4 EJ, 47 percent). 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 transport sub-sectors are approximately proportional to their energy use (IPCC, 2007).

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

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

Another crucial aspect of our transport system is that much of the world is not yet motorized because of low incomes. The majority of the world's population does not have access to personal vehicles, and many do not even have access to motorized public transport services of any sort. 33 percent of China's population and 75 percent of Ethiopia's still did not have access to all-weather transport.

GHG mitigation technologies in the transport sector

Many technologies and strategies are at hand to reduce the growth or even, eventually, reverse transport GHG emissions. Most of the technology options discussed here were mentioned in the IPCC Third Assessment Report (TAR). The most promising strategy for the near term is incremental improvements in current vehicle technologies. Advanced technologies that provide great energy and emissions savings include greater use of electric-drive technologies, including hybrid-electric power trains, fuel cells and battery electric vehicles. The use of alternative fuels such as natural gas, biofuels, electricity and hydrogen, in combination with improved conventional and advanced technologies, provides the potential for even larger reductions in energy demand and GHG emissions (IPCC, 2007).

Even with all these improved technologies and fuels, it is expected that oil based transport technology will remain the dominant mode of transport and that transport energy use and GHG emissions will continue to increase into the foreseeable future. Only with sharp changes in economic growth, major behavioral shifts, and/or major policy intervention would transport GHG emissions decrease substantially.

Road transport

GHG emissions associated with vehicles can be reduced by four types of measures:

1). Reducing the loads (weight, rolling and air resistance and accessory loads) on the vehicle, thus reducing the work needed to operate it;

2). Increasing the efficiency of converting the fuel energy to work, by improving drive train efficiency and recapturing energy losses;

3) . Changing to a less carbon-intensive fuel; and

4). Reducing emissions of non-CO2 GHGs from vehicle exhaust and climate controls.

The loads on the vehicle arise largely from five forces; specifically, (a) the force needed to accelerate the vehicle, to overcome inertia; (b) vehicle weight when climbing slopes; (c) the rolling resistance of the tyres; (d) aerodynamic forces; and (e) accessory loads. In urban stop-and-go driving, aerodynamic forces play a 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 90 km/h are four times the forces at 45 km/h. Reducing inertial loads is accomplished by reducing vehicle weight, with improved design and greater use of lightweight materials. Reducing tyre losses is accomplished by improving tyre design and materials, to reduce the tyres' rolling resistance coefficient, as well as by maintaining proper tyre pressure; weight reduction also contributes, because tyre losses are a linear function of vehicle weight. And reducing aerodynamic forces is accomplished by changing the shape of the vehicle, smoothing vehicle surfaces, reducing the vehicle's cross-section, controlling airflow 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 (that is, to move the vehicle and provide comforts like air conditioning and other services to passengers), will also reduce GHG emissions. Such efficiency increases include measures to improve engine efficiency and the efficiency of the rest of the drive train 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. Improvements in transmissions can reduce losses in the transmission itself and help engines to operate in their most efficient modes. 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 drive trains).

Some fuel improvements would require changes to vehicles, while others would not. For example, the use of different liquid fuels, either in blends with gasoline and diesel or as 'neat fuels', requires minimal or no changes to the vehicle, while a variety of gaseous fuels and electricity would require major changes. Alternative liquid fuels include ethanol, biodiesel and methanol, and synthetic gasoline and diesel made from natural gas, coal, or other feedstocks. Gaseous fuels include natural gas, propane, dimethyl ether (a diesel substitute) and hydrogen. Each fuel can be made from multiple sources, with a wide range of GHG emission consequences. In evaluating the effects of different fuels on GHG emissions, it is crucial to consider GHG emissions associated with fuel production and distribution in addition to vehicle tailpipe emissions (see the section on well-to-wheels analysis). For example, the consumption of hydrogen produces no emissions aside from water directly from the vehicle, but GHG emissions from hydrogen production can be quite high if the hydrogen is produced from fossil fuels (unless the carbon dioxide from the hydrogen production is sequestered).

Rail

Railway transport is widely used in many countries. In Europe and Japan, electricity is a major energy source for rail, while diesel is a major source in North America. Coal is also still used in some developing countries. Rail's main roles are high speed passenger transport between large (remote) cities, high density commuter transport in the city and freight transport over long distances. Railway transport competes with other transport modes, such as air, ship, trucks and private vehicles. Major R&D goals for railway transport are higher speeds, improved comfort, cost reductions, better safety and better punctuality.

Many energy efficiency technologies for railways are discussed in the web site of the International Union of Railways. Some of their 29 R&D programmes aimed at CO_2 reduction include:

Reducing aerodynamic resistance

For high speed trains such as the Japanese Shinkansen, French TGV and German ICE, aerodynamic resistance dominates vehicle loads. It is important to reduce this resistance to reduce energy consumption and CO_2 emissions. Aerodynamic resistance is determined by the shape of the train. Therefore, research has been carried out to find the optimum shape by using computer simulation and wind tunnel testing. The latest series 700 Shinkansen train has reduced aerodynamic resistance by 31 percent compared with the first generation Shinkansen.

Reducing train weight

Reduction of train weight is an effective way to reduce energy consumption and CO_2 emission. Aluminium car bodies, lightweight bogies and lighter propulsion equipments are proven weight reduction measures.

Regenerative braking

Regenerative brakes have been used in railways for three decades, but with limited applications. For current systems, the electric energy generated by braking is used through a catenary for powering other trains, reducing energy consumption and CO_2 emissions. However, regenerative braking energy cannot be effectively used when there is no train running near a braking train. Recently, research in energy storage devices, be they onboard or trackside, is progressing in several countries. Lithium ion batteries, ultracapacitors and flywheels are candidates for such energy storage devices.

Higher efficiency propulsion system

Recent research on rail propulsion has focused on superconducting onboard transformers and permanent magnet synchronous traction motors.

Apart from the above technologies mainly for electric trains, there are several promising technologies for diesel switchers, including common rail injection system and hybridization/onboard use of braking energy in diesel-electric vehicles.

Aviation

Fuel efficiency is a major consideration for aircraft operators as fuel currently represents around 20 percent of total operating costs for modern aircraft (2005 data, according to ICAO estimates for the scheduled airlines of Contracting States). Both aircraft and engine manufacturers pursue technological developments to reduce fuel consumption to a practical minimum. There are no fuel efficiency certification standards for civil aviation. On the question of whether such a standard would be desirable, ICAO has discussed the issue but has been unable to develop any form of parameter from the information available that correlates sufficiently well with the aircraft/engine performance. As a result, ICAO has been unable to define a fuel efficiency parameter that might be used for a standard at this time. ‘Point’ certification could drive manufacturers to comply with the regulatory requirement, possibly at the expense of fuel consumption for other operational conditions and missions. Market pressures therefore determine fuel efficiency and CO_2 emissions.

Some operational measures can be used immediately. One is speed reduction and the other is improved air traffic management (ATM).

Shipping

In the past few years, the International Maritime Organization (IMO) has started research and discussions on the mitigation of GHG emissions by the shipping industry. The potential of technical measures to reduce CO_2 emissions was estimated at up to 30 percent in new ships and up to 20 percent 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 tonnes (GT), 96 percent of this energy is produced by diesel power. These engines typically have service lives of up to 30 year. It will therefore take a long time before technical measures can be implemented in the fleet on any significant scale. As a result of this delay, 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.

The IPCC estimates the short-term potential of operational measures at up to 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, because ship utilization varies across different segments of shipping and the operational aspects of shipping are not well defined.

The IPCC also estimated the long-term CO_2 reduction potential for the world shipping fleet , assuming implementation of technical or operational measures, 17.6 percent in 2010 and 28.2 percent 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 (Marintek, 2000). Speed reduction was found to offer the greatest potential for reduction, followed by the implementation of new and improved technology (such as main engine retrofit and propeller upgrade). Speed reduction is probably only economically feasible if policy incentives, such as CO_2 trading or emissions charges are introduced.

A significant shift from a primarily diesel-only fleet to a fleet that uses alternative fuels and energy sources cannot be expected until 2020, as most of the promising alternative techniques are not yet tested to an extent that they can compete with diesel engines (Eyring et al., 2005b). Furthermore, the availability of alternative fuels is currently limited and time is needed to establish the infrastructure for alternative fuels.

For these reasons, in the short term switching to alternative fuels provides a limited potential in general, but a significant potential for segments where a switch from diesel to natural gas is possible. Switching from diesel to natural gas has a 20 percent CO_2 reduction potential and is being pursued as a measure in Norway for inland ferries and offshore supply vessels operating on the Norwegian Continental Shelf. Main obstacles to the increased utilization of natural gas is the access to LNG (Liquefied Natural Gas), the technology's level of costs compared to traditional ship solutions based on traditional fuel, and storage and safety concerns. A co-benefit of a switch from diesel to natural gas is that it also reduces emissions of SOx and NOx, gases which contribute to air pollution around ports.

For the long-term (2050), the economical CO_2 reduction potential in the shipping sector might be large. One potential option is a combination of solar panels and sails (wind kites and wind engines). The use of large sails for super tankers is currently being tested in Germany and looks promising and may even be a cost-effective measure in the short term in case oil prices continue to soar. The use of large sails does not require fleet turnover but can be retrofitted to existing vessels. Other possibilities include the introduction of hydrogen-propelled ships and the use of fuel cell power for the auxiliary engines. For larger vessels, capable and reliable fuel-cell-based ship propulsion systems are still a long way into the future, but might be possible in 2050. Local pollutant emissions and GHG emissions can be eliminated almost entirely over the full life cycle using renewable primary energies. The direct use of natural gas in high temperature fuel cells employed in large ships and the use of natural gas derived hydrogen in fuel cells installed in small ships allows for a GHG emission reduction of 20 – 40 percent.

'Wedges' Analysis by Pacala and Socolow

Pacala and Socolow (2004) mention three options related to mitigation of GHG emissions in the transportation sector:

- Improved fuel economy
- Reduced reliance on cars
- Biofuels.

A wedge is defined as (a group of) technologies that enable a reduction of GHG emissions equal to 1 GtC-eq/yr (giga-tonne carbon equivalent per year) in 50 years from 2004. In their paper, Pacala and Socolow say that three options could contribute to the wedges in the transport sector:

Option 1: Improving fuel economy. Suppose that in 2054, two billion cars (roughly four times as many as today) average 10,000 miles per year (as they do today). One wedge would be achieved if, instead of averaging 30 miles per gallon (mpg) on conventional fuel, cars in 2054 averaged 60 mpg, with fuel type and distance traveled unchanged.

Option 2: Reducing reliance on cars. A wedge would also be achieved if the average fuel economy of the two billion 2054 cars were 30 mpg, but the annual distance traveled were 5,000 miles instead of 10,000 miles.

Option 3: Using biofuels. Fossil-carbon fuels can also be replaced by biofuels such as ethanol. A wedge of biofuel would be achieved by the production of about 34 million barrels per day of ethanol in 2054 that could displace gasoline, provided the ethanol itself were fossil-carbon free. This ethanol production rate would be about 50 times larger than today's global production rate, almost all of which can be attributed to Brazilian sugarcane and United States corn. An ethanol wedge would require 250 million hectares committed to high-yield (15 dry tons per hectare) plantations by 2054, an area equal to about one-sixth of the world's cropland. An even larger area would be required to the extent that the biofuels require fossil-carbon inputs. Because land suitable for annually harvested biofuels crops is also often suitable for conventional agriculture, biofuels production could compromise agricultural productivity.

