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Energy Efficiency in the Transport Sector

Discussion paper prepared for the PEEREA Working Group on Energy Efficiency and Related Environmental Aspects

Report

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Contents

Summary

The transport sector represents the largest oil consumer sector in the world and therefore one of the main challenges for climate change and energy security of supply policies. Improving energy efficiency in this sector is a matter of urgency.

This report presents a concise overview of technical and non-technical measures that can be applied to improve energy efficiency in the transport sector as well as of policy instruments that may be implemented to promote application of these measures. Various options are discussed in the context of current trends and of short and long term environmental and economic objectives in the transport sector. Furthermore energy efficiency initiatives and relevant activities of various international organisations are mapped.

The report has served as a discussion paper for the Meeting of the PEEREA Working Group on Energy Efficiency and Related Environmental Aspects, 9-10 November 2006.

1 Introduction

1.1 Scope of the report

Energy efficiency in transportation is an important issue amongst an array of other issues related to transport policies, ranging from technology improvements to traffic organisation and modal shifts. This report presents a concise overview of technical and non-technical measures that can be applied to improve energy efficiency in the transport sector as well as of policy instruments that may be implemented to promote application of these measures. Various options are discussed in the context of current trends and of short and long term environmental and economic objectives in the transport sector. Furthermore energy efficiency initiatives and relevant activities of various international organisations are mapped. The report serves as a discussion paper for the PEEREA group[1] meeting in November 2006.

1.2 Environmental and economic objectives in the transport sector

Transport and economy
Transport is often called the 'engine' of economy, although 'lubricant' would seem a more appropriate automotive metaphor. Affordable modes of freight transport allow other economic sectors to optimize the various steps in the value chain from raw materials to final products. Personal mobility offers freedom to people and allows them to optimally organise work, living and recreation. As such transport is inextricably connected to the structure of our modern society. Transport policies therefore aim to improve the mobility of people and goods as a prerequisite for further economic growth.

The transport sector in itself represents a large amount of economic activities, comprising the activities of e.g. transport companies, vehicle manufacturers, oil companies, building companies for construction and maintenance of infrastructure, and a range of supply industries and services. In some large European countries 10% of the population directly or indirectly works for the automotive industry.

Energy security
Worldwide 98% of the energy consumption by transport is based on oil (IEA 2004). For that reason the transport sector is very dependent on the price and availability of oil. Recent years have shown that the oil price can increase to unexpected heights due to e.g. geopolitical instabilities (e.g. in the Middle East), natural disasters (e.g. hurricanes in the Gulf of Mexico shutting down production and refineries in the region) and technical setbacks (e.g. corroded pipelines in Alaska). Furthermore the worldwide demand for oil is increasing due to increased demand from Western countries and the rapid economic development of some

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1 PEEREA: Protocol on Energy Efficiency and Related Environmental Aspects. A working group involving 51 member countries under the umbrella of the Energy Charter. See: http://www.encharter.org/index.jsp.

Asian countries. Although worldwide oil resources are still considerable, they are much more limited than the resources of coal and gas. New reserves are mostly found in the form of unconventional oil, but the question is whether e.g. large-scale exploitation of Canadian oil sands is acceptable in the long term from an environmental and ecological point of view. In any case exploitation costs of oil are expected to increase. At the same time various analysts expect that in the next one to three decades the world-wide oil production will reach a peak ('peak oil'), with supply no longer able to meet growing demand. This is expected to lead to large fluctuations in oil price with possible negative economic consequences.

At the moment it is difficult to quantify the value of energy efficiency improvement and alternative fuels in relation to the issue of energy security. The economic value certainly seems larger than the avoided fuel consumption alone. In order to better balance various objectives in the formulation of new policy measures it would be advisable to develop a methodology to quantify energy security aspects in such a way that they can be made comparable to environmental indicators such as greenhouse gas abatement costs.

Transport and environment

Besides its beneficial impacts on economy the transport sector also has a range of negative impacts. The combustion of fossil fuels produces emissions that contribute to environmental problems at a local, regional (e.g. acidification) and global level. At the local level air pollution and noise are the most important problems. At a regional level acidification is one of the main issues while at the global level the contribution of carbon dioxide (CO_2) and other greenhouse gases to global warning is the main problem.

With the introduction of emission legislation for road vehicles in many countries the local and regional environmental impact of transport has dramatically decreased over the past two decades. This does not mean that all objectives are being met. The real-world emissions of nitrogen dioxide (NO_2) and fine particulate matter (PM_{10}) have decreased at a slower rate than expected at the time when air quality standards and National Emission Ceilings were planned for 2010. As a consequence local concentration limits for NO_2 and PM_{10} are still exceeded in many densely populated areas and national emission reduction targets for NO_x ($NO + NO_2$) are not met in some countries. The slow rate of decrease in emissions at the vehicle level is partly due to the fact that emission reductions measured on the type approval test do no longer correspond to equal emission reductions in real life (for both passenger cars and heavy duty vehicles), and partly to the increased share of diesel vehicles in the passenger car fleet. Euro 3 diesel cars emit 10 times more NO_x and PM than equivalent petrol vehicles. Fortunately, with Euro 4 and especially with the recently adopted Euro 5 limits, which require the application of particulate filters in diesel passenger cars, the difference is decreasing. Application of SCR-deNO_x (Selective Catalytic Reduction) in trucks is finally allowing drastic reductions of NO_x from freight transport. For the short term air quality problems still pose significant challenges to the transport sector, but for the longer term these problems are expected to be solved by the use of advanced after treatment systems in response to further tightening of emission limits.

In the EU-15, transport now accounts for 21% of total greenhouse gas (GHG) emissions (excluding international aviation and maritime transport) (EEA, 2006). For the EEA[2] area as a whole the number is slightly lower. While GHG emissions of many other sectors are decreasing, the contribution from transport keeps growing. Since 1990, the emissions have grown by around 23% (excluding international aviation and maritime transport). Transport furthermore contributes to global warming through:

- Direct vehicle emissions of methane (CH_4), nitrous oxide (N_2O) and hydrocarbons.
- Indirect emissions in the fuel chain of CO_2, CH_4, N_2O and hydrocarbons.
- Emissions of chlorofluorocarbons (CFCs) and hydrofluorocarbon (HFCs) used as refrigerants in mobile air conditioners and cooling systems for trucks.

In the short term many developed countries will be able to meet their CO_2 reduction goals under the Kyoto protocol[3] without drastic measures in the transport sector. For the long term, however, CO_2 emission reductions of 40 to 60% compared to 1990 are expected to be necessary in order to limit the effects of global warming to acceptable levels. Given the expected growth of the transport sector in the next decades and its strong reliance of fossil fuels, such long term reduction goals can not be met without significant contributions from the transport sector.

1.3 The role of efficiency in reaching long term objectives

The present attention for biofuels and what could be called the hype around the future hydrogen economy seem to suggest a picture in which all problems in the transport sector related to greenhouse gas emissions, local air quality and dependence on finite resources may be solved without significant changes in our behaviour, in economic activities or in the efficiency of vehicles. In this report we hope to make clear that long term goals related to global warming and energy security can only be met through a combination of various measures, and that none of the options by itself is able to yield the required reductions in CO_2 emissions and energy consumption. In fact, improving the energy efficiency of vehicles may even be a prerequisite for the cost effective application of sustainable fuels, as these fuels will remain scarce and costly for a long time. A more detailed discussion of the role of efficiency improvement in transport in relation to the implementation of biofuels and measures aimed at reducing (the growth of) the volume of transport is presented in section 2.5.

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2 European Environment Agency, see: http://www.eea.europa.eu.

3 For EU-15 the target is a reduction of the average annual emissions in the 2008-2012 period by 8% compared to 1990.

2 Trends in energy efficiency and energy policy in the transport sector

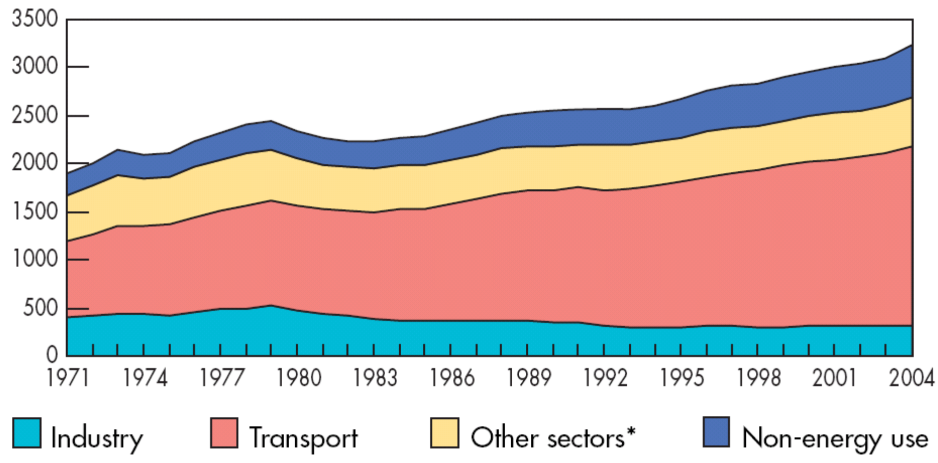
2.1 Trends in energy consumption and CO_2 emissions

Figure 1 shows that the share of transport in worldwide oil consumption is steadily growing, in relative as well as in absolute terms. A similar picture emerges from Figure 2 in which the historic evolution of worldwide CO_2 emissions per sector is indicated. Trends in energy consumption of various transport modes in Europe are shown in Figure 3. It is clear that the growth is dominated by road transport. Worldwide international shipping and aviation are also fast growing transport sectors as can be seen from Figure 4.

A further increase in energy consumption by the transport sector over the next decades is predicted by various scenario studies, such as the ones represented in Figure 5.

Figure 6 shows the evolution of the oil price over the past decades. Although the present peak is expected to level off, it is clear that increased demand will lead to high prices over the next decades. This increases the need for efficiency improvement measures but also improves their cost-effectiveness due to higher fuel cost savings.

Figure 1 Evolution of worldwide final oil consumption per sector in Mtoe



Source: IEA, 2006.

Figure 2 Worldwide CO_2 emissions per sector between 1980–2004

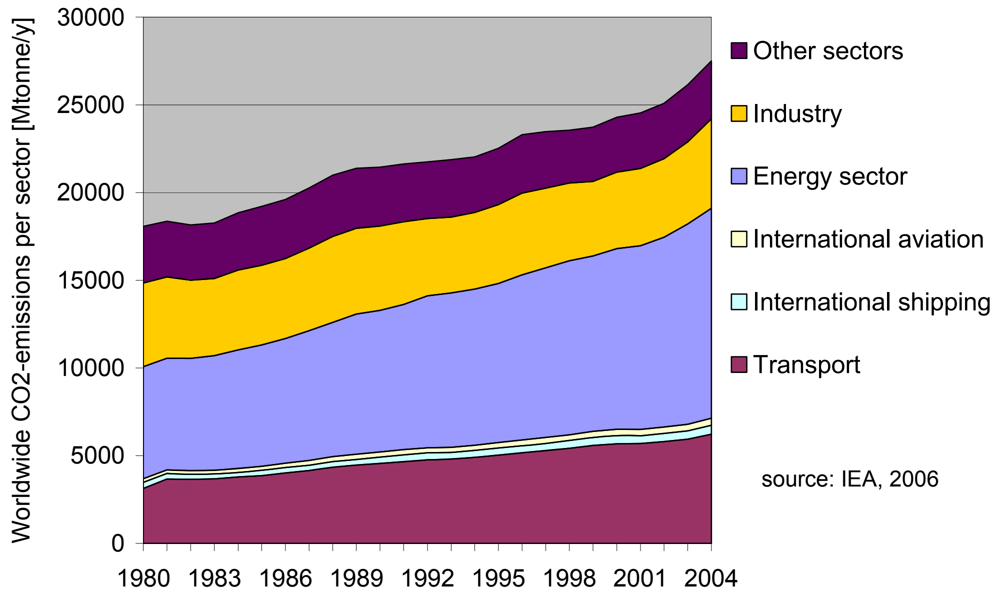
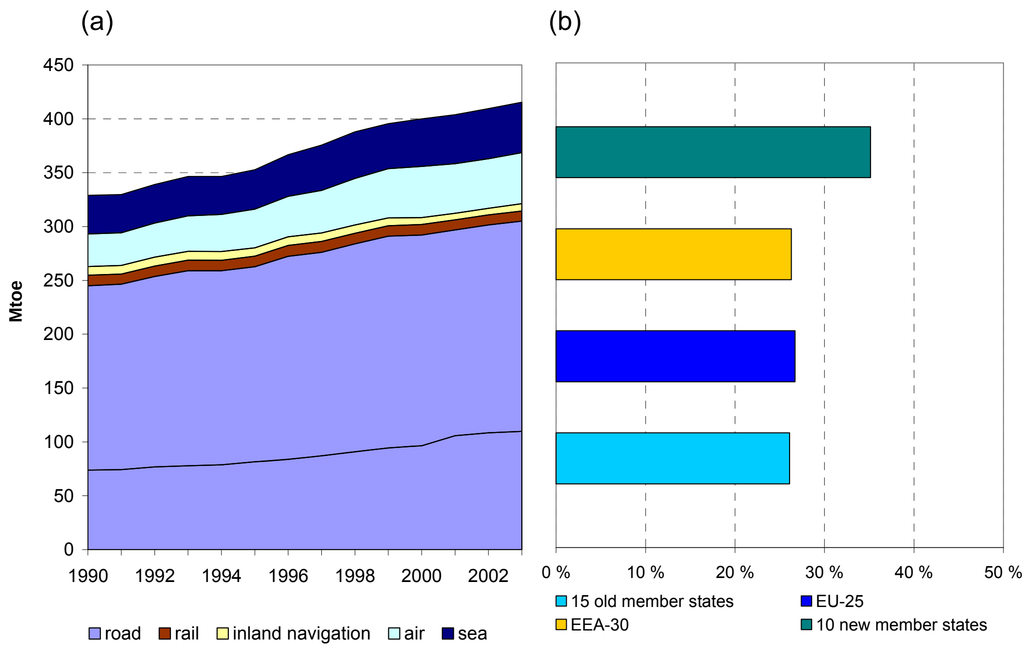
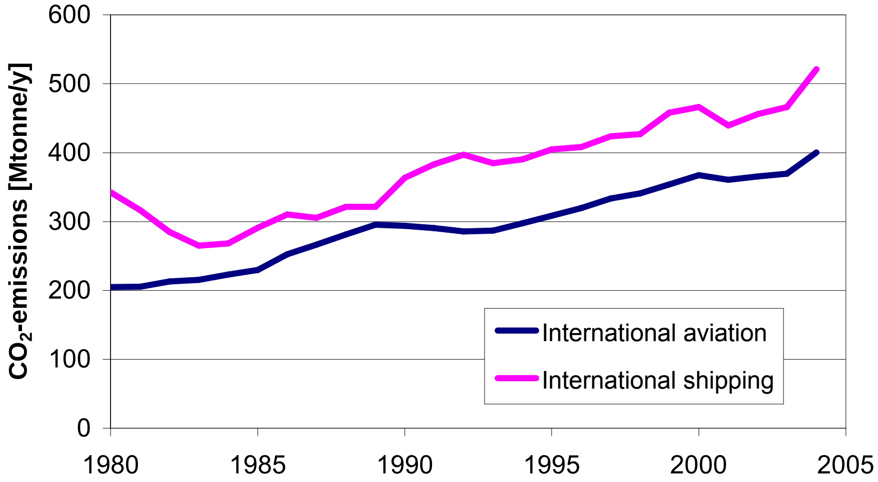


Figure 3 (a) Total energy consumption in transport (EEA-30), 1990–2003 (Mtoe) and (b) growth in transport energy consumption by region between 1990–2003



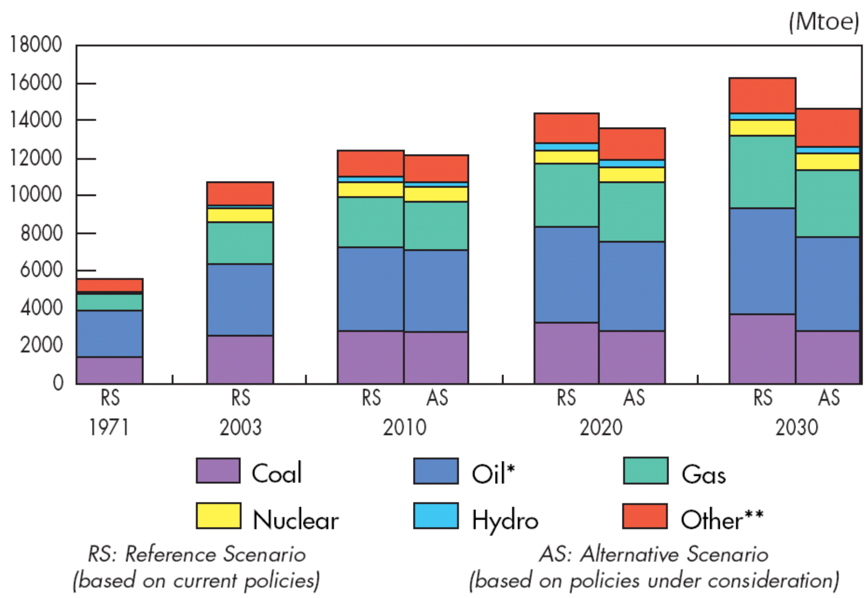
Note: Inland navigation includes transport on inland waterways and coastal transport. The line dividing road transport distinguishes the share of freight (*lower part*) from passenger (*upper* part) transport. The division is based on information from the 25 EU countries. Transport by pipelines is excluded, as its contribution is far less than 1% of total energy consumption by transport. EU-25 refers to the 25 EU member states as of May 2004. EEA-30 refers to EU-25 plus Norway, Iceland, Bulgaria, Romania, and Turkey.
Source: Eurostat & EEA, 2005.

