



How do we convert the transport sector to renewable energy and improve the sector's interplay with the energy system?

Background paper for the workshop on transport - renewable energy in the transport sector and planning, Technical University of Denmark, 17-18 March 2009

Larsen, Hans Hvidtfeldt; Kristensen, Niels Buus; Sønderberg Petersen, Leif; Kristensen, Hans Otto Holmegaard; Pedersen, Allan Schrøder; Jensen, Thomas Christian; Schramm, Jesper

Publication date:
2009

Document Version
Publisher's PDF, also known as Version of record

[Link back to DTU Orbit](#)

Citation (APA):

Larsen, H. H., Kristensen, N. B., Sønderberg Petersen, L., Kristensen, H. O. H., Pedersen, A. S., Jensen, T. C., & Schramm, J. (2009). *How do we convert the transport sector to renewable energy and improve the sector's interplay with the energy system? Background paper for the workshop on transport - renewable energy in the transport sector and planning, Technical University of Denmark, 17-18 March 2009*. Technical University of Denmark.

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HOW DO WE CONVERT THE TRANSPORT SECTOR TO RENEWABLE ENERGY AND IMPROVE THE SECTOR'S INTERPLAY WITH THE ENERGY SYSTEM?

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Prepared by Organising Committee:
 Hans Larsen (chairman), Niels Buus Kristensen,
 Leif Sønderberg Petersen, Hans Otto Kristensen,
 Allan Schrøder Pedersen, Thomas C. Jensen and
 Jesper Schramm,
 Technical University of Denmark

Author: Prepared by Organising Committee:

Hans Larsen (chairman), Niels Buus Kristensen, Leif Sønderberg Petersen, Hans Otto Kristensen, Allan Schrøder Pedersen, Thomas C. Jensen and Jesper Schramm, Technical University of Denmark

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The Technical University of
Denmark
DK-2800 Lyngby
Denmark
Telephone +45 46774004
bibl@risoe.dk
Fax +45 46774013
www.risoe.dtu.dk

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1. Summary

The global energy scene is currently dominated by two overriding concerns that strongly affect decisions on energy development priorities. The first is security of supply and the second is climate change. The transport sector is one of the most complex sectors to manage with regard to these concerns, since it on the whole is based on fossil fuels and shows a very fast growth rate.

The transport sector plays a crucial and growing role in world energy use and emissions of GHGs. Motorized transport relies almost 100 % on oil, and in 2004 transport energy use amounted to 26% of total world energy use and the transport sector was responsible for about 23% of world energy-related GHG emissions.

Economic development and transport are close linked. 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; accelerating globalization has greatly increased these flows.

Worldwide the transport activity will continue to grow at a rapid pace for the foreseeable future. Therefore it is necessary to have the transport sector integrated in the energy system and increase the share of fuels based on sustainable energy.

Around 90% of global merchandise is transported by sea. For many countries sea transport represents the most important mode of transport for trade. Taking into account the historical developments in energy efficiency in shipping and the principles for any future climate regulation of shipping, the industry is prepared to enter into discussions on the different legislative options that can be both practical and attainable. One option is to introduce a CO₂ index limit for new ships. For the purpose of identifying and developing mechanisms needed to achieve reduction of GHG emissions from international shipping, IMO is in the process of evaluating the organization's CO₂ emission indexing expressing the amount of CO₂ emissions per tonne/km of actual net transport work carried out. Setting a limit for such an index could have an environmentally positive impact on the specification and performance of new ships.

Civil aviation is one of the world's fastest growing transport means. ICAO (2006) analysis shows that aviation scheduled traffic (revenue passenger-km, RPK) has grown at an average annual rate of 3.8% between 2001 and 2005 and is currently growing at 5.9% per year. Technology development plays a significant role in reducing aircraft emission impacts on global climate in next generation flights. Alternative sustainable fuels could in the near-term horizon be synthetic Fischer-Tropsch jet fuel used in a blend with conventional jet fuel. In the longer term aviation fuels like cryogenic hydrogen and liquid methane are being considered, but a number of technological challenges have to be solved prior to their use. Lower flight speeds would reduce the fuel consumption. By using the efficient propfan engines the typical maximum speed for an aircraft would drop from 550 mph to 400 mph. Improved air traffic management system could save between 13% and 15% of fuel. Lower fuel consumption and emissions can be achieved by new flight control methods. Optimized route selection could reduce fuel consumption on both short and long haul routes. Infrastructure improvements present a major opportunity for fuel and CO₂ reductions in the near term.

Transport of persons and personal belongings or goods in private cars is a fundamental part of the modern welfare society and has grown steadily over many decades. At the moment it is not possible to point out a future winning traction technology, that may adequately substitute present fossil-based techniques and most likely no single new technology will be able to cover the entire range of private car transport needs. A combination of batteries and hydrogen/fuel cells – a new form of hybrid cars – seems promising from several points of view, but it is also likely that a technology separation will take place, meaning that we will use different traction technologies – different vehicles - depending on the particular

transport work (driving distance) required. The final decisions on these topics are likely to be made by the market forces based on (still unknown) technical and economical developments.