In the paper, these three options are inside the technology options from IPCC report. And this report will provide more detailed technology description for the options here.

CHAPTER 2: Key mitigation technologies/goods within the transport sector that are commercially available

Introduction

This chapter will give an overview of 'key mitigation technologies and associated goods within the transport sector that are commercially available'. This description is specified as follows:

Technologies and associated goods are assumed to be commercially available if they are mature or if they are in the pre-commercial stage after having been demonstrated. This specification is meant as a differentiation from technologies that are currently not mature, viz. assumed to become commercially available about five to ten years from now. However, this demarcation is not straightforward. Some technologies may be in the demonstration stage, but are hampered by economic infeasibility and may therefore not be commercial on short notice. Other technologies may not yet be considered as commercial or sufficiently demonstrated and must wait a couple years to enter the commercial stage.

Technologies that are covered in this Chapter include:

- Load reducing technologies
- High efficiency vehicles
- Hybrid vehicles
- Electric vehicles
- Alternative fuels
- High efficiency high speed trains
- High efficiency aircraft
- Energy saving ships

2.1 Road transport

In the road transport sub-sector, a wide array of technologies is available for saving energy and reducing GHG emissions: technologies for load reduction and efficiency improvement, hybrid and electric vehicles and alternative fuels.

2.1.1 Load reducing technologies

There are two ways to reduce load: lightweight materials and aerodynamics improvement. A ten percent weight reduction from a total vehicle weight can improve fuel economy by four to eight percent, depending on changes in vehicle size and whether or not the engine is downsized. There are several ways to reduce vehicle weight, such as switching to high strength steels (HSS), replacing steel with lighter materials such as aluminium, magnesium and plastics and devising lighter design concepts and forming technologies.

While the amount of lighter materials in vehicles has been progressively increasing over time, the expected gain to fuel economy has been often wiped away by increasing vehicle sizes and performance. In fact, the average weight of a vehicle in the USA and Japan has increased by ten to twenty percent in the last ten years, partly due to increased concern for safety and customers' desire for comfort (IPCC, 2007).

Steel is still the main material used in vehicles, currently averaging 70 percent of kerb weight. Aluminium usage has grown to roughly 100 kg per average passenger car, mainly in the engine, drive train and chassis in the form of castings and forgings. Aluminium is twice as strong as an equal weight of steel, allowing the designer to provide strong yet lightweight structures. Aluminium use in body structures is limited, but there are a few commercial vehicles with all aluminium bodies (like Audi's A2 and A8). In more than 11 cases where more than 200 kg of aluminium is used and secondary weight reductions are gained by down-sizing the engine and suspension, 13 percent weight reduction has been achieved. Ford's P2000 concept car has demonstrated that up to 300 kg of aluminium can be used in a 900 kg vehicle.

Magnesium has a density of 1.8 grams per cubic centimeter (g/cc) or about a quarter of that of steel, while attaining a similar volumetric strength. Major hurdles for automobile application of magnesium include its high cost, as well as performances issues such as low creep strength and contact corrosion susceptibility. At present, the use of magnesium in vehicle is limited to only 0.1 – 0.3 percent of the whole weight. However, its usage in North American-built family vehicles has been expanding by ten to fourteen percent annually in recent years. Aluminium has grown at four to six percent; plastics by one to two percent; and high strength steels by three to four percent. Since the amount of energy required to produce magnesium and aluminium is large compared with steel, life cycle analysis is important in evaluating these materials' potential for CO_2 emission reduction. Also, the extent of recycling is an important issue for these metals.

The use of plastics in vehicles has increased to about eight percent of total vehicle weight, which corresponds to 100-120 kg per vehicle. The growth rate of plastics content has been decreasing in recent years, however, probably due to concerns about recycling, given that most of the plastic goes to the automobile shredder residue (ASR) at the end of vehicle life. Fibrereinforced plastic (FRP) is now widely used in aviation, but its application to automobiles is limited due to its high cost and long processing time. Nevertheless, its weight reduction potential is very high, maybe as much as 60 percent.

Examples of FRP structures manufactured using resin transfer method (RTM) technology are wheel housings or entire floor assemblies. For a compact size car, these FRP structures would make it possible to reduce the weight of a floor assembly (including wheel housings) by 60 percent, or 22 kg per car compared to a steel floor assembly. Research examples of plastics use in the chassis are leaf or coil springs manufactured from fibre composite plastic. Weight reduction potentials of up to 63 percent have been achieved in demonstrators using glass and/or carbon fibre structures.

Aside from the effect of the growing use of non-steel materials, the growing shift from conventional steels to high strength steels (HSS) drives the reduction in the average steel weight of a car. HSS is low carbon steel with minute amounts of molybdenum, niobium, titanium, and/or vanadium included;it is also known as high strength alloy steel or high-strength, low-alloy steel. Their properties allow thinner gauges to be applied throughout an auto body and thereby produce a stronger, lighter vehicle without significant changes in cost structure. As HSS content rises, its positive impact on fuel economy, emissions and safety will give OEMs the vital breathing room needed to build cars and trucks that still appeal to consumers.

There are various types of HSS, from relatively low strength grade (around 400 mega pascal (MPa), such as solution-hardened and precipitation-hardened HSS, to very high strength grade (980–1400 MPa), such as transformation induced plasticity (TRIP) steel and tempered martensitic HSS. At present, the average usage per vehicle of HSS is 160 kg (eleven percent of whole weight) in the USA and 75 kg (seven percent) in Japan. In the latest Mercedes A-class vehicle, HSS comprises 67 percent of body structure weight. The international ULSAB-AVC (Ultra Light Steel Auto Body – Advanced Vehicle Concept) project investigated intensive use of HSS, including advanced HSS, and demonstrated that using HSS as much as possible can reduce vehicle weight by 214 kg (–19 percent) and 472 kg (–32 percent) for small and medium passenger cars, respectively (IPCC, 2007).

In this concept, the total usage of HSS in body and closures structures is 280–330 kg, of which over 80 percent is advanced HSS (Nippon Steel, 2002) and has the potential for over 90 percent. Since heavy-duty vehicles such as articulated trucks are much heavier than passenger vehicles, their weight reduction potential is much larger. It is possible to reduce the weight of a tractor and trailer combination by more than 3000 kg by replacing steel with aluminium (EAA, 2001).

In the quest for safer and lighter cars, automotive and steel companies are rapidly introducing new advanced high-strength steels (AHSS) for body structures. AHSS alloys include high tensile strengths--500 MPa or greater--with good formability, and include grades like dual phase (DP), complex phase (CP), transformation-induced plasticity (TRIP) and some martensitic steels (see figure 1). The high strengths of these materials allow for mass-efficient designs for improved fuel economy, while simultaneously increasing crashworthiness. Unlike many competitive materials, AHSS can accomplish these objectives with little or no overall cost to the manufacturer. Several full-vehicle concept designs and subsystem concept designs, such as the steel industry's UltraLight family of research, have demonstrated 25 percent mass savings over conventional steel designs while improving crash performance, without increasing cost.

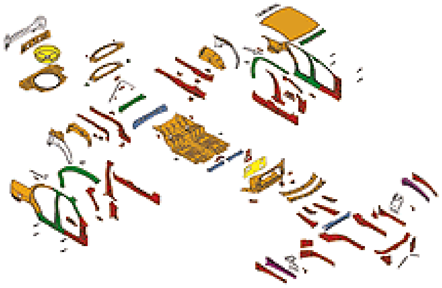

Figure 1 *High-strength and ultra-high-strength steels are used for more than 90 percent of the body structure (colored parts), which allows designers to reduce weight and increase strength (internet source 1).*

Advanced high-strength steels (AHSS) including dual-phase (DP) alloys and transformation-induced-plasticity (TRIP) steels. TRIP steels contain martensite and retained austenite and have higher formability than DP steels, which contain primarily ferrite and martensite.

Many vehicles on the road today contain significant amounts of AHSS, one of which is the 2008 Mercedes C-Class whose body-in-white contains 70 percent high-strength steels and 20 percent advanced high-strength steels. Mercedes-Benz states in an S-Class media release that advanced high-strength steels are indispensable when it comes to meeting the stringent Mercedes requirements with respect to durability and safety (figure 2).

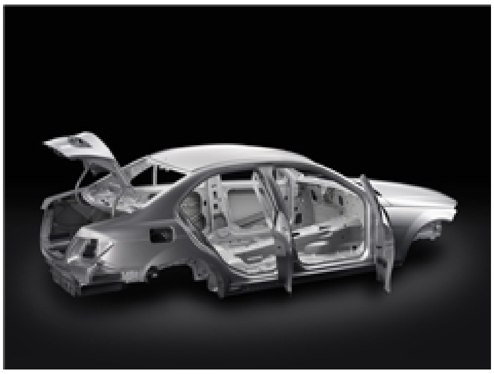

Figure 2 The body-in-white for the 2008 Mercedes C-Class contains 70 percent high-strength steels and 20 percent advanced high-strength steels.

Aerodynamics improvement

Improvements have been made in the aerodynamic performance of vehicles over the past decade, but substantial additional improvements are still possible. Enhancement in aerodynamic performance offers important gains for vehicles operating at higher speeds, e.g., long-distance trucks and light-duty vehicles operating outside congested urban areas. For example, a 10% reduction in the coefficient of drag (CD) of a medium sized passenger car would yield only about a 1% reduction in average vehicle forces on the US city cycle (with 31.4 km/h average speed), whereas the same drag reduction on the US highway cycle, with average speed of 77.2 km/h, would yield about a 4% reduction in average forces. These reductions in vehicle forces translate reasonably well into similar reductions in fuel consumption for most vehicles, but variation 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.

There are numerous methods to improve the aerodynamic efficiency of a car. An important one is to use the modern technology to test the aerodynamic efficiency of a particular car. This leads to a potential improvement in car design. The possible testing technologies are wing tunnel data, on track data, and even computational methods, such as Computational Fluid Dynamic (CFD).

For highway driving conditions, driveline uses about 15 percent of the total energy required to push a vehicle down the highway, and tire rolling resistance represents about 25 percent and air drag about 60 percent. There are greater gains that can be made by modifying the aerodynamics, engine, and rolling resistance of a vehicle. These modifications are not without cost, but are within reach of even those of with meager incomes.

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 five years demonstrate that improvement potential still remains for the fleet. The Lexus 430, a conservatively styled sedan, attains a coefficient of aerodynamic drag (CD) of 0.26 versus a fleet average of over 0.3 for the US passenger car fleet.

Other fleet-leading examples are:

• Toyota Prius, Mercedes E-class sedans, 0.26

• Volkswagen Passat, Mercedes C240, BMW 320i, 0.27

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

The current generation of heavy-duty trucks in the United States has average 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 percent or so (worth about 12 percent reduced fuel consumption at a steady 65 mph), can be obtained with a package of base flaps (that is, simple flat plates mounted on the edges of the back end of a trailer) and side skirts. The US Department of Energy's 2012 research goals for heavy-duty trucks (USDOE, 2000) include a 20 percent reduction (from a 2002 baseline, with CD of 0.625) in aerodynamic drag for a 'class 8' tractor-trailer combination.