Figure 4 Trend in CO_2 emissions from international aviation and shipping



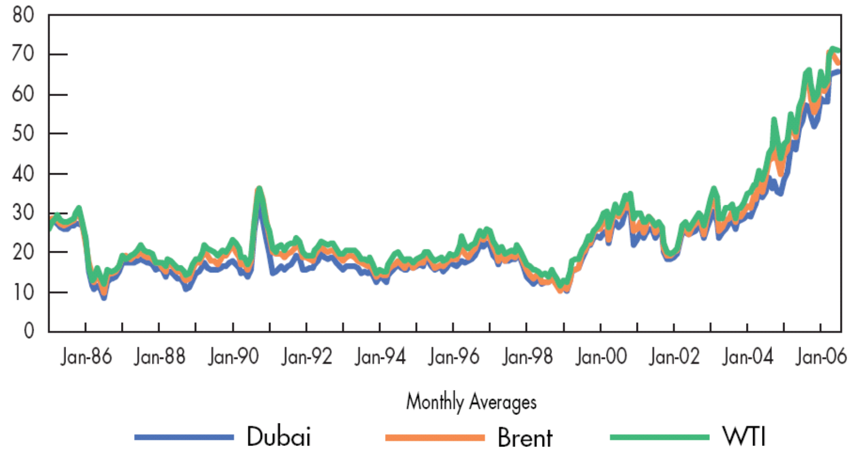
Source: IEA, 2006.

Figure 5 Projections of worldwide consumption of various types of primary energy



Source: IEA, 2006.

Figure 6 Evolution of the crude oil spot market price over the past 20 years in US$/bbl

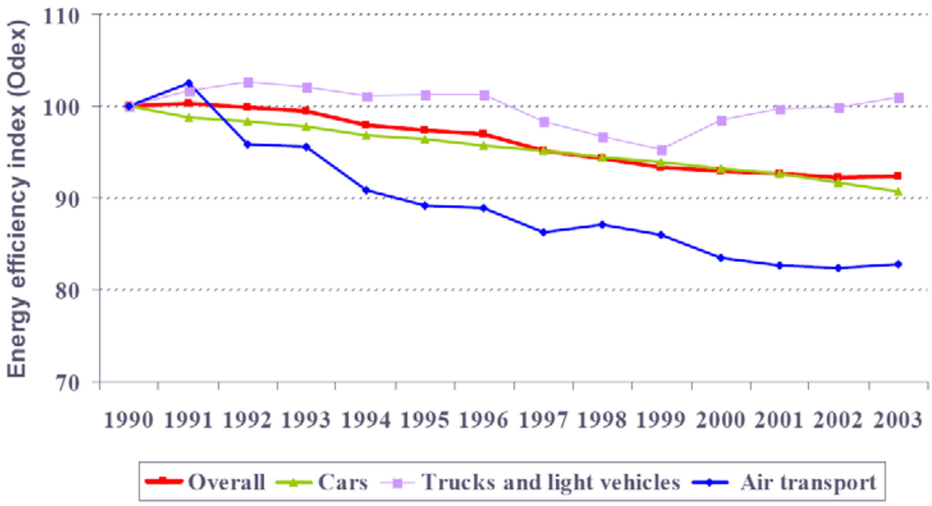


Source: IEA, 2006.

2.2 Trends in energy efficiency

Trends in the energy efficiency for various transport modes are presented in Figure 7, Figure 8 and Figure 9 (derived from: Odyssee, 2006). As there have not been any major fuel switches in these modes, the trends in fuel consumption and CO_2-emissions (per unit transport performance) will be similar. A net efficiency improvement between 1990 and 2003 can be seen for passenger cars and for aviation. For freight transport the a net improvement in fuel consumption per tonne km occurred between 1993 and 1999, mainly due to improved logistics and management, but since 1999 this value is rising again leading to a net efficiency in 2003 that is almost equal to the 1999 value.

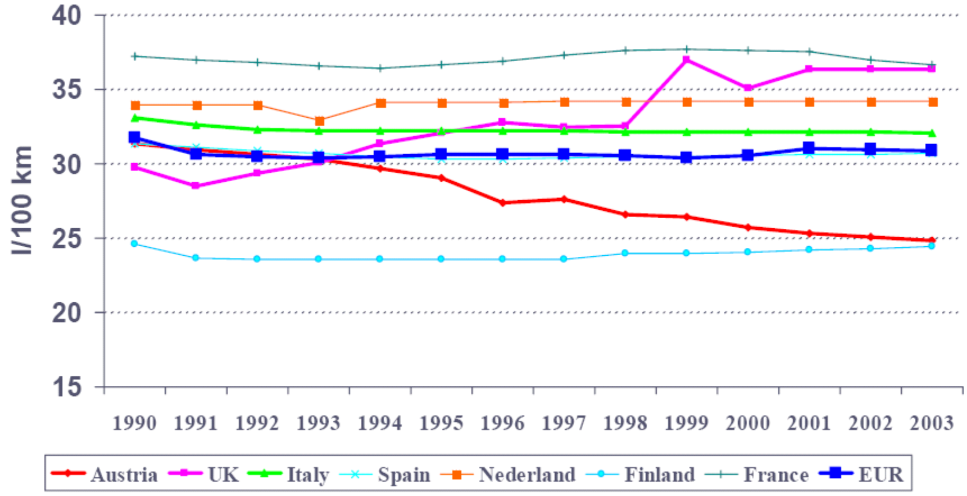
Figure 7 Energy efficiency index for transport in the EU15, 1990-2003[4]



Source: Odyssee, 2006.

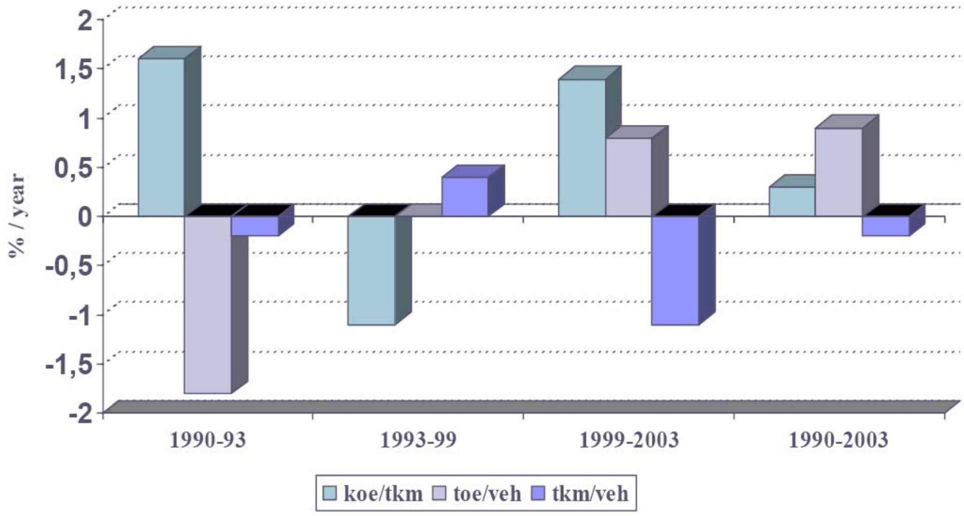
[4] Calculated on the basis of 7 modes: passenger cars (l/100km), trucks & vans (toe/tkm), aviation (toe/pkm), rail and water (toe/tkm or pkm), motorcycles and buses (toe/veh) (Odyssee, 2006).

Figure 8 Fuel consumption [l/100km] of trucks by country and for EU15, 1990-2003



Source: Odyssee, 2006.

Figure 9 Changes in specific fuel consumption per unit of transport performance [koe/tkm], average annual fuel consumption [toe/veh] and average transport performance [tkm/veh] of trucks in EU15 for the periods 1990-1993, 1993-1999, 1999-2003 and for the total period 1990-2003



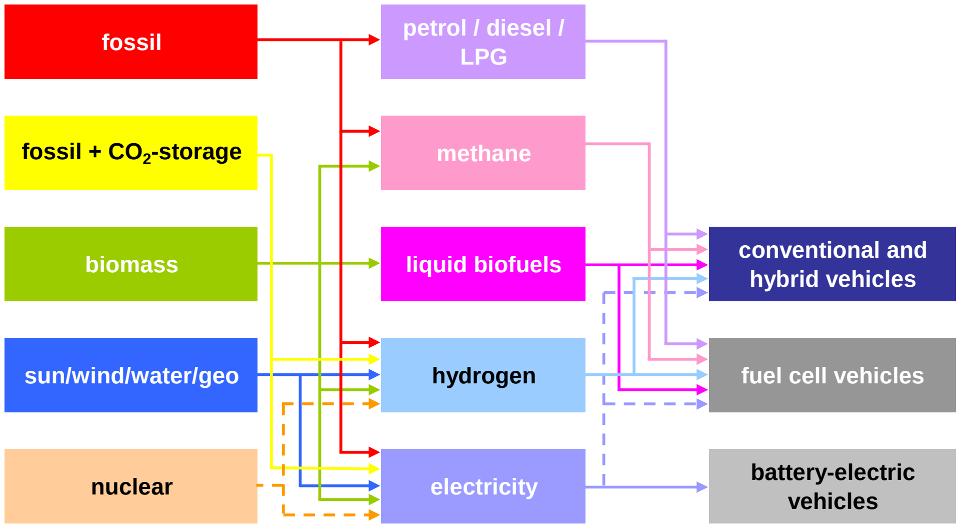
Source: Odyssee, 2006.

2.3 Alternative fuels

In principle the energy for propelling vehicles can be derived from different sources. At present oil is the dominant energy source for the transport sector, but in the long term a multitude of energy chains could become available on the basis of fossil energy, various sustainable sources and nuclear power. This is illustrated in Figure 10.

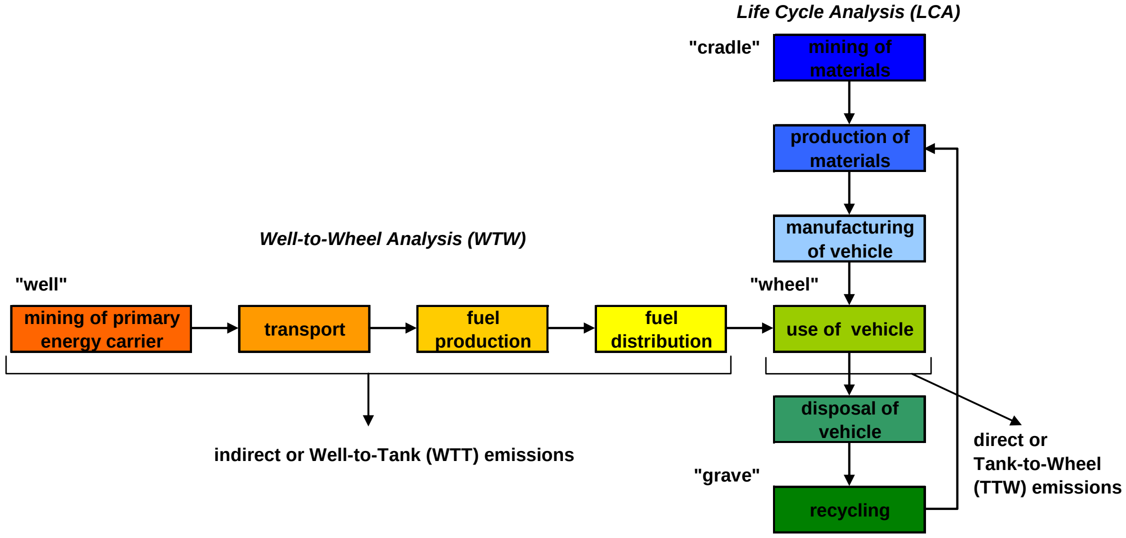
In the left hand column of Figure 10 the range of available primary energy sources is presented. The centre column shows the various categories of secondary energy carriers, into which the primary energy sources can be converted for distribution to final energy use applications. Energy carriers include traditional fuels (petrol, diesel and LPG, from refining of oil or synthetically produced from gas or coal), various fossil and renewable alternative fuels (e.g. natural gas, biogas, bioethanol, biodiesel, biomass-to-liquids (BTL), hydrogen), as well as electricity. On-board vehicles these energy carriers are converted into propulsion energy using various powertrain technologies. These are displayed in the right-hand column of Figure 10. It is clear from this graph that an advantage of hydrogen and electricity is that both can be produced from all possible primary sources. Similarly internal combustion engine based powertrains (conventional as well as hybrid) and fuel cell powertrains can be fed with all possible fuels, whereby hybrid configurations are also able to (partly) use electricity.

Figure 10 Various routes from primary energy sources, via secondary energy carriers to final use of energy in vehicles with different propulsion systems



Comparison of different fuels (secondary energy carriers) with respect to energy efficiency and CO_2 emissions only makes sense if the complete energy chain from Well-To-Wheel (WTW) is taken into account. Similarly for comparing different vehicle technologies Life-Cycle Analysis (LCA) may be necessary to assess possible negative aspects of the use of new materials. This may be relevant e.g. for the use of batteries in hybrid and electric vehicles and for the use of platinum and other materials in fuel cells. The concepts of WTW analysis and LCA are illustrated in Figure 11. So far, however, differences in energy consumption for production and recycling for new propulsion technologies seem to be far smaller than differences in WTW energy consumption, so that in this report only the latter aspect will be taken into account.

Figure 11 Illustration of the concepts of Well-to-Wheel (WTW) analysis of energy chains and Life Cycle Analysis (LCA) of products



2.3.1 Alternative fossil fuels

Liquefied Petroleum Gas (LPG) and especially Compressed Natural Gas (CNG) are presented as clean fossil alternatives for petrol and diesel. By the application of 3-way catalysts and tightening of emission limits the air quality related advantages of LPG and CNG vehicles compared to petrol have been greatly reduced (TNO, 2003). CO_2 emissions of LPG vehicles are in between those of petrol and diesel vehicles. The well-to-wheel greenhouse gas emissions of CNG vehicles are some 20% lower than those of petrol vehicles and as such comparable to those of diesel vehicles. The CO_2 benefit of CNG, however, is strongly affected by the origin of the natural gas and the associated transport distances. As Europe by now is a net importer of natural gas, it may be assumed that the additional demand for natural gas from future vehicles on CNG is met by imports from Russia, the Middle East and south-west Asian countries. Data from (Concawe, 2006; TNO, 2006) show that while NGVs on average EU-mix natural gas have 23% lower WTW greenhouse gas emissions, this benefit reduces to 17% resp. 8% when imported gas is used that is transported over a distance of 4,000 resp. 7,000 km. The role of LPG and CNG in the context of a CO_2 policy for the transport sector will therefore be limited in Europe. CNG could play a role in various transition paths towards the use of biogas and hydrogen[5], but in this context an investment in a CNG distribution infrastructure for transport probably only makes sense if it is part of a more integral, regional approach to promote the use of natural gas, biogas or hydrogen[6].

The same can be said for LNG and for new alternatives such as DME (dimethyl ether) and synthetic diesel derived from natural gas (GTL: Gas-To-Liquid) or coal

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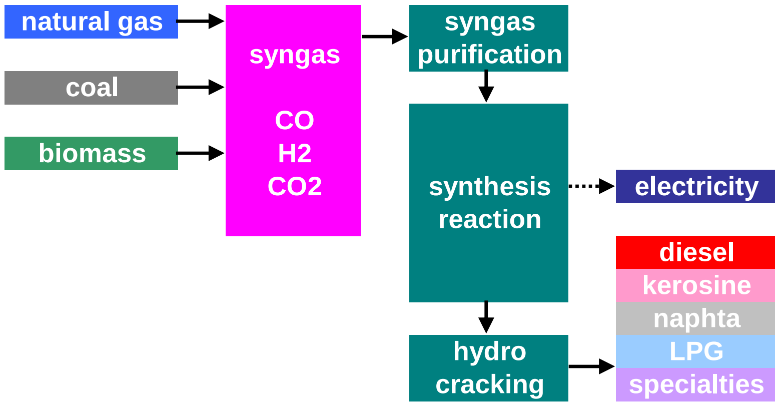
5 Biogas can be mixed with fossil methane at any rate, provided it is upgraded to the right fuel specifications. Hydrogen can be blended into natural gas at a percentage that is limited right now, but which could increase in the future provided that appliances and distribution infrastructure are adapted.

6 See e.g. the example of the Swedish city of Malmø, where biogas from waste disposal is used in wide range of urban applications including public transport.

(CTL: Coal-To-Liquid). GTL and CTL allow the production of high value (premium) transport fuels from other fossil sources. This is economically attractive on the one hand because remote sources of especially natural gas can be exploited and on the other hand because blending of synthetic components into diesel enables further improvements in fuel quality which are necessary to improve the efficiency and emissions of modern combustion engines.

Figure 12 Schematic representation of the production of synthetic fuels (GTL, CTL, BTL) on the basis of the Fischer-Tropsch process



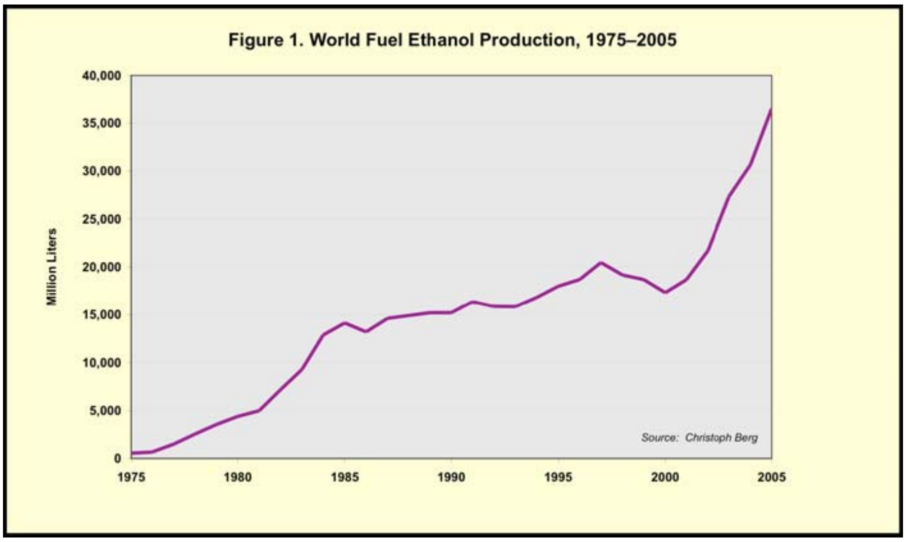
2.3.2 Biofuels

Production and use of biofuels are increasing strongly in recent years, both in the EU and globally. The current biofuels industry is composed of two main sectors: biodiesel and bioethanol. Globally, bioethanol production exceeds biodiesel production by a factor 10, as can be seen in Figure 13 and Figure 14. In the EU, this ratio is reverse, with biodiesel production being 10 times higher than bioethanol production, see Figure 15. This has to do with government policies of various member states, the rapeseed production potential of the EU (rapeseed oil is one of the main raw materials that can be converted to biodiesel) and the relatively high share of diesel in EU fuel sales. In 2005, 3.9 million tons of biofuel were produced in the European Union in 2005, marking a 65.8% growth in production. Production of bioethanol is lagging behind in the EU, but also increased significantly, by 70.5% between 2004 and 2005.