Freight transport has been growing even more rapidly than passenger transport and is expected to continue to do so in the future. Around the world rail remains an important mode especially in large countries like Russia, USA and China. In EU trucks constitute the dominant mode when it comes to land based transport, whereas rail is only marginal. Worldwide road transport is gaining market shares. Trucks are getting larger and the average haul distances are growing too. Still being superior in flexibility, these increases in capacity mean gain of competitiveness compared to other modes. During the years considerable efficiency gains have been harvested in road based freight transport. Aero dynamics, larger units, more effective engines and improved logistics have all contributed to a decrease in energy consumption per tonne-km. Among the future possibilities for innovations and improvements are further development of HCCI, turbo chargers and electronic control. Wider use of lightweight materials could save weight and thus fuel. The development of hybrid trucks is a way to integrate road based freight transport in the energy system and use more sustainable energy. Finally alternative fuels like BtL, RME, DME, methanol/ethanol, natural gas/biogas and hydrogen can reduce CO₂ emissions.

Even with improved technologies and fuels, it is expected that petroleum will retain its dominant share of transport energy use and that transport GHG emissions will continue to increase into the foreseeable future. Only with large changes in economic growth, major behavioral shifts, and/or major policy intervention would transport GHG emissions decrease substantially.

The Danish challenges in the transport sector

The challenge for researchers and professionals in the field of transport will be to develop technological solutions which can provide the international community with the options to achieve much lower CO₂ emissions while maintaining a very high level of mobility for goods and people. The Danish research community possesses the necessary competencies in many central areas, but the research needs to be strengthened and coordinated to obtain full impact with spin off to existing and new innovative contractor and subcontractor companies.

The challenge for the political-administrative system is to create new frames for transport research in Denmark. Today transport research is mainly focused on planning, safety and regulation, while the research in the technological aspects in many ways is incoherent or non-existing. This could partly be due to the fact that Denmark lacks car or airplane manufacturing industry to demand that kind of research. But as mentioned above the Danish research community possesses the relevant competencies for taking an active role in the technological development of the future transport system.

2. How do we reduce the CO₂ emissions from the transport sector?

The global energy scene is currently dominated by two overriding concerns that strongly affect decisions on energy development priorities. The first is security of supply and the second is climate change. IPCC's 4th Assessment Report states that if anticipated climate change is to remain in the order of 2 to 3 degrees C over the next century then the world's CO₂ emissions must peak within the next 10 – 15 years and ultimately by the middle of the century be reduced to 50% of present level.

The transport sector is one of the most complex sectors to manage with regard to these concerns, since it on the whole is based on fossil fuels and has hitherto experienced a very fast and steady growth which has exceeded fuel efficiency gains. Hence, transport-related energy consumption and CO₂ emissions have grown significantly over the past decades, whereas it has stagnated or fallen in most other industrial sectors.

On a global scale energy consumption for transport accounts for approximately 20% of all energy used worldwide, and approximately 25% in many OECD countries. In order to lower the CO₂ emissions it is an absolute necessity to introduce renewable energy in the transport sector and have the sector integrated in the energy system.

The workshop will discuss state-of-the-art and development perspectives for transport technologies, new transport fuels, new transport system concepts, energy efficiency improvements, and policy measures. Furthermore, it will summarize the present status and trends with regard to the transport sector. The ambition is to prepare the ground for an estimate of the reduction potentials for the transport sector in Denmark as well as globally. Among the major challenges are:

- Efficiency improvements – how far can they take us?
- How much renewable energy can we introduce in the transport sector?
- How much can biofuel and electricity contribute?
- How could we integrate the transport sector in the energy system?
- Can a shift from private to public transport realistically provide a significant contribution?
- What can be done in the short term, and what are the long term solutions?

This background paper has been prepared in order to inspire and structure the discussions and target the issues for the working groups at the workshop.

The workshop will discuss what the organizing committee considers the four most important areas of transportation:

- Intercontinental sea transport
- Passenger air transport and its competitors
- Private car transport
- Road based freight transport and its competitors

3. Transport in a changing climate

The global energy scene is currently dominated by two overriding concerns that are strongly affecting decisions about energy development priorities:

- Climate change
- Energy security

This is especially true for industrialized countries and the more rapidly developing economies, while many developing countries still do not provide widespread access to modern energy.

Security and Green House Gas (GHG) emissions are interlinked, and ideally national energy policies and development programmes should address both issues. In practice, however, many national policy landscapes have been dominated by just one of these factors. In the political debate the access to energy is often seen as a potential climate problem, but most studies indicate that access to basic energy services for the poorest one billion people, even based on fossil resources, will make very marginal contributions to global GHG emissions. A more relevant and pressing political concern is how to limit global emissions and allow the emerging economies to continue their economic growth.

Climate change is widely recognized as the major environmental problem facing the globe and evidence is building that impacts are already being felt in the form of melting icecaps in the polar areas and increased variability of temperature, rainfall and storms in virtually all regions and increasing intensity and frequency of climate extremes.

The transport sector plays a crucial and growing role in world energy use and emissions of GHGs. Motorized transport relies almost 100% on oil, and in 2004 transport energy use amounted to 26% of total world energy use and the transport sector was responsible for about 23% of world energy-related GHG emissions.

Economic development and transport are closely interlinked. Development of a fast and reliable international transport system at low cost has been a precondition for the economic growth driven by globalization in terms of steadily increasing international division of labor, trade and specialization. Industrialization and growing specialization have created the need for large shipments of goods and materials over substantial distances; accelerating globalization has greatly increased these flows. Urbanization has been extremely rapid in the past century.

Increasing economic wealth and higher travel speeds have been the core drivers in the historically strong growth in transport demand at both local and international level. Worldwide travel studies show that the average time budget for travel is roughly constant across countries as well as over time, with the speed of travel determining distances travelled yearly. As incomes have risen, travellers have shifted to faster – and more energy-intensive – forms of transport, from walking and bicycling to public transport to automobiles and, for longer trips, to aircraft.