Coefficient drag 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. A complete package of aerodynamic improvements for a heavy-duty truck, including pneumatic blowing, might save about 15 – 20 percent of fuel for trucks operating primarily on uncongested highways, with substantial cost reductions possible over time (IPCC,2007).

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, such as the US during the period following the 1973 oil embargo. US tests on nine vehicles with model years from 1988 to 1997 demonstrated an average 17.1 percent fuel economy loss in driving at 70 mph compared to 55 mph. Recent tests on six contemporary vehicles, including two hybrids, showed similar results – the average fuel economy loss was 26.5 percent in driving at 80 mph compared to 60 mph, and 27.2 percent in driving at 70 mph compared to 50 mph.

2.1.2 High efficiency vehicles

By improving drive train efficiency and recapturing energy losses, a high efficiency vehicle increases the efficiency of converting fuel energy to work.

Internal combustion engines (ICE)

The internal combustion engine is an engine in which the combustion of a fuel occurs with an oxidiser (usually air) in a combustion chamber. In an internal combustion engine the expansion of the high temperature and pressure gases, that are produced by the combustion, directly apply force to a movable component of the engine, such as the pistons or turbine blades and by moving it over a distance, generate useful mechanical energy (figure 3 and figure 4).

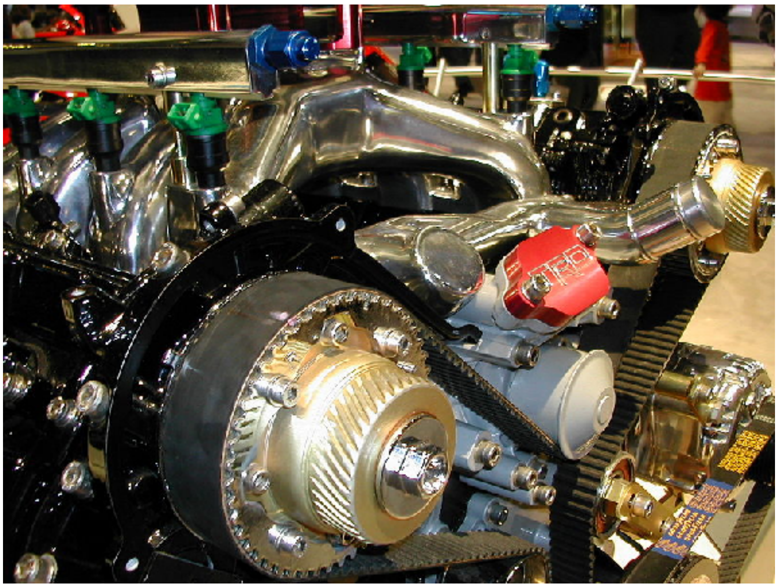

Figure 3 A typical ICE

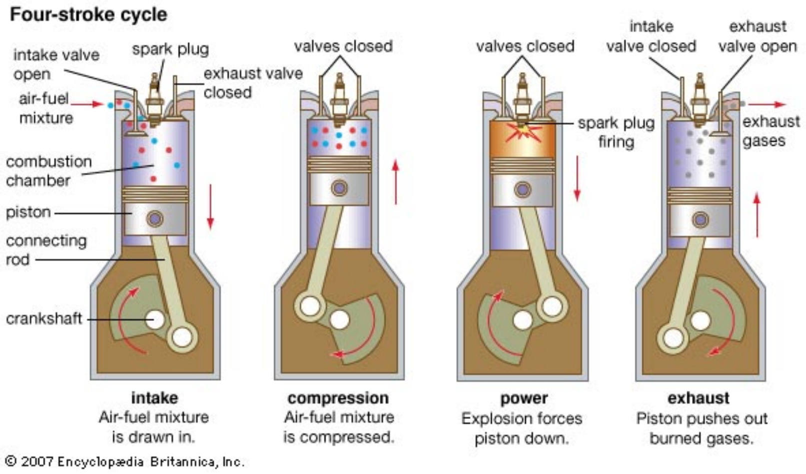

Figure 4 *Description of ICE's operation*

The term internal combustion engine usually refers to an engine in which combustion is intermittent, such as the more familiar four-stroke and two-stroke piston engines, along with variants, such as the Wankel rotary engine. A second class of internal combustion engines use continuous combustion: gas turbines, jet engines and most rocket engines, each of which are internal combustion engines on the same principle as previously described.

Over the next 30 years ICE technology will continue to improve, given the availability of suitable and appropriate cleaner enabling fuels. For gasoline technology, downsized spark ignition engines are expected to take a much greater share of the gasoline engine market in the near future. Static downsizing with redesigned engines can reduce engine displacement by up to 30 percent, which in turn leads to significant reductions in fuel consumption and CO_2.

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

Direct injection diesel engines

Direct injection diesel engines yielding about 35 percent 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 US (European taxes on diesel fuel generally are substantially lower than on gasoline, which boosts diesel share). Euro 4 emission standards were enforced in 2005, with Euro 5 (still undefined) to follow around 2009 – 2010. These standards, plus Tier 2 standards in the US, 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 percent better fuel efficiency than conventional gasoline engines, may cost about 2000 – 3000 US$ more than gasoline engines (IPCC, 2007).

Direct injection injectors mount in the top of the combustion chamber. The problem with these vehicles was the harsh noise that they made. Fuel consumption was about 15 to 20 percent lower than indirect injection diesels, which for some buyers was enough to compensate for the extra noise (Figure 5).

This type of engine was transformed by electronic control of the injection pump, pioneered by the Volkswagen Group in 1989. The injection pressure was still only around 300 bar (4350 psi), but the injection timing, fuel quantity, EGR and turbo boost were all electronically controlled. This gave more precise control of these parameters which made refinement more acceptable and emissions lower.

Mercedes' M271 turbocharged direct injection engine is estimated to attain 18 percent reduced fuel consumption, part of which is due to intake valve control and other engine technologies (SAE International, 2003a); cylinder shutoff during low load conditions (Honda Odyssey V6, Chrysler Hemi, GM V8s) (SAE International, 2003a) and improved valve timing and lift controls (Figure 6).

Figure 5 *Direct injection diesel engines (internet source 4)*

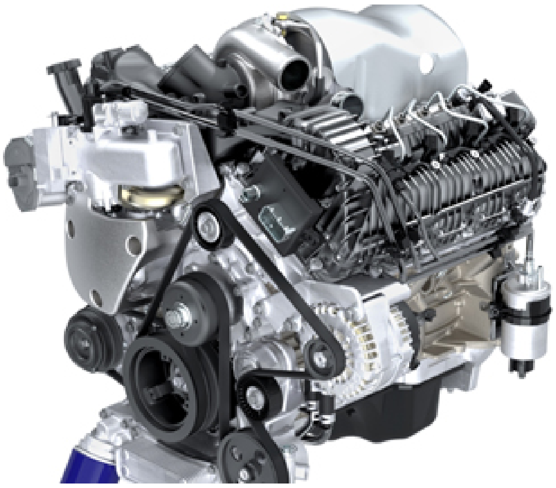

Figure 6 *A new GM diesel engine*

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, with strong estimated fuel economy improvements ranging from four to eight percent over a four-speed automatic for the Ford/GM six-speed to a claimed 13 percent over a manual, plus faster acceleration, for the VW/Audi BorgWarner six-speed. The six and seven speed automatics have an extra cog in the gearbox, but the new transmission is smaller and lighter. A wet starting clutch with dual-mass flywheel replaces the conventional torque converter. This, in combination with the seventh gear, allows for improved acceleration and reduced fuel consumption. Also improving performance, the advanced seven speed automatic is designed for today's high power and torque engines, and is able to safely accept 443 lb-ft of torque. With fewer components on board, and the absence of the torque converter, the transmission housing can be shortened by up to 0.8 inches (20 mm).

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 drive trains, are gradually rising in their power-handling capabilities and are moving into large vehicles.

The best diesel engines currently used in heavy-duty trucks are very efficient, achieving peak efficiencies in the 45 – 46 percent range. Although recent advances in engine and drive train technology for heavy-duty trucks have focused on emissions reductions, current research programmes in the US Department of Energy are aiming at 10 – 20 percent improvements in engine efficiency within ten years, with further improvements of up to 25 percent foreseen if significant departures from the traditional diesel engine platform can be achieved.

Engines and drive trains can also be made more efficient by turning off the engine while idling and drawing energy from other sources. The potential for reducing idling emissions in heavy-duty trucks is significant. In the US, a nationwide survey found that, on average, a long-haul truck consumed about 1,600 gallons, or 6,100 litres, per year from idling during driver rest periods. A variety of behavioral and technological practices could be pursued to save fuel. One technological fix is to switch to grid connections or use onboard auxiliary power units during idling (IPCC, 2007).

Despite the continued tightening of emissions standards for both light-duty vehicles and freight trucks, there are remaining concerns about the gap between tested emissions and on-road emissions, particularly for diesel engines. Current EU emissions testing uses test cycles that are considerably gentler than seen in actual driving, allowing manufacturers to design drive trains so that they pass emissions tests but ‘achieve better fuel efficiency or other performance enhancement at the cost of higher emissions during operation on the road’ (ECMT, 2006).

Other concerns involve excessive threshold limits demanded of onboard diagnostics systems, aftermarket mechanical changes (replacement of computer chips, disconnection of exhaust gas recirculation systems) and failure to maintain required fluid levels in Selective Catalytic Reduction systems (ECMT, 2006).

Low-rolling resistance tires

Tires play a key role in improving safety. Within a few years tires will be fitted with pressure sensors preventing the risk of a burst, consequence of leakage, or underinflation. Low-rolling resistance tires capable of providing information on adherence to the road (by sensors embedded in the tire) are under development. In this case data provided could be processed instantaneously allowing ESP or ABS to prevent adherence loss (WBCSD, 2005).

For a given vehicle, the percentage of fuel consumption accounted for by rolling resistance depends on the speed and acceleration at each moment of the driving cycle in question, the vehicle's characteristics (mass, streamlining, internal friction, transmission), and the tires' rolling resistance coefficient. The consumption caused by rolling resistance (in litres per 100 km) also depends on the engine's efficiency at each moment in a cycle. From one type of driving cycle to another, a tire with a rolling resistance coefficient of 12 kg/t accounts for between 20% (motorway cycle) and 30% (urban cycle) of fuel consumption. Expressed as an absolute value, the tire's contribution varies between 1.4 litres per 100 kilometres (motorway cycle) and 2.6 litres per 100 kilometres (urban cycle) for a small size passenger car (Renault Clio type, 51 kW).

Low-rolling resistance tires are designed to minimize the energy wasted as heat as the tire rolls down the road. This improves the fuel efficiency of a vehicle or reduces the effort required in the case of human-powered ones. Approximately 5–15% of the fuel consumed by a typical car may be used to overcome rolling resistance. A 2003 California Energy Commission (CEC) preliminary study estimated that adoption of low-rolling resistance tires could save 1.5–4.5% of all gasoline consumption, but that current data were also insufficient to compare safety and other characteristics (CEC,2006). A database of much more complete data will be released by the CEC pending completion of an ongoing study.(internet source 5)

In 2003, California signed into law the "World's First Fuel-Efficient Tires Law" and the California Energy Commission had until July 7, 2007 to develop the standards. The law goes into effect in July of 2008.