Biofuels have the advantage that the CO_2 that is emitted during combustion is equal to the CO_2 that is taken up by the biomass during cultivation. However, they still contribute to climate change because of greenhouse gas emissions during cultivation of the biomass (N_2O emissions mainly, due to fertilizer use), transport and production of the biofuel.

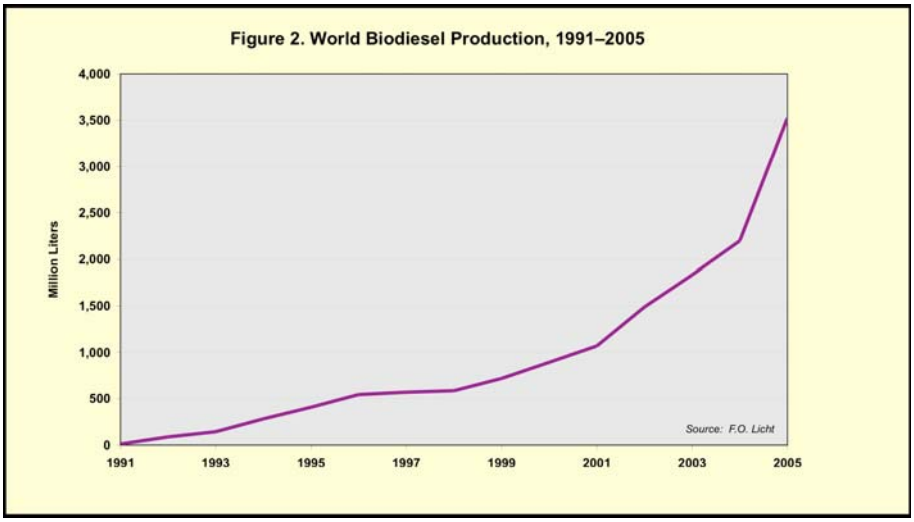
Compared to fossil diesel and petrol, current European biofuels (biodiesel and bioethanol) achieve, on average, GHG reduction percentages between 30 and 60% (using the WTW approach explained in section 2.3) (Concawe, 2006). However, new biofuels processes are currently under development, that are expected to achieve a GHG reduction of 80-90%. In the coming years, these new biofuels, often called second generation biofuels, will have to be developed further.

Figure 13 Development of global fuel ethanol production, 1975-2005



Source: WWI, 2006.

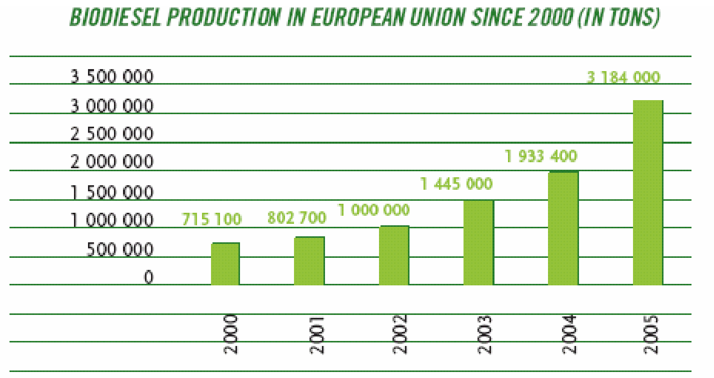
Figure 14 Development of global biodiesel production, 1991-2005

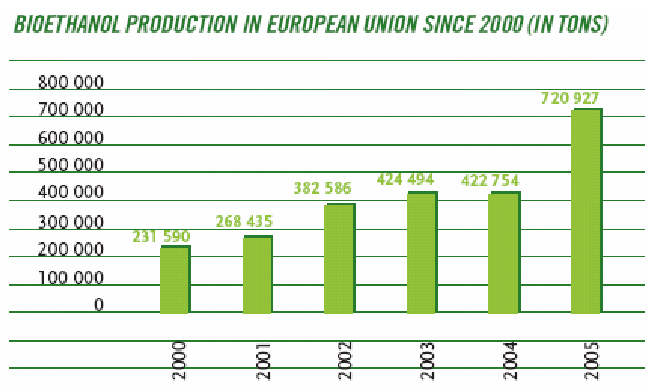


Source: WWI, 2006.

Even though biofuels have a GHG emission advantage, they also have some negative effects. First of all, the cost of most biofuels is higher than that of fossil fuels. The only exception is bioethanol from Brazil, that has started stimulating the use of this fuel in the 1970s. Likewise, costs from European biofuels may come down in the future due to learning effects. However, costs will also depend on demand en supply. Secondly, concerns about the potential negative effect of biofuels on biodiversity are growing. The substantial rise of the demand for biomass from both the biofuel and bioenergy sector puts additional pressure on farmland and forest biodiversity as well as on soil and water resources. It may also counteract other current and potential environmental policies and objectives, such as waste minimisation or environmentally-oriented farming (EEA, 2006). This study also concludes that significant amounts of biomass can technically be available to support ambitious renewable energy targets, even if strict environmental constraints are applied. However, it also concludes that environmental guidelines need to become an integral part of planning processes at the local, national and EU level. Other studies confirm that the biofuel potential is certainly not unlimited, due to constraints regarding biodiversity, food production, water availability, etcetera (see e.g. (WWI, 2006)).

Figure 15 Development of biofuel production in the EU, 1991-2005 (from: EurObersv'ER, Biofuels Barometer 2006)





2.3.3 Long term options: hydrogen and electricity

In the long term also hydrogen and electricity can be envisaged to play a role in the energy supply of the transport sector. It should be noted here that both are energy carriers and not energy sources. As such the WTW efficiency and CO_2-emissions depend on the primary source and conversion processes that are used to produce hydrogen and electricity. With the present EU-mix for electricity generation application of electricity in transport may already now have WTW efficiency benefits. For hydrogen this is only the case if it is produced from renewable sources (see e.g. (Concawe, 2006)) and further discussion on fuel cell vehicles in section 3.1.1). By many authors visions are presented of a 'hydrogen economy' that will solve all our future energy problems. It is, however, highly questionable whether distribution of energy in the form of hydrogen is the most optimal solution from a system point of view. Possibly a more limited role for the production of hydrogen as a buffer to match demand patterns with the supply patterns of renewable energy in the context of an 'all electric society' is more appropriate.

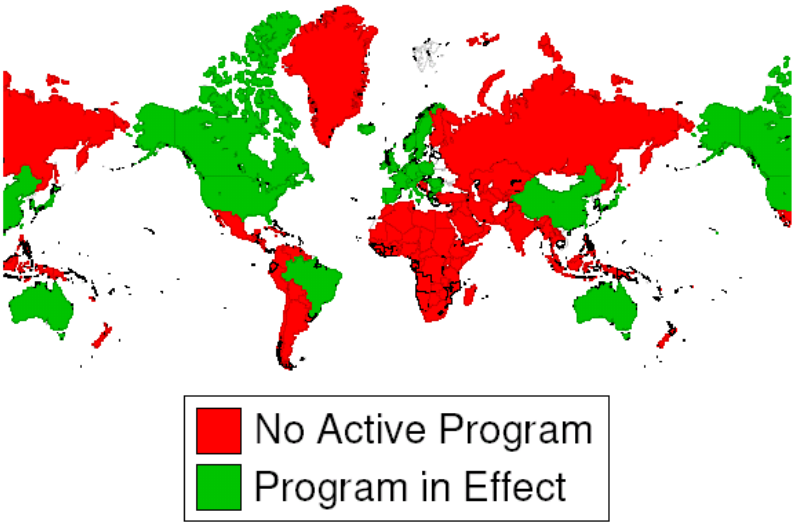
A system efficiency perspective

The example of hydrogen shows that in some cases measures to improve the energy efficiency of the transport sector should not just be reviewed at the level of a vehicle to vehicle comparison or a Well-to-Wheel comparison but that a system approach is necessary in which the relation of a given energy source with other applications outside the transport sector is taken into account and in which the overall target is optimisation of system efficiency rather than optimisation of the efficiency of transport. Already now the efficiency of e.g. refineries is closely to processes in other sectors through the use of process energies and the generation of by-products. This will probably be even more the case for future fuel production systems. An interesting example already is the Fischer-Tropsch process for production of synthetic fuels, of which the overall system efficiency and WTW CO_2-emissions are strongly dependent on the whether and where the electricity, that can be generated as a by-product, is used.

2.4 Current policies and trends

As can be seen from Figure 16, many countries worldwide have implemented policies to reduce fuel consumption and CO_2 emissions from transport. A brief overview of some interesting examples in various regions is given below.

Figure 16 Overview of countries with programmes in effect to reduce fuel consumptions and CO_2-emissions from transport



Source: Walsh, 2006.

2.4.1 EU

The EU passenger car CO_2 strategy rests on three pillars:

- The so-called car industry's 'self commitments' or 'voluntary agreements'.
- Consumer information through CO_2 emission labelling.
- CO_2 differentiation of taxation.

The goal of the industry's self commitments is to reduce the sales averaged CO_2 emissions of new vehicles to 140 g/km in 2008 (ACEA) or 2009 (JAMA and KAMA). This is to be realised mainly through technical measures. According to EU communications labelling and fiscal measures are intended to create a market for fuel efficient vehicles and should further reduce the type approval emissions of new vehicles to 120 g/km in 2010. Energy efficiency of the transport sector is also being discussed in the review of the EU's White Paper on Transport Policy and in the recent Green Paper on Energy Efficiency.

The industry self-commitments

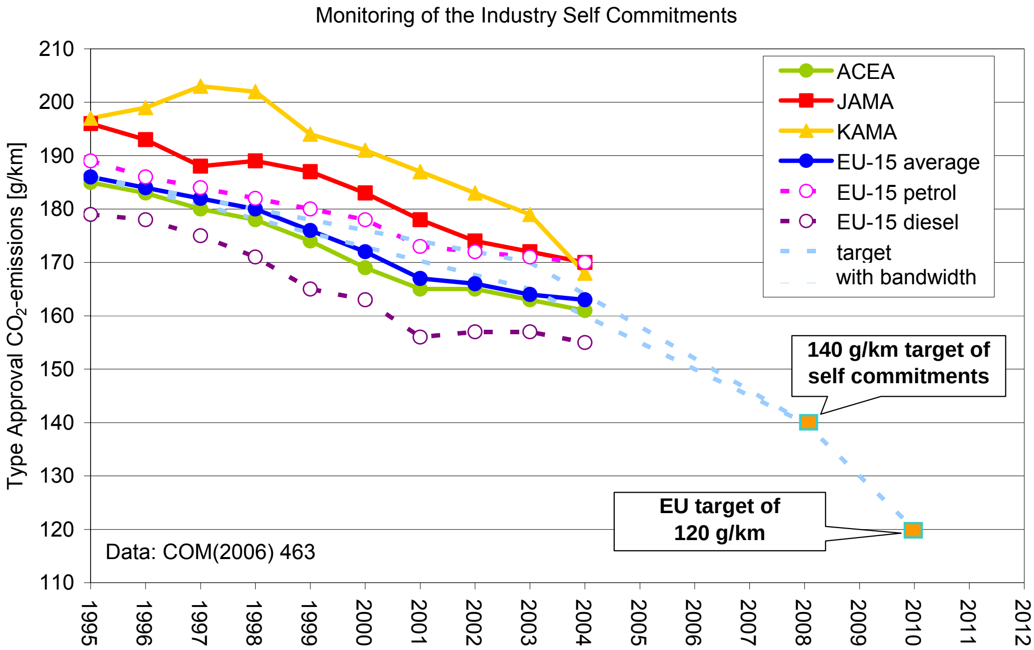
The automotive manufacturer associations ACEA, JAMA and KAMA have committed themselves to reducing the sales-averaged type approval CO_2 emissions of new vehicles to 140 g/km in 2008/9. The recent evaluation of progress made by the associations in 2004 (COM(2006) 463) shows that annual reduction rates have decreased to a level that raises concern with the European Commission about whether the 140 g/km target will actually be met (see Figure 17). Although the associations are formally still on track, i.e. within the band-widths of their intermediate targets, the gaps to be closed, expressed in required annual decrease, have further increased during 2004. Between 2004 and 2008/8 annual reduction rates of around 3.5% will be necessary to meet the 2008/9 target.

Currently the European Commission is evaluating the effectiveness of its CO_2 policy for cars, and is considering various options for a new CO_2-policy aiming at passenger cars and light duty commercial vehicles for the period after 2008. By the end of 2006 the Commission intends to present a Communication in which it outlines the first draft proposals. One option under consideration is a regulatory CO_2 emission limit for new vehicles to replace the voluntary agreements. In addition it is likely that key elements of the so-called 'Integrated Approach' will be adopted. The concept of an Integrated Approach was launched by ACEA and was the subject of a CARS21 Working Group, which has given additional impetus to this approach. The essence of the Integrated Approach is that:

- A 2012 CO_2 target may be reached more cost-effectively by a combination of technical and non-technical measures to be carried out by the car industry and the other stakeholders (fuels & lubricants industry, tyre industry, consumers, authorities, etcetera).
- From an environmental perspective, there is a greater potential for CO_2 reductions when more elements of the system are subject to reduction measures.
- Greater policy coherence could give more scope for synergism and avoidance of perverse effects.
- Adjustment costs can if appropriate be shared between a broader range of stakeholders.

Measures that could be included in an Integrated Approach are e.g. the use of energy efficient air conditioners, eco-driving, tyre pressure monitoring systems, low rolling resistance tyres and low viscosity lubricants for existing vehicles, inclusion of light duty commercial vehicles, traffic management measures, etcetera.

Figure 17 Monitoring of the effectiveness of the industry self commitments aiming at a reduction of the sales averaged type approval CO_2 emissions of new vehicles to 140 g/km in 2008 (ACEA) or 2009 (JAMA and KAMA)



Source: COM(2006) 463.

CO_2-labelling

The objective of labelling cars with information on fuel efficiency and CO_2 emissions is to provide potential buyers with information on these in the hope that this will influence their purchasing decision. Hence, the measure does not directly impact on a car's CO_2 emissions, rather it aims to increase the average fuel-efficiency of the car fleet and thus reduce total CO_2 emissions from transport. In addition, the measure is intended to stimulate the market for more fuel-efficient/lower emission cars through increasing awareness.

In the 1990s, a number of Member States developed fuel efficiency/CO_2 labels for cars. In 1999, Directive 1999/94/EC was adopted to require all EU Member States to display a fuel efficiency/CO_2 label on new cars, and set out certain requirements in order to ensure the consistency of the label and its contents. Directive 1999/94 requires that the label is attached to, or displayed near, the car in a clearly visible manner at the point of sale. It must include the official fuel consumption (in litres per 100 kilometres) and the official specific emissions of CO_2 (in grams per kilometre) for that particular mode, as measured in accordance with the harmonised methods and standards set out in Directive 80/1268 and its amendments (type approval test). The label should also include a reference to the fact that a free fuel economy guide is available, state that CO_2 is the main gas responsible for global warming and inform the consumer that driving behaviour and other non-technical factors also influence fuel economy and CO_2 emissions. In addition, the Directive requires the production and provision of a fuel economy guide, showroom information posters and references to fuel consumption and CO_2 emissions to be made in the relevant promotional literature.

A review of EU-15 Member States' experience with implementing the Directive revealed that all 14 Member States of the EU-15 that responded (i.e. all except Luxembourg) had implemented the Directive, including the introduction of the label, and that six had gone beyond the requirements of the Directive. In these cases, the countries have introduced energy rating systems with colour-coded classes (usually seven) along the lines of the household appliance energy label. In other words, the new car fleet is sub-divided into colour-coded vehicle classes and the label indicates the fuel efficiency and CO_2 emissions class into which the particular vehicle falls. In the case of Spain and the UK the energy rating label is voluntary, while in Belgium, Denmark, Portugal and the Netherlands it is mandatory (ADAC, 2005).

Additionally, the Dutch and Spanish schemes are relative in that the lower and upper ranges of the categories are not fixed. Such measures are based on the CO_2 emissions of the vehicle *relative* to some function of the vehicle, e.g. size or weight, to provide the basis for classes, whereas an *absolute* measure provides an energy efficiency category defined by CO_2, fuel reach or fuel consumption across all categories of vehicle. In the Netherlands, the relative energy efficiency of a vehicle is defined as the percentage by which its CO_2 emissions vary from a reference CO_2 emission value, which is defined as:

0.25(average CO_2 emission value of all new passenger cars) + 0.75* (average CO_2 emission value of all new passenger car of the same size),*

where vehicle size is given by a vehicle's pan area, i.e. its length * width. In Spain, the relative fuel efficiency index shows the relative fuel consumption of the car in question compared to the average fuel consumption of all passenger cars of the same size (again measured by pan area) and fuel type. The average fuel consumption is calculated statistically, as follows:

$$a \times e^{(b \times S)}$$

where *a*, *b* are constants (and vary for petrol and diesel cars), e is Euler's constant (2.7183) and *S* is the pan area. The relative classes in the Netherlands and Spain are given in Table 1.

Table 1 Relative energy rating classes in the Netherlands and Spain

	Relative energy efficiency index (%)	
Class	Netherlands	Spain
A	index < -20%	index < -25%
B	-20% <= index < -10%	-25% <= index < -15%
C	-10% <= index < 0%	-15% <= index < -5%
D	0% <= index < 10%	-5% <= index < 5%
E	10% <= index < 20%	5% <= index < 15%
F	20% <= index < 30%	15% <= index < 25%
G	30%<= index	25% <= index

Source: ADAC, 2005.