Public transport plays a crucial role in urban areas. Intercity and international travel is growing rapidly. Worldwide passenger air travel is growing 5% annually – a faster rate of growth than any other travel mode.

Worldwide the transport activity is expected to continue to grow at a rapid pace for a foreseeable future without intensified use of demand management measures. In this perspective significant reduction in transport related GHG

emissions will require a radical shift away from fossil fuels. Increasing the share of renewable energy sources and integration of transport in the energy system are unavoidable elements in the necessary global strategy. .

A parallel worldwide trend has been ‘urban sprawl’, i.e. the decentralization of cities spreading 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 private 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. A large part of the world is not yet motorized because of low incomes. However, many developing countries accounting for a very large share of the world population experience rapid economic growth which makes the prospects for a vast expansion of motorization and increase in fossil fuel use and GHG emissions very real. In addition, the gradual growth in the size, weight and power of passenger vehicles, especially in the industrialized world, has also contributed to the increase in transport energy consumption. Although the efficiency of engine and vehicle technology has improved steadily over time, much of the gains from these improvements have gone towards increased power and size at the expense of improved fuel efficiency.

Industrialization and globalization have also stimulated freight transport, which now consumes 35% of all transport energy, or 27 exajoules¹. Freight transport is considerably more conscious of energy efficiency considerations than passenger transport because of competition driven pressure on shippers to cut costs. Rail and domestic waterways’ shares of total freight movement have been declining, while road haulage’s share has been increasing and air freight, though it remains a small share, has been growing rapidly. Transport energy use in 2030 is expected to be about 80% higher than in 2002¹. Almost all of this additional consumption is expected to be in petroleum fuels, which is expected to remain between 93% and 96% of transport fuel use over the period. As a result, CO₂ emissions will essentially grow directly proportional to energy consumption. There will be a significant regional shift in transport energy consumption, with the emerging economies gaining significantly in share. In contrast, transport energy use in the mature market economies is projected to grow more slowly. The sectors propelling worldwide transport energy growth are primarily light-duty vehicles, freight trucks and air travel.

Civil aviation is one of the world’s fastest growing transport modes. ICAO shows that aviation scheduled traffic (revenue passenger-km, RPK) has grown at an average annual rate of 3.8% between 2001 and 2005 and is currently growing at 5.9% per year¹. The primary energy source for civil aviation is kerosene. It is projected that by 2025 traffic will increase by a factor of 2.6 from 2002, resulting in global aviation fuel consumption increasing by a factor of 2.1. Aviation emissions were approximately 492 Mt CO₂ and 2.06 Mt NO_x in 2002 and will increase to 1029 and 3.31 Mt respectively by 2025¹.

Around 90% of global merchandise is transported by sea¹. For many countries sea transport represents the most important mode of transport for international trade. For example, for Brazil, Chile and Peru over 95% of exports in volume terms (nearly 75% in value terms) are seaborne¹. Economic growth and the increased integration in the world economy of countries from Far East and South East Asia is contributing to the increase of international maritime transport. Developments in China are now considered to be one of the most important stimuli to growth for the tanker, chemical, bulk and container trades.

Transport can be fuelled by multiple alternative sources, beginning with liquid fuels from unconventional oil (very heavy oil, oil sands and oil shale), natural gas or coal, or biomass. Other alternatives include gaseous fuels such as natural gas or hydrogen and electricity, with both hydrogen and electricity capable of being produced from a variety of feedstock.

¹IPCC Fourth Assessment Report, Working Group III Report "Mitigation of Climate Change", Chapter 5: Transport and its infrastructure, 2007

However, all of these alternatives are costly compared to conventional oil products, and several – especially liquids from fossil resources – can increase GHG emissions significantly without carbon sequestration.

Longer term opportunities in the transport sector includes advanced technology as new second generation biomass fuels, fuel cells running on hydrogen and battery powered electric vehicles. The most promising strategy for the near term is incremental improvements in current vehicle technologies. Advanced technologies that provide great potentials include greater use of electric drive technologies, including hybrid- electric power trains, fuel cells and battery electric vehicles.

Even with all these improved technologies and fuels, it is expected that petroleum will at least over the next decade or so retain its dominant share of transport energy use and that global transport GHG emissions will continue to increase. Only with large reductions in economic growth, major behavioral shifts induced by major policy intervention would transport GHG emissions decrease substantially.

The R&D challenge

Transport volumes have increased steadily over the past with economic development and globalisation as important drivers. Passenger and freight transport in OECD-countries has grown by 2.0% and 2.5% per year respectively² since 1970. Hence, it will not be unrealistic to expect transport volumes to continue to grow but at a lower rate of, say, 1.5% per year. Assuming that the transport sector will take a proportionate share of total GHG emission reductions a global GHG emission reduction by 50% in 2050 will imply by simple math that the average CO₂-intensity per passenger/ton-kilometre will have to be reduced by 93% or a factor 15, still maintaining the equity principle of equal rights to CO₂ emissions but ignoring population growth. Similarly, an 85% overall GHG emission reduction will imply lowering of the CO₂-intensity by 98%, i.e. by a factor 50(!).

Consequently, the real issue of climate change is not to improve the energy efficiency of transport but to convert transport's energy consumption to practically *carbon-free* if dramatic increases in global temperature should be avoided in the long run.

