Eco-efficient Transport

Interim report on potentials of technologies and concepts supporting eco-efficient transport
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Abstract

The report offers an overview on relevant technologies and concepts that have the potential to support an eco-efficient transport system, and it provides an overview of important trends and challenges in the passenger and freight transport sector. As such the findings are used for the design of the scenarios conducted in phase 3.
A transition to a more eco-efficient transport system is needed to cope with recent challenges and the anticipated future developments in the transport sector. The project on eco-efficient transport will look at technologies and concepts supporting eco-efficient transport. Not only will it take the technical and organisational innovations themselves into account, but also the demand side of transport innovations. The idea of the project is to conduct technology assessment supported by a consultation of citizens and experts/stakeholders with scenario building as an integrative element. In phase one, an overview regarding the main issues of the projects was given. Conceptualisations of eco-efficiency were discussed and related literature was screened. It was decided that the project should refer to a broader conceptualisation of eco-efficiency: It is assumed that eco-efficient transport encompasses all approaches that help to reduce the ecological footprint of transport-related activities. In principle, point of reference should be the amount of resources needed for fulfilling a certain purpose (work, social contracts / produce or buy a good; economic growth).

The report at hand aims at discussing technologies and concepts that have the potential to support the eco-efficiency of the transport system. It will be used for the design of the scenarios in phase 3, which will then be discussed with different groups in phase 4. The final report will be compiled in phase 5.

The introduction (chapter 1) highlights that the rather different technologies and concepts supporting eco-efficiency can be allocated to the following three strategies:

- Making transport modes cleaner (e.g. cleaner fuels and propulsion technologies, lightweight construction)
- Modal shift towards more efficient transport modes (e.g. making public transport or freight rail more attractive)
- Reduction of transport volumes: avoiding journeys or reducing the length of journey (e.g. teleworking, land-use planning)

In chapter 2, an overview on important trends and challenges is given. The chapter starts by highlighting the key-dilemma of having the aim to ensure efficient, safe and affordable mobility for people and goods and thus to enable freedom of movement and trade and, on the other hand, the transport system has to deal with negative externalities such as the impact of transport on climate change, problems of congestion, noise, pollution and health hazards. Those externalities incur high costs and are increasingly the subject of public concern and policy actions. Furthermore, the strong oil dependency of the transport system is mentioned, which is also an important issue of the Commissions 2011 White Paper on Transport. In 2006, almost all of the energy used in the EU-27 was based on petroleum products. One of the main challenges are the high growth rates in the transport sector. Transport is the only sector, in which GHG emission continues to grow significantly.

In the passenger sector, road transport accounts for around 84% of the total transport performance. About 98% of the trips belong to the category “short distances” and do not exceed more than 100 km; the remaining 2,5% of trips account for 53% of all pkm. Passenger transport demand will be affected by several “external” effects in future, amongst them: ageing of EU population, international migration, urbanisation and urban sprawl, increasing energy prices, increasing usage of information and communication technologies (ICT) as well as lifestyle changes. Furthermore, the development of GDP will surely continue to have influence on transport growth. Regarding the freight sector, trucks and rail transport together accounted for 27% of the total energy consumed in 2006, about 90% of that...
Eco-efficient transport can be dedicated to trucks. Fuel efficiency gains were realised in the last years, which might be due to commercial drivers being more sensitive to fuel costs. Several developments are influencing the freight sector, amongst them: globalisation and liberalisation of markets, just-in-time procurement, internet-based electronic business, ICT led to improvements in travel time and reliability, terror and piracy as well as environmental concerns. Data from different EU countries show that load factors could be improved. Another challenge of the freight transport sector is to improve its logistic performance in order to increase the market share of rail and maritime freight transport.

Chapter 3 is focussing on fuels and propulsion technologies, which are one of the most important approaches for eco-efficiency of the transport system. A broad range of rather different approaches exist. It becomes obvious that the eco-efficiency of all the alternatives to oil-based fuels is strongly dependent on other developments in the energy sector. Biomass can be used in stationary as well as in mobile applications; the same is true for hydrogen, and, of course, also for electricity and natural gas. For electric engines the most open questions – in terms of eco-efficiency - are related to the production of electricity or hydrogen as well as to the integration of these production pathways into the energy system. Thus, the integrated perspective on the transport and the energy system is becoming highly relevant.

It can be observed that more and more car manufacturers start the commercialisation of battery electric vehicles (BEV). Weak points compared to the conventional internal combustion engine ICE are the low ranges, whereas the lower energy density is not expected to be improved too quickly. Furthermore, there are longer charging times, higher prices as well as open questions concerning reliability. This needs to be balanced by higher efficiency, lower energy cost per kilometre and, thus, by beneficial total cost of ownership. In terms of eco-efficiency, the whole life cycle needs to be considered. Assessments show, that the environmental impact of both BEV and ICE is dominated by the operation phase. Electric propulsion also plays a role in many hybrid concepts.

Cars with hydrogen and fuel cell technology use an electric engine for propulsion. Prototypes are tested in pilot projects, ranges around 400 km are possible, commercialisation seems to be close. However, the crucial issue is how the hydrogen is produced. The route via electrolyses allows for a high flexibility in terms of feedstock; wind power or photovoltaic can also be used. But this means that electricity is used to produce hydrogen and then, in the car, hydrogen is used to produce electricity again. This process is leading to considerable losses in usable energy. Some observers argue, that battery electric vehicles could be used for shorter distances and hydrogen cars with fuel cells could be used for longer distances. Because of low energy density and low storage capacities both batteries and hydrogen are not suitable for trucking and aviation. For these modes, biofuels are an alternative. However, biomass as feedstock is critically discussed for several reasons, amongst them competition with food production and the direct or indirect land use changes (e.g. deforestation). Other options are gaseous fuels such as natural gas. Its main component, methane, could also be produced by alternative methods on the basis of renewable feedstock. However, again it is crucial to consider the energy balance carefully.

In chapter 4 the focus is put on the different modes, on different approaches for improving vehicles and infrastructures. In particular lightweight materials are getting increasingly important. Approaches to improve eco-efficiency for trains are mentioned. In aviation, the so-called flying wing is discussed as completely new and more energy efficient design of aircrafts.

The second highly important technological strand, the development related to the progress of ICT in the transport system, are subject of chapter 5. Such applications are often subsumed under the title Intelligent Transportation System (ITS). The chapter highlights that ICT is playing an increasingly crucial role for the transport system, and many of these applications have the potential to improve the
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The eco-efficiency of the system. This can be done by reducing the need to travel (reducing volumes) or by increasing the competitiveness of more efficient modes or vehicles. ICT can improve the availability of information on public transport; it can facilitate the access to public transport with handy ticketing or integrated ticketing; it enables advanced car-sharing or bike-sharing services; it can support a more efficient use of infrastructures; it can substitute travel by enabling tele-working or video conferencing. However, the overall effects of these approaches are difficult to assess since it is also possible that so-called rebound effects occur: ICT-based applications might generate additional trips when capacities are enlarged or when travelling becomes easier and more enjoyable.

In the freight sector, a great impact is expected from progress in ICT applications. ICT plays a major role for the continuous and immediate exchange of information, tracking and tracing of goods, in enabling new concepts for production and services, for performances on time aspects and in determining shipment sizes. It helps to increase the reliability of transport chains. Increasing the load factors is a crucial issue. The capacity of transportation systems can be made more efficient by an integrated use of ITS. As it is the case for passenger transport, ICT might increase the transport distances. In chapter 5 four key areas for ITS in freight transport are subdivided: pre- and on-trip travel information, cargo and vehicles tracking and tracing, cooperative systems and advanced urban logistics.

Chapter 6 illustrates that organisational innovations are strongly enabled by progress in the ICT sector. Organizational innovations have the potential to improve the efficiency of mobility patterns by making them cleaner (e.g. better load factors, more efficient usage of infrastructure), they help to shift loads (e.g. by making public transport and freight rail more attractive) and they can help to reduce volumes (e.g. tele-working; video-conferencing). Prominent examples are carsharing and bike sharing schemes. It can be assumed that both approaches would not have such significant growth rates in several European countries without sophisticated ICT applications that allow for easy booking, easy access and easy charging. It is interesting to observe that several car manufacturers recently started to test own approaches that are similar to carsharing. One reason for these surely is that the younger generation, in particular in urban areas, seems to be less interested in ownership than the generation before. Again it is difficult to quantify the effects of car sharing or bike sharing on eco-efficiency. In general, car sharing fleets have smaller cars than the average fleets in a country and the organisations themselves usually claim to use eco-efficient vehicles. Furthermore, car sharing is seen as a good concept for introducing alternative fuels and propulsion technologies into the market, since customers would be enabled to choose a specific car for a specific purpose. However, for these approaches it should not be overseen that they can also induce traffic or rebound effects.

Organisational innovations offer interesting potentials for the air sector. Regarding passenger air transport, an important issue is a better organization of traffic flows at airports. Furthermore, a rather efficient way of reducing energy consumption and emissions is to use slower aircraft configurations. In the freight sector, organisational approaches offer interesting potentials for reducing CO₂-emissions. Again, many of these measures are strongly linked to ICT applications as a kind of enabling technology. Another promising approach is the delivery of goods at night with relatively quiet electric engines. A different example is using a tram for goods transport as it is done by the freight tramcar in Dresden, Germany.

Finally, in chapter 7 some concluding remarks are made. It is obvious, that the transport system is not static but underlies changes under several aspects. There are external pressures such as oil prices and climate change. There are societal trends that influence demand patterns. And there is a broad range of organisational and technical innovations for improving the eco-efficiency of the transport system be
making trips cleaner, by supporting the shift to more eco-efficient means of transport and by reducing transport volumes. It was mentioned several times in this report that the effect of these measures is rather difficult to quantify. Getting a better understanding of these potentials with the help of scenarios will be subject of the next phase of the project.
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General information

A transition to a more eco-efficient transport system is needed to cope with recent challenges and anticipated future developments in the transport sector. In the passenger as well as in the freight sector, a wide range of technologies, concepts, and business models supporting eco-efficient transport are available or emerging. The project on eco-efficient transport will look at established, emerging and more visionary technologies and concepts supporting eco-efficient transport. It will not only take the innovations themselves into account, but also the issue of the demand for transport innovations. The basic idea behind the project is to conduct technology assessment complemented by consultations with the general public as well as experts and stakeholders; scenario building is used as an integrative element. The consultations and assessments will consider the technical and organizational design of eco-efficient transport systems as well as the attitudes and preferences of their users.

This interim report is Deliverable 2a of the project. It offers an overview of the approaches of the most promising technologies and concepts for eco-efficient transport in Europe (excluding maritime shipping, which is the subject of Deliverable 2b). Qualitative and quantitative assessments of the potential of these technologies and concepts are presented. The overview is based on work done in other STOA projects as well as on literature reviews. Additionally, the web sites of relevant stakeholders were consulted to learn about their views regarding the potential of different technologies and concepts. This report serves as a basis for the scenarios that will be developed in phase 3 of the project.

Acknowledgments

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1. **Introduction**

This is an interim report of the Science and Technology Options Assessment (STOA) project on eco-efficient transport. Its aim is to give an overview of the main developments relevant to the eco-efficiency of the transport system. It discusses relevant technological and organizational innovations with regard to their potential contributions to the eco-efficiency of the transport system.

As was mentioned in the scoping report (DEL 1 of the project), different definitions and framings of “eco-efficiency” can be found. In this project, we assume that eco-efficient transport encompasses all approaches that help to reduce the ecological footprint of transport-related activities. Eco-efficient transport is understood in a broader sense:

- by using economic growth and the quality of life (welfare) as a point of reference (one which goes beyond the pure resources input per person per kilometer/per metric ton per kilometer).
- by focusing not only on technologies but also on organizational measures and behavioral changes.

In principle, three basic strategies can be applied to increase the eco-efficiency of the transport system (see STOA 2008):

- **Cleaner modes**: the individual modes/vehicles can be made cleaner. This involves approaches such as cleaner fuels and propulsion technologies, lightweight construction, and also soot filters or catalytic converters.
- **Modal shift**: the idea is to shift trips to more efficient modes. This includes, for example, a shift from road to rail or, in the urban passenger sector, a shift from motorized modes to cycling.
- **Reduce volumes**: the reduction of trip lengths and the avoidance of trips fall into this category. This can be the consequence of a virtualization of activities: tele-working offers a prominent example. It can also be the result of land-use planning strategies that try to avoid extreme suburbanization processes and instead promote the City of Short Distances (decentralized concentration).