Fiscal measures

The third pillar of the EU strategy, CO_2 differentiation of vehicle taxation, is the least developed, at least until a few years ago. In July 2005, the Commission published a proposal for a Directive on passenger car taxes (COM(2005) 261). The proposal seeks to increase the harmonization of Circulation Tax and Registration Tax across Member States by a phase out of RT over a five to ten year time frame, a refund of RT and CT for consumers penalised by the movement of vehicles between Member States, and a restructuring of the tax base of RT and CT to be totally or partially CO_2 based. The main environmental rationale for the proposal is to introduce the 'polluter pays' principle in the area of passenger cars and to implement the third strand of the Community Strategy on Passenger Car CO_2 Emissions (COM(95)689) on fiscal instruments. The proposed phase out of RT, however, will make it more difficult to design a CO_2-based vehicle taxation that effectively influences consumer behaviour at the moment of car purchase.

Over the last few years many Member States have introduced various forms of CO_2-based vehicle taxation or have started considering the options. In the UK tax bands for Circulation Tax are coupled to the absolute CO_2 emission of vehicles. In July 2006 the Netherlands introduced a CO_2 based differentiation of Registration Tax coupled to the Dutch labelling system which is based on the relative CO_2 performance of a vehicle compared to other vehicles in the same class. Vehicles with A and B labels receive a tax rebate while vehicles with D to G labels face an additional RT charge. Higher rebates are available for hybrid vehicles with A or B label. France has adopted an RT scheme for business cars where a charge per gram of CO_2 per kilometre is introduced. This charge is a function of the label, in-creasing from € 2 per g/km for A-label cars to € 19 per g/km for G label vehicles. In Denmark circulation tax is differentiated in 24 bands related to fuel consumption. This has resulted in a significantly increased share of low CO_2 vehicles in recent new vehicle sales

White Paper on Transport Policy

In the EU White Paper on Transport ('European transport policy for 2010: time to decide' (COM(2001) 370)), energy efficiency of transport is hardly mentioned. This White Paper is currently under review. In a recent communication from the European Commission on this review (COM(2006) 314), improving energy efficiency in transport is mentioned as important factor in EU's energy policy: 'A

European energy policy which aims at ensuring competitiveness, security of supply and environmental protection has to focus, inter alia, on further transport policies which reduce energy consumption by improving fuel efficiency on the vehicle side and gradually replacing oil by other fuels be it biofuels, natural gas, hydrogen, electricity or others.' It also states that major RTD efforts and investments are necessary in the field of transport and energy, including energy efficiency.

In the review, the following actions are listed regarding transport and energy: 'promote energy efficiency at EU level on the basis of the forthcoming action plan, encourage EU actions, including voluntary agreements; support research, demonstration and market introduction of new technologies such as optimisation of engines, intelligent vehicle energy management systems or alternative fuels, such as advanced biofuels and hydrogen or fuel cells or hybrid propulsion; launch user awareness actions on smarter and cleaner vehicles and a major future-oriented programme for green propulsion and energy efficiency in transport.'

Green Paper on Energy Efficiency
The Commission intends to come forward in autumn 2006 with an Action Plan on energy efficiency. In 2005, the Green Paper on energy efficiency ('Doing more with less') was published (EC, 2005). In this document, the ideas of the Commission on energy efficiency are drafted. A public consultation on this paper was held subsequently, as part of the process. In this Green Paper, improving energy efficiency in transport is mainly related to modal shift, optimising traffic and transport management and road pricing.

2.4.2 USA

CAFE
Under the 1975 Energy Policy and Conservation Action the US introduced the corporate average fuel economy (CAFE) standards. Between 1978 and 1987 CAFE has resulted in a fuel economy increase of passenger cars from 15 mpg to 28 mpg. For vans (called 'light duty trucks' in US) targets are less ambitious and fuel economy improved from 14 mpg to 21 mpg. Because of lack of political will the standards were not updated after 1987, and as a consequence the fuel economy of passenger cars and light duty trucks has remained constant since then. The average fuel economy of American cars has even declined a.o. due to the increased share of SUVs in the fleet.

California
In September 2004 the Californian Air Resources Board has approved regulations to reduce greenhouse gas emissions from cars. Each large manufacturer selling cars in California has to meet a fleet average greenhouse gas emission standard (in grammes CO_2 equivalent per mile). A certain degree of banking is allowed. The regulation applies to passenger cars and light duty trucks, and not only considers direct CO_2 emissions, but also includes tailpipe emissions of other greenhouse gases (CH_4 and N_2O) as well as emissions of CO_2 and HFC-refrigerants related to airco use and vehicle scrappage and

upstream emissions associated with the production of fuels. Legislation will phase in with model year 2009. It is anticipated that the required reductions can be achieved mostly with already available technologies and without vehicle down-sizing.

Table 2 Californian CO_2 equivalent fleet average emission standards

Tier	Year	CO_2-equivalent emission standard (g/mi)	
		PC/LDT1 (Passenger cars and small trucks/SUV's)	LDT2 (Large trucks/SUV's)
Near-term	2009	323	439
	2010	301	420
	2011	267	390
	2012	233	361
Mid-term	2013	227	355
	2014	222	350
	2015	213	341
	2016	205	332

Stimulation of R&D

The Partnership for a New Generation of Vehicles (PNGV) was established in 1993. PNGV was a co-operative effort between government agencies and car manufacturers Chrysler, Ford and GM with the objective to develop an affordable, 80 mpg (2.94 l/100 km) family sedan by 2004. Early 2000 all three manufacturer presented their prototypes to the press and Vice President Gore. The prototypes do come close to meeting the 80 mpg target, but contain so many exotic technologies and materials that further development into production-ready vehicles was considered not viable. Furthermore the propulsion systems used were based on diesel engines which did not meet the EPA's Tier 2 emission standards. The government PNGV spending amounted to $ 814 million, while the industry spent over $ 980 million. PNGV was abandoned and replaced by Freedom Car programme in 2002, which is a public-private partnership, geared towards developing a hydrogen fueled vehicle of the future, focusing on the research needed to develop technologies such as fuel cells and hydrogen from domestic renewable sources.

For R&D on technologies to increase fuel economy of heavy duty trucks the US government coordinates and sponsors the 21st Century Truck Programme. The programme's cost-shared investments in advanced technologies are intended to lead to production prototypes within 10 years.

2.4.3 Japan

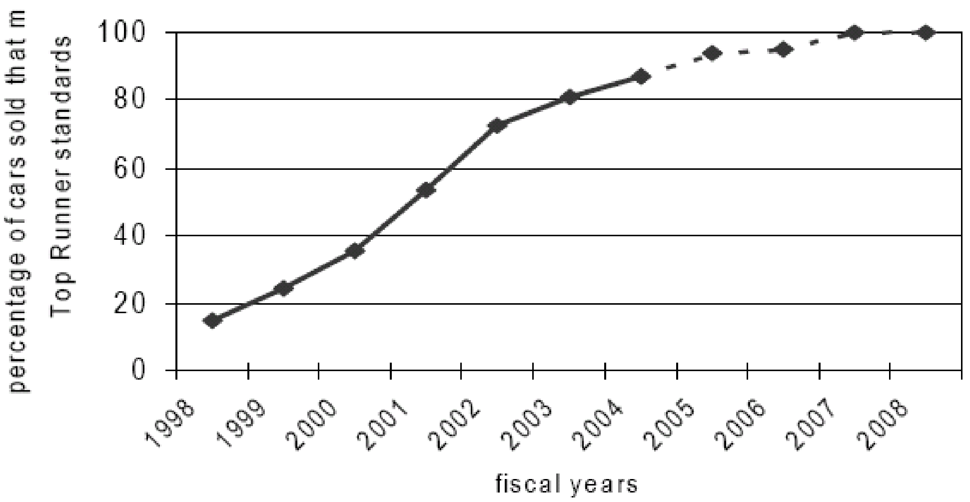
In Japan a policy to promote fuel efficient cars is based on the 'top runner approach'. For different weight classes target standard values (expressed in km/l on the Japanese 10-15 test cycle) are set which are based on the fuel economy of the most fuel efficient vehicle on sale in that class at the time the targets are set. For petrol vehicles the target year is 2010, for diesels it is 2005. Separate standards are set for petrol and diesel. For trucks and buses Japan has also set target standard values which aim at a fuel economy improvement of about 12% between 2002 and 2015. An evaluation of the Top Runner Approach can be found in (SEPA, 2005).

Table 3 Energy efficiency standards for passenger cars under the Top Runner Program (unit = km/l on the 10/15 mode test)

Parameters	Type of fuels used		
Weight (kg)	Gasoline	Diesel	Liquefied petroleum gas
Less than 703	21.2	18.9	15.9
703-828	18.8	18.9	14.1
828-1016	17.9	18.9	13.5
1016-1266	16.0	16.2	12.0
1266-1516	13.0	13.2	9.8
1516-1766	10.5	11.9	7.9
1766-2016	8.9	10.8	6.7
2016-2266	7.8	9.8	5.9
2266 and above	6.4	8.7	4.8

Source: SEPA, 2005.

Figure 18 Change in the number of cars sold that meet the Top Runner standards



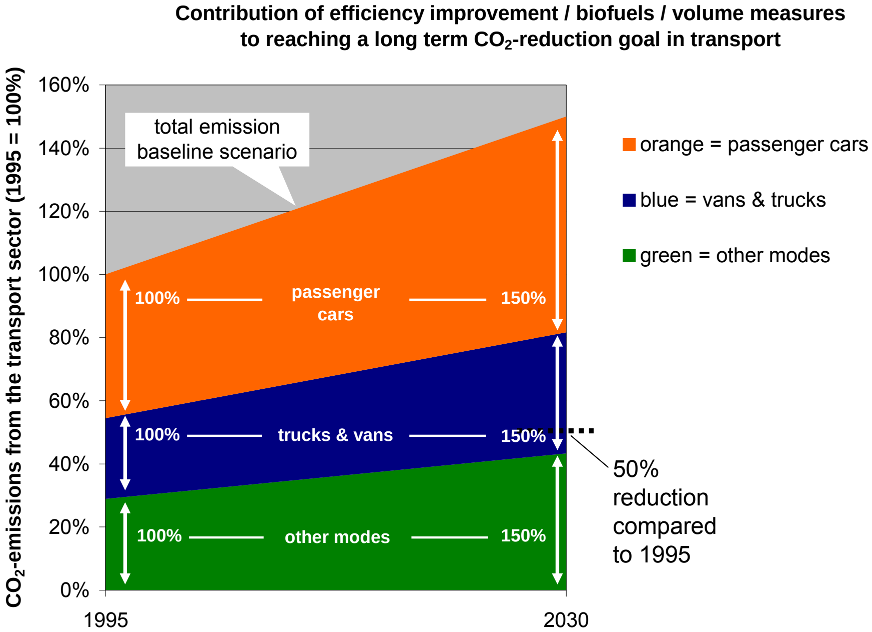
Source: SEPA, 2005.

2.5 Trade-off between efficiency improvement, structural measures and volume control

Figure 19 to Figure 21 show a hypothetical exercise which illustrates the role of efficiency improvements in reaching an ambitious long term CO_2 reduction goal for the transport sector and the trade-off with or necessity for additional other measures, especially the application of biofuels and measures to reduce (the growth of) transport volume. The example assumes a baseline scenario with a 50% increase of CO_2 emission from passenger cars, freight transport (vans and trucks) and other transport modes between 1995 and 2030 as depicted in Figure 19. The vertical axis is the total CO_2 emission of the transport sector with the

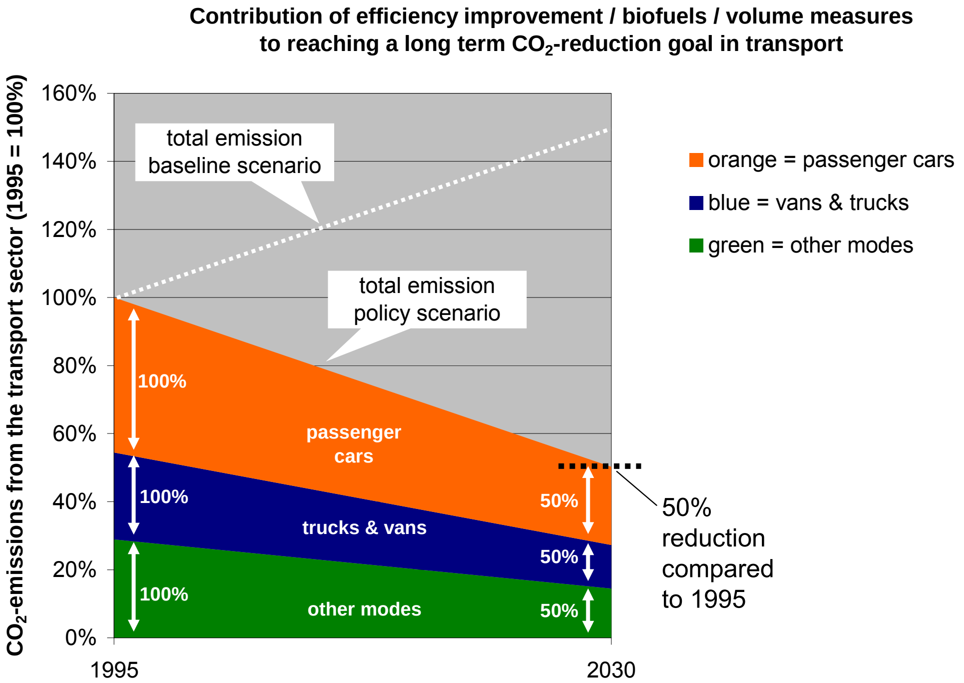
1995 value set to 100%. Various scenario studies predict growths of this magnitude. It is assumed in this baseline that CO_2 emission factors remain more or less constant after 2010 in the absence of new CO_2 policies for the transport sector, so that volume growth directly translates into an equivalent growth in CO_2 emissions.

Figure 19 Hypothetical example of the contribution of efficiency improvements, biofuels and volume measures to reaching a 2030 CO_2-reduction target in the transport sector: General growth trends for CO_2 emissions from passenger cars, trucks & vans and other modes in the baseline scenario



For the long term many governments have specified the ambition to reduce CO_2 emissions by 40 to 60% compared to 1995 or 1990. In this example a goal of 50% is taken which is assumed to be applied equally to all sub-sectors of the transport sector (in this case: passenger cars, trucks & vans, other modes). The resulting desired development of CO_2 emissions in the policy scenario is depicted in Figure 20.

Figure 20 Hypothetical example of the contribution of efficiency improvements, biofuels and volume measures to reaching a 2030 CO_2 reduction target in the transport sector: Development of CO_2 emissions from passenger cars, trucks & vans and other modes in a policy scenario aiming at a 50% reduction of CO_2 emissions compared to 1995

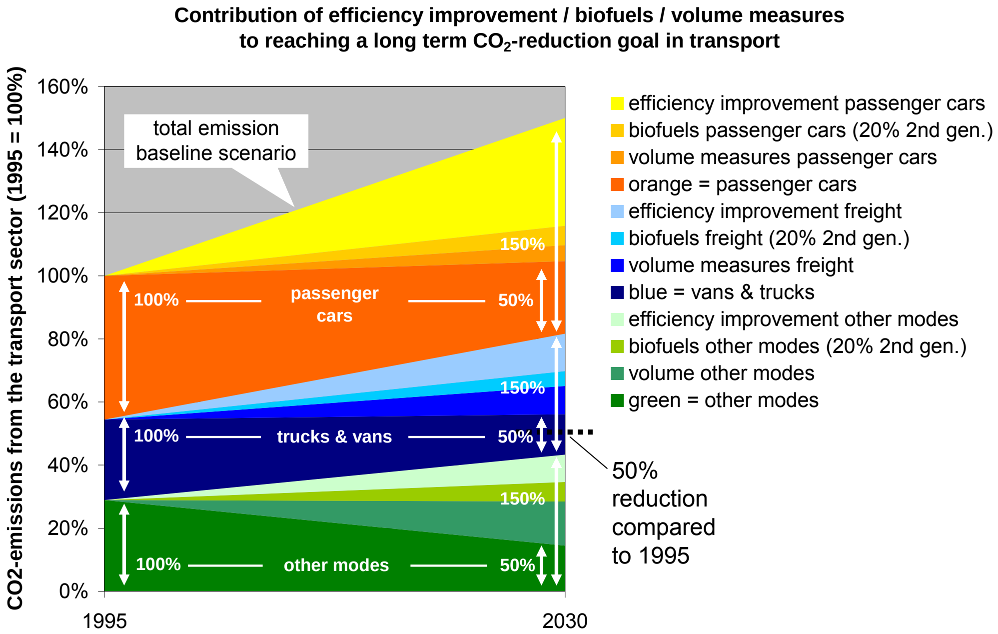


The question now in which way the targets of the policy scenario can be met.

- **Efficiency improvement**: As a starting point let us assume that for passenger cars a CO_2 reduction potential at the vehicle level of 50% compared to the 2030 baseline is possible. This is a very optimistic estimate of the potential which assumes that average fleet in 2030 could consume 3 to 4 l/100km on average. This is in principle attainable through technical measures (including hybridisation) and a certain degree of vehicle down-sizing. For freight transport we assume a reduction potential at the vehicle level of 40% for vans and 25% for trucks (see section 3.1 for technical options). The reduction potential for trucks and vans is smaller as a result of the smaller difference between installed engine power and average engine load.
- **Biofuels**: As a second reduction step for passenger and freight transport the graph we assume that for all modes 20% of the consumed fuel (petrol, diesel, kerosene, etc.) is replaced by 2nd generation biofuels with a Well-to-Wheel (WTW) CO_2 emission reduction of 90%. For the given time period and taking into account the competition with other sectors for the available (land for cultivation of) biomass 20% can be considered an optimistic assumption.
- **Volume**: If for a given sub-sector (passenger cars, trucks & vans, other modes) the total reduction potential resulting from adding the above potentials of efficiency improvement and biofuels is not sufficient to meet the goal of 50% reduction compared to 1995, then the remaining reduction has to be achieved through a reduction of the transport performance (volume) of that subsector compared to the baseline.