At the same time an efficient transport system is a vital and integral part the modern, globalized society where people have a high willingness-to-pay for mobility and cheap freight transport is a precondition for the high industrial productivity enabled by worldwide marketing possibilities.

The challenge for researchers and professionals in the field of transport will be to develop technological solutions which can provide the international community with the options to achieve much lower CO₂ emissions while maintaining a very high level of mobility for goods and people.

² <http://www.internationaltransportforum.org/statistics/trends/TotalFreight.xls> and <http://www.internationaltransportforum.org/statistics/trends/PassengerTotal.xls>

4. Intercontinental sea transport

Around 90% of global merchandise is transported by sea. Economic growth and the increased integration in the world economy of countries from Far East and South East Asia are both contributing to the increase of international sea transport. Although the large amount of transportation done by shipping the CO₂ from all shipping activities only contributes to 3.3 % of the global CO₂ emissions according to the latest IMO studies on Greenhouse Gas Emissions from December 2007 and September 2008 (IMO = International Maritime Organization)

The need for improvement - options for the shipping industry

Reduction of CO₂ emissions is directly linked to saving fuel, because CO₂ is one of the products of combustion being proportional to the fuel consumption. Fuel is a significant part of the total cost of operating a ship. Shipowners have therefore focused on fuel economy long before the greenhouse effect became an issue and the climate debate began. Shipbuilding is a mature technology, and engines have been optimized for fuel economy using best available technology ever since the introduction of diesel engines in the beginning of last century.

Although there are practical difficulties involved in reducing CO₂ emissions from shipping, the need to improve on performance remains. The 2007 IMO study on Greenhouse Emissions from Ships has identified a variety of options to achieve this and there is a need to further examine the pros and cons of the following ones in particular.

Technical and operational options

These options have a direct impact on the emissions per unit of transport work.

Increased efficiency of the power plant - Over the last decades there has been continuous development in producing more efficient engines. There are several existing options not fully utilized due to their high cost and/or complexity as well as novel ideas not fully explored.

Optimization of hull and propeller design - Extensive R&D has resulted in ever more efficient hull and propeller systems. It is therefore believed that the remaining potential is diminishing, but there remains room for improvement.

Energy optimal fleet operation - Significant reductions in fuel consumption, and thus CO₂ emissions, in relation to the sea transport can in theory be achieved by maximizing the utilization of the cargo carrying capacity on all voyages and by improving logistics. However, there has always been a focus on this aspect from shipping companies in order to obtain maximum exploitation of the tonnage, and the scope for further improvement is therefore probably limited.

Reduction of ship speeds will reduce the CO₂ emissions per unit of transport, but the feasibility of the option will largely depend on the type of shipping involved; for the bulk sector, for example, the option has considerable potential which should be explored further, while for the container trades in particular it presents significant difficulties. In the latter regard, it would require the consent of major customers as they would in general have to wait longer to receive their goods; there would also be a requirement to hold larger inventories in some cases. Shippers seek to maintain supply continuity and time of delivery is often an essential competitive parameter.

In relation to ferries, travelling time for passengers and goods is a key issue in the extensive competition with other transport modes; in addition, they should be considered as a bridge between areas forming essential and reliable infrastructure. It should also be noted that reducing ship speed will reduce the transport capacity, and in order to maintain

the same transport capacity more crews will have to be recruited – which is already problematic today - and more ships may have to be built which will require additional use of energy in the production process and thus more CO₂ emissions. Further analysis will therefore be needed on the pros and cons of this option.

Better waste heat utilization – The exhaust gas and cooling water from ships contain substantial energy and by better utilizing this energy the overall thermal efficiency of the engine system can be improved, in many cases by 5-10%, thus reducing the overall fuel consumption.

Alternative fuels and means of energy - There are several possibilities for replacement by energy sources which reduce the dependence on fossil fuel:

Bio fuel seems questionable because of the limited capacity and ethical problems, but is an environmentally sound solution when looked at from the point of view of an individual ship. Bio fuel in the form of bio diesel works well in ship engines and reduces the emission of CO₂ considerably. If bio diesel is used 100% then the CO₂ emissions would no doubt be reduced significantly. Bio diesel can be blended with the normal fuel and, for example, 5% bio diesel in the fuel can result in a CO₂ reduction of about 4%. An additional positive factor is that bio diesel does not contain sulphur. A clear disadvantage is the very high price as well as the risk that it will not be available in usable amounts due to the likely high demand by land transport, notably cars.

Nuclear power, whilst having a proven track in military vessels, requires a large critical mass and involves significant political problems as well as complex legal issues e.g. the relation to the International Atomic Energy Agency. Crew competency is also likely to be a significant barrier to the commercial application of nuclear power, with the controversial issue of disposal of nuclear waste being a further complicating factor.

Gas (LNG) will in the short term be able to reduce the CO₂ emission, for example, of auxiliary engines, and also of the main engine for shorter distances. While this type of fuel takes up a lot of space on board and is less relevant for ocean going ships, it could be of benefit to short sea shipping, e.g. ferries. There are large reserves of gas, making it one of the fuels for the future.

Fuel cells are a possibility in the long term but currently they are not energy efficient.

Wind and solar energy could become a supplementary source on selected routes but are not considered realistic options for the foreseeable future.