These strategies will play a role in the scenarios in phase 3 of the project. In the present report, technological and organizational innovations supporting these strategies are discussed. In chapter 2, an overview of important trends and challenges is given. Chapter 3 focuses on fuels and propulsion technologies, which are two of the most important approaches to the eco-efficiency of the transport system. In chapter 4, attention is focused on different approaches for improving the vehicles and infrastructures of the different modes. A second highly important technological strand, the developments related to the progress of Information and Communication Technologies (ICT) in the transport system, are the subject of chapter 5. Chapter 6 illustrates the fact that organizational innovation is strongly facilitated by progress in the ICT sector. At the same time, it is becoming increasingly relevant for the transport sector. Finally, Chapter 7 offers some concluding remarks.
2. Trends and challenges

The transport sector is faced with a dilemma. On the one hand, it aims to ensure efficient, safe and affordable mobility for people and goods and thus to enable freedom of movement and trade; on the other hand, it has to deal with negative externalities. Besides concerns about the sector’s dependence on oil, there are worries about the impact of transport on climate change and problems related to traffic congestion, noise, pollution and health hazards. These externalities incur high costs and are increasingly the subject of public concern and of policy actions. The recently published White Paper on Transport also emphasizes that greater efforts are needed: “a reduction of at least 60% of GHG [greenhouse gas] by 2050 with respect to 1990 is required from the transport sector, which is a significant and still-growing source of GHGs. By 2030, the goal for transport will be to reduce GHG emissions by around 20% from their 2008 level. Given the substantial increase in transport emissions over the past two decades, this would still put them 8% above the 1990 level.”1 This will require significant efforts related to all modes of transport. One of the key challenges outlined in the 2011 White Paper “is to break the transport system’s dependence on oil without sacrificing its efficiency and compromising mobility.”2

Almost 72% of the total oil product deliveries to the EU are consumed by the transport sector, which is accordingly the largest consumer of oil products in the EU. Today, transport relies almost entirely on oil; in 2006, almost 97% of the energy used in the EU-27 (i.e. including data from all present members of the EU, regardless of when they became members) for transport (including all modes) was based on petroleum products. Only 1.7% of the energy came from electricity, 1.5% from renewables and 0.2% from natural gas (see Figure 2.1).3 Transport’s share of the final energy consumption was around one third (31.5%), up from 26.3% in 1990. The main contributors to this increase have been growing goods and passenger fleets and a strong rise in air transport. Road transport is the most energy-consuming mode of transport, while aviation shows the fastest growth rates. 82% of the total energy used in transport can be attributed to road transport and another 14% to air transport.4 Passenger cars account for 55.9% and trucks for 39.4% of the total energy consumption in road transport.5

GHG emissions in the transport sector continue to grow, while they are decreasing in other sectors. In 2006, the transport sector in the EU-27 accounted for around 23% of carbon-dioxide (CO2) emissions and is thus the second largest emitter of CO2 (after the energy industry).6 The transport sector is the only sector that has not shown reductions in emissions; during the period from 1990 to 2006, it actually showed average annual growth rates of 1.5%7 and thus cancelled out the reductions of emissions in all other end-use sectors.8

1 CEC (2011a),p. 3.
3 See Eurostat (2009).
4 See Eurostat (2009).
6 See CEC (2009).
7 See Eurostat (2009).
8 See CEC (2008).
The vast majority of Europe’s transport GHG emissions can be attributed to road transport, aviation and navigation (see Figure 2.2). According to the International Transport Forum (ITF 2008), the freight transport sector is estimated to contribute a third of the CO2 emissions of the world transport sector. The European Environment Agency (EEA) estimates that recent increases in international aviation will continue and thus render it an ever greater contributor to the transport sector’s GHG emissions.9

Continuously increasing growth rates in the transport sector are a substantial driver behind the increases in energy consumption and GHG emissions. According to the ITF, air transport, international maritime transport and road freight transport are showing particularly substantial growth rates, while passenger transport is increasingly showing saturation.10 However, statistics show that in Europe — apart from the period of the economic downturn in 2008 and 2009 — both passenger and freight transport have shown constant growth rates over the past decades. Between 1995 and

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9 See EEA (2009).
2009, the gross domestic product (GDP) grew annually by 1.8%, while passenger transport grew an average of 1.4% and freight transport 1.2%.

At present, most vehicles on European roads still operate on the basis of internal combustion engines (ICE), mainly using gasoline or diesel oil. The European Commission has set itself the goal to “halve the use of ‘conventionally-fuelled’ cars by 2030”.

Natural gas, in forms such as liquefied petroleum gas (LPG), compressed natural gas (CNG) or biogas, offers a possible fossil-fuel substitute for petroleum. Compared to other countries (e.g. Argentina, Brazil, India, Iran, Pakistan), natural gas does not play a significant role in the transport fuel mix of the EU, although it very probably possesses great potential, especially for heavy-duty vehicles. Biofuels are another fuel type that is relevant for freight and passenger transport. Biofuels derive from biomass feedstock. Due to concerns about effects on food prices, recent growth rates (the global biofuels supply increased by 37% in 2006) are not expected to continue. In 2006, biofuels’ share of the total energy used in road transport in Europe was 2%. However, primarily as a result of the EU Biofuels Directive 2003/30/EC, biofuels are becoming more widespread in Europe; however, this development is still on a small scale. In 2008, EU leaders reached an agreement on a new renewable energy directive. This requires all member states to reach the mandatory target of a 10% share of biofuels in transport gasoline and diesel consumption by 2020. Hydrogen could represent another relevant substitute for conventionally fuelled cars. In general, if hydrogen is processed using renewable energies it has almost no emissions on a life-cycle basis. Hydrogen can be used in combination with fuel cells or in slightly modified Otto engines. Fuel cell vehicles would make zero tailpipe emissions possible, as they only emit water. A few years ago, many observers considered the combination of hydrogen and fuel cell technology a highly promising future alternative to conventional ICE technology. Since then, as a result of progress in battery technology, many observers assess the potential of battery electric vehicles (BEV) much more optimistically. Nonetheless, the limited range of electric vehicles’ batteries renders them relevant only for short-distance transport in the near future.

2.1 Passenger transport

In 2009, a total of 6.503 billion passenger-kilometers (pkm) were undertaken by Europeans with all motorized means of transport; this corresponds to an average of 13,063 km per person. Road transport plays a dominant role in passenger transport: Around 84% of the total transport performance is to be attributed to road transport (see Figure 2.3). Low-cost airlines have constantly grown in importance for the passenger transport sector. Between 1995 and 2009, annual growth rates for intra-EU air transport were at 3%. However, this sector was particularly affected by the economic crisis; in 2009, total performance of air transport was 7% lower than in 2008. Due to fuel efficiency improvements in the passenger transport sector, specific CO₂ emissions from road transport have decreased since 1995.
However, increases in transport volumes have outstripped those improvements. There is therefore a strong need for further development toward a more eco-efficient transport sector.

Figure 2.3: Modal split in passenger transport in the EU-27 in 2009

![Modal split in passenger transport in the EU-27 in 2009](image)

Source: Based on data from the European Commission (2011b).

About 98% of trips belong to the category “short-distance” and do not exceed more than 100 km. The remaining 2.5% of trips account for 53% of all pkm and thus also need to be taken into account in this project.\(^16\) Several external factors will affect the passenger transport demand in future:\(^17\)

- The European population is projected to become older in almost all regions in Europe, and this is likely to increase the number of medium- and long-distance trips by car and air and short-distance trips by public transport.
- Europe is expected to become one of the primary destinations of international migration, and this is likely to result in more short-distance trips by car and public transport, since migrants are expected to live in urban agglomerations and their surrounding areas.
- Urbanization, and thus urban sprawl, is projected to increase. Not only private households, but also investors (e.g. peripheral retail centers) tend to move outside downtown areas, and this is likely to increase short- and medium-distance trips by car and public transport.
- Energy prices are expected to increase in the future. Since countries with higher fuel prices tend to have lower per capita passenger travel, it is likely that people will increasingly shift from car to alternative modes of transport for short-distance trips.
- Transport activity generally correlates closely with economic development, despite the fact that passenger transport volumes grow more slowly than the economy. However, GDP growth might still lead to higher demand for long-distance transport (leisure) and increased short-distance trips by car due to higher rates of car ownership in the new member states.

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\(^{16}\) See Sessa et al. (2010).

\(^{17}\) See Sessa et al. (2010), STOA (2010) and Petersen et al. (2009).
• Increased use and development of information and communication technologies (ICT) may lead to more (short- and long-distance) transport due to the new opportunities that new technologies offer. On the other hand, ICT can substitute transport or facilitate modal shift to public transport.

• Lifestyle changes, such as a greater concern for environmental issues, could affect transport behavior and lead to lower car-ownership rates. This could lead to a higher demand for public transport and a reduction in long-distance trips, although this is certainly not easy to predict.

### 2.2. Freight transport

In 2009, a total of 3.632 billion (metric) ton-kilometers (tkm) were produced in the EU-27, not including transport activities between the EU and the rest of the world. Road transport accounts for 47% of the total performance, followed by intra-EU maritime transport, which accounts for 37% (see Figure 2.4).

**Figure 2.4: Modal split in goods transport in the EU-27 in 2009**

![Modal split in goods transport in the EU-27 in 2009](image)

Source: Based on data from the European Commission (2011b).

Since the first White Paper on the Completion of the Internal Market in 1985, many barriers to freight transport have been removed. The simplification of border controls and the creation of a free market have led to a continuous increase in freight transport. Until 2007, i.e. before the economic crisis curtailed the demand for goods, freight transport consistently grew slightly faster than the economy (2.7% between 1995 and 2007, compared to a GDP growth of 2.5%)18, with road and air transport showing the largest increases. Freight transport is estimated to grow at a rate similar to that of the GDP (2.1%) for the period from 2000 to 2020.19

According to the International Energy Agency (IEA 2009b), truck and rail transport accounted for a combined 27% of the total energy consumed in 2006. About 90% of this can be attributed to trucks. Numerous improvements in engine and non-engine technology have led to significant fuel efficiency

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18 See CEC (2009).

19 See CEC (2010).
gains in recent years. This is most likely due to the fact that commercial drivers are usually more sensitive to fuel costs and other operating costs than private persons are. This led the EU to assume that most practicable options for fuel consumption reductions have already been implemented. However, the European Commission now considers there to be room for further improvement.\textsuperscript{20} Besides the high level of cost-awareness among commercial drivers, external factors determine the performance of the freight sector and have led to far-reaching changes in logistics chains:\textsuperscript{21}

- The globalization and liberalization of markets have led to more long-distance transport of goods, especially from the so-called emerging markets outside the EU-27; within the European Union, the eastern countries are expected to have the largest increase in freight transport.

- Just-in-time procurement practices have led to more frequent deliveries that are smaller and increasingly transported via air.

- The development of internet-based electronic businesses (e.g. e-commerce) has led to an increasing share of individuals who conduct transactions in virtual space. This might reduce the need for movement (e.g. music downloads), but might also increase the proportion of smaller goods that need to be delivered.

- The development of ICT has led to savings in terms of reliability and travel time.

- Events and developments such as 9/11, the war on terrorism and piracy represent potential hindrances to the flow of goods.

- Concerns about the environment and energy are increasingly gaining importance for shippers as well as for consumers.

These changes have affected transport logistics chains in recent years and have led to several challenges in the freight transport sector. One pressing challenge facing the freight transport sector is the need to increase its load factors. Load factors are an essential component of efficient vehicle utilization, and a better exploitation can lead to significant efficiency gains. No comparable and current data are available for the EU-27, but the data from various member states indicates that load factors are still insufficient. In 2000, occupancy rates in freight transport varied from 47\% in Denmark to 63\% in the UK, not including empty trips. On average, around 30\% of total truck vehicle-kilometers in 2000 were empty runs, though there are large country-specific differences.\textsuperscript{22} Even though high load factors increase the total weight of a vehicle, increased load factors are still preferable in terms of increasing overall efficiency. According to the EEA (2000), a fully loaded truck (with about 40 metric tons) uses around one eighth of the fuel per tkm used by a light delivery truck carrying 200 kg.

Another challenge facing the freight transport sector is the need to improve its logistic performance in order to increase the market share of rail and maritime freight transport. According to Giannopoulos (2004), the demand for intermodal freight services has leveled out at about 5-7\% of total tonnage. In the long run, rail freight and maritime freight transport are expected to gain in importance, since increases in external trade will tend to be concentrated among fewer centers, which will thus increase

\textsuperscript{20} See IEA (2010b).

\textsuperscript{21} See Sessa et al. (2010), Crainic et al. (2009) and Banister et al. (2004).

\textsuperscript{22} See EEA (2000).
the likeliness of reliance on rail and maritime transport. Technology-led solutions, in particular ICT, are playing an important role in enabling modal shift in the freight transport sector, but organizational innovations are also very important.

23 See Sessa et al. (2010).
3. Fuels and propulsion technologies

Research into alternatives to oil-based ICEs has a long history, which has featured many controversies. There is a broad range of rather diverse approaches that could contribute to eco-efficiency under various aspects. The most relevant approaches have been the subject of different STOA projects. In the following, a brief overview is given. The main focus is to be on the controversies related to technical feasibility as well as to the assessment of impacts on eco-efficiency. The different assessments of stakeholders and experts will be explicitly addressed.

It will become obvious that energy consumption in the transport sector cannot be discussed in an isolated manner. The transport system and the energy system are merging. All alternatives to oil-based fuels are strongly dependent on other developments in the energy sector. Biomass can be used in stationary as well as in mobile applications; the same is true of hydrogen and, of course, also of electricity and natural gas. For hydrogen and electricity, most of the questions open to debate are not related to technologies for using them in cars; the most important controversies are related to the production of hydrogen and electricity as well as to the integration of these production pathways into the energy system. Thus, an integrated perspective on transport and the energy system is becoming highly relevant.

3.1. Battery Electric Vehicles and hybrids

Technology options

Electricity can be used as a “fuel” to directly power an electric engine. It is not only the energy carrier that is replaced in this system; the fuel tank also makes way for a battery, and the energy transformation is carried out in an electric rather than in a combustion engine. Present battery technologies are not able to provide the same energy densities as conventional fuels; this means that pure electric vehicles are currently unable to provide the same performance characteristics in terms of range and speed. One main reason for this is the much lower energy density of current batteries. Compared to the conventional liquid fuels (diesel and gasoline), with an energy density of around 12 kWh/kg, today’s batteries have — at the very best — an energy density of 200Wh/kg. Even if the combustion engine can only use a fraction of the energy contained in fuel for propulsion, one kilogram of fuel still contains twenty times more energy usable for propulsion than modern Li-ion batteries. This relatively low energy density is not expected to improve very quickly; experts assume an increase rate in storage capacity of around 5% per year.

These technical conditions lead to a series of performance and usability characteristics such as shorter range, lower maximum speed and longer time frames for charging batteries as compared to average ICE cars.