2.1.3 Hybrid vehicles

A hybrid vehicle is driven by a hybrid engine, which is any engine that combines two or more sources of power, generally gasoline and electricity. There are two types of gasoline-electric hybrid cars; the parallel hybrid, and the series hybrid. Both use gasoline-electric hybrid technology, but in radically different ways (IPCC 2007; internet source 7; internet source 8).

In a parallel hybrid car, a gasoline engine and an electric motor work together to move the car forward, while in a series hybrid, the gasoline engine either directly powers an electric motor that powers the vehicle, or charges batteries that will power the motor. Both types of hybrids also use a process called regenerative braking to store the kinetic energy generated by brake use in the batteries, which will in turn power the electric motor.

Both parallel and series hybrids have small gasoline engines, and produce much less pollution than standard gasoline cars, but also produce much less power; hybrids generally produce between 60-90 horsepower, while the average gasoline engine probably produces about double that. To overcome this power gap, hybrid cars are constructed with ultra lightweight materials like carbon fiber or aluminum. Hybrid cars are also designed to be more aerodynamic than most cars, allowing them to "slice" through air instead of pushing it out of the way. All these factors combined equate to a super efficient form of car that fetches excellent fuel economy and helps the environment by cutting down on pollution.

Hydraulic and pneumatic hybrid vehicles use an engine to charge a pressure accumulator to drive the wheels via hydraulic or pneumatic (i.e. compressed air) drive units. The energy recovery rate is higher and therefore the system is more efficient than battery charged hybrids, demonstrating a 60% to 70% increase in energy economy in EPA testing. Under tests done by the EPA, a hydraulic hybrid Ford Expedition returned 32 miles per US gallon (7.4 L/100 km; 38 mpg-imp) City, and 22 miles per US gallon (11 L/100 km; 26 mpg-imp) highway.

While the system has faster and more efficient charge/discharge cycling and is cheaper than gas-electric hybrids, the accumulator size dictates total energy storage capacity and requires more space than a battery.

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 braking losses by using the electric motor to brake and using the electricity generated to recharge the battery;

• Using the motor to boost power during acceleration, allowing engine downsizing and improving average engine efficiency;

• Using the motor instead of the engine at low load (in some configurations), eliminating engine operation during its lowest efficiency mode;

• Allowing the use of a more efficient cycle than the standard 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 drive train technology has advanced substantially, expanding its markets and 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 8 percent fuel economy benefit under US driving conditions to ‘full hybrids’ such as the Prius offering perhaps 40 – 50 percent fuel economy benefits (the Prius itself more than doubles the fuel economy average – on the US test – of the combined 2010 US model year compact and medium size classes, although some portion of this gain is due to additional efficiency measures). Also, hybrids may improve fuel efficiency by substantially more than this in congested urban driving conditions, and so might be particularly useful for urban taxis and other vehicles making frequent stops. Hybrid sales have expanded rapidly: in the US, sales were about 7,800 in 2000 and have risen rapidly, to 352,000 in 2007.

Improvements made to the Prius since its introduction demonstrate how hybrid technology is developing. For example, the power density of the Prius’ nickel metal hydride batteries has improved from 600 W/kg1 in 1998 to 1310 W/kg1 in 2009 - a 120 percent improvement. Similarly, the batteries’ specific energy has increased 37 percent during the same period (EEA, 2003).

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 US CAFE cycle, with 0 – 60 mph acceleration time of 14.5 seconds; the 2004 version is larger (medium size) but attains 55 mpg and a 0 – 60 of 10.5 seconds. Prius-type hybrid systems will add about 4,000 US$ to the price of a medium sized sedan (EEA, 2003), but continued cost reduction and development efforts should gradually reduce costs.

Hybrid drive trains' strong benefits in congested stop-and-go travel mesh well with some heavier-duty applications, including urban buses and urban delivery vehicles. An initial generation of hybrid buses in New York City obtained about a 10 percent improvement in fuel economy as well as improved acceleration capacity and substantially reduced emissions (Foyt, 2005).

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 50 cc hybrid scooter prototype that offers about a one-third reduction in fuel use and GHG emissions compared to similar 50 cc scooters. 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 hybrid electric vehicles (PHEVs), merge hybrid electric and battery electric systems. PHEVs get some of their energy from the electricity grid. Plug-in hybrid technology could be useful for both light-duty vehicles and for a variety of medium duty vehicles, including urban buses and delivery vehicles.

Substantial market success of PHEV technology is, however, likely to depend strongly on further battery development, in particular on reducing battery cost and specific energy and increasing battery lifetimes. PHEVs' potential to reduce oil use is clear – they can use electricity to 'fuel' a substantial portion of miles driven.

The US Electric Power Research Institute estimates that 30 km hybrids (those that have the capability to operate up to 30 km solely on electricity from the battery) can substitute electricity for gasoline for approximately 30–40 percent of miles driven in the USA. With larger batteries and motors, the vehicles could replace even more mileage. However, their potential to reduce GHG emissions more than that achieved by current hybrids depends on their sources of electricity. For regions that rely on relatively low-carbon electricity for off-peak power, e.g., natural gas combined cycle power, GHG reductions over the PHEV's lifecycle will be substantial; in contrast, PHEVs in areas that rely on coal-fired power could have increased lifecycle carbon emissions. In the long-term, movement to a low-carbon electricity sector could allow PHEVs to play a major role in reducing transport sector GHG emissions.

2.1.4 All-electric vehicles

Fuel cell and hybrid vehicles gain their energy from chemical fuels, converting them into electricity onboard. All-electric vehicles operating today are either powered from off-board electricity delivered through a conductive contact – usually buses with overhead wires or trains with electrified 'third rails' – or by electricity acquired from the grid and stored on-board in batteries. Future all-electric vehicles might use inductive charging to acquire electricity, or use ultracapacitors or flywheels in combination with batteries to store electricity on board.

The plug-in-electric-vehicle (PEV) is becoming more and more common. It has the range needed in locations where there are wide gaps with no services. The batteries can be plugged in to house (mains) electricity for charging, as well being charged while the engine is running.

The electric vehicles are driven by electric motors with high efficiencies of more than 90%, but their short driving range and short battery life have limited the market penetration. Even a limited driving range of 300 km requires a large volume of batteries weighing more than 400 kg (JHFC, 2006). Although the potential of CO2 reduction strongly depends on the power mix, well-to-wheels CO2 emission can be reduced by more than 50% compared to conventional gasoline-ICE (JHFC, 2006).

Vehicle electrification requires a more powerful, sophisticated and reliable energy-storage component than lead-acid batteries. These storage components will be used to start the car and also operate powerful by-wire control systems, store regenerative braking energy and to operate the powerful motor drives needed for hybrid or electric vehicles. Nickel metal hydride (NiMH) batteries currently dominate the power-assist hybrid market and Li ion batteries dominate the portable battery business.

Ultracapacitors offer long life and high power, but low energy density and high current cost. Prospects 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 ultracapacitors has increased to 15 – 20 Wh kg – 1 (Power System, 2005), compared with 40 – 60 Wh kg – 1 for NiMH batteries. The cost of these advanced capacitors is in the range of several 10s of dollars/Wh, about one order of magnitude higher than Lithium batteries.

Given suitable infrastructure, permissions and vehicles, battery electric vehicle (BEV) can be recharged while the user drives. The BEV establishes contact with an electrified rail, plate or overhead wires on the highway via an attached conducting wheel or other similar mechanism (see Conduit currassent collection). The BEV's batteries are recharged by this process—on the highway—and can then be used normally on other roads until the battery is discharged.

This provides the advantage, in principle, of virtually unrestricted highway range as long as you stay where you have BEV infrastructure access. Since many destinations are within 100 km of a major highway, this may reduce the need for expensive battery systems. Unfortunately, private use of the existing electrical system is nearly universally prohibited.

The technology for such electrical infrastructure is old and, outside of some cities, is not widely distributed (see Conduit current collection, trams, electric rail, trolleys, third rail).

Updating the required electrical and infrastructure costs can be funded, in principle, by toll revenue, gasoline or other taxes.

2.1.5 Alternative fuels

Biofuels

The term biofuel describes fuel produced from biomass. A variety of techniques can be used to convert a variety of CO_2 neutral biomass feedstocks into a variety of fuels. These fuels include carbon-containing liquids such as ethanol, methanol, biodiesel, di-methyl esters (DME) and Fischer-Tropsch liquids, as well as carbon-free hydrogen. Figure 5.8 shows some main routes to produce biofuels: extraction of vegetable oils, fermentation of sugars to alcohol, gasification and chemical synthetic diesel, biodiesel and bio oil. In addition, there are more experimental processes, such as photobiological processes that produce hydrogen directly (IPCC, 2007).

Biofuels can be used either ‘pure’ or as a blend with other automotive fuels. There is a large interest in developing biofuel technologies, not only to reduce GHG emission but more so to decrease the enormous transport sector dependence on imported oil. There are two biofuels currently used in the world for transport purposes: ethanol and biodiesel.

Ethanol is currently made primarily by the fermentation of sugars produced by plants such as sugar cane, sugar beet and corn. Ethanol is used in large quantities in Brazil where it is made from sugar cane, in the US where it is made from corn, but only in very small quantities elsewhere.

Ethanol is blended with gasoline at concentrations of five to ten percent on a volume basis in North America and Europe. In Brazil, ethanol is used either in its pure form, replacing gasoline, or as a blend with gasoline at a concentration of 20–25 percent. The production of ethanol fuelled cars in Brazil achieved 96 percent market share in 1985, but sharply declined shortly thereafter to near zero. Ethanol vehicle sales declined because ethanol producers shifted to sugar production and consumers lost confidence in reliable ethanol supply. A 25 percent blend of ethanol has continued to be used. With the subsequent introduction of flexfuel cars, ethanol fuel sales have increased.

For the future, the conversion of ligno-cellulosic sources into biofuels is the most attractive biomass option. Ligno-cellulosic sources are grasses and woody material. These include crop residues, such as wheat and rice straw, and corn stalks and leaves, as well as dedicated energy crops. Cellulosic crops are attractive because they have much higher yields per hectare than sugar and starch crops, they may be grown in areas unsuitable for grains and other food/feed crops (and thus do not compete with food), and their energy use is far less, resulting in much greater GHG reductions than with corn and most food crops (IEA, 2006a).

A few small experimental cellulosic conversion plants were being built in the USA in 2006 to convert crop residues (e.g., wheat straw) into ethanol, but considerably more R&D investment is needed to make these processes commercial. These investments are beginning to be made. In 2006, BP announced it was committing 1 billion US$ to develop new biofuels, with special emphasis on bio-butanol, a liquid that can be easily blended with gasoline. Other large energy companies were also starting to invest substantial sums in biofuels R&D in 2006, along with the US Department of Energy, to increase plant yields, develop plants that are better matched with process conversion technologies and to improve the conversion processes. The energy companies in particular are seeking biofuels other than ethanol that would be more compatible with the existing petroleum distribution system.Biodiesel is less promising in terms of cost and production potential than cellulosic fuels but is receiving increasing attention. Bioesters are produced by a chemical reaction between vegetable or animal oil and alcohol, such as ethanol or methanol. Their properties are similar to those of diesel oil, allowing blending of bioesters with diesel or the use of 100 percent bioesters in diesel engines, and they are all called biodiesel.