Requirements to meet a unitary CO₂ index limit value

Taking into account the historical developments in energy efficiency in shipping and the principles for any future climate regulation of shipping, the industry is prepared to enter into discussions on the different legislative options that can be both practical and attainable. One option is to introduce a CO₂ index limit for new ships. For the purpose of identifying and developing mechanisms needed to achieve reduction of GHG emissions from international shipping, IMO is in the process of evaluating the organization's CO₂ emission indexing expressing the amount of CO₂ emissions per tonne/km of actual net transport work carried out. Setting a limit for such an index could have an environmentally positive impact on the specification and performance of new ships.

Questions to be discussed in the working group for intercontinental sea transport:

1. How much can we further increase the efficiency of ships?
2. Are nuclear powered merchant ships a solution for some types of shipping - large container ships as an example?
3. There is no doubt that slow steaming, i.e. reduced service speed, is an efficient measure to reduce CO₂ emissions from shipping. Are we willing to accept a slower freight rate – also when we are sailing with a ferry as an example?
4. Which kind of renewable energy is possible for shipping in the future?
5. Are we willing to accept engine assisted sailing ships, i.e. sailing ships mainly driven by wind, but assisted by a low powered diesel engine?
6. What policy instruments are suitable for reducing climate gas emissions from ships? - standards, regulation, taxes, grants ...

5. Aviation and climate change

Global aviation (civil and military) consumed 176 million metric tons of kerosene in 2002, civil aviation contributes up to 156 million metric tons, while in 2002, 209 million metric tons of kerosene was produced³. Approximately 25,600 million metric tons of carbon dioxide were emitted globally by anthropogenic sources during the same time period. Global air traffic thus contributed between 1.9 and 2.6% of the total anthropogenic CO₂ emissions in 2002.

The transport capacity of air traffic increased by 5.4% per year between 1990 and 2004, but the fuel consumption only increased by 2 to 3% per year. Aviation has thus achieved a reduction in specific fuel consumption (per seat and kilometre)³. Based on the current trends, the percentage of CO₂ emissions from air traffic worldwide could double by 2050.

The International Civil Aviation Organization (ICAO) requested in 1999 the Intergovernmental Panel on Climate Change (IPCC) to prepare a Special Report on Aviation and the Global Atmosphere. The study concluded that, overall, aviation increased radiative forcing in 1992 by about 0.05 watts/sq.m., with about 40% of this total being due to carbon dioxide⁴. Oxides of nitrogen lead to the formation of ozone and the reduction of methane in the upper atmosphere, both of which in turn affect radiative forcing. The warming effect of the ozone is in fact greater than that of carbon dioxide, but this is partially offset by the cooling effect of the methane. The effect of water vapour, in the form of contrails, is very similar in magnitude to that of the carbon dioxide. Estimates projected for 2050 were relatively similar for each constituent, but the total radiative forcing is considerably greater. In general carbon dioxide is considered to be the primary global cause of increased radiative forcing, but in the case of aviation, other species are equally important. The future estimates indicate a steady increase in the aviation induced radiative forcing out to 2015, followed by possibly much more dramatic increases thereafter, depending on the aviation activity growth scenario chosen. The report notes that there had been significant advances in aircraft and engine technology which had reduced emissions on a passenger mile basis, and that further improvements could be expected. There are several options for reducing the climate impact from aviation some of them are discussed in the following sections.

Next generation flights: Technology development plays a role in reducing aircraft emission impacts on global climate in next generation flights. Among key technology areas are:

1. Propulsion Systems
2. Materials
3. Structure
4. Aero & Systems Design & Methods
5. Manufacturing Processes

Smart wing designs makes use of passive and active flow and load control technologies and will help to reduce the drag of the wing in cruise. This concept will increase overall aircraft fuel efficiency. The architecture of the smart wing will

³ Air Transport Impact on Climate, Deutsches Zentrum für Luft- und Raumfahrt e.V., 2008

⁴ ICAO Environmental Report 2007

enable the application of the most advanced passive and active loads control strategies, which are reducing the loads in turbulence not only acting on the wing, but also on the entire aircraft.

The increasing use of composite materials coupled with other advanced materials, loads alleviation, other systems optimizations, and new manufacturing techniques can lead to significant weight savings.

The engines of next generation flights should be radically different from those in service today. Bypass ratios need to be much higher, engine nacelles may even disappear, power off takes will increase as the size of the core reduces and real time diagnostics will enable engine maintenance to be optimized. There is a need for new solutions for the complete range of the market, with engines for the narrow body fleet, high thrust engines for wide body aircraft, regional aircraft engines and helicopter engines.

Alternative fuels: An obstacle in developing alternative fuels for aviation is that safety and reliability cannot be compromised. Also, there are unique requirements for operation of the conventional turbine engine in commercial service that make a rigorous approval process necessary for any alternative fuel. Bio-derived fuels for today's fleet face significant challenges because of the molecular transformations required to convert biomass into kerosene-type hydrocarbons. It will be easier to develop bio-derived fuels that can be used in blends with conventional jet fuel than to develop a stand-alone bio-jet fuel. From an environmental perspective, bio-derived fuel could help to reduce aviation's carbon footprint. While there continues to be significant investment in the research and development of alternative jet fuels, the only alternative to conventional jet fuel on the near-term horizon is synthetic Fischer-Tropsch jet fuel used in a blend with conventional jet fuel. In longer-term aviation fuels like cryogenic hydrogen and liquid methane are being considered, but a number of technological challenges have to be solved prior to their use.