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24 See Kaiser et al. (2011).
25 See Kaiser et al. (2011).
Additionally, the high cost and weight of the battery are further obstacles to a fast market penetration by electric vehicles. As an attempt to deal with this situation, further concepts with different levels of hybridization exist (see Figure 3.1); these range from electrified assistance functions, such as automatic engine start-stop and regenerative braking, to various levels of hybrid electric propulsion and even to pure electric driving, which is realized in the battery electric vehicle (BEV).

**Figure 3.1: Overview of different hybrid types and their functionalities**

<table>
<thead>
<tr>
<th>Hybrid Main Function</th>
<th>Engine Stop/Start</th>
<th>Regenerative Braking</th>
<th>Motor Assistance</th>
<th>Electric Drive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hybrid System Type</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>Possible</td>
<td>Minimal</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Micro 14V</td>
<td>Yes</td>
<td>Minimal</td>
<td>Minimal</td>
<td>No</td>
</tr>
<tr>
<td>Mild ~42V (e.g.: BMW Active Hybrid 7)</td>
<td>Yes</td>
<td>Modest</td>
<td>Modest</td>
<td>No</td>
</tr>
<tr>
<td>Medium ~144V</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Modest</td>
</tr>
<tr>
<td>Full &gt;200V (e.g.: Toyota Prius, BMW Active Hybrid X6)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Source: replica from Karden et al. (2007).

All of the hybrid types mentioned here are primarily designed to assist gasoline engine operation. The Plug-in-Hybrid (PHEV) concept is similar to that of the Full-Hybrid, but goes one step further and generally has a stronger electric drive train and a larger sized battery, which is not only recharged by on-board processes like recuperation, but can also receive an external input of electricity through power outlets. The Range Extender Electric Vehicle (REEV) is a related option that swaps the responsibilities of combustion and electric engine; here the electric engine is solely responsible for propulsion and the combustion engine is used to convert fuel into electrical energy for the battery while in operation. This concept reduces the range limitation and the need for a large-sized battery. The Opel Ampera is a well-known current example of this technology.

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28 Offer et al. (2010) name the example of 150 kg battery weight for lithium ion cells to provide a range of 200 km.

29 See Karden et al. (2007).

30 See Kaiser et al. (2011).

31 See Heymann et al. (2011).
Challenges and controversies

One central controversy relates to the environmental benefits of BEVs (see below). The question as to whether battery technology will make progress in terms of cost, range, loading time and reliability is also critically discussed. The question has been raised: At what point will electric mobility become competitive? Do lower ranges and longer loading times fit in with most of the travel patterns of European citizens or not? Will customers get used to the specific characteristics of BEVs or do BEVs need to provide the same performance as conventional vehicles?

Another serious challenge is the availability of raw materials, in particular raw earth and lithium. Materials that contribute to lightweight construction are also crucial.

Assessment of impacts

For BEVs and all of the different hybrid types, the question of the source of their energy is a key factor in estimating their GHG emission potential. Because — in electric driving mode — the tailpipe emissions of CO2 and other greenhouse gases are zero, the comparison of electric against conventional cars has to consider emission from well to wheel (WTW). A study by Thiel et al. (2010) looks at the WTW CO2 emissions of conventional cars, PHEVs and BEVs for the years 2010, 2020 and 2030.32 The result is that even in 2010 (see Figure 3.2), the PHEV and BEV have lower CO2 emissions than the other vehicles; the BEV has the lowest emissions and maintains this position in 2020 and 2030 (see Figure 3.3).

Figure 3.2: Comparison of WTW CO2 emissions for 2010

![Figure 3.2: Comparison of WTW CO2 emissions for 2010](image)

Source: Thiel et al. (2010).

Figure 3.3: WTW CO2 comparison for 2020 and 2030

![Figure 3.3: WTW CO2 comparison for 2020 and 2030](image)

32 For the details and assumptions on future energy mix, see Thiel et al. (2010).
The authors also highlight the great variety of CO2 emissions between European countries when it comes to energy production. For example, a BEV in 2010 would have 60 g of CO2 emissions based on the EU-27 average energy mix; however, this could drop to 8 g in one country with an already high share of renewable energy sources and increase to up to 203 g CO2 emissions in another one. The figures depend on the type and weight of the car.

This dependency on the energy production site is, on the one hand, an opportunity for major improvements; on the other hand, it illustrates that the electrification of engines alone is not sufficient for reducing the CO2 emissions of the motorized individual transport sector.

In addition to the pure production of the electricity, the integration of the electric vehicles into the grid is something that ought to be looked at. Here, the electric vehicle can have two main functions. The first is its role as a user of electricity, with the amount and timing of its charging being managed to help the electric utility industry to integrate fluctuating energy sources better into the grid. Electric vehicles could also serve the function of storing electric energy at times when much energy is available and feeding electricity back into the grid at times when the electricity demand is high. This concept of the interaction between the vehicle and the electric grid is called vehicle-to-grid (V2G). In order to fulfill these V2G functions, a vehicle must have a power connection to the electric grid, a control device allowing the grid operator to access the battery and a device for tracking the energy flow on board the vehicle.

Further issues that should be mentioned in the context of eco-efficiency and electric vehicles are the production, use and recycling of the metal products used for the battery and other components that could have a potentially harmful impact on the environment. Unfortunately, environmental impact assessments or life cycle assessments (LCA) for electric vehicles are at an early stage. One study from the Swiss Federal Laboratories for Materials Science and Technology (Empa) has ventured an attempt and compares a conventional gasoline car (Euro 5 standard, 5.2 l/100 km) with an electric vehicle (VW Golf size, 200 km range, battery capacity 0.114 kWh/kg) using four different impact assessment methods. Because the aim of this study was to determine the potential contribution of Li-ion...
batteries to the overall burden of mobility, the modeling in the pre-life and end-of-life stages was done in such a way that it resulted in the highest possible environmental burden for the battery (e.g. all burdens were allocated to the first-life use of the vehicle, no recycling or other uses were considered).

**Figure 3.4:** Comparison of shares of total environmental impact of an ICE car and a BEV. The impact assessment methods used were: abiotic depletion potential (ADP), nonrenewable cumulated energy demand (CED), global warming potential (GWP) and Ecoindicator 99 H/A (EI99 H/A). The share “Road” includes construction, maintenance and end-of-life treatment (EOL); “Glider” includes chassis, car body parts, wheels, interiors, safety devices, acclimatization devices.

Empa’s assessment shows that the environmental impact of both BEVs and ICEs is dominated by the operation phase (see Figure3.4). The environmental burden of the ICE is higher in all four assessments, and the share of the Li-ion battery on the overall environmental impact of the BEV is only between 7% (CED) and 15% (EI99 H/A).

**Prospects/tendencies**

The current trend among electric cars is not only to wait for further battery improvements and to hope for cost reductions, but also to find niches for electric cars: where their capabilities in terms of range are already sufficient, or where other attributes such as low noise level or zero tailpipe emissions make them attractive. One of these sectors is the delivery service sector, and the Deutsche Post, together with industry and research partners, just announced the development of a future electric car specially designed for their postal and parcel delivery.\(^{36}\)

Another tendency seems to be to look into smaller and compacter forms for shorter distances, as demonstrated by concepts like the VW Nils and Audi’s “Urban Concept” (see Figure 3.5).

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\(^{36}\) Deutsche Post and streetscooter (2011).
Selected stakeholder statements

The following list of quotations illustrates the variety of opinions and perspectives related to the use of BEVs in the transport sector:

**ACEA (2010)** – European vehicle makers welcome policy coordination around e-mobility: “EU vehicle manufacturers are world-wide technology leaders in fuel efficiency and safety and they are determined to retain that position. The industry is transforming its product portfolio to include a broad range of electrically chargeable cars, trucks and buses, including plug-in hybrid, extended range electric (including fuel cells) and battery electric vehicles.”

**Zetsche (2010)** – The Future of Electric Cars. The Automotive Industry Perspective. Speech: “… And electric cars are not the ‘silver bullet’ solution that some people might be waiting for. That said, we are now at a point where electric propulsion is finally becoming a viable alternative: As oil gets more expensive, the alternatives become more attractive. And customer awareness for ‘green’ vehicles has never been higher than today.”

**Kendall (2008)** – Plugged In - Summary Report, p.6: “Grid-connected vehicles – enabling all or part of every journey to be powered by electricity taken from the grid – are a ready-to-use solution to such challenges based on existing infrastructure and current technology. Battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) can dramatically reduce the oil dependency of automotive transport in an efficient and sustainable manner.”

**T&E (2011)** – Are electrics really more climate-friendly than other cars?: “… The study by the Ricardo automotive consultancy shows that electric and hybrid cars generate more carbon emissions in their manufacture than traditional cars, but when total lifetime emissions are taken into account they have fewer overall carbon emissions. For example, 46% of a battery electric vehicle’s lifetime emissions are caused in the factory before it has driven a single kilometre, but it will only generate around 18 tonnes of CO2 during its life, compared with around 24 tonnes for the average petrol/diesel car.”

**LowCVP (2010)** – Position “Electric and plug-in hybrid vehicles can make an important contribution to reducing road transport GHG-emissions - but will require significant initial incentives to encourage their adoption.”
3.2. **Hydrogen and fuel cells**

Until only a few years ago, many experts considered a combination of hydrogen and fuel cells to be the most promising option for the future of car-based transport. In the meantime, BEVs are seen as a favorite by many observers and have become an important issue in public debate and research funding activities. It is still uncertain whether or not this situation will change again; thus, it is not yet clear which of the two will be dominant in the future — hydrogen, batteries or a combination of both.

**Technology options**

Hydrogen can be burned directly in an ICE or it can be used in a fuel cell to generate electric power, which is then used in an electric engine. Because of its low efficiency and the problems involved in storing the needed amounts of hydrogen on board, direct burning is not considered an interesting option by most experts. In the meantime, the use of hydrogen in a fuel cell has become feasible. In field trials over the last decade, hydrogen was usually stored on board in gaseous form at 300 or 700 bar. Some experiments with liquefied H2 were done to reduce the volume. However, the need to cool hydrogen down to -253 °C in order to keep it liquefied made this route less attractive. Another promising option seems to be provided by the metal hydrides, which offer an interesting hydrogen-storage capacity: They absorb the hydrogen molecules like a sponge.

Daimler just started a field trial with 200 B-Class vehicles featuring fuel cells and gaseous hydrogen storage. Ranges are supposed to be around 400 km, reloading is to take only a few minutes. It has been announced that the vehicles are to be made commercially available in 2015. The main obstacles to a fast market penetration seem to be a lack of infrastructure as well as the price for the vehicle, which needs to be competitive with hybrid vehicles.

Apart from the production costs and some technical difficulties, the central question — in particular in terms of eco-efficiency — is how the hydrogen is produced. Hydrogen does not lead to any tail-pipe emissions at the vehicle itself. However, the production of hydrogen can lead to impacts in terms of eco-efficiency.

Different routes for the generation of H2 exist. One important route is the production of electricity via electrolysis. The hydrogen produced is as clean as the power mix that is used for the process. If photovoltaic or wind power is used, the production is fairly clean. If the power generation is based on fossil fuels, such as coal, natural gas or oil, considerable CO2 emissions will result. An inexpensive and mature method of producing hydrogen is the steam reforming of natural gas. Large-scale production is feasible. If applied in combination with Carbon Capture and Storage (CCS; which has so far only been used in pilots), natural gas could become a relatively clean route for producing hydrogen. If a larger amount of hydrogen proves to be needed in the near future, it is likely that the natural gas route will play an important role (but without CCS, since this is not expected to become applicable before 2020-2040).

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37 See Bakker et al. (2011).

38 Water vapor does not have negative effects on eco-efficiency in road transport. However, if used in aviation (which would be linked with various technical and security challenges), it is assumed that water vapor could contribute significantly to global warming (see Sausen et al. 2005).


40 See Rösch et al. (2009).
Another option — also for the middle-long term — could be the use of biogas as a feedstock. The additional conversion steps would lead to a worsening of the energy and GHG balance. Additionally, coal could be used, which is attractive if local feedstock is available (European coal). However, the overall efficiency of this route is not good when compared to the direct use of coal in the production of energy and heat. JRC et al. stipulate that for hydrogen as a transportation fuel virtually all GHG emissions occur during the production process, making it particularly attractive for CCS.\(^41\) On the other hand, CCS would further reduce the overall efficiency. Furthermore, the production of hydrogen via electrolysis powered by nuclear energy is being discussed as an option. This could be done in a relatively clean and efficient way in off-peak hours at night.

Mainly Proton Exchange Membrane Fuel Cells are used in the transport sector. They offer an adequate operating temperature, a high power density and a solid electrolyte. An alternative could be the Direct Methanol Fuel Cell (DMFC). The potential advantage is that it allows the direct use of methanol instead of hydrogen as a fuel. For an assessment, the production routes of hydrogen and methanol and their strategic fit within the energy system would have to be compared carefully. For the transport sector, the performance of the DMFC would have to be further improved.

**Challenges and controversies**

The main controversies relate to the energy balance of hydrogen — and are thus strongly related to the eco-efficiency of this technological approach. For the electrolysis route, the conversion of electric energy into chemical energy (H\(_2\)) and then again into electrical energy leads to considerable losses.\(^42\) Therefore it is argued that it makes more sense to use electricity (or natural gas) directly in the car. On the other hand, a crucial challenge for fluctuating renewable energies such as photovoltaic and wind power is that the electric energy can hardly be stored. Power is only available if the sun is shining or the wind is blowing. The use of hydrogen, even if the conversion leads to losses, could balance mismatches between energy demand and energy supply by offering a way of storing electric power. Furthermore, it is questioned whether or not the large-scale production of hydrogen from wind and sun can be made commercially available. A crucial benefit of hydrogen is the high flexibility in usable feedstock (which is true for electricity as well). The controversy about the nuclear power route is related to the risks of nuclear power, including the unsolved problems related to radioactive waste.

Furthermore, hydrogen already offers much longer ranges and shorter loading times than BEVs.