Blends of 20 percent biodiesel with 80 percent petroleum diesel (B20) can generally be used in unmodified diesel engines. Diesel fuel can also be produced through thermochemical hydrocracking of vegetable oil and animal fats. This technology has reached the demonstration stage. In Finland and Brazil a commercial production project is under way. The advantage of the hydrocracked biodiesel is its stability and compatibility with conventional diesel (Koyama et al., 2006).

A large drawback of biodiesel fuels is the very high cost of feedstocks. If waste oils are used the cost can be competitive, but the quantity of waste oils is miniscule compared to transport energy consumption. If crops are used, the feedstock costs are generally far higher than for sugar, starch or cellulosic materials. These costs are unlikely to drop since they are the same highly developed crops used for foods and food processing. Indeed, if diverted to energy use, the oil feedstock costs are likely to increase still further, creating a direct conflict with food production. The least expensive oil feedstock at present is palm oil. Research is ongoing into new ways of producing oils. The promising feedstock seems to be algae, but cost and scale issues are still uncertain.

For 2030, IEA (2009) reports mitigation potentials for bioethanol between 500 – 1200 $MtCO_2$, with possibly up to 100 – 300 $MtCO_2$ of that for ligno-cellulosic ethanol (or some other bio-liquid). The long-term potential for ligno-cellulosic fuels beyond 2030 is even greater. For biodiesel, it reports mitigation potential between 100 – 300 $MtCO_2$.

The GHG reduction potential of biofuels, especially with cellulosic materials, is very large but uncertain. IEA estimated the total mitigation potential of biofuels in the transport sector in 2050 to range from 1800 to 2300 $MtCO_2$ at 25 US$/$tCO_2$- eq. based on scenarios with a respective replacement of 13 and 25% of transport energy demand by biofuels (IEA, 2009). The reduction uncertainty is huge because of uncertainties related to costs and GHG impacts.

Only in Brazil is biofuel competitive with oil at 50 US$ per barrel or less. All others cost more. Biofuel production costs are expected to drop considerably, especially with cellulosic feedstocks. But even if the processing costs are reduced, the scale issue is problematic. These facilities have large economies of scale. However, there are large diseconomies of scale in feedstock production.

The cost of transporting bulky feedstock materials to a central point increases exponentially, and it is difficult assembling large amount of contiguous land to serve single large processing facilities.

Another uncertainty is the well-to-wheel reduction in GHGs by these various biofuels. The calculations are very complex because of uncertainties in how to allocate GHG emissions across the various products likely to be produced in the biorefinery facilities, uncertainties in how to handle the effects of alternative uses of land, as well as the large variations in how the crops are grown and harvested and the uncertain efficiencies and design configurations of future process technologies.

Particularly in Brazil where there is large ethanol availability as an automotive fuel, there has been a substantial increase in sales of flexfuel vehicles (FFV). Flexfuel vehicle sales in Brazil represent about 81 percent (Nov. 2006) of the market share of light-duty vehicles. The use of FFVs facilitates the introduction of new fuels. The incremental vehicle cost is small, about 100 US$.

The FFVs were developed with systems that allow the use of one or more liquid fuels, stored in the same tank. This system is applied to OTTO cycle engines and enables the vehicles 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 the engine control system makes the suitable adjustments allowing the running of the engine in the most adequate condition.

One of the greatest advantages of FFVs is their flexibility to choose their fuel depending mainly on price. The disadvantage is that the engine cannot be optimized for the attributes of a single fuel, and therefore results in foregone efficiency and higher pollutant emissions (though the latter problem can be largely addressed with sophisticated sensors and computer controls, as it is in the US).

In the US, the number of FFVs is close to six million and some US manufacturers are planning to expand their sales. However, unlike in the Brazilian experience, ethanol has not been widely available at fuel stations (other than as a ten percent blend) and thus the vehicles rarely fuel with ethanol. Their popularity in the US is due to special fuel economy credits available to the manufacturer.

Natural Gas (CNG / LNG / GTL)

Natural gas, which is mainly methane (CH_4), can be used directly in vehicles or converted into more compact fuels. It may be stored in compressed (CNG) or liquefied (LNG) form on the vehicle. Also, natural gas may be converted in large petrochemical plants into petroleum-like fuels (the process is known as GTL, or gas-to-liquid). The use of natural gas as a feedstock for hydrogen is described in the hydrogen section.

CNG and LNG combustion characteristics are appropriate for spark ignition engines. Their high octane rating, about 120, allows a higher compression ratio than is possible using gasoline, which can increase engine efficiency. However, this requires that the vehicle be dedicated to CNG or LNG. Many current vehicles using CNG are converted from gasoline vehicles or manufactured as bifuel vehicles, with two fuel tanks. Bifuel vehicles cannot take full advantage of CNG's high octane ratio.

CNG has been popular in polluted cities because of its good emission characteristics. However, in modern vehicles with exhaust gas after-treatment devices, the non-CO2 emissions from gasoline engines are similar to CNG, and consequently CNG loses its emission advantages in term of local pollutants; however it produces less CO2.

Important constraints on its use are the need for a separate refuelling infrastructure system and higher vehicle costs – because CNG is stored under high pressure in larger and heavier fuel tanks. Gas-to-liquids (GTL) processes can produce a range of liquid transport fuels using Fischer-Tropsch or other conversion technologies. The main GTL fuel produced will be synthetic sulphur-free diesel fuel, although other fuels can also be produced. GTL processes may be a major source of liquid fuels if conventional oil production cannot keep up with growing demand, but the current processes are relatively inefficient: 61 – 65 percent and would lead to increased GHG emissions unless the CO_2 generated is sequestered.

DME can be made from natural gas, but it can also be produced by gasifying biomass, coal or even waste. It can be stored in liquid form at five to ten bar pressure at normal temperature. This pressure is considerably lower than that required to store natural gas on board vehicles. A major advantage of DME is its high cetane rating, which means that self-ignition will be easier. The high cetane rating makes DME suitable for use in efficient diesel engines.

DME is still at the experimental stage and it is still too early to say whether it will be commercially viable. During experiments, DME has been shown to produce lower emissions of hydrocarbons, nitric oxides and carbon monoxide than diesel and zero emissions of soot. There is no current developed distribution network for DME, although it has similarities to LPG and can use a similar distribution system. DME has a potential to reduce GHG emissions since it has a lower carbon intensity (15 tC/TJ) than petroleum products (18.9 – 20.2 tC/TJ) (IPCC, 1996).

2.2 Railway: high efficiency locomotive and train

High efficiency low emission locomotive

Railroads are already four times more fuel efficient than any land-based form of transportation, but new developments are underway. GenSet locomotives are locomotives that have three smaller, separate engines compared with one large engine in conventional locomotives. The locomotive uses the three engines when required, but will automatically shut down the engines that are not required, thereby efficiently conserving fuel. The GenSet enters "sleep" mode after a certain length of inactivity to eliminate the environmental unfriendliness of idling. The engines can also be turned on as quickly as that of a truck, further eliminating the need to leave the engines running when unnecessary. The maintenance requirements have even been reduced by as much as 35 percent thanks to the engine load sharing system. The GenSets also address the issue of noise pollution and is substantially quieter than traditional locomotives. GenSet locomotives have been certified as ultra-low emitting, as outlined by EPA standards. The international transportation company CSX has managed to achieve an 80 per cent reduction in nitrous oxide and particulate matter emissions with these trains.

General Electric made progress on a new model of locomotive to meet the more stringent Tier II emissions requirements from the US Environmental Protection Agency. GE's new GEVO 12-cylinder diesel engine in the Evolution™ Series Locomotive produces the same 4,400 horsepower as its 16-cylinder predecessor. And it does so using less fuel. The GEVO-12 engine produces 40 percent fewer emissions than our prior models. The Evolution™ Series Locomotive incorporates our most advanced cooling system in rail transport to increase reliability while lowering maintenance costs.

Reducing aerodynamic resistance

For high speed trains such as the Japanese Shinkansen, the French TGV and the German ICE, aerodynamic resistance dominates vehicle loads. It is important to reduce this resistance to reduce energy consumption and CO_2 emissions. Aerodynamic resistance is determined by the shape of the train. Therefore, research has been carried out to find the optimum shape by using computer simulation and wind tunnel testing. The latest series 700 Shinkansen train has reduced aerodynamic resistance by 31 percent compared with the first generation Shinkansen.

Reducing train weight

Reduction of train weight is an effective way to reduce energy consumption and CO_2 emissions. There are two ways to achieve weight reduction:

- component-based lightweight design, which focuses on the elements of the system "train" without any changes to basic principle of the train configuration

- system-based lightweight design, which tries to find the weight-optimised solution for the whole system

Aluminium car bodies, lightweight bogies, lighter propulsion equipments, single-axle running gears, and sandwich structures are proven weight reduction measures.

Regenerative braking

Energy recovery from braking power is powerful on local and regional lines with frequent stops. Nevertheless, even on high speed traffic regenerative braking offers potential for energy efficiency. For current systems, the electric energy generated by braking is used through a catenary for powering other trains. Recent research in energy storage devices, be they on-board or trackside devices, is progressing in several countries. Lithium ion batteries, ultracapacitors and flywheels are candidates for such energy storage devices.

Higher efficiency propulsion system

Recent research on rail propulsion has focused on superconducting on-board transformers and permanent magnet synchronous traction motors.

Apart from the above technologies mainly for electric trains, there are several promising technologies for diesel switchers, such as common rail injection systems, as well as hybridization and on-board use of braking energy in diesel-electric vehicles (also see the web site of the International Union of Railways).

2.3 Air: high efficiency aircraft

Aviation's dependence on fossil fuels, likely to continue for the foreseeable future, drives a continuing trend of fuel efficiency improvement through aerodynamic improvements, weight reductions and engine fuel efficient developments. New technology is developed not only to be introduced into new engines, but also, where possible, to be incorporated into engines in current production. Fuel efficiency improvements also confer greater range capability and extend the operability of aircraft. Evolutionary developments of engine and airframe technology have resulted in a positive trend of fuel efficiency improvements since the passenger jet aircraft entered service, but more radical technologies are now being explored to continue this trend.

Engine developments

Engine developments require a balancing of the emissions produced to both satisfy operational need (fuel efficiency) and regulatory need (reducing NOx, CO_2, smoke and HC). This emissions performance balance must also reflect the need to deliver safety, reliability, cost and noise performance for the industry.

Several manufactures made effort on new technology design. GE and Pratt & Whitney have spent two decades developing the geared turbofan engine (GEnx) that burns 12 to 15 percent less fuel than other jet engines and cuts carbon dioxide emissions by 1,500 tons per plane per year. A gearbox lets the fan and turbine spin independently. The fan is larger and it spins at one-third the speed of the turbine, creating a quieter, more powerful engine.

Based on GE90 architecture, the GEnx represents proven and advanced GE propulsion technology. With innovations like the TAPS combustor, high-pressure 10-stage compressor, lightweight composite fan case and fan blades, and a virtually maintenance-free fan module.

For example, the GEnx provides up to 15 percent better specific fuel consumption than the engine it replaces—helping operators save whenever they fly. The GEnx is also designed to stay on wing 20 percent longer, while using 30 percent fewer parts, and keeping maintenance costs in check.