Lower flight speeds: Speed comes at a cost in terms of fuel burn, although modern jet aircraft are designed to fly at optimum speeds and altitudes to maximize the efficiencies of their design. Flying slower would reduce the fuel consumption, but would require modified engine design in order to maximize the efficiencies at lower speeds. The propfan, a conventional gas turbine powering a highly efficient rotating propeller system, is an obvious alternative. The typical maximum speed for an aircraft powered with such engines is 400 mph, compared to 550 mph for conventional aircraft.

Air traffic management system: Between 13% and 15% of fuel is consumed through excessive holding either on-ground or in-flight and through indirect routing and non-optimal flight profiles. It has therefore been targeted to save 5% to 10% of the fuel consumed through radical changes to the air traffic management system to minimize wasted time and route aircraft directly to their destination with minimum or no holding. Within the current air transport system, half of the CO₂ emitted is generated by flights below 1200nm, the sector of the market that, for economic and passenger convenience reasons, operates the least fuel efficient aircraft, whereas for longer range operation low fuel consumption is necessary to realize economic operation. However if CO₂ production were to become a primary design consideration, the choice of design speed, range and altitude would need to be re optimized. The most likely result would be to fly more slowly on short haul routes and to stop more frequently on long haul operations⁵.

Flight control methods: Lower fuel consumption and emissions can be achieved by new flight control methods with better utilization of tail winds and less formation of cirrus cloud condensation trails. Change in cruise speed, altitude selection and new climb, cruise and descent profiles can reduce fuel consumption on long haul routes, but result in longer flight times. Optimized route selection could reduce fuel consumption on both short and long haul routes.

⁵ The Challenge of the Environment, volume 2, STRATEGIC RESEARCH AGENDA 1, Advisory Council for Aeronautics Research in Europe (ACARE)

Infrastructure: Infrastructure improvements present a major opportunity for fuel and CO₂ reductions in the near term. By addressing airspace and airport inefficiencies, governments and infrastructure providers could eliminate up to 12% of CO₂ emissions from aviation³.

Duty free: Abandoning luxury goods trolleys and duty free shopping in airports on departure leads to weight reduction and thus reduced fuel consumption.

Inclusion of aviation in the EU ETS: EU adopted in October 2008 the inclusion of aviation in the EU ETS (Emission Trading System) from 2012. This limits the CO₂ emissions from air transportation in EU, to and from EU, including aircraft operators from e.g. Asia and USA. If the aircraft operators emit more than the limit they have to buy quotas in the ETS system or JI/CDM credits from climate projects in developing countries to account for additional CO₂ emissions. The new quota system will become effective from 2012 and will include all departures and landings in European airports, also planes from e.g. Asia and USA. The share of quotas that comes up for auction will be 15%. There is an option for raising this share after 2012 in connection with the revision of the ETS. The price of permits in the EU ETS has historically been in the range of €15 per tonne of CO₂ – equivalent to 3.8 cents per litre of kerosene. The EU Commission's Impact Assessment suggests that this will reduce aviation emissions by only 3%, less than a year's growth of emissions. Fuel taxes in road transport are around 65 cents per litre – more than 10 times higher than equivalent CO₂ prices in the EU ETS. Furthermore, high carbon prices in aviation would not put the EU aviation industry at a competitive disadvantage since every airline on each route covered by the scheme would be treated equally. Therefore, environmental NGOs insist on introduction of fuel taxation and VAT on airline tickets alongside integration of aviation into the EU ETS.

Questions to be discussed in the working group for aviation and climate change:

1. How much can we further increase the efficiency of planes?
2. Lower flight speeds is an efficient measure to reduce CO₂ emissions from aviation. Are we willing to accept the corresponding longer travel times?
3. Which kind of renewable energy is possible for aviation in the future?
4. What is the reduction potential in optimizing the overall air traffic management and flight control system?
5. What policy instruments are suitable for reducing climate gas emissions from aviation? - standards, regulation, taxes, grants ...
6. Are there realistic alternatives to passenger air transport?

6. Private car transport

Transport of persons and personal belongings or goods in private cars is a fundamental part of the modern welfare society and has grown steadily over many decades. Although electronic communication develops with extreme speed and fulfils increasingly many demands for information interchange, human beings seem to be constructed in a way that requires personal meetings and personal presence at different places at different times – in the private as well as in the professional sphere.

As we try to solve problems related to emissions and use of resources by private car transportation, it is therefore not viable to dictate strong reductions in availability of transportation, but rather we need to develop new technologies that may not only fulfil the present demand for private transport in an acceptable way, but may also meet an expectedly increasing demand for personal transport caused by increasing population and probably also by increasing need for transportation for each individual.

Naturally public transport has to assume a major part of the future need for personal transportation – particularly in urban areas and in long distance transport – but private cars will inevitably also be an important part of the solutions to the future demand for sustainable transportation of persons.

Internal Combustion Engines (ICEs)

CO₂ reduction potential of existing technologies

Present car and engine technologies hold a significant potential for improvements concerning fuel consumption and CO₂ emission, which may be illustrated by the recent development of hybrid ICE/electric cars like the Toyota Prius. However, even the present fossil-fuel engine technology in itself holds a potential for reduction of emissions. Vehicle weight is paramount for fuel consumption and for a long time the car industry has worked intensively on using light-weight construction materials (e.g. polymer composites in place of iron-based materials and aluminium or even magnesium instead of cast iron) in cars and in a way this development has been quite successful. The reason that the average car weight in Europe – in spite of this development - has not decreased is that new cars carry still more weight for installations related to safety and comfort and maybe particularly, that ordinary consumers tend to prefer large cars with large and fast engines. Only recently this trend seems to have been broken by rocketing oil prices and economic recession, and the consumers now seem to pay more attention to fuel economy when purchasing new cars. Nevertheless, the potential still exists and may be activated or accelerated by legal and/or economical incentives.