Another issue in the discussion about hydrogen is the need for building a new infrastructure for transport and storage, which is technically feasible but would require considerable investments. Different concepts are conceivable, for example a more centralized generation close to the energy sources or a decentralized generation closer to the consumers.

Regarding transport modes, hydrogen and fuel cells are mainly discussed for the road sector, particularly for cars. For trucking, it could be an alternative, but the required storage capacities make it scarcely competitive with conventional fuels. Similar arguments apply to the air sector. In addition, the tough safety standards on aviation could be a barrier to the implementation of hydrogen.

**Assessment of impacts**

\(^{41}\) See JRC et al. (2007), p. 6.

\(^{42}\) See, for example, Bossel (2006).
As mentioned above, the eco-efficiency of hydrogen and fuel cells in the transport sector mainly depends on the production process of the hydrogen. In the short term, natural gas is the only viable and the cheapest source of large-scale hydrogen production. WTW GHG emissions savings can only be achieved if hydrogen is used in fuel cell vehicles, albeit at high costs. The Joint Research Centre (JRC) further points out that electrolysis using EU-mix electricity results in higher GHG emissions than producing hydrogen directly from natural gas, whereas hydrogen from non-fossil sources (biomass, wind, nuclear) offers low overall GHG emissions (ibid.). A study by a German organization with positive attitudes towards hydrogen illustrated that the energy demand of the EU-25 transport sector could be covered by hydrogen produced from renewable power.

The Daimler hydrogen- and fuel-cell-powered Daimler B-Class, which is announced for commercialization in 2015, will use an amount of hydrogen that is comparable to 3.3 liters of diesel/100 km. Akkermans et al. estimate that, for the year 2050, the relative CO2 reduction potential for hydrogen from coal and gas is around 40% (or 57% if CCS is applied), and that of hydrogen produced from water electrolysis is around 65%.

Prospects/tendencies

About ten years ago, in his book on the “hydrogen economy”, Jeremy Rifkins framed hydrogen as the “next great economic revolution”. One key element of his vision is that hydrogen will replace oil as the primary energy carrier. Even if one does not follow his far-reaching vision, the book clearly illustrates that the integration of H2 production into the energy system could become a crucial factor for its use in transport. Thus, the further development of hydrogen surely depends not only on technical progress (also in batteries) and the development of the automotive sector, but also on the future design of the European energy system.

Figure 3.6 Application map for various electric vehicle technologies

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46 See Akkermans et al. (2011).
47 See Rifkins (2002)
Recently, the often apparent dichotomy between hydrogen and battery electric was replaced by the notion of coexistence in the rhetoric of many experts and stakeholders. A good example is offered by a recent announcement of the European Regions and Municipalities Partnership for Hydrogen and Fuel Cells (HyRaMP), which refers to “fuel cell electric vehicles”. Other experts share this view.

**Selected stakeholder statements**

The following list of quotations illustrates the variety of opinions and perspectives related to the use of hydrogen and fuel cells in the transport sector:


“The study which presents a portfolio of power-trains - battery electric vehicles (BEV), plug-in hybrids and fuel cell electric vehicles (FCEV) - highlights the complementary nature of these technologies, with each providing a solution for different environments and driving behaviours.

Although internal combustion engines still have the potential to reduce emissions by a further 30%, only electric drive cars can dramatically reduce CO2 and improve local emissions. FCEVs appear to be the lowest-carbon solution for long distance driving and family-size cars. With more than 500 fuel cell cars of all sizes covering more than 15 million kilometres and 90,000 refuellings over the past few years, car manufacturers have signalled their readiness to move into large-scale production of FCEVs.

Since a full portfolio of power-trains is required to meet the needs of consumers, the environment and several refuelling infrastructures to ensure the long-term sustainability of personal mobility in Europe, are needed.”

(FCH JU 2010 – FCH JU welcomes a fact-based analysis on a portfolio of power-trains for Europe)

Headline: Expanding and strengthening the carbon accounting of renewables in transport.

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49 See Eberle & von Helmolt (2010), Figure 3.6.
“Based on current data, it is likely that the most cost-effective hydrogen production method will remain Steam Methane Reforming (SMR) from natural gas until at least 2020. Therefore using methane from renewable feedstocks to displace some of this natural gas could be a likely pathway to introduce renewables in hydrogen production.”

“… Until 2020 it is also unlikely that the penetration rate of renewable electricity production on the grid will make it cost- and energy-efficient to use hydrogen electrolysis as an energy buffer for intermittent power generation.”

(T&E 2011 – Expanding and strengthening the carbon accounting of renewables in transport)

Headline: Cars should plug-in to a new future.

“Oil companies continue to promote a vision of an automotive future based around hydrogen and fuel cells. […] However, based on the information available to us today, the hydrogen pathway makes little sense either energetically or economically. Assuming that in the future all of our energy services will be derived from sustainable renewable sources, the hydrogen / fuel cell solution suffers bi-directional efficiency losses as hydrogen must first be manufactured from electricity and then recombined to create electricity within the fuel cell. As a carrier of sustainable renewable energy, electricity can be three times more efficient than hydrogen. Furthermore, an entirely new parallel infrastructure will need to be developed before hydrogen powered vehicles can make any impression on the automotive market.”

(Kendall 2008 – Plugged In - Summary Report, p. 7)

Headline: Positions.

“Renewable hydrogen, used in combination with fuel-cells offers a promising long-term solution for low carbon transport and should be supported within a portfolio of promising solutions.”

(LowCVP 2010 – Positions)

3.3. Biofuels

Technology options

The term biofuels encompasses a broad range of rather different technologies, which all have in common that they use biomass as a basis for the production of fuels (see STOA 2007). Diesel as well as gasoline can be produced from biomass. In Europe, blends are usually used; examples include E10 (10% bioethanol, 90% conventional gasoline) or B5 (5% biodiesel). Current vehicles are already E10 (for the model years 2005 and upwards) and B7 compatible. Compatibility with higher biofuel blends has yet to be proven. However, so-called flexible fuel vehicles for higher blends have been commercialized. For example, E85 is widespread not only in Brazil, where sugar cane can be used as feedstock, but is also available in Sweden and the USA. One of the most striking advantages of biofuels is that existing infrastructures can be used, even if some adjustments may be necessary. Biofuels can be used in conventional ICEs; thus, the established vehicle concepts do not have to be changed.
An important distinction is made in relation to the feedstock and processing: First generation biofuels, mainly biodiesel and bioethanol, are already established, at least in some national markets. They have in common that only certain parts of the plants, generally the fruit, are used for their production. A typical example is biodiesel produced from rapeseed or from palm oil. Bioethanol uses different feedstocks, such as corn or sugar cane.

Second generation biofuels make use of more parts of the plants than only the fruits. They are still the object of extensive research and development efforts. These fuels are produced by synthesis, in most cases from synthesis gas, which is then treated in a so-called “biomass-to-liquid” process (BTL). One decisive benefit of these routes is the ability to define the properties of the fuels by setting the synthesis parameters. In this way, engine and fuel can be very well adjusted to each other. This results in increased efficiency and reduced emissions, which explains engine developers’ great interest in these “synfuels” or “designer fuels”.

Challenges and controversies

There are several serious controversies: Firstly, the large-scale application of second generation fuels needs to be established, and it is not clear how much time and money will need to be invested. For example, further technological progress is needed to make use of lingo-cellulose as a feedstock. It is also still not fully clear that liquid fuels are the most promising path; the production of biomethane might be another option.

The most important controversies, however, are related to the ecological footprint of biofuels and to the competition with food production and natural conversion.

Some recently published statements highlight the controversy (for example, Neslen 2011)\(^50\) surrounding biofuels’ potential to significantly reduce GHG and, thus, to support reaching the target of 10% of transport fuels being produced from renewable sources by 2020. There are disagreements between scientists, the European Commission and some stakeholders. Recently, several NGOs, such as Oxfam and the Transport and Environment European Environmental Bureau, wrote a letter to the President of the European Commission, José Manuel Barroso.\(^51\) The letter quotes five studies. The authors fear that the mass production of biofuels may have a significant impact on Indirect Land Use Change (ILUC). Furthermore, land-use conflicts between food and fuel crops may lead to social tensions in affected areas. In addition, scientists argue that the method used to identify CO2 emissions may be inaccurate.

Assessment of impacts

Biofuels are seen as an alternative to oil-based fuels. They are supported by politicians because of their environmental benefits, primarily the reduction in GHG emissions. The energy efficiency itself is not necessarily improved. The cultivation of feedstock leads to changes in land use and can have far-reaching effects, which are relevant in terms of eco-efficiency. The environmental benefits are debated particularly controversially in cases where forest is turned into arable land. Biodiversity might be reduced, which is problematic in areas where biodiversity is already weak. The use of fertilizer also

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\(^{50}\) Neslen (2011): Brussels slammed for bad science on biofuels, EU in fresh row over biofuels ‘green’ claims and Top scientists condemn EU land use values for biofuels.

\(^{51}\) EEB 2011 – Letter European Commission, ILUC biofuels.
induces N₂O emissions, which contribute to the greenhouse effect. The magnitude of this contribution is not yet fully known.⁵²

Because of the challenges mentioned above, it is hard to identify reliable assessment criteria for biofuels’ contribution to eco-efficiency. For example, the TransPoRD Study concludes that it is not possible to determine the theoretical GHG abatement potential of biofuels.⁵³ The authors argue that biofuels compete for resources at various levels; these include competition with food and fodder for the available land area, but also with natural conversion. The latter is crucial for the general eco-efficiency of the transport sector. “The land area that can eventually be used for biofuel feedstock production hence depends on further trends in food and changes in the diet, assumptions on the stringency of future and current nature protection rules, farming practices (and related yields), and eventually on the price paid for the biofuel feedstock compared to other commodities”.⁵⁴

The question as to whether the available European biomass should be used in transport or in stationary energy production, as a base-load-compatible energy carrier, can only be answered by applying an integrative view of the energy and transport systems. This would go beyond the scope of this report. However, it can be argued that because the GHG emissions in the transport sector are growing more than those in other sectors, all options should be taken into account when it comes to increasing eco-efficiency in the transport sector. Some symptomatic figures can be found in the literature:

- The JEC Biofuels Programme has investigated the potential of biofuels and other alternative energy sources to achieve the 10% renewable energy target for the EU transport sector by 2020, as mandated by the Renewable Energy Directive.⁵⁵,⁵⁶ With the help of scenarios, the authors show that this target can be reached. However, they also show that none of the scenarios in question achieve the minimum 6% GHG reduction target mandated in the Fuel Quality Directive.⁵⁷

- An IEA (2010; quoted in Schade et al. 2011) review on the global bioenergy potential concludes that 10% of the global forestry and agricultural residues would be sufficient to produce some 4.2–6.0% of the current global transport demand for second generation fuels.

- According to an estimate by UNEP (2010; quoted in Schade et al. 2011), 118-508 Mha of arable land would be required to provide 10% of the global transport fuels in the form of biofuels by 2030. This would correspond to 8-36% of current world cropland.

- McKinsey (2009) calculates that globally, by 2030, 380 Mt CO₂ could be avoided at relatively low costs through a 25% blend of biofuels in the gasoline supply of road transport as well as an increase in biodiesel.

**Prospects/tendencies**

⁵² See Crutzen et al. (2008).
⁵³ See Akkermans et al. (2011).
⁵⁶ See JRC et al. (2011).
Much remains unclear regarding the prospects of biofuels in the transport sector. It seems clear that biomass will be an important energy carrier in the future; however, it remains uncertain whether the potential of biomass will be used in transport, for power generation or rather for material use. Biomass may be needed for the production of power since it offers a carbon-neutral approach for producing base load, and it could be combined with CCS. Technological progress can be expected and will probably increase the flexibility of biomass’s use in various forms. This might be needed in the future if stronger environmental standards are applied to the production of biofuels.

One approach that is considered promising is the bio-refinery. The idea is that different products can be produced from a variety of feedstock.\(^{58}\) Ideally, one complex facility would thus be able to produce not only different kinds of fuels in addition to heat and electricity, but also materials or food.\(^{59}\)

It is likely that the growing world population and the rising standard of living in emerging countries will increase the need for arable land and lead to strong competition between the production of biofuels and the production of food. An important route to circumvent the competition for arable land could be the production of biofuels on the basis of algae. Algae can be cultivated in specific reactors.\(^{60}\) These are very flexible in terms of location and could be installed on wasteland that is not suitable for agriculture. This technological strand offers a promising perspective in terms of eco-efficiency, but is far from being mature. For algae, but also for other feedstock, it is conceivable (and critically discussed) that the plants could be biotechnically optimized for the production of biomass. Furthermore, there is the concept of an artificial photosynthesis, which could offer completely new options. However, this approach is still in a state of basic research.

**Selected stakeholder statements**

The following list of quotations illustrates the variety of opinions and perspectives related to the use of biomass in the transport sector:

The Spokesman for Transport and Environment, Nusa Urbanici noticed that: "If you really want sustainable biofuels, you should look to move bioenergy crops away from prime agricultural land into unused degraded land that is not so fertile …"\(^{61}\)

ACEA 2008 – biofuel statement: “Biofuels are foreseen to be a necessary part of the EU’s renewable energy strategy that is presently being debated in Brussels as a means to reduce CO2 emissions and ease concerns on security of supply.”

Robbie Blake, the biofuels spokesman for Friends of the Earth told EurActiv: "All of the scientific reports are showing that the carbon benefits of biofuels as well as bioenergy are increasingly doubtful. It seems to me that these eminent groups of scientists can’t be ignored so easily and we should take note of what they are saying, particularly in its uncensored form."\(^{62}\)

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\(^{58}\) E.g. straw, wood, sugar, crops etc.; see Jörissen et al. (2010).

\(^{59}\) See Schade et al. (2011), p. 245.