Figure 21 shows for all sub-sectors the contribution of efficiency improvements, biofuels and possible volume measures to reaching the 2030 CO_2 reduction target as specified in Figure 20. For each of the transport modes the (growth of the) CO_2 emission is indicated in a specific colour. In different shades of the same colour the potential reductions related to efficiency improvement, biofuels and necessary volume reduction are indicated for each sub-sector separately.

Figure 21 Hypothetical example of the contribution of efficiency improvements, biofuels and volume measures to reaching a 2030 CO_2 reduction target in the transport sector: Shares of efficiency improvement, biofuels and volume reduction in reaching a 50% CO_2 emission reduction per sub-sector (passenger cars, trucks & vans, other modes) compared to 1995



Given the above described optimistic assumptions on the reduction potential of efficiency improvement and biofuels, Figure 21 clearly shows that for each sub-sector also volume measures are required to reach a long term reduction goal of 50% compared to 1995. The level of allowed volume growth compared to 1995 resp. 2030 is given in Table 4. All sub-sectors require a volume reduction compared to the baseline situation for 2030. Compared to 1995 the passenger car sector could still grow while meeting the 2030 CO_2 target, though significantly less than the 50% of the baseline scenario. For vans & trucks and for the other modes even a net reduction of transport volumes compared to 1995 is necessary for reaching a 50% reduction target.

Table 4 Allowed growth of the 2030 transport volume in the policy scenario relative to 1995 and relative to the 2030 baseline

	Allowed 2030 volume growth relative to	
	1995	2030 baseline
Passenger cars	23%	-18%
Vans & trucks	-11%	-41%
Other modes	-24%	-49%

Obviously the required contribution from volume measures will depend strongly on the assumed autonomous growth of CO_2 emissions in the baseline scenario (which depends e.g. on economic growth) and on the effectiveness of policy measures to be implemented for promoting the use of efficient vehicles and biofuels. Furthermore it makes sense to divide the reduction of CO_2 emissions differently over the sub-sectors. Instead of a uniform 50% target reductions it is more likely that the reductions are divided in relation to the CO_2 abatement costs in the different sub-sectors. Nevertheless, the hypothetical example presented above clearly shows that it is unlikely that ambitious long-term CO_2 reduction goals can be achieved solely by technical measures. Volume measures will be required to augment efficiency improvement and the application of biofuels.

3 Technical and non-technical measures to improve efficiency

3.1 Road transport

In road transport energy efficiency can be improved by means of technical and non-technical measures. These are discussed separately in the sections below.

3.1.1 Technical measures at the vehicle level

Conventional technology as 'moving target'

In recent years various new technologies have been developed and proposed as cleaner and more efficient alternatives for the conventional car on petrol or diesel. Important examples are natural gas vehicles, electric vehicles, hybrid vehicles and fuel cell vehicles. A common error in the presentation of these technologies is that they are often compared with the status of conventional technology at that time. However, the lead time between development and actual large scale market penetration of a new technology often spans several decades. Over the past two decades the environmental performance and energy efficiency of conventional vehicles has improved greatly. Since the introduction of emission limits the emissions of petrol cars have decreased by a factor of 20. With the introduction of particulate filters and possibly $deNO_x$ after treatment a similar reduction will be achieved in diesel vehicles over the next 5 to 10 years. In the end this results in so-called 'zero-effect level' emissions: emissions which are so low that they no longer cause environmental problems. In relation to air quality issues, the benefits of zero-emission technologies such as electric and fuel cell propulsion thus have already evaporated to a large extent and will be negligible some ten years from now. A similar development may take place in relation to energy efficiency. The combination of engine improvements, hybrid propulsion, improved aerodynamics, reduced weight and various other technologies will allow a reduction of the fuel consumption of petrol and diesel cars by 30 to 50% compared to the present situation. This will reduce the absolute fuel consumption benefits of fuel cell vehicles.

In general technical measures for improving energy efficiency of road vehicles can be grouped into the following categories:

- Combustion engine efficiency improvements.
- Powertrain efficiency improvements (advanced gearboxes).
- Alternative propulsion systems (hybrid, fuel cell, battery-electric).
- Weight reduction.
- Reduction of resistance factors: improved aerodynamics, low rolling resistance tyres, low viscosity lubricants.
- Energy efficient auxiliaries: improved air conditioning systems, water pumps, electric power steering, et cetera.

Furthermore the average fuel consumption and CO_2 emissions of the fleet can be reduced if consumers would buy smaller and less powerful cars.

When looking at technical measures for improving fuel efficiency of passenger cars it is useful to make a distinction between options that can be used in the short to medium term and options that might become viable in the long term.

Options for passenger cars and vans in the short term

Table 5 presents a list, identified in a recent study for the European Commission (TNO, 2006), of technical options which could be used to improve the fuel economy and reduce CO_2 emissions of passenger cars on petrol and diesel in the period between 2002 and 2012. The options for which a reduction percentage was given were taken into account in an assessment of the costs for reducing the type approval CO_2 emissions from new vehicles form 140 g/km to 120 g/km.

As can be seen from the list, the number of options for petrol cars is larger than for diesel vehicles. The reason for this is that through the introduction of DI engines (with turbo-charging) diesel vehicles have already made a significant step in fuel efficiency improvement in the period before 2002. Most of the engine-based measures have in common that they improve the part-load efficiency of the combustion engine. The essence of various hybrid configurations on the other hand is that part-load operation is avoided. Further efficiency improvement then comes from recuperation of braking energy.

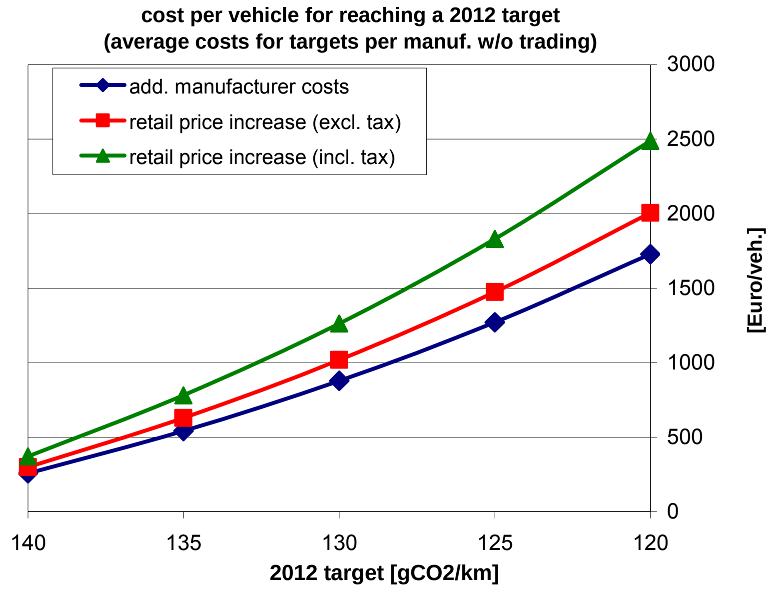
Based on a survey of available literature (e.g. (IEA, 2005; CARB, 2004; Ricardo, 2003; Concawe, 2006)), data received from the automotive industry through detailed questionnaires, and expert judgement the CO_2 reduction potential and costs of each of these options were assessed. In TNO (2006) compatible options from the list above were combined into packages of measures of which the overall CO_2 reduction and costs were assessed. Results were translated into cost curves for various vehicle size segments that were used to assess the overall costs and cost effectiveness of reaching a reduction of new vehicle CO_2 emissions beyond the 140 g/km target as set by the industry self-commitments for 2008/9. The resulting average costs at the vehicle and CO_2 abatement costs are displayed in Figure 22 and Figure 23. Abatement costs in Figure 23 are calculated based on additional vehicle costs exclusive of taxes minus the net present value of the real-world fuel savings exclusive of taxes over the lifetime of the vehicle, divided by the lifetime CO_2 emission reduction including Well-to-Tank GHG emissions.

Table 5 Technical options to improve fuel economy and reduce CO_2 emissions of passenger cars on petrol and diesel in the period between 2002 and 2012

	Petrol vehicles		Diesel vehicles	
Engine	Reduced engine friction losses	4%	Reduced engine friction losses	4%
	DI / homogeneous charge (stoichiometric)	3%	4 valves per cylinder	--
	DI / Stratified charge (lean burn / complex strategies))	10%	Piezo injectors	--
			Mild downsizing	3%
	Medium downsizing with turbocharging	10%	Medium downsizing	5%
	Strong downsizing with turbocharging	12%	Strong downsizing	7%
	Variable Valve Timing	3%		
	Variable valve control	7%		
	Cylinder deactivation	--	Cylinder deactivation	--
	Variable Compression Ratio	--		
	Optimised cooling circuit	1.5%	Optimised cooling circuit	1.5%
	Advanced cooling circuit + electric water pump	3%	Advanced cooling circuit + electric water pump	3%
			Exhaust heat recovery	1.5%
Trans-mission	Optimised gearbox ratios	1.5%	6-speed manual/automatic gearbox	--
	Piloted gearbox	4%	Piloted gearbox	4%
	Continuous Variable Transmission	--	Continuous Variable Transmission	--
	Dual-Clutch gearbox	5%	Dual-Clutch gearbox	5%
Hybrid	Start-stop function	4%	Start-stop function	3%
	Start-stop + regenerative braking	7%	Start-stop + regenerative braking	6%
	Mild hybrid (motor assist)	11%	Mild hybrid (motor assist)	10%
	Full hybrid (electric drive capability)	22%	Full hybrid (electric drive capability)	18%
Body	Improved aerodynamic efficiency	1.5%	Improved aerodynamic efficiency	1.5%
	Mild weight reduction	1%	Mild weight reduction	1%
	Medium weight reduction	2.5%	Medium weight reduction	2.5%
	Strong weight reduction	6%	Strong weight reduction	6%
Other	Low rolling resistance tyres	2%	Low rolling resistance tyres	2%
	Electrically assisted steering (EPS, EPHS)	2.5%	Electrically assisted steering (EPS, EPHS)	2.5%
	Efficient alternator	--	Efficient alternator	--
	Heat batteries for accelerated engine warm-up	--	Heat batteries for accelerated engine warm-up	--

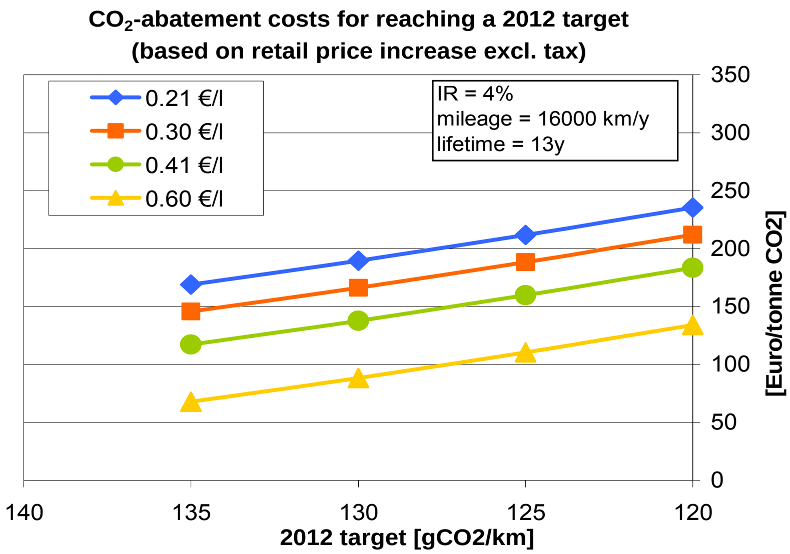
Notes:
- *Reduced engine friction losses:* includes low friction engine and gearbox lubricants.
- *Mild downsizing with turbocharging:* ≈ 10% cylinder content reduction.
- *Medium downsizing with turbocharging:* ≈ 20% cylinder content reduction.
- *Strong downsizing with turbocharging:* ≈ 30% cylinder content reduction.
- *Mild weight reduction:* ≈ 5% reduction of weight on Body-In-White.
- *Medium weight reduction:* ≈ 15% reduction of weight on Body-In-White.
- *Strong weight reduction:* ≈ 30% reduction of weight on Body-In-White.

Figure 22 Average additional costs per vehicle for reaching various 2012 targets compared to the 2008 situation



Source: TNO, 2006.

Figure 23 CO_2 abatement costs (in Euros per tonne of CO_2 avoided) of reaching various 2012 targets through technical efficiency improvement measures at the vehicle level, depending on fuel costs[7]



Source: TNO, 2006.

Most of the technologies listed in Table 5 can also be applied to light duty commercial vehicles (vans). CO_2 reduction potentials may be somewhat different

[7] The fuel cost values (excl. taxes) of 0.21, 0.30, 0.41 and 0.60 €/liter correspond to an oil price of respectively 25, 36, 50 and 74 €/bbl.

due to the different duty cycle experienced by engines used in vans[8]. Due to the fact that the baseline situation for vans is different reaching a certain absolute level of CO_2 emission reduction may be achieved more cost-effectively in vans than by further reducing the CO_2 emission of new passenger cars beyond the 140 g/km target of 2008/9.

Important conclusions from TNO (2006) are:

- Without changes in vehicle sales over segments a significant share of hybrid vehicles is necessary to reach a type approval CO_2 emission value of 120 g/km in 2012.
- CO_2 abatement costs for reducing CO_2 emissions from passenger cars beyond the 2008/9 target of 140 g/km can be significantly higher than current CO_2 abatement costs in other sectors[9].
- The CO_2 abatement costs for reducing CO_2 emissions from passenger cars depend strongly on oil price and the resulting cost of fuel.
- Reducing new vehicle CO_2 emissions from 140 to 120 g/km involves additional vehicle costs which are higher than the lifetime fuel cost savings. This is true for prices exclusive and inclusive taxes (costs to society vs. cost to consumers).
- Especially at higher fuel prices the calculation of CO_2 abatement costs is very sensitive to variations in the assessed additional costs at the vehicle level (see section 3.3).

Efficiency improvement potential for passenger cars in the medium term

The hybrid Toyota Prius has a combined fuel consumption (urban + extra-urban) on the type approval test cycle of 4.3 l/100km. This is about 35% lower than that of comparable conventional vehicles. The hybrid version of the Honda Civic and the Lexus R400h have a 23% resp. 20% lower fuel consumption than their conventional counterparts. In the case of the Prius the 35% reduction is not only the result of the hybrid drive. Additional fuel economy improvement is caused by additional measures such as weight reduction, improved aerodynamics, and low rolling resistance tyres. In real life driving also the electric power steering and the electric drive for the air conditioner contribute to lower fuel consumption.

Obviously the Prius is not the final stage of technological development with respect to fuel efficient cars. Through further improvement of the applied technologies and further system integration and optimisation an overall fuel consumption reduction of 50% seems feasible. Combination of hybrid drive with a diesel engine is expected to yield the lowest fuel consumption. Such an approach has recently been announced by PSA, which showed diesel-hybrid concept versions of the Peugeot 307 and Citroën C4. In the medium term the combination of hybrid drive with optimised engines and various other technologies reducing the energy demand of the vehicle may be expected to result in vehicles consuming 3 to 3.5 l/100km on the type approval test, with a performance similar to or better than that of present day vehicles. Learning effects, economies of

8 Smaller power-to-weight ratio and different driving pattern (speed as function of time), resulting in different shares of part-load and full load operation.

9 The price of CO_2-emission credits under EU-ETS is currently 15 to 20 €/tonne.

scale and further innovations may be expected to also significantly reduce the additional costs of fuel efficient vehicles.

Options for trucks and buses in the short and medium term

Fuel costs are a significant part of the operating costs of heavy duty vehicles. For this reason efficiency improvement has traditionally been an important driver in vehicle and engine developments for freight transport. Furthermore the engine in a heavy duty application is generally used in a more energy efficient way[10]. As a consequence the potential for further efficiency improvement in road vehicles for freight transport is rather limited, especially in the sector of long distance transport. For urban distribution trucks and city buses the driving pattern is generally more dynamic, so that engine improvements increasing part load efficiency and application of a hybrid powertrain may offer significant fuel economy benefits.

Technical options for improving energy efficiency in trucks and buses are:

- Low rolling resistance tyres (≈6%).
- Engine improvements (≈5%).
- Reduction of air resistance (≈6%).
- Increased weight limit to 44 or 60 tonne (≈9 - 20%).
- Lightweight construction(≈7%).
- Hybrid propulsion for city buses and distribution trucks (≈15%).

The percentages between brackets are fuel consumption reduction values for new vehicles.

Long term options

For further improvement of the energy efficiency of passenger cars in the long term, options such as fuel cells or battery-electric propulsion come into view. Application of advanced light-weight materials will further reduce the energy demand of vehicles, provided that the costs of these materials can be brought to an acceptable level. In the field of energy-efficient auxiliaries also significant innovations may be expected.

In 1997 various car manufacturers promised that they would bring their first commercial fuel cell vehicles to the marketing 2003. In the meantime the consensus is that this will not happen before 2015 and that large scale application of fuel cell vehicles is not likely to occur before 2030. By that time the air polluting exhaust emissions from vehicles with an internal combustion engine will have been reduced to such low levels that the ‘zero emission’ quality of fuel cell vehicles will be of no value from an air quality point of view. Also the efficiency advantage of fuel cell vehicles compared to conventional or hybrid vehicles with a combustion engine will have greatly diminished.