Developments that can reduce weight, reduce aerodynamic drag or improve the operation of the aircraft offer all-round benefits. Regulatory compliance for emissions and noise hinders the quest for improved fuel efficiency, and is often most difficult for those engines having the highest pressure ratios (PR). Higher PRs increase the temperature of the air used for combustion in the engine, and exacerbate the NOx emissions challenge. Increasing an engine's pressure ratio is one of the options engine manufacturers use to improve engine efficiency. Higher pressure ratios are likely to be a continuing trend in engine development, possibly requiring revolutionary NOx control techniques to maintain compliance with NOx certification standards.

A further consideration 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.

Aircraft developments

Fuel efficiency improvements are also available through improvements to the airframe. Most modern civil jet aircraft have low-mounted swept wings and are powered by two or four turbofan engines mounted beneath the wings. Such subsonic aircraft are about 70 percent more fuel efficient per passenger-km than 40 years ago. The majority of this gain has been achieved through engine improvements and the remainder from airframe design improvements. Relative to equivalent aircraft produced today, a 20 percent improvement in fuel efficiency of individual aircraft types is projected by 2015 with a further 40 – 50 percent improvement by 2050 (IPCC, 2007; internet source 10).

The current aircraft configuration is highly evolved, but has scope for further improvement. Technological developments have to be demonstrated to offer proven benefits before they will be adopted in the aviation industry, and this, coupled with the overriding safety requirements and a product lifetime that has 60 percent of aircraft in service at 30 years age, results in slower change than might be seen in other transport forms.

For the near term, lightweight composite materials for the majority of the aircraft structure are beginning to appear and promise significant weight reductions and fuel burn benefits. The use of composites, for example in the Boeing 787 aircraft (that has yet to enter service), could reduce fuel consumption by 20 percent below that of the aircraft the B787 will replace. Other developments, such as the use of winglets, the use of fuselage airflow control devices, and weight reductions, have been studied by aircraft manufacturers and can reduce fuel consumption by around seven percent. But these can have limited practical applicability – for example, the additional fuel burn imposed by the weight of winglets can negate any fuel efficiency advantage for short haul operations.

Longer term, some studies suggest that a new aircraft configuration might be necessary to realize a step change in aircraft fuel efficiency. Alternative aircraft concepts such as blended wing bodies or high aspect ratio/low sweep configuration aircraft designs might accomplish major fuel savings for some operations. The blended wing body (flying wing) is not a new concept and in theory holds the prospect of significant fuel burn reductions; estimates suggest 20–30 percent reductions compared with an equivalent sized conventional aircraft carrying the same payload. The benefits of this tailless design result from the minimised skin friction drag, as the tail surfaces and some engine/fuselage integration can be eliminated. Its development for the future will depend on a viable market case and will incur significant design, development and production costs.

Laminar flow technology (reduced airframe drag through control of the boundary layer) is likely to provide additional aerodynamic efficiency potential for the airframe, especially for long-range aircraft. This technology extends the smooth boundary layer of undisturbed airflow over more of the aerodynamic structure, in some cases requiring artificial means to promote laminar flow beyond its natural extent by suction of the disturbed flow through the aerodynamic surface. Such systems have been the subject of research work in recent times, but are still far from a flight-worthy application. Long-term technical and economic viability have yet to be proven, despite studies suggesting that fuel burn could be reduced by between 10 and 20 percent for suitable missions.

In 2001 the Greener by Design (GbD) technology subgroup of the Royal Aeronautical Society considered a range of possible future technologies for the long-term development of the aviation industry and their possible environmental benefits. It offered a view of the fuel burn reduction benefits that some advanced concepts might offer. Concepts considered included alternative aircraft configurations, such as the blended wing body and the laminar flying wing, and the use of an un-ducted fan (open rotor) power plant. The study concluded that these two aircraft concepts could offer significant fuel burn reduction potential compared with a conventional aircraft design carrying an equivalent payload. Other studies (Leifsson and Mason, 2005) have suggested similar results.

In summary, airframe and engine technology developments, weight reduction through increased used of advanced structural composites, and drag reduction, particularly through the application of laminar flow control, hold the promise of further aviation fuel burn reductions over the long term. Such developments will only be accepted by the aviation industry should they offer an advantage over existing products and meet demanding safety and reliability criteria.

Recently some new airplane models from Boeing and Airbus made progress on efficiency. The Boeing 787 uses lightweight composites for 50 percent of the aircraft’s body. It is estimated that aircraft entering service today are 70 percent more fuel efficient than the jets of the 1960s, and engine technology is largely responsible for the savings. The 787 will use next-generation engines developed by General Electric and Rolls Royce, meaning the Dreamliner will produce 20 percent fewer emissions and consume 20 percent less fuel than other comparably sized aircraft.

The manufacturing process that happens before an aircraft even leaves the ground is an important part of its overall efficiency, and the 787’s assembly line is employing some innovative techniques. For example, the use of larger component sections for the airframe speeds production and requires 80 percent fewer fasteners than before. As a result of this lower requirement, just 10,000 holes need to be drilled, compared to a million for a 747 jumbo jet. Fewer parts and more efficient designs also mean 30 percent less maintenance is required once the aircraft enters service. And because it is costly and inefficient to fly half-full planes or to use long-range jets for short trips, Boeing will produce three unique versions of the Dreamliner that will be optimized for different passenger loads and distances.

Alternative fuels for aviation

Kerosene is the primary fuel for civil aviation, but alternative fuels have been examined. A potential non-carbon fuel is hydrogen and there have been several studies on its use in aviation. An EU study (Airbus, 2004) developed a conceptual basis for applicability, safety, and the full environmental compatibility for a transition from kerosene to hydrogen for aviation. The study concluded that conventional aircraft designs could be modified to accommodate the larger tank sizes necessary for hydrogen fuels. However, the increased drag due to the increased fuselage volume would increase the energy consumption of the aircraft by between nine percent and fourteen percent. The weight of the aircraft structure might increase by around 23 percent as a result, and the maximum take-off weight would vary between +4.4 percent to − 14.8 percent dependent on aircraft size, configuration and mission. The hydrogen production process would produce CO_2 unless renewable energy was used and the lack of hydrogen production and delivery infrastructure would be a major obstacle.

The primary environmental benefit from the use of hydrogen fuel would be the prevention of CO_2 emissions during aircraft operation. But hydrogen fuelled aircraft would produce around 2.6 times more water vapour than the use of kerosene and water vapour is a GHG. The earliest implementation of this technology was suggested as between 15 − 20 years, provided that research work was pursued at an appropriate level. The operating cost of hydrogen-powered aircraft remains unattractive under today’s economic conditions.

The introduction of biofuels could mitigate some of aviation’s carbon emissions, if biofuels can be developed to meet the demanding specifications of the aviation industry, although both the costs of such fuels and the emissions from their production process are uncertain at this time.

Continental Airlines successfully flew a Boeing 737 with a 50-50 mix of regular fuel and an organic biofuel. Prior to that, a similar test saw Virgin Atlantic send a jet from London to Amsterdam with one of its fuel tanks filled entirely with organic, oil-based fuel. Additionally, two other airlines, Air New Zealand and Japan Airlines, have recently run biofuel test flights (internet source 11).

Although these test flights were all relatively short in duration, they proved a large passenger plane could run efficiently with alternative fuel options. This is a big step considering most of the usual biofuels, like ethanol, are not viable for airplane flight. So, researchers had to come up with other biofuel types.

An Airbus A380 aircraft has successfully completed the world’s first ever flight by a commercial aircraft using a liquid fuel processed from gas (Gas to Liquids - GTL) in the first stage of a test flight programme to evaluate the environmental impact of alternative fuels in the airline market.

The limitations of biofuel should also be taken into account though. First, biofuel can compete with food corpland; second, the life cycle emissions analysis is uncertain and varied depending on biofuel sources; and third, it will be a long time until biofuel can be commercially used in airplanes.

Aviation potential practices

The operational system for aviation is principally governed by air traffic management (ATM) constraints. If aircraft were to operate for minimum fuel use (and CO_2 emissions), 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.

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 ‘TRADE-OFF’. 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 O3 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 percent by flying the global fleet 6,000 feet lower, but at a fuel penalty of six percent compared with a base case. Williams et al. (2003) also found that regional contrail coverage was reduced by flying lower with a penalty on fuel usage. By flying lower, NOx emissions tend to increase also, but the removal rate of NOx is more efficient at lower altitudes: this, compounded with a lower radiative efficiency of O3 at lower altitudes meant that flying lower could also imply lower O3 forcing (Grewe et al., 2002). Impacts on cirrus cloud enhancement cannot currently be modeled 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 on modeling. However, as Fichter et al. (2005) note, to a first order, one might expect aviation-induced cirrus cloud to scale with contrails. The overall ‘trade-offs’ are 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 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 easily avoided – in principle – by relatively small changes in flight level, due to the shallowness of ice supersaturation layers. However, this more finely tuned operational change would not necessarily apply to O3 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.

2.3 Shipping: energy saving 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 tonnes (GT), 96 percent of this energy is produced by diesel power. These engines typically have service lives of 30 years or more. 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(IPCC, 2007; internet source 12).

Short-term potential of operational measures at 1 – 40 percent. 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, because ship utilization varies across different segments of shipping and the operational aspects of shipping are not well defined.

The long-term reduction potential, assuming implementation of technical or operational measures, was estimated for the major fuel consuming segments of the world fleet as specific case studies. The result of this analysis was that the estimated

CO2 emission reduction potential of the world fleet would be 17.6 percent in 2010 and 28.2 percent 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. 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.

Diesel engines are the principle source of power in the vast majority of the world’s ships. In the optimum operating range, fuel efficiency is considerably higher and pollution lower than at low speeds. Therefore, the solution is to keep engines operating in this optimum range in all situations. With traditional mechanical transmission this is not possible, as engine speed is rigidly coupled to propeller speed. Using electric transmission (generators and motors connected by cables), this is no longer the case. Additionally, power reserves can be shared with the vessel’s on-board service supply, which decreases the total power installed while raising reliability. Furthermore, cables are more flexible than shafts and permit greater freedom in the location of the engines. This can increase the vessel’s payload or permit more efficient loading and unloading. All these advantages translate into greater productivity and savings for the owner.

When diesel engines are operating at constant and optimum service speed, fuel consumption is lower than running the same engines at variable speed. In addition, with a “geared” propulsion system, which involves the slowing down and changing from two-engine mode to single engine mode, the propeller speed and pitch has to be controlled to avoid overloading the diesel engines. This need for control lowers the efficiency of the propeller, which must be compensated by additional installed power.

In a diesel-electric power plant, the propulsion motor is capable of providing the required torque at all times, over the entire speed range, even through zero speed and into reverse. It is therefore ideally suited for driving a fixed pitch propeller. This contributes to system efficiency: when the vessel speed is low, a controllable pitch propeller consumes energy just to maintain its rotation.

The machinery on ocean-going container ships consists of a low-speed main engine directly connected to a fixed pitch propeller. As the ship speed is relatively high, the required propulsion power becomes very high for the larger vessels, and the biggest 2-stroke engines (80 MW) on the market are used in container vessels. Particular attention has to be paid to the design of the propeller blades to ensure good cavitation performance and high efficiency

The high power levels in propulsion make the possibility of utilizing waste heat from the main engine exhaust gas very attractive. The energy in the exhaust can be recovered with power turbines and heat economisers producing steam for steam turbines.

Another contribution to fuel efficiency is provided by Counter-Rotating Propellers (CRP). These improve the hydrodynamic properties of the propulsion system, further reducing fuel consumption.