\(^{60}\) See Rösch et al. (2009).

\(^{61}\) Neslen 2011 – EU in fresh row over biofuels’ green’ claims.

\(^{62}\) Ibid.
The debate about E10 in Germany

The ongoing controversy about biofuels and ILCU has involved scientists, the European Commission and several other stakeholders. It focuses on different aspects. For example, there is a heated debate about end-user reactions during and after the introduction of E10 in Germany last spring.

The German government attempted to implement the EU Biofuel Directive (10 percent of EU-wide fuels produced by renewable energy sources by 2020) by law. It ruled that oil companies should offer E10—blended with 10% bioethanol — at a lower price than conventional fuel (98 octane). For several years, there has been a standard blend containing 5 percent bioethanol. The lower price is intended to encourage German consumers to accept the new fuel. In practice, this goal has not been achieved, and E10 has become a kind of shelfware.

Obviously, the fear that E10 fuel could damage the engines of cars overrode the economic advantage for end users. It is argued that the failed introduction of E10 fuel derived from a divergence of interests. In this case, car manufacturers, the petroleum industry and German policy makers were blamed for not cooperating closely enough. Instead of improving public relations, e.g. by a cooperative press campaign, participants published contradictory positions. It became difficult for the public to understand the advantages and disadvantages of the E10 fuel. This lack in transparency was increased by a controversy that questioned the environmental benefit of E10. The E10 controversy has proven the importance of controversial public discourses being underpinned by scientific evidence. This process should include all significant stakeholders before any measure is taken.

3.4. Methanol

Technology options

Methanol is the simplest alcohol; it is a light, flammable and toxic liquid. It is one of the safest fuels, because it is much less flammable than gasoline. A disadvantage is the fact that methanol is toxic. Another problem is its corrosivity to some metals. Methanol is playing an important role in the chemical industry. The largest use of methanol by far is in making other chemicals. About 40% of methanol is converted to formaldehyde. There is profound experience in handling and storing of methanol.

Methanol is discussed and tested as a transport fuel for longer times, since it offers a range of advantages compared to conventional fuels. It can be produced from a wide range of feedstock. Typical routes are the production via CNG or from biomass. Other options are imaginable, such as the generation of methanol from hydrogen and carbon dioxide, with a relative unfavourable overall energy balance, but with the advantage of producing a clean fuel and, at the same time, enabling a
sort of CO$_2$-recycling. Olah is a prominent supporter of this idea of a carbon-cycle based on methanol.\textsuperscript{63} The different conversion steps go at the expense of the energy balance. But of these pathways argue that surplus energy for example for wind power in off-peak hours could be used. In Iceland, Carbon Recycling International is building a plant utilizing CO$_2$ flue gas and electricity from a geothermal power plant to make renewable methanol for vehicles and trucks on the island nation.\textsuperscript{64}

The burning of methanol in conventional engines only requires small modifications. It can be used in blends together with conventional gasoline or in its pure form. Extensive field trials were made in California the 1980’ies and 1990’ies, but were than abandoned because of several reasons, amongst them the low prices of conventional fuels. Methanol can as well be used in fuel cells. The option to use a Direct Methanol Fuels cell (DMFC) was mentioned in the hydrogen chapter. A different concept is using methanol for on-board energy storage only. An on-board reformer is then producing hydrogen for the methanol. The hydrogen is used in a Proton Exchange Membrane Fuel Cells (PEMFC).

Further, there is the option to use methanol via Dimethyl ether (DME). It is the simplest of all ethers. Its heating characteristics are similar to those of natural gas. Currently, DME is produced mainly from natural gas-derived methanol. DME can also be manufactured from methanol derived from coal or biomass; the production is similar to that of methanol and can be based on a broad variety of pathways. DME can be liquefied by low pressure and then used in diesel engines. Storage and distribution would be quite similar to that of LPG. As a fuel for compressed ignition engines it has very attractive characteristics such as clean burning and producing virtually no particulates. “DME can be produced from natural gas or biomass with better energy and GHG results than other GTL or BTL fuels. DME being the sole product, the yield of fuel for use for Diesel engines is high.”\textsuperscript{65}

**Controversies**

Controversies are related to the safety in usage and to the toxicity of Methanol. If methanol is generated from biomass, controversies similar to those described in the biomass pathways emerge. The hydrogen/CO2 pathways is critically discussed in terms of energy balance and economic feasibility.

**Assessments of impacts**

It is difficult to assess the exact potentials of the Methanol routes in quantitative terms. GHG emissions strongly depend on the feedstock, the energy balance can differ considerably.

**Prospects**

It was mentioned in the section on hydrogen that, in 2003, Jeremy Rifkin envisioned the hydrogen age in his book on the hydrogen economy. In a similar way, in 2006, George Olah argued for methanol in his book called “Beyond Oil and Gas: The Methanol Economy”. As for other alternative to fossil fuels, the future role of methanol strongly depends on developments in the energy system. Methanol is extremely flexible in terms of feedstock, but so are hydrogen, electricity or methane. The striking advantage is that is allows for energy storage in liquid form. It offers an easily manageable form of

\textsuperscript{63} See Olah (2010).

\textsuperscript{64} http://www.methanol.org/Energy/Resources/Alternative-Fuel/Methanol-Flexible-Fuel-Vehicles.aspx

storage with relatively high energy density per volume and per weight. Key questions are whether there will be a need to store large amounts of energy in form of Methanol and whether there will be strong demand for liquid fuels in the future?

### 3.5. CNG and LPG

#### Technology options

The central difference between Natural Gas and Liquefied Petroleum Gas (LPG) is that Natural Gas can be found in nature or gained through the production of biogas or bio-methane whereas LPG is an artificial by-product from refining processes or can be extracted from natural gas. LPG, also called Autogas, is a mixture of butane, propane and low amounts of other gases and commonly fuels Otto ICES. It is important to note that LPG, propane and butane are “automatically” generated during the extraction of natural gas and the processing of methane. So, there is some flexibility in terms of feedstock.

Natural gas is a gaseous fossil fuel consisting primarily of methane (CH4). It nearly needs no processing for the use in automobiles which is a decisive advantage in terms of feasibility. Since the energy density of natural gas is low compared to diesel, the fuel has to be stored in compressed form as so called Compressed Natural Gas (CNG) or liquefied (LNG) at a very low temperature of -161°C. Accordingly, LNG offers a higher energy density than CNG, but CNG is much easier to handle. CNG can be transported in pipelines over long distances; the transport of LNG in specialised “reefer” vessels becomes more and more common but is comparatively costly. In terms of security the storage of both CNG and LPG is not dangerous.

Autogas can be compressed to a liquid at very low pressures too. In this form it is used in conventional spark-ignition engines with only small alterations.

The advantages of Natural Gas as a fuel are the comparatively clean burning process and the low carbon content which allows for significant reductions of particulate matters, NOx and CO emissions.

Natural Gas vehicles were introduced in the mid 1930s in Italy and the technology was spreading from there to other countries, especially Argentina, Brazil and Pakistan. The technology is not only used by passenger vehicles but also for trucks and urban buses.

#### Controversies

There is a lack in CNG filling stations in most European countries. Together with the limited range of pure CNG cars, this can be a hurdle for commercialisation. However, bivalent cars are also on the market. They usually have a small gasoline tank that can be used by moving a switcher when the gas tank is empty.

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66 Kumar et al. (2011).
67 See STOA (2007).
68 See Yeh (2007).
69 Currently around 3000 NGV stations and over 33000 LPG refueling stations in the EU Palmer et al., (2010)
Both, CNG and LPG are fossil fuels, as long as they are not produced from biomass. Some observers see Natural Gas as the next dominant fossil fuel on a global scale. On the other hand, it is argued that Natural Gas and also LPG are imported to a large extent in the EU from politically sensitive regions which significantly reduce their potential contribution to Europe’s mid-term energy security. If you consider the phasing out of coal (and nuclear power in some countries), the overall demand for Natural Gas is expected to grow strongly and it’s use for transport has to compete with its application for the generation of electricity and heating.

Assessments of impacts

The use of Natural Gas along with other alternative fuels is one strategy to tackle air quality issues and GHG emissions. Regarding the potential of Natural Gas to reduce GHG emissions a study from Arteconi et al. in 2010 found for heavy-duty vehicles in Europe (EU15) that LNG-TER had a 10% GHG emission reduction potential from Well to Wheel (WTW) compared to diesel fuel.\[70\]

Figure 3.1: Total life-cycle emissions in kg CO2eq/km\textsubscript{truck} divided by well-to tank and tank-to-wheel components Arteconi et al., (2010).

They took two production pathways for LNG into consideration, a decentralized option where LNG is produced directly at the service station (small-scale liquefaction = SSL) and the LNG-TER option, where the liquefied natural gas is purchased from the regasification terminal. In all three cases (see Figure 3.1) most GHG emissions were produced in the combustion phase, the lower tailpipe emissions of the LNG-SSL were compensated by higher emissions during the production phase though due to lower efficiency.\[71\]

Another report from JRC concludes for CNG: “Today, the WTW emissions for CNG lie between gasoline and diesel, approaching diesel in the best case.\[72\] Beyond 2010, greater efficiency gains are predicted for CNG vehicles, especially with hybridisation. WTW GHG emissions become lower than

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\[70\] See Arteconi et al. (2010).

\[71\] See Arteconi et al. (2010).

those of diesel. WRW energy use remains higher than for gasoline except for hybrids for which it becomes lower than diesel.” The report further emphasises, that the origin of natural gas and the supply pathway are critical to the overall WTW energy and GHG balance. An assumption for the calculation is that the gas is transported over an average distance of 4.000 km. On this basis, Krail and Schade calculate a reduction of 54 Mt of CO₂ in 2050 by replacing conventional with CNG cars.\(^{73}\)

The JRC report points out that LPG provides a small WTW GHG emissions saving compared to gasoline and diesel (ibid).\(^ {74}\)

**Prospects:**

The JRC estimates that infrastructure and market barriers (e.g. cost, acceptance) are likely to be the main factors constraining the development of CNG.\(^ {75}\)

Other aspects seen as important are governmental support (e.g. tax shelters) and in general the higher vehicle costs.\(^ {76}\)

**Selected stakeholder statements**

“The paradigm shift from liquid to gaseous fuels will create enormous new business opportunities – initially mainly for methane-powered vehicles, but eventually also for hydrogen fuel cell vehicles” Peter Boisen, former Volvo executive and chairman of ENGV Europe; quoted in ENGV 2006.\(^ {77}\)

A current report from the European Expert Group on Future Transport Fuels EU sees no single fuel as the solution for the future mobility but a mix of several different complementary fuels.\(^ {78}\)

“Alternative fuel options for substituting oil as energy source for propulsion in transport are:

- Electricity/hydrogen, and biofuels (liquids) as the main options
- Synthetic fuels as a technology bridge from fossil to biomass based fuels
- Methane (natural gas and biomethane) as complementary fuels, in compressed gaseous form or in liquefied form as LNG
- LPG as supplement, up to possibly 10%, possibly also bio-LPG in future”

Vice President Siim Kallas sees a great potential to increase the fuel share of LPG in Europe also due to an expected increased production rate of natural gas worldwide.\(^ {79}\)

“This supply situation could allow an increase of the current fuel share of LPG in Europe, from about 3% to 10% by 2020. With around 7 million cars in greater Europe running on LPG this is a vast increase from this already significant number. Estimates of the total number could be as high as 30 million vehicles.”

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76 See Palmer et al. (2010).
77 See ENGV (2006).
78 See European Expert Group on Future Transport Fuels (2011)
79 See Autogas Network (2011).
4. Vehicles and infrastructures

In the previous chapter, the most important fuel and propulsion technologies that are discussed in the context of eco-efficiency were introduced. The main controversies and different views on their potential were highlighted. This chapter offers a brief overview of approaches more strongly related to vehicles and infrastructures across the different modes of the transport sector; the mode of maritime shipping is not dealt with because it is the subject of an extra report. This overview has been completed as part of the interim report. It is intended to serve as a basis for the process of scenario building in the next phase of the project. Some elements will be further developed later in the project.

4.1. Road transport

The road sector accounts for a huge portion of the environmental effects of the transport sector. About 93% of CO2 emissions result from road transport. Both the car fleet and trucks for freight transport are discussed intensively in terms of potential technical improvements that could reduce these environmental effects.

For the passenger sector, a wide range of approaches has been discussed for the reduction of energy consumption and GHG emissions. An overview is given in Krail and Schade (2011; see Figure 4.1).80

Figure 4.1 Technical CO2 emission saving potentials for 2020 and 2050

<table>
<thead>
<tr>
<th>Measure</th>
<th>Saving Potential in 2020</th>
<th>Saving Potential in 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Relative</td>
<td>Absolute (in Mt)</td>
</tr>
<tr>
<td>Injection Technology</td>
<td>10%</td>
<td>92</td>
</tr>
<tr>
<td>Electrical System – Energy Supply</td>
<td>10%</td>
<td>89</td>
</tr>
<tr>
<td>Heat/Cooling Management</td>
<td>10%</td>
<td>89</td>
</tr>
<tr>
<td>Lightweight Construction</td>
<td>8%</td>
<td>72</td>
</tr>
<tr>
<td>Engine Control System</td>
<td>7%</td>
<td>65</td>
</tr>
<tr>
<td>Hybrid Vehicles (new registered conventional</td>
<td>7%</td>
<td>61</td>
</tr>
</tbody>
</table>

80 See Krail & Schade (2011)
The table illustrates that, in addition to the measures related to fuels and propulsion technologies, other measures can contribute significantly to the eco-efficiency in road transport. Many of these approaches could be implemented immediately. On this basis, Krail and Schade point out that a significant reduction of CO2 emissions could be achieved without a strong proliferation of alternative fuel cars.\( ^{81} \)

Thus, quantifications are possible for certain impacts, but have to deal with a high degree of uncertainty. For example, a category such as the utilization of different lightweight materials subsumes very different materials, such as carbon fibers, aluminum and plastic elements. A detailed analysis of eco-efficiency would need to look at the entire life cycle of these materials. This is a scientific challenge; because of limited resources, it cannot be carried out in the STOA project on eco-efficient transport.