The conversion efficiency of a fuel cell system may be of the order of 50%, while a combustion engine has a peak efficiency of around 40% but mostly operates at much lower efficiency at part-load. Nevertheless this does not necessarily make fuel cell vehicle more energy efficient than conventional vehicles. The reason for

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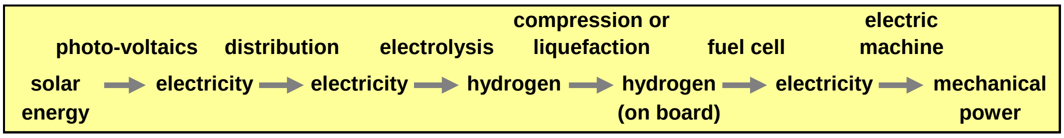
[10] Smaller power-to-weight ratio than passenger cars and use of optimised gearbox.

this lies in the origin of the fuel that is used and the energy conversion steps occurring in the well-to-wheel energy chain. Fuel cell vehicles can be made to run on fossil fuel by equipping them with an on board reformer. Various studies, however, have shown that the relatively poor efficiency of this reformers reduces the overall vehicle efficiency to such an extent that fuel cell vehicles with on-board reformer are not more efficient than future conventional diesel vehicles of diesel-hybrid vehicles. Concawe (2006) shows that a fuel cell vehicle running on hydrogen produced with fossil energy may emit up to a factor of 2 more CO_2 in the WTW-chain than a comparable conventional vehicle when electrolysis is used and about the same amount of CO_2 as a conventional vehicle when steam-reforming from natural gas is used. Only if the hydrogen is derived from renewable sources will the WTW CO_2 emission be lower. In that case, however, still the number of conversion steps in the chain is such that fuel cells vehicles may turn out to be a very inefficient and therefore not very cost-effective application for using sustainable energy (see Figure 24).

Figure 24 Energy conversion steps in the well-to-wheel energy chain from solar electricity for fuel cell propulsion



Application of fuel cells and hydrogen in the transport sector will thus only make sense if the hydrogen is derived from CO_2 neutral sources (which may included fossil sources combined with CO_2-storage or thermonuclear production), but even then the question is whether the transport sector should be the prime market for hydrogen. Initially the direct use of electricity from renewable or otherwise CO_2 neutral resources of energy (which for a long time will be relatively scarce and expensive) in other sectors seems to be more cost effective (CE, 2006a).

From the perspective of efficient use of renewable resources battery-electric vehicles would be more favourable as they may have an even higher WTW efficiency than fuel cell vehicles. About 10 year ago battery-electric vehicles seemed close to market breakthrough, but in the end did not become a success due to their limited driving range and the high cost and limited reliability and durability of the available battery technologies. With sufficient R&D efforts battery-electric vehicles might in the long run again become a promising option.

3.1.2 Non-technical measures

Besides technical measures also a number of non-technical measures can be implemented to reduce fuel consumption in passenger cars, vans and heavy duty vehicles.

Eco-driving
The main elements of a fuel efficient driving style (eco-driving) are:

- Maintaining a low engine rpm by early shifting to higher gear during acceleration and driving in the highest possible gear at more constant speeds. At a given power demand the engine load (torque) is higher when the engine is operated at low rpm. At higher loads the engine's efficiency is better than under part-load conditions.
- Anticipative and smooth driving in order to avoid unnecessary (strong) accelerations and to reduce the unnecessary waste of kinetic energy by strong braking.

Depending on their initial driving style drivers of passenger cars may save between 5 and 25% fuel directly after an eco-driving course. TNO (2006) estimates, however, that the long term average improvement is of the order of 3%. The potential may be improved by the use of a gear shift indicator or a fuel economy meter.

Although the maximum reduction potential for trucks is smaller than for passenger cars, for this application the fuel consumption reduction potential of eco-driving is estimated to be 5%. The reason for this higher potential lies in the fact that professional drivers may be expected to better maintain an efficient driving style and that they may be expected to receive more intensive or more frequent training. The CO_2 abatement costs associated with ecodriving depend on the costs of lessons, the assumed effectiveness and the fuel price. Both for passenger cars and for trucks the abatement costs are expected to be negative for most combinations of fuel price and costs of lessons (TNO, 2006).

In the long term the effectiveness of eco-driving is expected to decrease as many technical measures implemented to improve energy efficiency of vehicles do this by improving the part-load efficiency of the engine.

Traffic measures
Various traffic measures can be implemented to smoothen traffic flow and reduce driving dynamics. Examples are synchronisation of traffic lights and lower speed limits on congested highways. These undoubtedly reduce fuel consumption and CO_2-emissions per vehicle kilometre. On the other hand such measures also tend to improve the flow of traffic and to reduce congestion, which may result in increased traffic. This may counteract possible benefits per vehicle.

Improved logistics
According to Pischinger (1998) and Bates (2001) improved logistics could lead to a reduction in road freight kilometres resulting in 10 to 20% fuel consumption reduction based on the following measures:

- Improved logistic organisation.
- Better co-ordination between all transport operators (also intermodal).
- Improved route planning.

CO_2-avoidance costs are estimated to be negative, meaning that the cost of implementation of these measures are lower than the total cost savings. The resulting reduction of the overall cost of transport may in turn increase transport demand which may (partly) counteract the absolute reduction in fuel consumption and CO_2 emissions.

3.2 Other transport modes

For other transport modes the number of technical efficiency improvement measures and the available information seem to be more limited. Below a brief discussion of rail transport, aviation and shipping is given.

3.2.1 Rail transport

Diesel trains are responsible for only 0.5% of the EU25 CO_2 emissions. Efficiency improvement for these vehicles therefore does not have a high policy priority. The efficiency of modern electric trains has improved greatly due to the use of power electronics and regenerative braking. The effects of this, however, are partly compensated by the relatively high energy consumption per passenger kilometer of high-speed trains. For electric trains further well-to-wheel efficiency improvements or CO_2 emission reductions are achieved by the fact that electricity generation is part of the EU ETS emission trading system (CE, 2006a).

3.2.2 Aviation

Despite improvements in fuel efficiency of 1 to 2% per year, it is foreseen that the CO_2 emissions from aviation worldwide will increase by some 110% in the period 2002-2025. The present contribution of aviation to CO_2 emissions in the EU is about 3%. Its share in overall CO_2 emissions from the EU transport sector is about 12%. Eurocontrol predicts an annual growth of the number of flights in Europe of 3%. The growth in passenger kilometers is expected to be even higher as the traveled distances tend to increase. Efficiency improvement has high priority in the aviation industry. European aircraft manufacturers aim to reduce the fuel consumption per passenger kilometer of new aircraft by 50% between 2000 and 2020.

For aviation is important to also take the non CO_2 related impacts on climate change into account. The are partly heating effects, partly cooling effects, such as atmospheric chemical reactions on the basis of NO_x which increase ozone concentrations in the atmosphere (heating) and which convert methane (cooling), soot emissions from aircraft engines (heating), sulphur aerosols (cooling), and formation of condensation trails (cooling in daytime and heating at night) and possibly cirrus clouds. IPCC estimates the total climate change impact of aviation (excluding the effect through formation of cirrus clouds) to be 2 to 4 times higher than the impact of CO_2 emissions alone. More recent studies indicate in the direction of a factor of 2.

3.2.3 Shipping

In terms of tonnes transported shipping is the largest transport mode in the EU. Sea shipping has a higher share than inland shipping. In general shipping is a more energy efficient means of transportation than rail, aviation and road transport (in MJ/tonnekm). As a result of the growth of the shipping sector, however, the contribution of shipping to world-wide emissions is significant and growing. Sea and inland shipping together have a share of 14% in the greenhouse gas emissions from transport in the Europe. Technical and operational measures to improve the fuel efficiency of ships do exist but little information is available about the cost effectiveness of these measures.

3.3 Considerations on cost effectiveness

Measures to improve energy efficiency obviously result in fuel cost savings. These, together with possible other changes in operation and maintenance costs, can be deducted from the investment cost associated with the measure to calculate its cost effectiveness. More generally, for measures that reduce CO_2 emissions one can calculate CO_2 abatement costs by dividing the present value of the net lifetime costs by the CO_2 emission reduction over the lifetime of the measure. The result is expressed in Euros per tonne of CO_2 avoided (€/tonne).

From a purely economic point of view, CO_2 reduction goals should in principle be met by implementation of the most cost effective measures. For this reason a comparison of CO_2 abatement costs between options is useful. These options can be technical or policy measures within the same (sub)sector or even options in different economic sectors. In the calculation of CO_2 abatement costs and in the comparison of results from different studies, however, care should taken of the following issues:

- Formulas for calculating CO_2 abatement costs are very sensitive to variations in the input data due to an inherent leveraging effect. If for example the fuel cost savings amount 60% of the investment costs, then a variation of 10% in the estimate of the investment costs leads to a 25% variation in calculated abatement costs. In more extreme cases abatement costs may even change from positive to negative as a result of relatively small changes in the estimated investment costs.
- Especially for options with relatively high fuel costs savings the CO_2 abatement costs depend strongly on fuel price assumptions. In the transport sector, which strongly relies on oil, fuel prices tend to be more volatile than in other sectors. Assessments should preferably be made for different levels of fuel costs, and comparisons should be made between numbers derived under the same assumptions for fuel prices.
- Ex-ante assessments generally tend to overestimate cost. A recent comparison between ex-ante and ex-post assessments of environmental technologies and policies (IVM, 2006) has shown that the difference between estimated costs and the real costs for application of environmental measures may be a high as a factor of 2 to 6. Unfortunately the reasons for this overestimation seem to differ from case to case. In all cases, however, it seems clear that in general not sufficient information is available to

adequately assess the possible impacts of innovation, learning effects and economies of scale on the development over time of costs and performance of new technologies.

- Different studies include different cost aspects and impacts in the calculation of abatement costs. In a 1st order approach abatement costs can be assessed solely on the basis of the additional costs of the technology and its impacts on operating costs (including fuel cost savings). More advanced approached, however, use modelling tools to also estimate 2nd order effects of changes in the costs of a service or product on e.g. the demand for that service or product and on resulting overall costs, fuel use and emissions. In the case of transport technologies this includes impacts on sales distributions over different vehicle market segments, modal shifts and overall transport volume. Impacts on emissions and possible other impacts (e.g. safety) can furthermore be monetised into the calculation by means of external cost assessments.

Straightforward comparison of CO_2 abatement costs generated by different studies is therefore not possible. Also the absolute level of CO_2 abatement costs calculated by a given study should be judged in the context of the applied methodology and assumptions.

4 Policy measures to promote energy efficiency in the transport sector

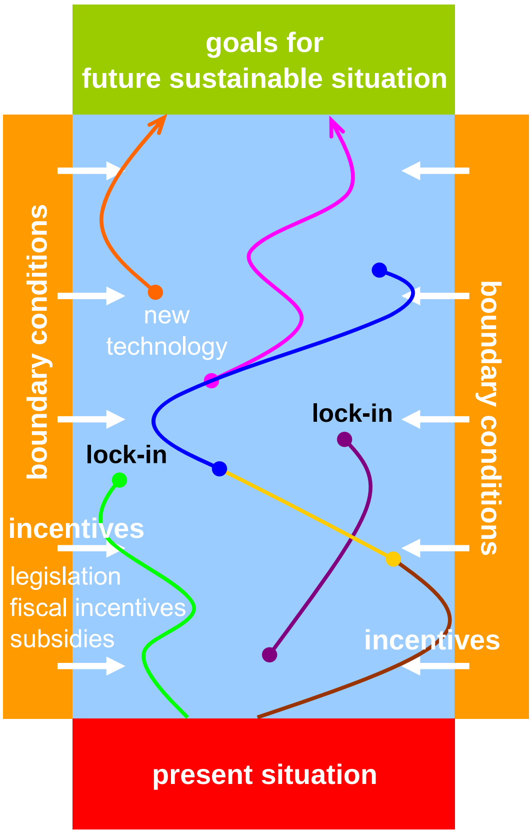
4.1 Introduction

In freight transport, aviation and shipping fuel costs are a large part or the operating costs so that these sectors pay significant attention to efficiency improvement. Nevertheless it is found that even in these subsectors not all cost effective measures are being implemented. In the passenger car sector purchase decisions are taken in a less rational or at least bounded rational way, taking into account many practical criteria and personal preferences. As a result energy efficiency is on average not playing a significant role in consumer behaviour related to cars. For this reason governments need to implement policy instruments to promote the application of energy efficient technologies and behaviour.

4.1.1 Managing energy transitions

Reaching long term energy efficiency and CO_2 reduction goals in the transport sector requires a transition at the system level from the present environmentally non-sustainable situation to a future situation that is more inherently sustainable. A blue-print for that future system, however, does not exist. There is not one technical solution that is able to solve all environmental and energy problems associated with the transport sector. Furthermore, solutions for improving the sustainability of transport also have to be sustainable from an economic point of view, and as such have to fulfil a wide range of other demands. In the end it is the market, which at every point in time has to decide which options meet all demands in the most optimal way. Without government intervention, however, the market is not likely to develop and/or implement the required sustainable solutions, especially not those options that lead to a net cost increase but which may be necessary to meet ambitious long term goals. For this reason a gradual approach is necessary in which concrete intermediate goals are set based on a clear perspective of what the long term sustainability goals are, and in various policy instruments are used to stimulate the various stakeholders in the market to explore transition routes to meet these intermediate goals. These policy instruments may be regulatory requirements setting boundary conditions to the environmental impact of technologies or activities, but can also be incentives to stimulate e.g. R&D or early market introduction of new technologies. The overall policy vision on this process is often referred to as 'transition management'. A graphical illustration of the above is depicted in Figure 25. By means of step-wise changes, involving either a change in propulsion technology, a change in fuel / energy carrier or a new infrastructure, a transition path may lead from a non-sustainable system in the present situation to a sustainable system in the future situation. Transition paths, however, may also end in a 'dead-lock' situation, where further steps to improve sustainability of the system are either not available or not economically feasible. In the future also new systems or technologies may emerge that replace current systems.

Figure 25 Energy transition management



4.1.2 Generic vs. specific policy instruments

This chapter describes various options for policy instruments to promote energy efficiency and discusses these options in terms of pros and cons, implementation aspects, relations with other sectors, etcetera. Policy instruments aiming to improve energy efficiency can be grouped into generic and specific instruments.

Generic instruments create generally favourable conditions that promote the use of energy efficient technologies or behaviour or set overall fuel consumption or CO_2 reduction goals to be met irrespective of the technology used. They do not stimulate a specific technical or non-technical option. Generic instruments usually also target a wide range of stakeholders. Specific instruments may promote specific measures or actions from specific stakeholders. Within the context of generic policy instruments additional specific instruments may be used to correct market imperfections or to create temporary incentives for specific technologies.

Regulation, CO_2 labelling and government campaigns promoting eco-driving are examples of specific measures. Emission trading and CO_2 differentiated taxation are examples of generic instruments.

4.2 Regulation

Setting regulatory emission limits is a policy instrument that forces manufacturers to improve the energy efficiency of vehicles. Regulatory limits can be set on various levels. In analogy to emission limits for air polluting exhaust gases CO_2 emission limits (in g/km) can be set at the vehicle level. Targets, however, can also be set at the level of manufacturers. Manufacturers could be obliged to realise a certain sales averaged CO_2 emission (in g/km) or fuel consumption value (in l/100km). Targets at the vehicle as well as manufacturer level can be set in different ways:

- A fixed or uniform target.
- A percentage reduction target compared to a baseline situation.
- A utility-based target, in which the allowed CO_2 emission is a function of objectively measurable parameters of the vehicle that relate to the functionality of the car as perceived by users (in essence e.g. bigger or more powerful cars are allowed to emit more CO_2 or to consume more fuel).

In the case of targets at the manufacturer level the above definitions are applied in relation to the sales averaged emissions or fuel consumption. A mix of the above is possible in a system using bins (such as the proposed Californian greenhouse gas regulation). Targets set at the level of manufacturers can be accompanied by the possibility to bank or trade CO_2 credits.

Vehicle-based targets expressed as a uniform target or a percentage reduction target do not seem very practical. The first option leads to huge costs for large cars, and as a result to strong market impacts, and the second is difficult to define as car models come and go. A utility-based target appears intuitively the best and fairest option if one chooses to respect consumer choice and the resulting distribution of sales over vehicle segments to some extent. However, the viability depends on the exact formulation of the utility function *E(U)*, the allowed emissions as a function of the utility parameter *U*. Options worked out in IEEP (2004) and TNO (2006) are based on a linear function $E = a \times U + b$, with e.g. $U = V^{2/3} \times P^{1/3}$ (with *V* the vehicle's internal volume and *P* engine power) or $U = l \times w$ (pan area, with *l* the length and *w* the with of the vehicle).

Manufacturer-based targets, with or without trading, certainly are feasible and are also being discussed as ingredient for a new EU policy of CO_2 emissions of cars after 2008/9. Trading in a closed system allows manufacturers to optimise their efficiency improvement efforts in relation to their market positioning expressed in the distribution of sales over different segments, and distributes the required efforts in the most cost-effective way over all manufacturers. However, the cost can still vary substantially from manufacturer to manufacturer depending on the target definition.

Instead of a regulatory approach also an extension of the voluntary agreement / self commitments of the industry beyond 2008/9 could be considered. The success of the present voluntary agreements in reaching the target for 2008/9, however, seems questionable and for a future EU-policy voluntary agreements do not seem a preferred option anymore.

Need for appropriate type approval test procedures

CO_2 emission limits are to be based on a standardised measurement protocol included in the test procedure for type approval. Such a protocol needs to be available at the time when emission regulation enters into force. For passenger cars CO_2 emission measurement is already included in the type approval test procedures in many regions of the world (e.g. EU and other countries adopting UN-ECE regulations). For light-duty commercial vehicles CO_2 measurement has only recently been included in European type approval procedures. For heavy duty vehicles this is not yet the case. A complicating factor is that for HD vehicles type approval of emissions is carried out at the level of the engine and not of the complete vehicle. The existing procedures can be expanded to include measurement of the fuel efficiency of the engine and the related CO_2 emissions per kWh of energy delivered. Developing a type approval test procedure that is also able to measure the effects of other efficiency improving measures taken at the vehicle level may not be feasible.

Similarly type approval test procedures need to be able to deal with new, fuel efficient propulsion technologies or new fuels as soon as they come to the market. Under UN-ECE auspices the test procedures for passenger cars have been amended to include provisions for testing hybrids. Provisions for testing vehicles on hydrogen are under preparation. However, adapting the procedure for heavy duty vehicles to enable testing of hybrid powertrains is extremely difficult, again due to the fact that the test procedure is engine-based. This may at some point hinder the large scale market introduction of hybrid propulsion in HD applications.

4.3 Cap & trade systems

Another way to regulate emissions in the transport system is the definition of cap on the overall emissions. In order to allow stakeholders to meet this cap in the most cost-effective way such an approach needs to be accompanied by some form of emission trading system. Parties involved are allocated emissions (for example, based on historic trends), or can buy them at an auction. Over time the cap on overall emissions (i.e. the number of emission allowances allocated or auctioned) needs to be reduced. The price of traded emission allowances will generally be determined by the marginal costs of abatement measures in those sectors where these abatements are the most cost-effective.