Alternative fuels for ICEs

The fuel for ICEs may be provided in ways that do not contribute to emission of greenhouse gases. One such way is the production of bio fuels, which is, however, intensively debated for reasons of ethics and use of land. Another way is the production of synthetic fuel based on renewable electricity, e.g. from wind power. The renewable electricity may be converted by electrolysis and use of CO₂ from atmosphere into liquid CO₂-neutral fuels, which may readily substitute today's fossil based liquid fuels. Along these two ways the already existing infrastructure for distribution and use of liquid fuels may be utilized also in a future scenario and tremendous investments in a new infrastructure may be unnecessary. On the other hand, production and use of liquid fuel from electricity is highly energy extensive and it may be a technical and economical question if this option is actually viable.

Electric vehicles

Electric cars appear attractive for certain private car transport operations. Particularly in cities, where the driving distances are often short, electric vehicles may fulfil most ordinary transport functions. In addition, electric vehicles are very energy efficient in terms of converting electricity to mechanical work (traction). The drawbacks of electric cars are the long recharging time and the low energy density of batteries, especially on weight basis, which means that the car needs to carry a considerable and inappropriate dead weight. For long driving ranges this becomes quite clear and is the reason that electric vehicles typically show operation distances about 100-150 km or lower. Yet another problem for battery-driven cars is the insufficiency to supply heat for internal comfort in the car cabin. Cabin heat is actually required in many regions during a considerable part of the year and should not be ignored.

Hydrogen and fuel cells

Hydrogen is the simplest synthetic fuel that may be produced from electricity and used in cars, either for direct combustion (ICE) or for electrochemical conversion in a fuel cell. Hydrogen may be stored on-board the vehicle by use of a variety of technologies, where compressed gaseous hydrogen is presently preferred among the car manufacturing industry. This storage technology has the advantage of short recharging time and a relatively high energy weight density (an order of magnitude higher than that of a battery), which means availability of acceptable driving ranges. The drawbacks of hydrogen technology are the low electricity to mechanical energy conversion efficiency and still insufficient storage properties.

The future private car

It is not for the moment possible to point out a future winning traction technology, that may adequately substitute present fossil-based techniques and most likely no single new technology will be able to cover the entire range of private car transport needs. A combination of batteries and hydrogen/fuel cells – a new form of hybrid cars – seems promising from several points of view, but it is also not unlikely that a technology separation will take place, meaning that we will use different traction technologies – different vehicles - depending on the particular transport (driving distance) required. The final decisions on these topics are likely to be made by the market forces based on (still unknown) technical and economical developments

Questions to be discussed in the working group for ~~aviation and climate change~~

1. How will private car transportation (person-kilometres per year) develop over the next decades in Europe? In the world?
2. What should preferably be the dominating traction technology in future private cars (fuel and engine/motor)
3. Will households need two or more cars to solve their future need for private transportation?
4. How should/could taxes be used to control private car transportation?
5. How can we encourage and accelerate technical developments to solve problems related to private car transportation?
6. How can policy for private car transportation have a social and regional dimension?

7. Road based freight transport and its competitors

Freight transport has been growing even more rapidly than passenger transport and is expected to continue to do so in the future. Around the world rail remains an important mode especially in large countries like Russia, USA and China. But in EU trucks constitute the dominant mode when it comes to land based transport, whereas rail is only marginal. Worldwide road transport is gaining market shares. Trucks are getting larger and the average haul distances are growing too. Still being superior in flexibility, these increases in capacity mean gain of competitiveness compared to other modes.

According to the Stern Review trucks are responsible for approximately 23% of the CO₂ emissions from the transport sector on a global scale corresponding to approximately 5% of total CO₂ emissions and according to IPCC WG III 4th Assessment Report these shares are expected to increase in the future. From European Energy and Transport Trends 2030 (2007 update) it appears that trucks emitted approximately 33 % of the transport related EU CO₂ emissions in 2005 (excluding international navigation).

Efficiency improvements

During the years considerable efficiency gains have been harvested in road based freight transport. Aero dynamics, larger units, more effective engines and improved logistics have all contributed to a decrease in energy consumption per tonne-km. In Europe the decrease has been around 0,8% p.a. as can be derived from European Energy and Transport Trends 2030 (2007 update) . But the growth in truck activity has been strong measured in tonne-km: around 4% a year since 1970 on a global scale (according to World Business Council for Sustainable Development, Mobility 2001) and a little less in Europe. Therefore, the efficiency gains have far been offset and fuel consumption from trucks in EU has been increasing by around 2,5% p.a. from 1990 to 2005. The same holds for the CO₂ emissions.

Diesel engines are dominant in heavy-duty vehicles and their efficiency improved strongly especially during the 90'ties. Improvements have been seen especially in development of new fuel injection systems with injection pressures up to about 2000 bar. This has improved the combustion process and resulted in better fuel economy and lower emissions. Also fuel injection control and electronic control in general has lead to significant improvements. Better adaption of turbo chargers and development of efficient exhaust after treatment systems are other important development features as well as improved design of the combustion chamber. Introduction of homogeneous charge compression ignition (HCCI) engines, which combines the good fuel economy of the compression ignition engine with the low emission features of the spark ignition engine are being introduced in these years.