Recently, new versions of vehicles have emerged in the passenger sector. First of all, there are e-bikes, which have become extremely widespread in China and, more recently, in Europe as well. The same is true of electric scooters. In terms of eco-efficiency, it will be interesting to observe whether these e-bikes and e-scooters tend to replace old vehicles or support a shift from other modes of transport. Aside from this, the environmental friendliness of BEVs depends primarily on how their power is produced.

For the freight sector, one of the most discussed approaches is the introduction of the so-called Giga-Liners or Mega-Trucks, which are longer (25.25 m long/up to 44 t of load) than conventional trucks (18.75 m/40t; EU regulation), and thus able to carry a greater load. Supporters of the idea expect reductions in energy consumption per tkm and a reduction in trips. Nevertheless, the concept is debated controversially, since it is not clear to what extent they are suited to the existing infrastructure; they might damage the roads, for example. Furthermore, there is discussion that they will make the rail sector less competitive, which would lead to additional goods being transported on the roads. In several European countries, the concept is being tested in pilot projects, which will also show how car drivers interact with the Giga-Liners. Sweden and Finland are already exceptions to the rule and are permitted to use trucks that are up to 25.25 m long and weigh up to 60 t.

\( ^{81} \) Krail & Schade (2011).

<table>
<thead>
<tr>
<th>Category</th>
<th>%</th>
<th>2020</th>
<th>%</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerodynamics/Resistance</td>
<td>7%</td>
<td>60</td>
<td>9%</td>
<td>83</td>
</tr>
<tr>
<td>CNG/LPG</td>
<td>6%</td>
<td>54</td>
<td>8%</td>
<td>75</td>
</tr>
<tr>
<td>Battery Electric Vehicles (market penetration of 19.3 Million in 2020 and 100% in 2050 is assumed)</td>
<td>6%</td>
<td>54</td>
<td>77%</td>
<td>689</td>
</tr>
<tr>
<td>Electric System – Energy Demand</td>
<td>5%</td>
<td>47</td>
<td>7%</td>
<td>64</td>
</tr>
<tr>
<td>Drive and Transmission</td>
<td>3%</td>
<td>29</td>
<td>6%</td>
<td>50</td>
</tr>
</tbody>
</table>

Source: Krail and Schade 2011.
In urban areas, goods delivery could be an interesting opportunity for phasing in alternative modes of transport. The routes are often similar each day, so that drivers know what distance they have to travel; thus, BEVs’ limited range becomes irrelevant. In addition, the loading of the battery can take place during the night.

Regarding infrastructures, several approaches have been discussed, including:

- Improving the degree of capacity utilization of infrastructure by dynamic pricing (high prices in peak hours, low prices in off-peak hours: this could include lower prices for low-emission cars).
- Promoting higher occupancy levels in cars (which are around 1.5 persons per car; see Figure 4.2) by the introduction of high occupancy lanes. For example, the city of Leeds introduced a High Occupancy Vehicle (HOV) or ‘2 Plus’ Lane in 1999 that is available to buses, coaches and other vehicles carrying two or more people as well as to motorcycles and pedal cycles. The scheme has reduced inbound journey times for buses and other high-occupancy vehicles by four minutes during the morning peak, and it has also increased bus patronage and average car occupancy.82
- Promoting the delivery of goods at night by electric vehicles.
- New infrastructures, such as extra freight tunnels in urban areas, would be a new element in the transport system.

![Figure 4.2: Car occupancy rates in selected European countries](image)

Source: EEA.83

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4.2. Railways

The final report of the Seventh Framework Programme (FP7) report “Toska” identifies several technology options for passenger as well as for freight transport.

- Low aerodynamic drag:
- Low train mass
- Energy recovery
- Space efficiency (passenger) and heavy trains (freight)
- Eco-driving (driving advice)
- Energy efficiency (train equipment and supply systems)

In the case of a combination of the six measures, the authors assume an average reduction in GHG emissions of around 45-50% for the passenger sector and around 40-45% for the freight sector (in both cases with constant load factors and the same GHG context of electricity as in 2009).

The train sector is of particular interest in the context of the transport system’s eco-efficiency. A shift of shares in passengers and goods to trains could be seen as a means to increase the overall efficiency of the transport system. Hence, in many projections of a more sustainable transport system, the rail sector is to take goods, commuters and other shorter and longer distance travelers from the roads and, with the help of competitive high-speed networks, also take passengers from the air sector. This would require major investments in infrastructure. So, apart from systemic disadvantages (for example, no direct door-to-door transport), the limits set by the infrastructure represent a major problem for growth in the rail sector. The hinterland areas of large harbors, such as Rotterdam and Hamburg, where goods arrive that need to be carried on to various destinations throughout Europe, are subject to a growing bottleneck.

In the train sector, the further development of the infrastructure is of the utmost importance for the competitiveness of the mode. This entails:

- closing gaps in the network,
- extending the network (separate tracks for passengers and goods),
- technologies supporting intermodality.

Examples are given in the STOA project on long-distance transport. The great importance of improvements in gross border freight transport has also been dealt with in that project.

As Figure 4.3 illustrates, the train occupancy rates in European countries vary considerably. It must be considered that the rates shown in the graph do not indicate to what extent the trains are full in peak hours. However, the figure illustrates that there are unused capacities in many countries.

Figure 4.3: Train occupancy rates in selected European countries
4.3. Aviation

Regarding alternative fuels, neither hydrogen nor batteries seem to meet the requirements of the air sector for energy storage in terms of volume and weight. It has been said that using hydrogen for fueling jets would require a complete redesign of aircraft. In addition, the corresponding infrastructure would need to be built; on the other hand, the relatively centralized demand patterns could be an advantage compared to the road sector. It ought to be possible to build an infrastructure for the production and storage of hydrogen at airports. Another option is offered by fuel-cell-based auxiliary power units, which can be used for delivering on-board electricity. But for propulsion, the only feasible alternative to fossil fuels so far seems to be biokerosene. Different feedstock has been discussed, including algae, and first trials with blends have been undertaken. However, a significant share of the global jet fuel being based on biomass as feedstock seems to be a long way off. In the aviation sector, the introduction of cleaner or more efficient propulsion technologies is generally hampered by the long lifetimes of airplanes (up to 40 years); however, a switch to a certain blend of biokerosene could — theoretically — take place rather quickly.

The STOA project on long-distance transport discussed the fact that the impact of water vapor emissions on global warming is not yet really understood. However, it seems likely that water vapor contributes a very high share of the GHG balance of airplanes. Based on a publication by Sausen, the Intergovernmental Panel on Climate Change (IPCC) report considers the impact of water vapor, and to some extent NOx as well, to be probably even greater than the impact of CO2 emissions. If these results are not to be rejected, it would mean that changing to biomass or hydrogen would not have too

84 See IEA (2008).
strong of an effect in terms of global warming. Both alternatives to kerosene, i.e. hydrogen and biokerosene, also emit considerable amounts of water vapor. While the water vapor emissions of biokerosene are expected to be similar to those of conventional kerosene, there is discussion that the water vapor emissions of hydrogen are more than twice as high. Thus, there are quite a lot of limitations to the improvement of the GHG-balance through using cleaner and/or more efficient fuels and propulsion technologies in the air sector.

In another vein, it has been argued that the construction of more radical aircraft configurations, such as the so-called flying wing, have a great potential to increase efficiency. A flying wing is a tailless fixed-wing aircraft with most of the crew, payload and equipment housed inside the main wing structure. Flying wings are supposed to significantly reduce energy consumption per pkm/tkm. However, the technology is far from being mature, and airplanes are used for periods of over 40 years. It would thus take a long time before the concept of the flying wing could become effective in terms of eco-efficiency.

4.4. Shipping:

Shipping is the subject of an extra report of this project (Deliverable 2b).

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86 See Akerman(2005).
5. Intelligent Transportation Systems (ITS)

ITS means “applying Information and Communication Technologies (ICT) to transport. These applications are developed for different transport modes and for interaction between them (including interchange hubs).”\(^{87}\) ICT plays a significant role in improving and supporting transport and may also play a major role for sustainable development. Advanced logistics as well as improved traffic management and information systems can be used to:\(^{88}\)

- make public transport more efficient;
- substitute digital information flows for physical travel;
- optimize travel patterns and improve driving styles;
- increase the flexibility and quality of systems;
- enable the collection of user charges;
- optimize the energy use of travel modes;
- optimize logistics chains;
- improve traffic flows;
- promote co-modality or modal shift to less polluting modes of transport;
- reduce road fatalities;
- exploit new technologies (such as Radio-Frequency Identification [RFID], Smart Tags or advanced ICT platforms).

With all of these possible contributions in mind, ICT definitely has great potential to support sustainable development and eco-efficiency in transport. However, several authors emphasize that it could also hold the risk of becoming counterproductive to environmental sustainability. It is reasonably assumed that it might generate new transport demand (as traveling becomes easier and more enjoyable) and also increased urban sprawl (as it becomes unnecessary to live in proximity to office or shopping facilities).\(^{89}\) According to Hilty et al., ICT applications have to be implemented in a way that takes into account the interactions between the developments of ICT and their impacts on socio-economic systems.\(^{90}\)

The idea of ITS is not new. Such applications, especially in transport telematics, started being developed in the 1990s. The novelty of today’s developments is the vision to set up a globally integrated framework that aims to realize synergies between previously isolated systems (such as vehicles and infrastructure).\(^{91}\) ITS development has long been hardware driven and has thus enabled the introduction of sophisticated technologies that allow extensive data-collection and transmission. However, according to Crainic et al., it is not yet possible to transform this data into useful

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\(^{87}\) See CEC (2008).

\(^{88}\) See Huschebeck et al. (2009) as well as WWF (2006).

\(^{89}\) See, for example, Black et al. (2006); Banister et al. (2004); Hilty et al. (2004).

\(^{90}\) See Hilty et al. (2006).

\(^{91}\) See Crainic et al. (2009).
information and to properly exploit it. They conclude that one reason is that the “software component of ITS, models, decision-support systems and so on has been dramatically lagging behind that of its hardware component.” Indeed, nearly all transport modes today incorporate applied hardware-driven ICT solutions. Highly important technical systems for transport are:

- Global System for Mobile Communications (GSM) and other relevant technologies for mobile communications and positioning;
- broadband communications;
- internet services for handheld devices;
- General Packet Radio Services (GPRS);
- RFID and Near Field Communication (NFC);
- global positioning satellite technologies.

This list of technologies is definitely not exhaustive, but it gives an idea of the importance of computers, satellites and sensors. Some member states of the EU already make extensive use of these applications, though deployments remain fragmented and uncoordinated throughout the EU and beyond. To the present day, considerable inefficiencies exist. Therefore, an “Action Plan for the Deployment of Intelligent Transport Systems in Europe” has been set up by the European Commission in order to integrate the many, but still separate, ICT applications in transport.

5.1. ITS applications for freight transport

Freight transport is an area where ITS is sure to have a great impact that is relevant for the transport system as a whole. ICT plays a major role in the continuous and immediate exchange of information, in the tracking and tracing of goods, in the enabling of new concepts for production and services, in performance related to time aspects and in the determination of shipment sizes. Though, as is the case for passenger transport, ICT might increase transport distances. As outlined in the 2011 White Paper on Transport, it is the EU’s task to optimize the multimodal logistics chains of freight transport, to increase the share of resource-efficient transport modes and to find ways to consolidate large volumes for transfers over longer distances. The appropriate response to this task is often to make the capacity of transportation systems more efficient through an integrated use of ITS.

In order to increase the quality of information about relevant transport conditions, advanced ICT can provide viable efficiency-improving solutions. And indeed, freight transport today is increasingly characterized by constantly increasing “intelligence” and ubiquitous data availability.
Eco-efficient transport

- Cargo is increasingly networking with other cargo, with infrastructure elements along the way and with mobile devices in order to handle transport in an optimal way (bi-directional communication without a human interface).
- Cargo is increasingly equipped with tags that provide all necessary information across all transport modes (i.e. RFID and Smart Tags).
- Interfaces for shipment processes are widely standardized.
- Dynamic data sources and real-time information are widely accessible.

The main driver for the implementation of ITS in freight transport was identified during the freightvision project (funded by the European Commission) in its use as an instrument to increase efficiencies (including cost efficiency, efficiency of use and energy efficiency), to reduce accidents and congestion and to increase the reliability of transport chains. In order to categorize the different ITS applications for freight transport, four key areas can be subdivided:

Figure 5.1: Key areas for ITS applications in the freight sector

<table>
<thead>
<tr>
<th>Key area</th>
<th>Aim</th>
<th>Key applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Pre- and on-trip travel</td>
<td>Improve logistics chains</td>
<td>Dynamic route planning</td>
</tr>
<tr>
<td>information</td>
<td>Exchange information and data flows</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Organize freight movements</td>
<td></td>
</tr>
<tr>
<td>2. Cargo and vehicle tracking and tracing</td>
<td>Control and regulate the status of goods,</td>
<td>Radio frequency identification (RFID)</td>
</tr>
<tr>
<td>and tracing</td>
<td>loading units and vehicles</td>
<td>Online freight exchanges (OFE)</td>
</tr>
<tr>
<td></td>
<td>Optimize the performance of ports and terminals</td>
<td>European Electronic Toll Service (EETS)</td>
</tr>
<tr>
<td>3. Cooperative systems</td>
<td>Optimize the performance of vehicles</td>
<td>Automated platooning</td>
</tr>
<tr>
<td>4. Advanced urban logistics</td>
<td>Bundle unorganized deliveries</td>
<td>Urban distribution centers</td>
</tr>
<tr>
<td></td>
<td>Optimize organization of last-mile</td>
<td></td>
</tr>
</tbody>
</table>

The purpose of the following section is to give an overview of the most relevant freight ITS applications for eco-efficient transport; it is organized according to the key areas mentioned above. Certainly, more applications exist (or are currently under development) than those that can be

100 See Böhmann, et al. (2009).
illustrated in the context of this project. This list is therefore intended to serve as an overview of approaches that are seen as promising for the reduction of the ecological footprint of activities related to freight transport.