This is a generic policy measure in which governments do not prescribe which technological or other measures are to be used, but allows consumers, transport companies, car manufacturers and other stakeholders to choose those reduction measures that best suit their individual situation. Financial aspects will be important in this choice but also other aspects such as comfort and travel time can play a role. The market itself is best able to make these choices.

One of the questions in a cap & trade approach is whether passenger cars and freight transport can be part of the same system or whether separate systems need to be applied. Passenger transport is less sensitive to international competition, so that the economic consequences (at the national level) of price increases in this sector will be less severe than in freight transport. People are not very likely to move to areas outside the region of the cap & trading system. On the other hand in freight transport additional costs can be avoided by hiring transport companies from outside the region or by moving production to other countries. This could be a motivation to deal with passenger and freight transport differently in the context of a cap & trading policy.

4.3.1 Aviation and freight transport in ETS

Transport sectors which are dealing with heavy international competition, such as aviation, shipping and freight transport by road, can best be incorporated in the EU Emission Trading System ETS. In these sectors a limited number of relatively large companies is active, so that an effective trading system can easily be set up under the condition that a feasible CO_2 monitoring system can be designed and implemented (see e.g. (CE, 2006a) for the case of aviation). The EU is at present seriously considering incorporation of aviation in the EU-ETS. A similar route for sea shipping is being explored in a recently contracted study for the EU.

The present price of CO_2 emission allowances under the EU ETS is around 16 €/tonne. Given the relatively high costs of many abatement options in the transport sector, the question is whether incorporation into the ETS will lead to implementation of efficiency improvement and CO_2 reduction measures in the transport sector itself. If this is not the case, then still the transport sector will help to reach overall reduction goals by buying emission allowances from other sectors and as such financing reduction measures taken in these sectors. A drawback of the situation, however, would be that is does not contribute to reduction of the dependence on imported oil nor to the innovative strength of the transport sector. For this additional, flanking policy may need to be implemented.

Freight transport by road can be incorporated into the ETS by allowing transport companies to trade emission allowances or by implementing a trading system at the level of fuel suppliers. The former would lead to a large number of involved companies, of many smaller ones produce relatively few emissions. This would lead to high costs both for the trading system as such and for the administrative actions needed at the level of transport companies. Also the difference in size between large industries under ETS and some smaller transport companies may be inappropriate. A trading system at the level of fuel producers / suppliers would have fewer trading parties. Such a system is described in section 4.3.2.

4.3.2 Alternative trading system

ETS is an open trading system covering various sectors and a wide range and large group of stakeholders / actors. Alternatively also closed trading systems can be envisaged which only cover a single (sub)sector or a specific group of stakeholders. The latter could e.g. be fuel suppliers producing fuels for road transport or the car industry.

Fuel producers can influence the Well-to-Wheel efficiency and CO_2 performance of their fuels, by implementing improved technologies for well exploitation, refining and transport of fuels, by blending biofuels into petrol and diesel or by creating niches for pure biofuels or other alternatives with lower CO_2 emissions. Fuel producers, however, do not have a direct influence on the efficiency with which these fuels are used. A closed trading system at the level of fuel suppliers, nevertheless, does seem a feasible option. Incorporation of the price of emission allowances in the fuel price will then lead to increased consumer / user demand for fuel efficient vehicles and alternative fuels and to increased supply of these technologies by car manufacturers. The main advantage of this system is the limited number of trading parties and the price transparency for other involved stakeholders (users and car manufacturers).

In the case of passenger cars individual car owners are the actors which decided about the purchase and use of energy efficient technology. Trading emission allowances at the level of individual citizens, however, leads to a very complex trading system with high transaction costs. Vehicle manufacturers do have influence on the fuel consumption per kilometre driven of the vehicles they produce, but not on the amount of kilometres driven nor on the driving style and fuel that is used (e.g. the percentage of blended biofuels). Vehicle manufacturers can therefore not be incorporated in ETS. For passenger cars, therefore, implementing a trading system at the level of fuel suppliers seems the only feasible trading option.

Such a trading system at the level of fuel suppliers can, at some stage, be incorporated in the ETS, but could also be implemented independently. The advantage of the latter is that the emission cap for the included transport sectors can be set such that fuel efficient vehicles are actually implemented so that meeting a CO_2 reduction goal also helps to meet energy security goals and stimulates innovation in the sector.

4.4 Fiscal and pricing measures

Especially in the case of passenger cars fuel efficiency and fuel costs do not play an important role in the purchasing decision. And even if these are taken into account, then consumers tend to look at savings over a shorter period than the lifetime of the vehicle. For this reason car manufacturers can only pass through part of the costs of efficiency improvement measures in the retail price of a vehicle. This market imperfection can be improved or resolved by various fiscal and pricing measures which increase the market attractiveness of fuel efficient vehicles.

The relatively high level of taxes on vehicles and fuels in Europe has convincingly led to a more fuel efficient vehicle fleet compared to e.g. the USA and other countries. Fiscal policies in Europe did not have this objective but do have this effect. The example shows that fiscal and other pricing measures can be an effective instrument to improve fuel efficiency of vehicles. In the context of a fuel efficiency or CO_2 policy fiscal and pricing measures can e implemented in different ways:

CO_2 differentiation of registration and circulation taxes
Registration tax (RT) and/or circulation tax (CT) can be designed in such a way that the level of taxation depends on the vehicle's fuel efficiency or CO_2 emissions. Although not all countries have RT, differentiation of this type of tax

appears most promising as it brings CO_2 emissions into the purchasing decision in the most direct way. CT is part of the vehicle's operating costs, which are usually not considered in detail in the purchasing decision. If CO_2 differentiation is implemented through CT then transparent information should be provided to the consumer at the moment of purchase on how CO_2 differentiated CT and fuel cost savings influence his overall costs of driving.

CO_2 differentiation can be designed in a tax neutral way with tax discounts for vehicles with below average CO_2 emissions and tax increases for vehicles with above average CO_2 emissions. Internalization of the external costs of CO_2 emissions and the need to also target the volume growth of transport and increase in average car size and performance could also justify a differentiated tax system that leads to a net increase in the average cost of driving.

CO_2 differentiation of taxation can be coupled to the systematic used for labeling. This increases transparency and is especially relevant when a relative labeling method is used (see section 4.5).

It should be noted that in many countries circulation tax is already based on cylinder content or vehicle weight, which both have a strong correlation with CO_2 emissions. As such a certain level of CO_2 differentiation thus is already in place.

Fuel excise duties
Increasing fuel excise duties will influence consumers to buy more efficient vehicles, will promote a fuel efficient driving style and will have an effect on transport volume. The increase can be related to the external costs associated with the CO_2 emissions resulting from the use of fuels.

Implementing an excise duty on kerosene would help to make the price of air travel compared to other modes more consistent with its relative environmental performance.

Road pricing
Road pricing by itself in first instance only affects travel patterns and possibly transport volume. If road pricing is differentiated according to the fuel efficiency or CO_2 emission of vehicles, it may also serve as a tool to promote the use of more efficient vehicles. Road pricing can be used to internalise various costs related to traffic on a specific road, including infrastructure and maintenance costs, accident costs and external costs related to air polluting emissions and CO_2).

Harmonisation issues
Tax regimes for passenger cars and other transport modes differ from country to country. Harmonisation of existing tax regimes would greatly facilitate the effective marketing of fuel efficient vehicles. CO_2 differentiation of vehicle related taxes should preferably be introduced in a harmonised way. As mentioned above the European Commission is proposing a level of harmonisation in (COM(2005) 261). However, European Member States, and countries in general, attribute great value to their freedom of implementing national tax regimes and will certainly want some freedom in implementing tax measures as part of their

national CO_2 policy. It therefore seems unlikely that vehicle tax harmonisation will be achieved in Europe in the sort term.

4.5 Other measures

Consumer information (e.g. labelling)

Information in itself does not change behaviour. But transparent information on energy efficiency, CO_2 emissions and the impacts on purchase and running costs are of paramount importance to allow consumers and other actors to make well-funded choices within the context created by policy measures to promote fuel efficiency or CO_2 emission reduction (emission trading, differentiated taxation, etc.). Information campaigns can furthermore help to improve the acceptance of policy measures.

CO_2 or efficiency labelling can be an important tool for providing consumer information. In its present form, as implemented in the EU, it does not seem to have a significant effect, but improved labelling schemes can be envisaged and can especially be effective if they are coupled to a registration and or circulation tax that is differentiated on the same basis as the label.

CO_2 labels can be based on the absolute CO_2 emission of vehicles as well as on the relative CO_2 performance compared to other vehicles in the same class. The latter requires a class definition, as already illustrated in the paragraph on labelling in section 2.4.1. Both systems have pros and cons, and for future labelling activities in the EU both are still an option.

Promotion of specific options

Governments can promote the application of specific technical and non-technical measures. In general stimulation of specific technical measures is not desirable, but subsidies or other types of stimulation can at some stage be useful to break through the typical chicken and egg problems associated with the early stages of market introduction of a new technology.

In Europe various governments promote the application of an energy efficient driving style. This is mainly done through information campaigns and by incorporating eco-driving into the lessons for new drivers.

Public procurement

The principle behind the use of public procurement is that through the large collective buying power of the public sector it could be possible to establish a market which is able to absorb the initially higher costs of new technologies. Manufacturers can then scale up production in this market segment and obtain sufficient economies of scale to reduce the overall costs of more fuel efficient vehicles. The benefits of this are then passed on to all consumers, thereby making the more fuel efficient vehicles more competitive in terms of cost compared to conventional vehicles; the result is that there is increased take-up of new, more fuel efficient vehicles.

The European Commission recently published a proposal for a Directive COM (2005) 634 on the promotion of clean road transport vehicles. The proposal sets a quota that 25% of the public fleet of Heavy Duty Vehicles (HDVs) weighing over 3.5 tonnes should meet the 'Enhanced environmentally friendly vehicle' (EEV) standard defined in Directive 2005/55/EC. This proposal does not deal with the CO_2 emissions of vehicles, but could serve as a starting point for formulating a policy on public procurement of fuel efficient or low-CO_2 vehicles.

R&D and demonstration

Innovation is of paramount importance for reaching ambitious long term CO_2 reduction and efficiency improvement goals. This not only concerns new technologies but also improvements in existing products and production technologies. Improvements can be incremental or revolutionary ('enabling technologies'). Subsidizing R&D is useful to make sure that new technologies are available in time and to stimulate the national (or e.g. European) industry to take a leading role in energy innovations. As such environmental and energy efficiency goals can also help to stimulate national economies.

4.6 Integration of energy efficiency measures in transport policies at the urban, national and international level

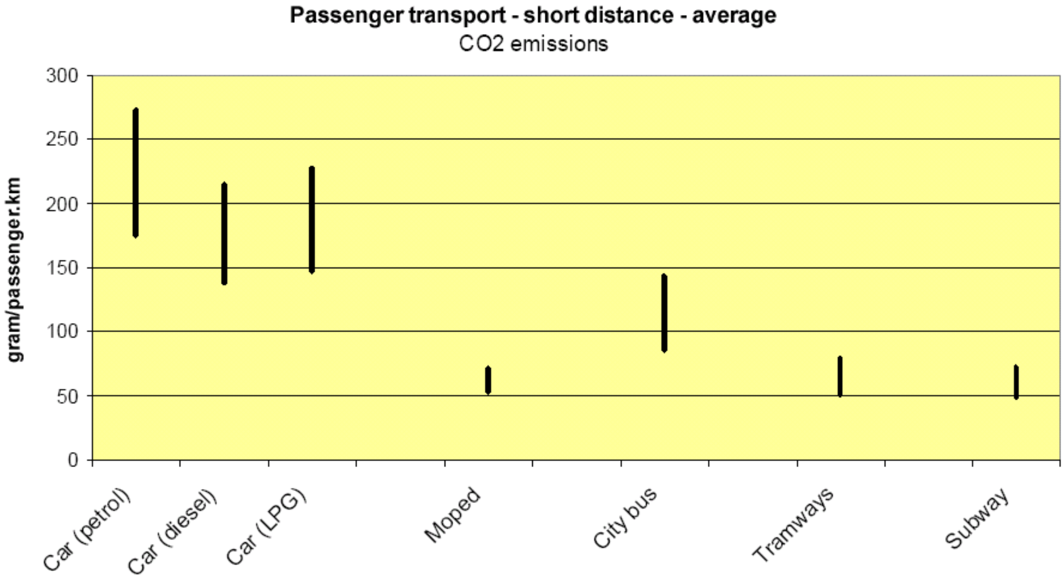
Urban transport policy

Transport policies at the urban level can be used to stimulate the use of energy efficient vehicles, e.g. through parking tariffs differentiated according to environmental performance (incl. CO_2) of vehicles. As CO_2 is not a local problem such policies, however, seem rather inappropriate. Public procurement by local authorities, on the other hand, might be a useful way to promote the market for efficient vehicles.

Transport efficiency in terms of fuel consumption or CO_2 emissions per unit of transport performance (passenger km or tonne km) can be promoted through local policies in several ways: Traffic measures, including speed limitations, synchronization of traffic lights and avoiding traffic jams, can be implemented to reduce the dynamics of traffic flow and as such reduce fuel consumption. Furthermore through clever infrastructure planning the driven distances can be minimized. Both options, however, also improve traffic flow and lead to reduced travel times. This may increase demand and as such counteract achieved efficiency improvements.

The availability of good public transport may also be a means to improve energy efficiency of transport at the local level. CE (2003) showed that CO_2 emissions per passenger kilometer are significantly lower for urban public transport than for passenger cars. Figure 26 shows a comparison based on average emissions. Marginal emissions, based the capacity of the existing public transport system, are even more favorable for public transport.

Figure 26 Average CO_2 emissions per passenger kilometer for short distance transport in 2000



Source: CE, 2003.

Interaction between governmental institutions

Energy efficiency policies for the transport sector touch the policy domains of ministries of environment, transport, finance and economic affairs. The greenhouse gas problem as such is traditionally the domain of environment, while solutions in the area of energy supply and end use are part of the domains of ministries of economic affairs respectively transport. Implementing fiscal and other financial policy measures to promote energy efficiency generally is the responsibility of finance ministries. Within each country the formulation of effective policies therefore requires close cooperation between these ministries as well as good mutual understanding of the relation between energy efficiency policy and other policy targets under the responsibility of the various ministries.

Because many of the actors involved (e.g. car manufacturers, oil companies) are international companies operating on an international market, effective energy efficiency policies require international coordination or even harmonisation and international agreements. Within the EU this clearly is the responsibility of the European Commission, but on a more global scale e.g. the United Nations can play a role. Intergovernmental organisations such as IEA, Energy Charter, and PEEREA can play an important role in information dissemination and in creating international consensus on goals and effective policy instruments.

Traditionally government agencies play a strong role in implementing stimulation policies such as subsidies for R&D and demonstration projects. Through their contacts with industrial and other stakeholders they have gained of have access to a wealth of experience related to implementation of efficiency improvement measures and the acceptance and effectiveness of policy measures to stimulate efficiency improvement. This experience can be of great value for designing effective new policies.

5 Relevant work by national and international organizations

In the previous chapters already various examples were given of activities and initiatives if various international organizations to contribute to improving the energy efficiency of transport. Below a bullet-wise summary is given of the main activities of some relevant organizations.

EU

- Development of energy efficiency and CO_2 reduction policies at the EU-level.
- Framework Programmes subsidizing R&D and technology deployment in e.g. demonstration projects.

IEA

- Overall energy studies and data compilation.
- Specific studies into aspects of energy efficiency and CO_2 emissions of the transport sector.
- International information exchange on energy-related topics:
  - Working Parties on ‘Fossil Fuels’ and ‘End Use’ as part of Committee on Energy Research and Technology (CERT), managing so-called Implementing Agreements (IA) in which member countries cooperatively carry out projects. Examples for the transport sector are:
    - IA on Alternative Motor Fuels: http://www.iea-amf.vtt.fi.
    - IA on Hybrid and Electric Vehicles: http://www.ieahev.org/about.html.
    - IA on Bioenergy: http://www.ieabioenergy.com.
  - Workshops, e.g.:
    - ‘Cooling cars with less fuel’, October 2006.
    - ‘Energy Efficient Tyres: Improving the On-Road Performance of Motor Vehicles’, November 2005.
  - Publications[11], e.g.:
    - Energy Technology Perspectives : Road Transport Technologies and Fuels, fact sheet, 2006.
    - Making Cars More Fuel Efficient- Technology for Real Improvement on the Road, 2005.
    - Alternative Fuels- An Energy Technology Perspective, 2005.
    - Biofuels for Transport- An International Perspective, 2004.
    - Reducing Oil Consumption in Transport- Combining Three Approaches, 2004.
    - Transportation & Energy, 2002.
    - World Energy Outlook 2004, to be downloaded from: http://www.worldenergyoutlook.org.
    - Prospects for Hydrogen and Fuel Cells, ISBN 92-64-10957-9, 2005.
    - Energy Technology Perspectives -- Scenarios & Strategies to 2050, ISBN 92-64-10982-X, 2006.

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[11] These publications can be downloaded or ordered from: http://www.iea.org/index.asp.

- Act Locally, Trade Globally -- Emissions Trading for Climate Policy, ISBN 92-64-10953-6, 2005.
- CO_2 Emissions from Fuel Combustion 1971-2003 -- 2005 Edition, ISBN 92-64-10891-2 (paper) 92-64-10893-9 (CD ROM), 2005.
- Saving Oil in a Hurry, ISBN 92-64-10941-2, 2005.