Among the future possibilities for innovations and improvements are

- Further development of HCCI, turbo chargers and electronic control
- Light weight materials
- Hybrid trucks
- Alternative fuels: BtL, RME, DME, methanol/ethanol, natural gas/biogas, hydrogen, electricity

Because of large and heavy batteries, the potential in electrified trucks is limited in the short and medium term. Intelligent traffic systems (ITS) seem to have limited impact on energy consumption and emissions and the same goes for driver education, but new logistic concepts may have a higher potential.

Some claim that eco-driving can have a considerable potential for those who have not yet introduced this – up to 10% reduction in fuel consumption can be expected. This potential is hard to realise, though.

Increased energy efficiency in the haulage sector contributes to lower freight rates and thus increasing demand. This will to some extent contribute to the off-setting of technical gains per km.

Future growth

According to European Energy and Transport. Trends to 2030 (2007 update) EU expects a growth in truck haulage measured in tonne-km of 1.8% p.a. in the course of the coming 25 years. This is in line with the expected 1.7% annual increase in goods transportation in general. Energy efficiency gains of trucks are assumed to be 0.4% per year in the future. Fuel demand from trucks is thus expected to grow by 1.4% a year, but EU expects a lower growth in CO₂-emissions as biofuels will substitute diesel to some extent. In comparison, energy consumption for private cars is estimated to grow by modest 0.4% a year mainly due to a slow growth in passenger transport demand compared to demand for goods.

Environmental damage

Greenhouse gas emissions are only responsible for a minor share of the serious environmental and social costs stemming from truck transportation. Emissions of SO₂, NO_x, CO, VOC and PM's from an average truck are decreasing in the USA and EU. In the EU this is mainly a result of the Euro norms that all new trucks must comply with. But the general growth in transport means that air pollution in many cities is still a serious problem. Noise, accidents, congestion and road wear are other important effects from truck driving harming the environment. Together these effects give rise to considerable external costs estimated by Danish Ministry of Transport to be of the order of €0.5 per km – higher in cities and lower in rural areas. But such estimates are highly uncertain.

Measures to reduce greenhouse gas emissions

Road pricing for trucks is gaining a footing in Europe these years. In Germany the LKW-MAUT system is taxing trucks 16-29 €cent for each kilometre driven on the highways depending on the truck. Similar systems are running in Austria and Switzerland and other countries are on the way. Such taxes may to some extent transfer goods from road to rail and reduce the transport volumes, but probably they will mainly increase transportation costs and the price of the goods transported by a small fraction. Other means for reducing the external costs from heavy traffic are fuel taxes, environmental zones in the cities, facilitating intermodal transport, encouraging short sea shipping and tax exemption for companies meeting environmental standards in their operation.

Competing modes

The market share of road in freight transport is increasing and is now around 73% in EU. The share of rail has dropped to around 18% mainly because of low flexibility and low speed compared to road as well as having lower priority than passenger trains. But in European Energy and Transport Trends 2030 EU expects the market share of rail to decline at a slower speed in the future, the main reason being that improvements in rail infrastructure are assumed.

In spite of the lack of statistical information, it is safe to say that air freight activity is rapidly increasing – typically by more than 5 % a year in EU countries – but it still has a negligible market share in freight transportation. From 2012 the EU CO₂ emissions trading system will include air transport and this will partly remove the tax advantage that air transport has had compared to road transport.

In some regions pipelines account for a large share of the transportation, but they are primarily suited for large amounts of liquids and gases – mainly oil and natural gas.

In e.g. central and eastern Europe, inland waterways play some role in freight transport. However, this mode of transport can only be operated along existing rivers and canals, but have a high potential along such corridors for especially mass transport.

Questions to be discussed in the working group:

1. What will be the fuel and engine technology in future road based freight transport?
2. Is one single fuel/technology the only option?
3. Can we achieve significant efficiency gains by reducing weight, increasing size, improve tyres etc.?
4. Is there any potential for the competing modes, especially rail?
5. Can we reduce the total amount of goods hauled? How? By suppressing globalisation?
6. Are economic policy instruments like taxes and subsidies always superior to standards and regulation?
7. Do we neglect other environmental effects when we put focus on climate change?

This report is part of a series of workshops and conferences arranged as a part of DTU Climate Change Technology, a research programme run by the Technical University of Denmark.

DTU Climate Change Technologies aims to take scientific research, present it to key players in the fields of energy and climate changes to produce new technologies and processes. The goal is to reduce CO₂ emissions and support industrial production and welfare in adapting to climate change. Read more at dtu.dk/subsites/klima/English.aspx

Workshops

Sustainable Buildings - 19 June 2008

Future Energy Systems - 19 - 20 November 2008

Sustainable Energies - 14 - 15 January 2009

Animal Health and Food Safety - March 2009

Transport - renewable energy in the transport sector and planning - 17 - 18 March 2009

Climate Changes and Ecosystem Productivity - May 2009

Combustion, Carbon Capture and Storage - 27 - 28 May 2009

InfraStructure and Climate Changes - 1 September 2009

Research conferences

Changes of the Greenland Cryosphere - 25 - 28 August 2009

Risoe DTU International Energy Conference - 14 - 16 September 2009

Final round-up forum

High-level Conference - 17 September 2009

The Technical University of Denmark

Anker Engeldsvej 1

Building 101A

DK-2800 Kgs. Lyngby

Denmark

Phone: +45 45 25 25 25

dtu@dtu.dk

www.dtu.dk