- **Pre- and on-trip travel information**

  Pre- and on-trip information informs the driver via internet — either before or during a trip — about relevant travel conditions, such as congestion, weather conditions or real-time traffic flow. It allows drivers to choose a different route or to cope with a foreseeable situation en route, and it enables forwarding agents to select a different mode of transport. In doing so, pre- and on-trip travel information might lead to less fuel consumption, fewer kilometers traveled and possibly to time savings. The impact of pre- and on-trip travel information depends on the diffusion of the technology, the number of times the data is accessed by the users and on how the information actually influences travel behavior.\(^\text{101}\) However, accurate road data for EU-wide applications is not yet available because rules for the collection of road and traffic data are lacking or incompatible in the different member states.\(^\text{102}\)

  **Dynamic route planning**

  The principle objective of dynamic route planning is to find the best possible route for each delivery job. So far, satellite-based navigation systems have fulfilled the requirements of this objective by providing distance-related route planning. Today, much more information is available and can be considered, including information on traffic and weather conditions. In this way, the system can ideally react to sudden changes of supply, for instance if new or canceled deliveries or pick-ups need to be integrated into the route. The benefits of dynamic route planning are that it can reduce the distances to be covered while, at the same time, reducing the amount of time required to complete a tour. Furthermore, it might minimize the vehicles that need to be used.\(^\text{103}\) A good example is the “SmartTruck” project that is described in DEL 2 of the STOA project on urban transport. In March 2009, DHL (a division of Deutsche Post AG) launched a three-month pilot project in Berlin, Germany, to reduce transport capacity per kilometer and simultaneously to increase the capacity load of trucks, as well as to enable rapid and reliable delivery of parcels.\(^\text{104}\) For the first time, advanced technology was combined with dynamic route planning. The “SmartTruck” uses RFID tags and readers to permanently screen the loading condition of the truck and to check whether the right parcels are on board.

- **Cargo and vehicle tracking and tracing**

  Cargo and vehicle tracking is the ability to trace goods from origin to destination. It is linked to information transfer by using technologies such as RFID.

  **RFID**

  \(^\text{101}\) See Böhmann, et al. (2009).

  \(^\text{102}\) See CEC (2011b).


  \(^\text{104}\) See Deutsche Post AG (2010).
RFID devices are low-cost tags that store and provide information or data about products and thus assist in the tracking of goods and vehicles. As such, they have much the same function as that presently served by barcodes. They are, however, far superior to barcodes, because they can also process data or communicate with other RFID tags and are simultaneously compatible with existing contactless infrastructures. RFID systems involve a reader that can use radio waves to wirelessly read and write data, in real-time, to an RFID tag. Real-time indication of processes and flow of goods is fundamental for freight transport and provides a basis for process improvement (see DEL 2 of the STOA project on Urban Transport).

**E-freight**

This approach is taken up in the integrated European project on e-freight, which is focused on the vision of paperless freight transport processes: Here, an electronic flow of information is linked to the physical flow of goods. Important elements are:

- a paperless cargo supply chain covering all transport modes and linked to the physical flow of goods;
- the replacement of a set of documents by electronic data in the process of shipping air cargo from origin to destination; this necessitates a set of standards and business processes (a “European Single Transport Document” for the carriage of goods with all legislative support);
- the need for electronic communication between forwarder, airline and ground handler at origin and destination;
- the benefits of reduced costs (because handling and processing are easier), reduced time, reduced paper volumes, increased visibility (tracking the status of freight), the development of “intelligent cargo” (goods that are self-, context- and location-aware and connected to a wide range of information services);
- the challenges of getting the entire supply chain to work together and of data-security;
- IATA’s vision of achieving 100% e-freight in all feasible trade lanes by the end of 2015 (currently at 10%).

**European Electronic Toll Service (EETS)**

The EETS incorporates:

- a system that functions throughout the EU, so that truckers can circulate without being concerned about different charging and payment systems or the need to install different equipment;
- online freight exchange;
- exchange terminals that aim to connect available loads to available trucks in order to prevent empty return journeys.

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Cooperative systems are based on the real-time transfer of information from vehicle to vehicle (V2V), vehicle to infrastructure (V2I) or infrastructure to infrastructure (I2I); they thus enable vehicles or infrastructures to communicate with each other. In this way, vehicles can function as sensors to report traffic, road and weather conditions.\textsuperscript{106}

\textit{Automated platooning}

Automated platooning (see Figure 5.2) is a technology that enables a number of vehicles to drive under precise automatic control at close spacing (1m). It thus falls within the range of applications that belong to cooperative systems, specifically the category of V2V. Automated platooning means that a number of vehicles travel together; they are electronically connected. A lead vehicle is controlled manually by a trained driver and followed by a number of vehicles that are controlled electronically. The lead vehicle gives commands to steer, brake or accelerate and the following vehicles within the platoon are driven without the intervention of a driver. By driving in platoons, vehicles can travel at high densities and with reduced aerodynamic drag; they might thus reduce fuel consumption and environmental emissions as well as relieve congestion.\textsuperscript{107}

\textbf{Figure 5.2: Automated platooning}

![Automated platooning](image)

Source: Bergenhem et al. (2010).

- Advanced urban logistics

\textit{Urban distribution centers}

The fundamental idea behind a city distribution center is to not consider every delivery, company or vehicle in isolation, but to understand them collectively as an integrated logistics system, which can be optimized through coordination and consolidation. A city distribution center is a facility where shipments are consolidated prior to distribution and then preloaded to city freighters for allocation. Urban distribution centers are organized to permit bundling and a better organization of traffic flows. It is conceivable that goods could be delivered from other destinations, stored for a while and then distributed in off-peak hours. This might include goods delivery at night, as envisioned in the Commission’s White Paper on Transport.\textsuperscript{108}

\textsuperscript{106}See CEC (2011b).

\textsuperscript{107}See Bergenhem et al. (2010) as well as Böhmann, et al. (2009).

\textsuperscript{108}CEC (2011).
In order to consider the transport system as a whole, it is necessary to consider not only technological improvements, but also the potential that a specific technology or organizational improvement has to facilitate modal shift or to reduce transport volumes (see figure 5.3)

### Figure 5.3: Technologies and strategies for improved eco-efficiency

<table>
<thead>
<tr>
<th>Dynamic route plannning</th>
<th>Increase efficiency</th>
<th>Modal shift</th>
<th>Reduce transport volumes</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFID</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automated platooning</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E-freight</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electronic road tolling</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban distribution centers</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 5.2. ITS for passenger transport

DEL 2 of the STOA project on Urban Transport described the broad range of ICT technologies that could potentially contribute to a more sustainable transport system. In the passenger sector, a better organization and management of the transport system is also expected to lead to improved traffic flows, less congestion and more efficiency through the use of less energy-consuming modes of transport.\(^{109}\)

In road transport, many of the applications for the freight sector, which were described in the previous section, would bring benefits for the passenger sector as well. Providing a better supply of information to both the commercial and the private user of transport services is a central aspect of ICT. Through user-friendly interfaces and better information about travel options, possible delays and congested networks, ICT applications help to better plan and execute a trip in an effective and comfortable way. Offering personalized information may help to reduce waiting times, encourage

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\(^{109}\) See CEC (2001); CEC (2006); Hummels (2006); STOA (2010).
multimodality, reduce travel time and develop more advanced applications for reservation services. At the same time, data can be used for establishing policies that influence the way transport is organized.\[^{110}\]

As in the freight sector, pre- and on-trip information can inform car drivers about optimal routes and thus help to reduce fuel consumption. There is certainly significant potential to improve eco-efficiency, but potential rebound effects need to be considered as well. Pre- and on-trip information as well as dynamic route planning can support an improved use of the infrastructure, which might lead to increased capacities. Many examples illustrate that increasing capacities can attract additional traffic (see Banister 2000).

V2V communication is one approach to generating on-trip information. As described in DEL 2 of the STOA project on Urban Transport (STOA 2010), intelligent cooperative systems enable vehicles to communicate wirelessly with one another (V2V) or with a roadside infrastructure (V2I). It is expected that the gathered real-time data can be used to improve traffic management and road safety.\[^{111}\] For example, it would be possible to send warnings about environmental hazards (e.g. aquaplaning on the asphalt) as well as traffic and road conditions (e.g. congestion, accidents or construction sites); it might even be possible to book a parking lot in advance.

**Figure 5.4: Internet access in Germany – youths aged 12-25 years (in %)**

<table>
<thead>
<tr>
<th>Year</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010 – 16.Shell Youth Study</td>
<td>97</td>
<td>95</td>
</tr>
<tr>
<td>2008 – 15.Shell Youth Study</td>
<td>83</td>
<td>80</td>
</tr>
<tr>
<td>2002 – 14.Shell Youth Study</td>
<td>68</td>
<td>66</td>
</tr>
</tbody>
</table>


The growing rates of internet access are certainly an important issue. Figure 5.4 illustrates that, in Germany, more than 95% of young people have access to the Internet. This means that, in principle, travel information is available online for people in this group. As Figure 5.5 shows, the average internet penetration in Europe is significantly lower. However, further growth is to be expected – also in the case of mobile access via smartphone. The latter comes close to the vision of transport information being available all the time and everywhere. This is particularly relevant for the competitiveness of public transport, since studies have indicated a close relationship between the availability of information and the use of public transport.\[^{112}\]

\[^{110}\] STOA (2010); see also Giannopoulos (2004).

\[^{111}\] See Luo et al. (2004).

\[^{112}\] See Brög (2009).
This need for information on public transport is not only related to timetables and connections, but also to convenient information about fare structures, as was found, for example, in a citizens consultation conducted during the STOA project on Urban Transport. In these interview meetings (see STOA 2011, DEL 4), young people in different European cities were asked about their transport-related views and perspectives. The fact that the fare structure of the public transport system in their own city is not easy to understand was an important issue for the young citizens, particularly in the German group.

As is pointed out in DEL 2 of the STOA project on Urban Transport, particularly young and random users consider the use of technology to be a standard of quality and experience innovation as a value in itself. A first and important step was the availability of real-time information on time schedules, as well as individualized online route planning. A further development was making it possible to print online tickets, which made purchasing tickets easy, flexible and more individual. Since then, information on time schedules has become continuously available via mobile phones, and mobile ticketing solutions have been implemented in many places. Mobile ticketing is a system where customers can obtain, buy and validate tickets from any location and at any time, using their own mobile phone. However, the fact that customers still needed reliable knowledge of valid fare systems in order to actually choose the right ticket was an unsolved disadvantage that mobile ticketing had to overcome. In other words, mobile ticketing did not provide the greatest possible support for ticket selection. New, upcoming solutions for location-based ticketing do indeed offer the possibility of buying a ticket via mobile phone, even without knowledge of valid fare systems. However, e-ticketing is actually not a new phenomenon at all; for the airline industry, it has been standard practice for a couple of years. Still, it is interesting to exploit the full potential of the approach by transferring it to other modes in the passenger sector.

Another important point is virtual mobility: this occurs when a substitution of trips is supported by ICT. Well-known examples are tele-working and video conferences. However, additional trips might also be induced in these cases, if the time gained from not traveling to work is used for other trips or if

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113 See Maertins et al. (2008).
video conferences increasingly permit work in global networks that have face-to-face meetings from time to time.

Additionally, ICT is an important enabler for innovative business models such as car sharing or bike sharing (see chapter 6).

It is difficult, if not impossible, to quantify the impacts of ICT applications on eco-efficiency in passenger transport. Nevertheless, rather simple calculations can be done in order to illustrate potential effects of single measures. A good example is offered by tele-working: If a person travels 50 km to work by car, this means a total distance of 100 km for commuting. If the car emits 140 g CO2 per km, this means that each workday causes 14 kg of CO2. Accordingly, each day of tele-working would save 14 kg of CO2. If, in one year, tele-working were substituted for 50 days of commuting, this would result in 700 kg of CO2 savings; if 100,000 people were to do exactly this, the result would be an annual savings of about 70,000 metric tons. Thus, the effect could be significant. However, it is of the utmost importance to consider rebound effects and side effects. It is possible that tele-workers would engage in other travel activities during the time saved by not traveling to work. Furthermore, tele-working would reduce transport volumes on roads, but many examples illustrate that free capacities may attract additional traffic (new trips or trips caused by a shift form public transport to road).

Similar quantifications were done by the World Wide Found for Nature (WWF; see Figure 5.6). In this case, as well, it is important to note that rebound effects might have significant impacts on the overall balance.