A significant shift from a primarily diesel-only fleet to a fleet that uses alternative fuels and energy sources cannot be expected until 2020, as most of the promising alternative techniques are not yet tested to an extent that they can compete with diesel engines (Eyring et al., 2005b). Furthermore, the availability of alternative fuels is currently limited, and time is needed to establish the infrastructure for alternative fuels. Besides biofuels, there are also tests with LNG, wind engines and solar powered engines.

In the short term switching to alternative fuels provides a limited potential in general, but a significant potential for segments where a switch from diesel to natural gas is possible (Skjølsvik, 2005). Switching from diesel to natural gas has a 20 percent CO_2 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 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 both contribute to local air pollution in the vicinity of ports.

For the long-term (2050), the economic CO_2 reduction potential might be large. One potential option is a combination of solar panels and sails. The use of large sails for super tankers is currently being tested in Germany and looks promising, and may even be a cost-effective measure in the short term in case oil prices continue to soar. The use of large sails does not require fleet turnover but can be added to existing vessels (retrofit). 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 capable and reliable fuel-cell-based ship propulsion systems are still a long way into the future, but might be possible in 2050 (Eyring et al., 2005b). Altmann et al. (2004) concluded that fuel cells offer the potential for significant environmental improvements both in air quality and climate protection. Local pollutant emissions

and GHG emissions can be eliminated almost entirely over the full life cycle using renewable primary energies. The direct use of natural gas in high temperature fuel cells employed in large ships, and the use of natural gas derived hydrogen in fuel cells

installed in small ships, allows for a GHG emission reduction of 20–40 percent.

Areas of engagement are for example:

- Designing environmentally sustainable ships
- Hull optimisation
- Alternative propulsion methods
- Energy saving devices
- Trim optimisation
- Ballast water treatment systems
- Cost-benefit analysis of operating the ship

Container vessels are usually equipped to carry a certain number of reefer containers, which are then the biggest electric power consumers on the ship. Auxiliary engine configuration is typically three or four generating sets, depending on the electrical load and number of reefer plugs.

Container vessels have a demanding steel structure to ensure sufficient longitudinal strength, with the shallow depth of the hull and the wide openings on deck (hatch covers). It is important to keep the steel weight down so as to minimize propulsion power requirements. Extensive use should be made of high tensile steel, and aluminium can also be utilized in deck house structures to keep the weight down.(internet source 13)

CHAPTER 3: Key mitigation technologies/goods subject to R&D but with strong prospects of near to medium term deployment in developing countries

Introduction

Some emerging transport technology could be expected to have strong prospects in medium term deployment, notably in a period of 5 to 10 years from now. In general, the technologies described below have not been demonstrated on a commercial scale. Fuel cell vehicles or hydrogen vehicles could be considered the most important technology for the transport sector in the medium term. In related long-term GHG mitigation studies, fuel cell vehicles or hydrogen vehicles are identified as a key component of transport to reach goblal climate change targets (IEA, 2009; Jiang et al., 2009)

Hydrogen/Fuel Cell Vehicles (FCVs)

A hydrogen vehicle is a vehicle that uses hydrogen as its on-board fuel for motive power. The term may refer to a personal transportation vehicle, such as an automobile, or any other vehicle that uses hydrogen in a similar fashion, such as an aircraft. The power plants of such vehicles convert the chemical energy of hydrogen to mechanical energy (torque) in one of two methods: combustion, or electrochemical conversion in a fuel-cell:

- In hydrogen internal combustion engine vehicles, the hydrogen is combusted in engines in fundamentally the same method as traditional internal combustion engine vehicles.
- In fuel-cell conversion, the hydrogen is reacted with oxygen to produce water and electricity, the latter being used to power an electric traction motor.

During the last decade, fuel cell vehicles (FCVs) have attracted growing attention and have made significant technological progress. Drivers for development of FCVs are global warming (FCVs fuelled by hydrogen have zero CO_2 emission and high efficiency), air quality (zero tailpipe emissions), and energy security (hydrogen will be produced from a wide range of sources), and the potential to provide new desirable customer attributes (low noise, new designs)(IPCC, 2007).

There are several types of FCVs; direct-drive and hybrid power train architectures fuelled 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 reformers (fuel processors), which leads to lower vehicle efficiency (30 – 50% loss), longer start-up time, slower response and higher cost. Because of these disadvantages and rapid progress on direct hydrogen systems, nearly all auto manufacturers are now focused on the pure hydrogen FCV (IPCC, 2007).

Hydrogen engine

Hydrogen engines come in two varieties, electric engines powered directly by hydrogen fuel cells and those engines that are converted from traditional gasoline powered combustion engines and powered by compressed hydrogen. The natural transitional vehicle, on a consumer level, most likely will be to have a car that has a hydrogen engine that has been converted from a gasoline powered engine and is fueled by pressurized hydrogen. Hydrogen-fueled internal combustion engines (H_2 ICEs) as they are called will most likely hit the consumer market first (internet source 14; internet source 15).

This "transitional" hydrogen H_2 ICE engine is already taking hold as both Mazda and BMW have introduced into limited production "dual-fuel" engines. With the flip of a switch, each car can switch back and forth between gasoline and hydrogen fuel. The Mazda RX-8 uses a RENESIS Hydrogen Rotary Engine, which is ideally suited to burn hydrogen without inviting the backfiring that can occur when hydrogen is burned in a traditional piston engine. Twin hydrogen injectors and a separate induction chamber help maintain safer temperatures with the hot running hydrogen fuel.

Hydrogen fuel cells

Hydrogen fuel cells are what will power the 'Hydrogen Highway' of the future. Hydrogen fuel cells are electrochemical engines that come in several different varieties with the most common being the Proton Exchange Membrane (PEM) fuel cells, also called Polymer Electrolyte Membrane fuel cells. PEM fuel cells use oxygen from the air and pressurized hydrogen to create electricity, heat and water (steam) as byproducts (figure 7).

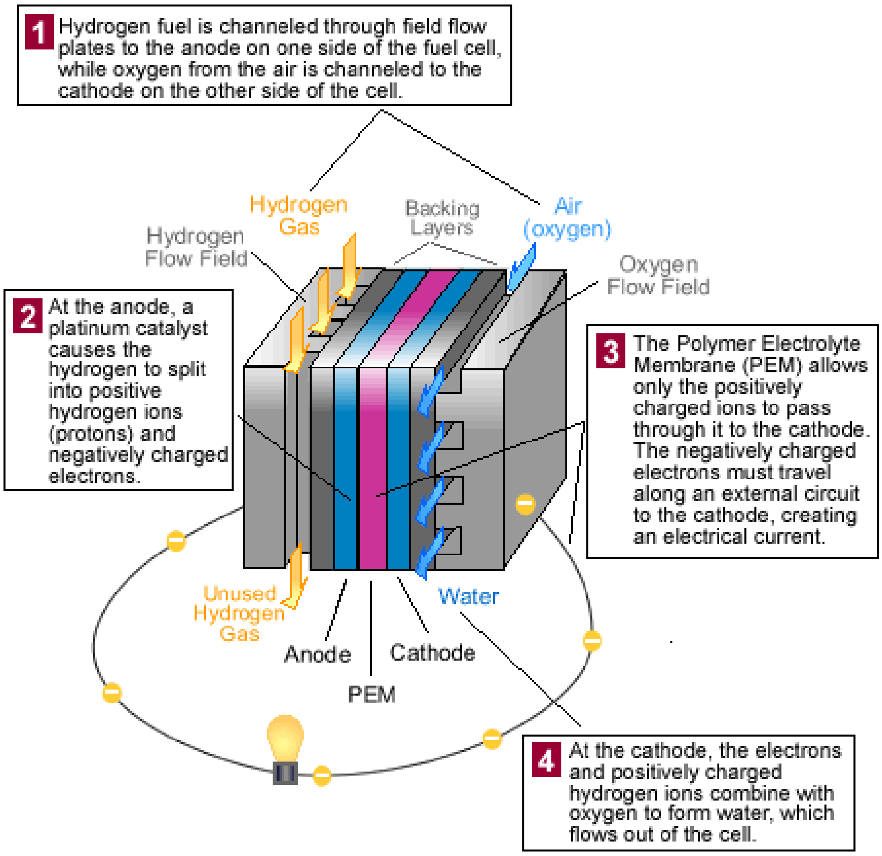

Figure 7 *different parts of a PEM fuel cell used to power hydrogen cars (internet source 16)*

Most hydrogen fuel cells do not produce enough voltage to power a car so fuel cells are typically arranged in "stacks." Because of recent engineering advances, a hydrogen fuel cell about the size of a small piece of luggage can power a car.

The difference between hydrogen fuel cells and typical batteries is that batteries eventually go dead. The hydrogen fuel cell keeps going as long as hydrogen and oxygen are introduced to the cell, producing electricity continuously.

The hydrogen car's electric induction motor/transaxle and electric power inverter will use the electricity generated from the PEM fuel cells to produce up to 90 kilowatts of power. The inverter turns the direct current (DC) into alternating current (AC) which can then power the electric motor that turns the wheels of the car. Most likely, other features of the car like air conditioning and electrical system will still be powered by a traditional car battery.

Hydrogen storage tanks are an issue for H_2 cars. Unlike gasoline tanks, hydrogen storage tanks need to be pressurized, perhaps cooled and contained with special materials.

Hydrogen storage tanks come in three popular kinds: compressed hydrogen, liquid hydrogen and metal hydride tanks. Figure 8 gives a picture of a hydrogen station.

Figure 8 *hydrogen station*

Fuel Cell Vehicles

FCVs look like conventional vehicles from the outside, but inside they contain technologically advanced components not found in today's vehicles. The most obvious difference is the fuel cell stack that converts hydrogen gas stored onboard with oxygen from the air into electricity to drive the electric motor that propels the vehicle. The major components of a typical FCV are illustrated below (internet source 17; internet source 18).

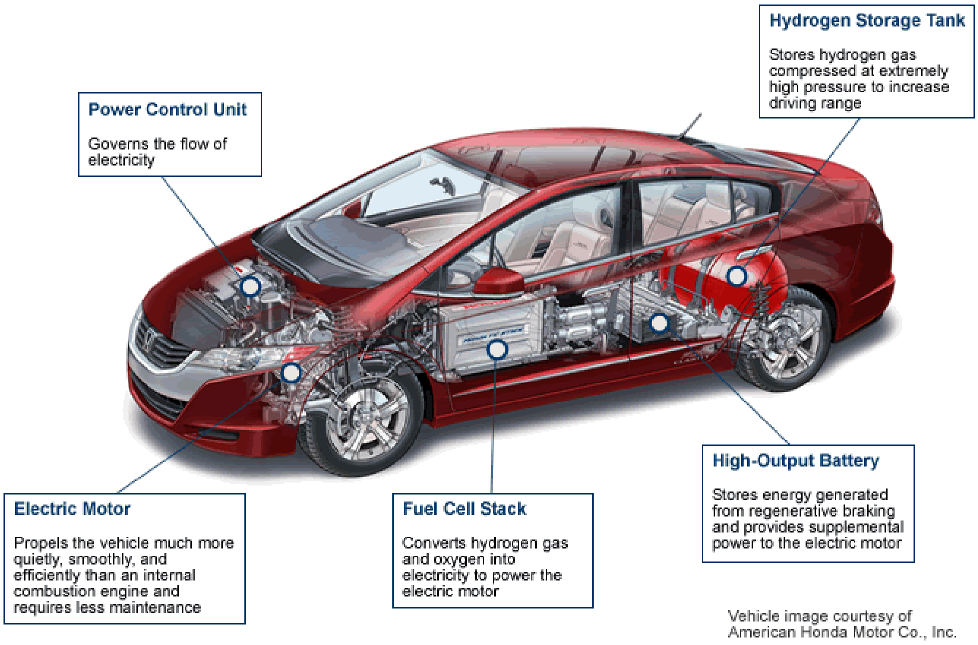

Figure 9 *overview of the FCV*

Figure 10 *BMW's hydrogen car*

Recent significant technological progress has been made including: improved fuel cell durability, cold start (sub-freezing) operation, increased range of operation, and dramatically reduced costs (although FCV drive train costs remain at least an order of magnitude greater than internal combustion engine (ICE) drive train costs) (IPCC,2007).