UN

- United Nations Environment Programme (UNEP):
  - Encourages partnerships between organizations, companies and governments in implementing sustainable technologies.
  - Information exchange, publications, events.
- Intergovernmental Panel on Climate Change (IPCC): http://www.ipcc.ch.
  Some relevant reports available from or via this website are:
  - Aviation and the Global Atmosphere, A Special Report of IPCC Working Groups I and III in collaboration with the Scientific Assessment Panel to the Montreal Protocol on Substances that Deplete the Ozone Layer, J.E.Penner, D.H.Lister, D.J.Griggs, D.J.Dokken, M.McFarland (Eds.), Cambridge University Press, UK, 1999.
  - Sectoral Economic Costs and Benefits of GHG Mitigation, Proceedings of the IPCC Expert Meeting held in Eisenach, Germany, 14-15 Feburary 2000, Edited by Lenny Bernstein and Jiahua Pan, Published for the IPCC by RIVM, 2000, ISBN: 90-6960-089-7, Available from WG III Technical Support Unit, E-mail: ipcc3tsu@rivm.nl.
  - Climate Change 2001: Mitigation, can be downloaded from: http://www.grida.no/climate/ipcc_tar/.
- UN-ECE: United Nations Economic Commission for Europe, website: http://www.unece.org/trans/main/welcwp29.htm:
  - Working Party on Pollution and Energy (GRPE): development and harmonization of (type approval) test procedures.

ECMT (European Conference of Ministers of Transport)[12]

- The European Conference of Ministers of Transport (ECMT) is an intergovernmental organisation established by a Protocol signed in Brussels on 17 October 1953. It comprises the Ministers of Transport of 43 full Member countries, 7 Associate countries and 1 Observer country. In Europe, the ECMT helps to create an integrated transport system that is economically efficient and meets environmental and safety standards.
- At their meeting in Dublin, Ireland, in May 2006, the Council of Ministers agreed on the creation of International Transport Forum, which would open to a much wider group of countries. The aim of the Forum is to bring high-profile, international attention to the essential role played by transport in the economy and society, while facilitating the integration of transport and logistics into key policy-making processes.
- In January 2004, the ECMT and the Organisation for Economic Co-operation and Development (OECD) brought together their transport research capabilities in setting up the Joint Transport Research Centre. The Centre conducts co-operative research programmes addressing all modes of inland

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[12] Text taken from: http://www.cemt.org/index.htm.

transport and their intermodal linkages, in support of policy-making processes in member countries.

- The ECMT has published a range of reports relating to emissions and energy consumption from transport[13]. Some examples are:
  - Performance-based Standards for the Road Sector, (75 2005 09 1 P), November 2005, ISBN 92-821-2337-5.
  - Can Cars Come Clean? Strategies for Low-Emission Vehicles, (77 2004 02 1 P), March 2004, ISBN 92-64-10495-X.
  - Transport Logistics. Shared Solutions to Common Challenges, (77 2002 06 1 P), August 2002.
  - Strategies to Reduce Greenhouse Gas Emissions from Road Transport, (77 2002 01 1 P), July 2002.
  - Benchmarking Intermodal Freight Transport, (77 2002 03 1 P), April 2002.
  - Performance Indicators for the Road Sector, (77 2001 02 1 P), July 2001.

[13] See: http://www.cemt.org/topics/env/envpub.htm.

6 Possible contributions from PEEREA to promoting energy efficiency in the transport sector

The work of the PEEREA group can contribute to the promotion of energy efficiency in the transport sector in the following ways:

- The PEEREA group can serve as a platform for knowledge transfer especially related to policy instruments. Experience with policy instruments from various countries can be exchanged and discussed, and best practices can be identified. Running policies and new initiatives can be monitored and reviewed.
- Energy efficiency policies for the transport sector touch the policy domains of ministries of environment, transport, finance and economic affairs. Within each country the formulation of effective policies therefore requires close cooperation between these ministries. Discussing energy efficiency for the transport sector in the PEEREA group may help to prepare the ministries of economic affairs from member countries for this interaction.
- As described in this report, international harmonisation of national policies, especially fiscal policies, is of great importance for creating a transparent context in which car manufacturers can market fuel efficient vehicles. Harmonised policies can create a more effective market pull for fuel efficient vehicles as they do not require specific technical solutions or marketing approaches for individual countries. Nevertheless, formal harmonisation of e.g. CO_2 differentiated vehicle taxation is not very likely to occur, not even within the European Union. Developing national policies on the basis of internationally agreed concepts and visions, however, may already be of great help to generate more homogeneous international market conditions for energy efficient vehicles and transport modes. In this context information exchange and discussions in the PEEREA group may help to align the mindsets of member countries.
- The international discussion on energy consumption in the transport sector is strongly focussing on reduction of CO_2 emissions as the main policy goal. Many studies in this field concentrate on quantifying CO_2 reduction potentials and CO_2 abatement costs. The PEEREA group's natural focus on energy and fuels could help to strengthen the role of the various aspects of energy security and dependence on imported oil in the overall assessment of policies aiming at reducing CO_2 emissions and energy consumption by the transport sector.

7 Conclusions

- Improvement of the energy efficiency of the transport sector serves two principal goals: It reduces CO_2 emissions but also relieves the dependence on imported oil. The technical innovations required for this efficiency improvement may provide an economic boost to automotive and other industries.
- Energy consumption and CO_2 emissions by the transport sector are expected to grow significantly over the next decades. Strong policies will be necessary if the transport sector is to provide a contribution to reaching CO_2 reduction goals under or beyond the Kyoto protocol.
- For reaching ambitious long term goals for CO_2 reduction a combination of efficiency improvement, CO_2 neutral fuels and volume measures is likely to be necessary. The required mix of measures depends on the availability, CO_2 abatement costs, and CO_2 reduction potential of efficiency measures and CO_2 neutral fuels as well as on the autonomous growth of the transport sector, which is strongly influenced by GDP.
- The availability of CO_2 neutral fuels, specifically biofuels and hydrogen, will be limited for a long time. In the short to medium term use of renewable energy in other sectors offers more cost effective options for CO_2 reduction than use as transport fuels.
- Care should be taken in comparing results from different studies on cost-effectiveness or CO_2 abatement costs of CO_2 reduction options. Results depend strongly on the applied methodology and the assumptions made in the assessment.
- A strong focus in policy studies on comparison of CO_2 abatement costs has the risk of under appreciating the value of new technologies with respect to other goals such as energy security.
- Volume measures require the willingness to influence consumer behaviour and to restrict the choices of consumers. The effectiveness of measures aiming to control the growth of transport depends strongly on economic development.
- Improving the energy efficiency of transport should be a dominant element in the energy policy for the transport sector for the next decades.
- Conventional vehicles are a ‘moving target’. They will become very clean over the next decade and will also show significant potential for efficiency improvements. The potential of new propulsion technologies and fuels, that still require one or more decades to reach large scale market penetration, should be assessed in comparison to the future environmental and energy performance of conventional vehicles, not to the present performance.
- Through a combination of engine improvements, improved gear boxes, light-weight materials, low rolling resistance tyres, optimised aerodynamics and application of hybrid-electric propulsion a reduction of the fuel consumption and CO_2 emissions of passenger cars of 50% compared to 1995 seems feasible. The CO_2 abatement cost for reaching this level of reduction, however, may be several hundreds of Euros per avoided tonne of CO_2. For

trucks and other heavy duty road vehicles the reduction potential is more limited.

- Policies promoting the use of biofuels should take account of the Well-to-Wheel energy efficiency and greenhouse gas emissions of the production of these fuels.
- From this perspective the use of hydrogen from renewable resources in road vehicles involves various rather inefficient energy chains, even if fuel cell vehicles are used. As long as sustainable energy is scarce and expensive, it should be implemented in applications with the best cost-effectiveness for reaching environmental and other goals.
- Regulation of CO_2 emissions, either by means of emission limits at the vehicle level or by setting binding targets per manufacturer to the sales-averaged CO_2 emissions of new vehicles, is a specific policy instrument to promote efficiency improvement.
- Overall reduction of the energy consumption and CO_2 emissions of (road) transport may be achieved through more generic policy instruments such as CO_2 differentiation of vehicle taxation or a cap & trade system setting a limit to the overall emissions and allowing stakeholders to reach this limit in the most cost-effective way by trading of emission allowances. Trading systems can be closed, i.e. within a single sector or group of stakeholders, or open, i.e. involving various sectors and a wide range of stakeholder groups.
- Emission regulation at the level of vehicles or the sales average of manufacturers and various forms of emission trading can be seen as alternative or as complementing policy instruments. Emission regulation for cars can be an additional instrument in the context of a CO_2 emission trading system to promote the speedy development and market introduction of fuel efficient vehicles, which is necessary to give consumers options to respond to the increased costs for driving. Within a regulatory approach trading of emission credits among manufacturers may help manufacturers to reach the overall target in a more cost effective way and to distribute the burden more evenly among manufacturers with different model ranges and market positions.
- For transport sectors with strong international competition and a limited numbers of actors (road freight transport, aviation, shipping) inclusion in an open trading system like the EU-ETS seems most appropriate. For passenger cars, and maybe also road freight transport, a closed trading system setting limits and allowances at the level of fuel suppliers seems a promising option. Such a system can be implemented in an international context, but also at a national level.
- Due to the relatively high CO_2 abatement costs incorporation of road transport in an open trading system such as EU-ETS will likely not lead to efficiency improvements in the transport sector itself, and will thus not significantly contribute to reduction of the dependence of imported oil. The effects on price will lead to some volume reduction.
- Implementing CO_2 emission limits or monitoring the effect of other measures on fuel efficiency and CO_2 emissions of vehicles requires timely availability of adequate test protocols to be incorporated into the type approval test

procedure. Developing such procedures for heavy duty road vehicles, especially in relation to hybrid propulsion, poses some challenging problems.

- International harmonisation of national policies, especially fiscal policies, is of great importance for creating a transparent context in which car manufacturers can market fuel efficient vehicles. Harmonised policies can create a more effective market pull for fuel efficient vehicles as they do not require specific technical solutions or marketing approaches for individual countries. Nevertheless, formal harmonisation of e.g. CO_2 differentiated vehicle taxation is not very likely to occur, not even within the European Union. Developing national policies on the basis of internationally agreed concepts and visions, however, may already be of great help to generate more homogeneous international market conditions for energy efficient vehicles and transport modes.

8 Literature

ADAC, 2005
Study on the effectiveness of Directive 1999/94/EC relating to the availability of consumer information on fuel economy and CO_2 emissions in respect of the marketing of new passenger cars, report for the European Commission (DG-ENV)
Brussels : March 2005

Bates, 2001
J. Bates, C. Brands, et al.
Economic evaluation of emission reductions in the transport sector in the EU
AEA Technology, 2001

CARB, 2004
Various reports:

Staff proposal regarding the maximum feasible and cost-effective reduction of greenhouse gas emissions from passenger cars
California : California Environmental Protection Agency and Air Resources Board, June 2004.

Economic impacts of the climate change regulations, Technical support document for Staff proposal regarding the maximum feasible and cost-effective reduction of greenhouse gas emissions from passenger cars
California : California Environmental Protection Agency and Air Resources Board, August 2004.

Public hearing to consider adoption of regulations to control greenhouse gas emissions from motor vehicles
California : Presentation by California Environmental Protection Agency and Air Resources Board, September 2004.

Staff Report: Initial Statement of reasons for proposed Rulemaking, Public hearing to consider adoption of regulations to control greenhouse gas emissions from motor vehicles
California : California Environmental Protection Agency and Air Resources Board, August 2004.

CARS21, 2005
CARS 21, A competitive automotive regulatory system for the 21st century
Final report, European Commission, December 2005. Can be downloaded from:
http://ec.europa.eu/enterprise/automotive/pagesbackground/competitiveness/cars21.htm

CE, 2003
Huib van Essen, et al.
To shift or not to shift, that the question, The environmental performance of the principal modes of freight and passenger transport in the policy making context
Delft : CE Delft and RIVM, March, 2003

CE, 2005a
Bettina Kampman and Bart Boon
Cool cars, fancy fuels, A review of technical measures and policy options to reduce CO_2 emissions from passenger cars
Delft : CE Delft, November 2005

CE, 2005b
R.C.N. (Ron) Wit, B.H. (Bart) Boon and A. (André) van Velzen (CE Delft), M. (Martin) Cames and O. (Odette) Deuber (Oeko-Institut), D.S. (David) Lee (Manchester Metropolitan University)
Giving wings to emission trading. Inclusion of aviation under the European Emission Trading System (ETS): Design and impacts
Delft : CE Delft, July 2005

CE, 2006a
Jeroen Klooster, Bettina Kampman
Dealing with Transport Emissions, An emission trading system for the transport sector, a viable solution?
Delft : CE Delft, March 2006

CE, 2006b
Bettina Kampman, Sander de Bruyn, and Eelco den Boer
Cost effectiveness of CO_2 mitigation in transport, An outlook and comparison with measures in other sectors
Delft : CE Delft, April 2006

COM(2001) 370
White Paper, European transport policy for 2010: time to decide
Brussels : European Commission, 2001

COM(2005) 261
Proposal for a Council Directive on passenger car related taxes
Brussels ; European Commission, 2005

COM(2005) 634
Proposal for a Directive of the European Parliament and of the Council on the promotion of clean road transport vehicles
Brussels : European Commission, 2005

COM(2005) 683
Proposal for a Regulation of the European Parliament and the Council on the type approval of motor vehicles with respect to emissions and on access to vehicle repair information, amending Directive 72/306/EEC and Directive …/…/EC
Brussels : European Commission, 2005

COM(2006) 314
Keep Europe moving - Sustainable mobility for our continentMid-term review of the European Commission's 2001 Transport White Paper
Brussels : European Commission, 2006

COM(2006) 463
Implementing the Community Strategy to Reduce CO_2 Emissions from Cars: Sixth annual Communication on effectiveness of the strategy
Brussels : European Commission, 2006

Concawe, 2006
Well-to-Wheels analysis of future automotive fuels and powertrains in the European context, CONCAWE / EUCAR / JRC, draft version
December 2006

EC, 2005
Doing more with less, Green Paper on energy efficiency
Brussels : European Commission, 2005

EEA, 2005
TERM 2005 Fact Sheets
Copenhagen : European Environment Agency, 2005

EEA, 2006
Transport and environment: facing a dilemma, TERM 2005: indicators tracking transport and environment in the European Union
Copenhagen : European Environmental Agency, EEA report No 3/2006

Hoogwijk, 2003
M. Hoogwijk, A. Faaij, R. v.d. Broek, R. Berndes, D. Gielen, W. Turkenburg
Exploration of the ranges of the global potential of biomass for energy
Biomass & Bioenergy 25 (2003) p.119-133

IEA, 2004
World Energy Outlook 2004
International Energy Agency, 2004. Downloaded from:
http://www.worldenergyoutlook.org

IEA, 2005
Making cars more fuel efficient: Technology for Real Improvements on the Road
International Energy Agency and European Conference of Ministers of Transport
Joint Report, 2005

IEA, 2006
Key World Energy Statistics, International Energy Agency, 2006
Downloaded from: http://www.iea.org/Textbase/nppdf/free/2006/Key2006.pdf

IEEP, 2005
Service contract to carry out economic analysis and business impact assessment of CO_2 emissions reduction measures in the automotive sector, contract nr. B4-3040/2003/366487/MAR/C2, carried out by IEEP, TNO and CAIR on behalf of the European Commission (DG-ENV), June 2005

IVM, 2006
F. Oosterhuis et al.
Ex-post estimate of costs to business of EU environmental legislation
Contract nr. ENV.G.1/FRA/2004/0081, by IVM / BIO / Ecologic / GHK, PSI, TME and VITO on behalf of DG-ENV, April 2006

Odyssee, 2006
Odyssee, Energy Efficiency Indicators in Europe
ADEME, EIE programme of the European Commission/DGTREN and European energy efficiency agencies
http://www.odyssee-indicators.org/index.php

Pischinger, 1998
S. Hausberger, R. Pischinger
Cost Effectiveness Study on Measures to Reduce CO_2-Emissions in the Transport Sector in Austria; FISITA Congress Manuscript; Paris, Sept. 1998. See also: Pischinger R. et al.: Volkswirtschaftliche Kosten-Wirksamkeisanalyse von Maßnahmen zur Reduktion der CO_2-Emissionen des Verkehrs in Österreich (Cost-Effectiveness Study on Measures to Reduce CO_2-Emissions from Transport Sector in Austria), a study for Bundesministeriums für Umwelt; Graz, Wien, Linz, 1997

Ricardo, 2003
Carbon to Hydrogen' Roadmap for Passenger Cars: Update of the Study
Ricardo, 2003

SEPA, 2005
The Top Runner Program in Japan – its effectiveness and implications for the EU, Swedish Environmental Protection Agency, Report 5515
November 2005

Smeets, 2005
Edward Smeets, André Faaij and Iris Lewandowski
The impact of sustainability criteria on the costs and potentials of bioenergy production, An exploration of the impact of the implementation of sustainability criteria on the costs and potential of bioenergy production, applied for case studies in Brazil and Ukraine
Utrecht : Copernicus Institute, Utrecht University, May 2005

TNO, 2003
P. Hendriksen, et al.
Evaluation of the environmental performance of modern passenger cars running on petrol, diesel, automotive LPG and CNG
TNO-report 03.OR.VM.055.1/PHE, TNO Automotive, December 2003

TNO, 2006
Richard Smokers, Robin Vermeulen, Robert van Mieghem & Raymond Gense (TNO), Ian Skinner, Malcolm Fergusson, Ellie Mackay & Patrick ten Brink (IEEP), Geroge Fontaras & prof. Zisis Samaras (LAT)
Review and analysis of the reduction potential and costs of technological and other measures to reduce CO_2-emissions from passenger cars
Service contract carried out by TNO, IEEP and LAT on behalf of European Commission DG-ENTR (contract SI2.408212), TNO report 06.OR.PT.040.2/RSM, October 2006

TRENDS, 2005
M. Giannouli, Z. Samaras, M. Keller, P. de Haan, M. Kalivoda, S. Sorenson, A. Georgakaki
Development of a Database System for the Calculation of Indicators of Environmental Pressure Caused by Transport
In : Science of the Total Environment 2005

Walsh, 2006
Michael Walsh
International experience in improving fuel efficiency and reducing greenhouse gases
presentation at T&E Symposium 'Driving Lower Emissions'
Brussels : September 13, 2006

WWI, 2006
Biofuels for transportation, global potential and implications for sustainable agriculture and energy in the 21st century
Worldwatch Institute, 2006