Figure 5.6: Emissions reductions by tele-commuting (only direct emissions considered)

<table>
<thead>
<tr>
<th></th>
<th>2005 emissions LDV MtCO2e</th>
<th>2030 baseline emissions LDV MtCO2e</th>
<th>% emissions from commuting</th>
<th>% of commuting emissions saved by individual telecommuters</th>
<th>Telecommuting take up</th>
<th>Emission reductions from telecommuting MtCO2e</th>
</tr>
</thead>
<tbody>
<tr>
<td>OECD North America</td>
<td>1,262</td>
<td>1,923</td>
<td>30%</td>
<td>75%</td>
<td>5%</td>
<td>18-110</td>
</tr>
<tr>
<td>OECD Europe</td>
<td>516</td>
<td>535</td>
<td>30%</td>
<td>75%</td>
<td>5%</td>
<td>6-36</td>
</tr>
<tr>
<td>OECD Pacific</td>
<td>219</td>
<td>219</td>
<td>30%</td>
<td>75%</td>
<td>5%</td>
<td>2.5-15</td>
</tr>
</tbody>
</table>


Finally, there is the argument that a far-reaching implementation of ITS will lead to improvements in the air sector (see STOA 2008, long-distance transport). An improvement in terms of energy consumption and GHG emissions could be achieved through better management and organization — mainly at the airports. The concept “one single European sky” aims to contribute to improvements related to management and organizational issues. The International Civil Aviation Organization (ICAO 2007, 110) supports the argument that more direct routings and the use of more efficient conditions, such as optimum altitude and speed, have a huge potential to contribute to energy savings. Shortening routes can, indeed, reduce CO2 emissions significantly.
6. Organizational innovations and concepts

Over the decades, a broad range of more or less organizational approaches have emerged that are relevant for the eco-efficiency of the transport system. The clean-shift-reduce scheme can also be applied for these approaches: Organizational innovations have the potential to improve the efficiency of mobility patterns by making them cleaner (e.g. better load factors, more efficient usage of infrastructure), helping to shift loads (e.g. by making public transport and freight rail more attractive) and helping to reduce volumes (e.g. tele-working; video conferencing). However, it is also true in the case of these approaches that it should not be oversee that they can induce traffic or rebound effects. Since most of these approaches have already been introduced in previous STOA projects, they are only mentioned very briefly in the following.

Some of these approaches were already mentioned in the chapter on ICT in this report. The different approaches are summarized here in an extra chapter to underline that improving eco-efficiency in transport is not only related to technologies, but also to issues of the organization and co-coordination of transport flows as well as to innovative business models. ICT is an important enabling technology for innovative concepts or business models that help to improve the eco-efficiency of transport. A good example is bike sharing: the system now used is in its third and fourth generation. In the course of this development, booking and identification via mobile phone have come to often play a decisive role for making the system attractive to the user. A well-known example of a successful bike sharing system is “Vélib”, in Paris, with 20,600 bikes at 1,500 docking stations.

As described in STOA DEL 2 of the Urban Transport project, fourth generation bikes are under development. Anticipated improvements over the third generation include more flexible docking stations, the use of smartcards (which can be used for other modes of transport as well, such as car sharing and public transport) and innovations in bicycle redistribution. Technological advances include GPS tracking, touch-screen kiosks and the use of electric bikes (pedelecs):

*Innovations in redistributing bikes*: Experience has shown that some stations have high demand and low supply, or vice versa. This means that staff needs to redistribute bicycles several times per day. This is time consuming, expensive and produces unnecessary emissions. Innovative programs will create stations that either encourage users to pick up or to drop off a bike using incentives such as free time, credit or even cash.

*Ease of installation*: So-called “technical platforms” are being installed: these include the bike-sharing station’s base and house the wires for its bike docks and pay station. Consequently, no asphalt or paving needs to be removed, and no subterranean installation of the structure and wires is necessary.

*Powering Stations*: Underground wiring to the nearest electrical source provides power to the stations. This renders the relocation of stations almost impossible due to cost. Solar panels remove this need.

*Tracking*: GPS will allow a better tracking of the bikes while facilitating data collection and the recovery of stolen bikes.

*Use of pedelecs*: In light of an aging society and also in areas with a challenging topography, the use of pedelecs is an interesting option. A bike-sharing fleet does not need to be composed entirely of pedelecs; rather, a percentage could be sufficient for such purposes.

Fig 6.1: Sophisticated bike-sharing and car-sharing systems are enabled by ICT
Along similar lines, it can be assumed that car sharing would not have such significant growth rates in Germany and Switzerland without sophisticated ICT applications that allow for easy booking, easy access and easy charging. Furthermore, car sharing is interesting as an organizational innovation under several aspects. Whereas the system was originally implemented by small organizations, global players have since entered the market. Carmakers such as Daimler and BMW are testing out new business models. There are at least two reasons for this tendency:

- First, consumer preferences seem to be changing. Young people, particularly those in urban areas, are losing interest in owning cars. Carmakers are thinking about new strategies to reach this group.

- Secondly, because of the predicted rise in oil prices and increasing environmental concerns, there is a growing interest in electric mobility as an alternative to oil. Because of the high price of batteries as well as relatively low ranges and long loading times, the established system of buying and owning cars might no longer be appropriate. It is conceivable that BEVs call for specific business models (e.g. car sharing, the leasing of batteries); there might be a need to change the way in which car-based mobility is practiced.

Car Sharing is getting increasingly widespread in Europe (see figure 6.2). It is a model of car rental where people generally rent cars for short periods of time, often by the hour, as an alternative to the privately owned car. The car is no longer the property of a single owner, but is owned by an organization that manages the fleet. Clients choose and book a vehicle in advance for a specific period of time; after using it, they bring it back to the initial parking lot. The fleet manager is responsible for the service organization, for maintenance (including tax and insurance), repair and fuel costs. In return, customers pay the fleet manager for the allocated service, mostly by time and mileage. Twenty-five percent of car-sharing users are from the business sector and use car sharing for business trips. More information is available in DEL 2 of the STOA project on Urban Transport.

Once again, it is difficult to quantify the effects of car sharing or bike sharing on eco-efficiency. It depends on several factors, such as patterns of use, the specific behavior of users (are they substituting cycling trips, car trips or public transport trips) and the car sharing fleet. In general, car-sharing fleets have smaller cars than the average fleets in a country, and the organizations claim to use energy-efficient vehicles. Furthermore, car sharing is seen as a good concept for introducing alternative fuels and propulsion technologies into the market, since customers would be enabled to choose specific cars

114 STOA 2011.
115 See Schippl (2010).
116 See www.carsharing.de
for specific purposes. Thus, positive effects can be expected but are hard to quantify. A study conducted in Switzerland concludes that car sharing reduces the number of cars in an area, making less space for parking necessary.\footnote{See Haefele et al. (2006).} Since users have to pay for the kilometers, they use the cars in a more careful way and try to reduce. The study further calculates that, in Switzerland, car-sharing users helped to save 4.8 million liters of fuel in 2005.

**Figure 6.2:** Car-sharing customers in European countries in 2009 (red) and 2011 (red + green)

![Bar chart showing car-sharing customers in European countries in 2009 (red) and 2011 (red + green).]

Source: Loose (2011).

It is obvious that the progress in ICT is quite often of an enabling character for such organizational approaches. Organizational measures also support the eco-efficiency of other modes of transport. In the case of passenger air transport, a better organization of traffic flows at airports is an important issue. Additionally, in the air sector, a rather efficient way of reducing energy consumption and emissions is to use slower aircraft configurations. This would mean flying at lower speeds. According to Akerman (2005, 129), this could involve an advanced turboprop aircraft cruising at 640-700 kph. The overall potential is not easy to assess because of NOx and water vapor, but the reduction of GHG emissions would probably be significantly more than 25%.

In the freight sector, organizational approaches offer interesting potentials for reducing CO2 emissions. Again, many of these measures are strongly linked to ICT applications as a kind of enabling technology. There is much discussion about making the rail sector more attractive and shifting loads from roads to rail (see STOA 2008, long-distance transport). In the STOA project on
Urban Transport, measures such as city logistics are described.\textsuperscript{118} Another promising approach is the delivery of goods at night, with relatively quiet electric engines. This could make better use of the existing infrastructure and, if accompanied by corresponding policies, could also support the market penetration of environmentally friendly fuels and propulsion technologies. One disadvantage would be that more people have to work at night. Additionally, the measure might again induce rebound effects.

\textbf{Figure 6.3: Cargo tram in Dresden, Germany}

Another example is using trams for goods transport, as is done with the freight tramcar in Dresden, Germany.\textsuperscript{119} The CarGoTram project involves a cooperation between the DVB (local cargo enterprise), Volkswagen (VW) and the local authorities (see Figure 6.3). The main key to the viability of the project is the length of the tram (60 m) and the capacity of three trucks (maximum load 60 t with a load space of 214 m$^3$). The CarGoTram runs six days per week and sixteen hours per day.\textsuperscript{120} It is used only for point-to-point transportation and is not readily transferable to different destinations. However, in recent years, different approaches have been developed by the DVB to adapt the idea of the CarGoTram to other branches. An adaption to hospital logistics, roadwork’s supply and disposal, theater logistics, extensive retail and the circular economy (waste transport) are conceivable in Dresden.\textsuperscript{121} So far, several cities have picked up the idea and have either introduced a cargo tram (Zurich, Amsterdam) or have undertaken a research project on it (Vienna).

\begin{itemize}
  \item \textsuperscript{118} See STOA (2010).
  \item \textsuperscript{119} See also STOA (2010).
  \item \textsuperscript{120} See Dresdner Verkehrsbetriebe AG (n.s.).
  \item \textsuperscript{121} Oehlmann 2007.
\end{itemize}
7. Conclusive Remarks

The report at hand gives an overview on crucial developments related to the eco-efficiency of the transport system. The main focus is on the potentials of technological and organisational innovations for supporting a transition to a more eco-efficient transport system.

The report illustrates the broad range of different options that exist to improve the eco-efficiency of the transport system. It is clear, that an improvement can only take place if something is changing in the present transport system. In principle, this is possible by making technologies cleaner, by reducing the number or the length of trips or by inducing a modal shift to more sustainable modes.

Figure 7.1: General approaches for improving the eco-efficiency of the transport system

<table>
<thead>
<tr>
<th>Focus on Technologies</th>
<th>Focus on Mobility patterns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleaner, vehicles, fuels, and Propulsion technologies</td>
<td>Modal shift</td>
</tr>
<tr>
<td></td>
<td>-Reducing number/length of Trips</td>
</tr>
</tbody>
</table>

Co-Evolution

Figure 7.2: Main focus of different measures

<table>
<thead>
<tr>
<th>Cleaners Modes</th>
<th>Modal Shift</th>
<th>Reduce number/length of trips</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuels and Propulsion Technologies</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Improved Vehicles</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Improved Infrastructures</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>ICT / ITS</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Organisational innovations</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Figure 7.1 is illustrating these approaches. It is obvious, that the approaches focusing on the left side of the graph are able to improve eco-efficiency without changing the travel behaviour significantly. Typical examples are biofuels, CNG or lightweight construction. For other examples such as battery
electric vehicles, the situation is more complicated, because the short ranges might also induce changes in travel behaviour (e.g. other modes or vehicles for longer distances). However, to a certain extent travel patterns and technologies develop together as a sort of co-evolution. Modern mobility patterns are enabled by modern technologies; and at the same time they induce a demand that fosters the development of further innovations.

The approaches focusing on the right side mean a change in travel behaviour. A different mode or a different destination is chosen or a trip is substituted by a virtual activity. Acceptance surely plays a greater role on the right side. For many approaches subsumed under the strategies two and three human routines are playing a much more important role, in particular when it comes to the passenger sector. Good examples are handy ticketing or integrated ticketing which should help to attract new customers for public.

For these approaches ICT as well as organisational innovations are of utmost importance (see also Figure 7.2). It is illustrated in this report that ICT is penetrating all areas of the transport sector, it is getting indispensable for information, organisation and management of the system. Citizens are getting used to these technologies and new priorities seem to emerge. For example, for many younger people it is more important to have access to the internet than having access to a private car.

Thus, it is obvious, that the transport system is not static but underlies changes under several aspects. There are external pressures such as oil prices and climate change. There are societal trends that influence demand patterns. And there is a broad range of organisational and technical innovations for improving the eco-efficiency of the transport system by making trips cleaner, by supporting the shift to more eco-efficient means of transport and by reducing transport volumes.

It can be assumed that the transport system in 20 or 30 years will be different from today, but it is difficult to tell what exactly will differ. It was mentioned several times in this report that it is generally not easy to quantify the effects of the described technologies and concepts. There are several reasons for these difficulties. The transport system is not at all a closed system. It was illustrated in this report that the ecological footprint of all alternative oil-based propulsion systems is strongly dependent on different factors and settings in the energy system. Battery electric vehicles can only be low-emission in the operating phase, if the power is generated on a low-emission basis, by wind or photovoltaic. A huge number of factors and options need to be considered and compared for a proper assessment. Furthermore developments and progress in the field of information and communication technologies are getting increasingly important for the transport sector. Uncertainty related to behaviour is another source for the difficulties in assessing effects, mainly in the categories two and three. Several times in this report it is mentioned that measures that are supposed to be beneficial might as well induce rebound effects. For example tele-working has the effect that people use the time gained for other activities that need transport. Another example is improving load factors of lorries, which might reduce the number of trips. But that way, the road is getting more inviting and additional traffic might be attracted.

However, a few studies give orientation about the pros and cons of the different fuel and propulsion strategies. Several studies illustrate that a significant improvement of the eco-efficiency of the transport system, needs a combination of all three strategies shown in figure 7.1 and 7.2. It will be subject of the next project-phase to get a better understanding of the potentials of the different

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122 See JRC et al. (2011).

123 See e.g. Hickman & Banister (2007); Skinner et al. (2011).
technologies and concepts due to the use of scenarios. Many of the approaches discussed in this report will be an element of the scenarios. They will be discussed in phase 4 of the project with different societal groups, e.g. policy makers, industrial representative and citizens, to get a better understanding of acceptance of the measures, and thus, on the demand side of innovations. What is crucial for beneficial measures to become effective in terms of eco-efficiency is that they are implemented and used, thus, they need to be accepted by users and decision makers.
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This document is the ‘Interim report on potentials of technologies and concepts supporting eco-efficient Transport’

The STOA studies can be found at:
http://www.europarl.europa.eu/stoa/cms/studies
or requested from the STOA Secretariat: STOA@ep.europa.eu

In addition, a short Options Brief is also accessible through the STOA studies website, or via this QR code:

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