Although the potential of FCVs for reducing GHG emissions 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 ICEs;

• To develop the infrastructure to provide hydrogen for the light-duty vehicle user;

• To sharply reduce the costs of hydrogen production from renewable energy sources over a time frame of decades.

Or to capture and store (sequester) the carbon dioxide byproduct of hydrogen production from fossil fuels.

The GHG impact of FCVs depends on the hydrogen production path and the technical efficiency achieved by vehicles and H_2 production technology. At the present technology level with FCV tank-to-wheel efficiency of about 50 percent and where hydrogen can be produced from natural gas at 60 percent efficiency, well-to-wheel (WTW) CO_2 emissions can be reduced by 50 – 60 percent compared to current conventional gasoline vehicles. In the future, those efficiencies will increase and the potential of WTW CO_2 reduction can be increased to nearly 70 percent. If hydrogen is derived from water by electrolysis using electricity produced using renewable energy such as solar and wind, or nuclear energy, the entire system from fuel production to end-use in the vehicle has the potential to be a truly 'zero emissions'. The same is almost true for hydrogen derived from fossil sources where as much as 90 percent of the CO_2 produced during hydrogen manufacture is captured and stored.

FCV costs are expected to be much higher than conventional ICE vehicles, at least in the years immediately following their introduction and H_2 costs may exceed gasoline costs. Costs for both the vehicles and fuel will almost certainly fall over time with larger-scale production and the effects of learning, but the long-term costs are highly uncertain. Figure 5.11 shows both well-to-wheels emissions estimates for several FCV pathways and their competing conventional pathways, as well as cost estimates for some of the hydrogen pathways.

Although fuel cells have been the primary focus of research on potential hydrogen use in the transport sector, some automakers envision hydrogen ICEs as a useful bridge technology for introducing hydrogen into the sector and have built prototype vehicles using hydrogen. Mazda has started to lease bi-fuel (hydrogen or gasoline) vehicles using rotary engines and BMW has also converted a 7-series sedan to bi-fuel operation using liquefied hydrogen (Kiesgen et al., 2006). Available research implies that a direct injected turbocharged hydrogen engine could potentially achieve efficiency greater than a direct injection (DI) diesel, although research and development challenges remain, including advanced sealing technology to insure against leakage with high pressure injection(IPCC,2007).

Appendix A Abbreviations and acronyms

ABS	Antilock Braking System
AEV	All Electric Vehicle
AFDC	Alternative Fuels and Advanced Vehicles Data Center (US Department of Energy).
AFV	Alternative fuel vehicle
AHSS	Advanced high-strength steels
ASR	Automobile shredder residue
BAT	Best available technology
BEV	Battery electric vehicle
BTL	Biomass-to-liquids (fuels)
CAFE	Corporate Average Fuel Economy
CD	Coefficient of drag
CEC	California Energy Commission
CFD	Computational Fluid Dynamic
CH_4	Methane
CNG	Compressed natural gas
CORBEV	Continuously outboard recharged battery electric vehicle
CO_2	Carbon dioxide
CP	Complex process
CRP	Counter-Rotating Propellers
DME	Di-methyl esters
DP	Dual Phase
EJ	Exa joule
EPA	Environmental Protection Agency (United States)
ERI	Energy Research Institute, National Development and Reform Commission, China
ESP	Electronic Stabilization Programme
EU	European Union
FCV	Fuel Cell Vehicles

FFV	Flexfuel vehicles
FRP	Fibrereinforced plastic
GbD	Greener by Design
g/cc	grams per cubic centimeter
GE	General Electric
GHG	Greenhouse gasses
GtC-eq/yr	Gigatons of Carbon equivalent
GT	Gross Tonnes
GTL	Gas-to-liquid
H_2	Hydrogen
HC	Hydrocarbon
HSS	High strength steels
ICAO	International Civil Aviation Organization
ICE	Internal combustion engine
ICTSD	International Centre for Trade and Sustainable Development
IEA	International Energy Agency
Kg	kilograms
LCA	Life cycle assessment
LDV	Light Duty Vehicle
Li	Lithium
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
MPa	Mega pascal
Mpg	Miles per gallon
Mph	Miles per hour
$MtCO_2$	Mega tons of carbon dioxide
MW	Mega Watt
NiMH	Nickel-metal Hydride
NOx	Nitrogen oxide

PEV	Plug-in-electric-vehicle
PHEV	Plug-in hybrid electric vehicle
RTM	Resin transfer method
SOx	Sulfur oxide
tC/TJ	Tons of carbon per Tera-Joule
TRIP	Transformation-induced plasticity
TRIPs	Trade-related Aspects of Intellectual Property Rights
ULSAB-AVC	Ultra Light Steel Auto Body – Advanced Vehicle Concept
WBCSD	World Business Council for Sustainable Development
Wh kg-1	Watt-hours per kilogram

Appendix B Transport Sector Goods with a Short Technical Description

Table 1: Climate Mitigation Goods Available on a Commercial Basis

ROAD TRANSPORT

Technology/ Function	**Technology sub-category and Goods (With Technical Description)**	**HS-Code/Ex-out** (*To be provided by trade expert)*
Reducing Vehicle Loads	Lightweight Materials • Vehicles switching to high strength steels : including relatively low strength grade (around 400 MPa) such as solution-hardened and precipitation-hardened HSS to very high strength grade (980–1400 MPa) such as TRIP steel and tempered martensitic HSS, which has the potential of weight reduction by 19% to 32% • Vehicles with replacing steel by lighter materials: including aluminum, magnesium and plastic, which has the potential of weight reduction by 19% to 21%.	
	• Mobile Air-Conditioning Systems • Mobile Air-Conditioning Systems using new refrigerants such as HFC-152a or CO_2	
	Internal combustion engines(ICE) Advanced Direct Injection(DI) Gasoline / Diesel Engines and Transmissions. • Direct injection diesel engines, yielding about 35% greater fuel economy than conventional gasoline engines. • electronic control of the	

	injection pump in DI is the key component. The injection timing, fuel quantity, EGR and turbo boost were all electronically controlled	
	• advanced 6 and 7 speed automatics transmission system	
	• continuously variable transmissions (CVTs)	
	• Hybrid-Drive Trains • • Hybrid Cars • Mild Parallel hybrid: use a generally compact electric motor to give extra output during the acceleration, and to generate on the deceleration phase • Powersplit hybrid, there are two electric motors and one internal combustion engine • Series Hybrid, uses an electric motor(s), which is powered by a single-speed internal combustion engine • Plug-in hybrid electrical vehicle (PHEV), is a general fuel-electric (parallel or serial) hybrid with increased energy storage capacity (usually Li-ion batteries).	870322/ex-out
Improving Drive-Train efficiency	Biofuels	
	• Flexible fuel engine: the engine could use fuel with ethanol mixed with gasoline from range 0% to 100%.	
	Natural Gas	
	• Natural gas engine:	
Alternative Fuels	Hydrogen/Fuel Cells • hydrogen internal combustion engine, burn fuel in the same manner that gasoline engines do. • Fuel cells, create electricity to power an electric motor using hydrogen fuel and oxygen from	850680/ex-out

	the air	
	• Hydrogen storage by cryogenic tank • Hydrogen storage by compressed hydrogen storage tank	
	• Electric Vehicles • Nickel metal hydride (NiMH) batteries • lithium-ion iron phosphate battery, uses LiFePO4 as a cathode material •	870390/ex-out
	• Lithium-Ion Batteries	
	•	

RAIL TRANSPORT

Technology/Function	**Technology sub-category and Goods (With Technical Description)**	**HS-Code/Ex-out** (*To be provided by trade expert)*
Reducing Aerodynamic Resistance	• Locomotives with shielding with an exterior cover, is proven to cut the train's air drag by about 10% • Locomotives with aerodynamic optimisation of pantograp	
Reducing Train Weight	• Trains with component-based lightweight design	
	• System-based lightweight design	
Regenerative Braking	• On-board energy storage in DC systems	
	• Stationary energy storage	
	• Batteries (storage technology)	
	• Superconducting Magnetic Energy Storage (storage technology)	
Higher Efficiency Propulsion Systems	• superconducting on-board transformers	
	• permanent magnet synchronous traction motors	

AVIATION

Technology/Function	**Technology sub-category and Goods (With Technical Description)**	**HS-Code/Ex-out** (*To be provided by trade expert)*
Engines	• geared turbofan engine, fan and turbine spin independently, The fan is larger and it spins at one-third the speed of the turbine, creating a quieter, more powerful engine	
	• TAPS combustor	
	• high-pressure 10-stage compressor	
Aircraft Developments	• lightweight composite materials	
	• Laminar flow technology, reduced airframe drag through control of the boundary layer	
	• blended wing bodies	

SHIPPING

Technology/Function	**Technology sub-category and Goods (With Technical Description)**	**HS-Code/Ex-out** (*To be provided by trade expert)*
Engines	• "geared" propulsion system, changing from two-engine mode to single engine mode when slowing down	
	• electric transmission, generators and motors connected by cables	
	• waste heat recovery technology, from the main engine exhaust gas	
Ship Design and Hydrodynamics (Hull and Propeller)	• Counter-Rotating Propellers (CRP)	
	•	

Table 2: Climate Mitigation Goods Undergoing R&D with Strong Prospects for Commercialisation- Same format as Table 1

ROAD TRANSPORT

Technonolgy/ Function	**Technology sub-category and Goods (With Technical Description)**	**HS-Code/Ex-out** *(To be provided by trade expert)*
	Hydrogen/Fuel Cells • hydrogen internal combustion engine, burn fuel in the same manner that gasoline engines do. • Fuel cells, create electricity to power an electric motor using hydrogen fuel and oxygen from the air	850680/ex-out
	• Hydrogen storage by cryogenic tank • Hydrogen storage by compressed hydrogen storage tank	

AVIATION

Technology/Function	**Technology sub-category and Goods (With Technical Description)**	**HS-Code/Ex-out** *(To be provided by trade expert)*
Alternative Fuels for Aviation	• Hydrogen engine	
	• Hydrogen fuel cell	
	• biofuels	

SHIPPING

Technology/Function	**Technology sub-category and Goods (With Technical Description)**	**HS-Code/Ex-out** (*To be provided by trade expert)*
Alternative Fuels for Shipping	• natural gas	
	• Biofuel utilization: Bio-diesel, ethanol • Solar PV	

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