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Institute of Transport Research

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University of Stuttgart,
Institute for Road and Transportation
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Renewable Fuels

for Cross Border Transportation

- Final Report -

to the European Commission,
Directorate-General for Environment,
for study contract
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This is the final report to the European Commission, Directorate-General for Environment, for study contract ENV.C.1/ETU/2001/0092 on "Renewable Fuels for Cross Border Transportation." The contract was signed in December 2001 and the study commenced with an initial meeting in Brussels on 18th February 2002. The study ran until the end June 2003.

The study is carried out by a consortium consisting of the

- Institute of Transport Research at the German Aerospace Centre in Berlin,
- Institute for Energy and Environment in Leipzig and the
- Department of Transportation Planning and Traffic Engineering at the University of Stuttgart.

In the autumn of 2002 the commission arranged two meetings with stakeholders in order to give them the opportunity to support the consortium with their expertise. The researchers strongly appreciate the fruitful discussions that took place as well as the inputs, comments and proposals of the participants which they have received afterwards.

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Table of contents

List of Figures:

List of Tables:

List of abbreviations:

ACEA	Association des Constructeurs Européens d'Automobiles
APU	Auxiliary Power Unit
CED	Cumulated Energy Demand (only fossil)
CNG	Compressed Natural Gas
CO_2 equiv.	Anthropogenic green house effect
Equ	Equivalent
ETBE	Ethyl Tertiary Butyl Ether
EU	European Union
FCV	Fuel Cell Vehicle
GDP	Gross Domestic Product
GWP	Global Warming Potential
HDV	Heavy Duty Vehicle
LCA	Life Cycle Assessment
LDV	Light Duty Vehicles
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
NASA	National Aeronautics & Space Administration
OECD	Organization for Economic Cooperation & Development
PO_4^{3-} equiv.	Nutrification
RME	Rapeseed oil methyl ester
SO_2 equiv.	Acidification of soil and waters
TES	Transport Energy Strategy (German joint initiative from politics and industry)
VAT	Value Added Tax
Veh	Vehicle
ZEV	Zero Emission Vehicle
FC	Fuel Cell

Unit abbreviations

€	EURO
a	year
Bio	Billion
g	gramme
GJ	GigaJoule
h/a	hours/year
kg	kilogramme
KJ	KiloJoule
KW	KiloWatt
Mio	Million
MJ	MegaJoule
PJ	PetaJoule
Tkm	ton-kilometres
US$	US-Dollar

Country abbreviations

European Union Countries

A	Austria
B	Belgium
D	Germany
DK	Denmark
E	Spain
EL	Greece
F	France
FIN	Finland
I	Italy
IRL	Ireland
L	Luxembourg
NL	The Netherlands
P	Portugal
S	Sweden
UK	United Kingdom

Other European Countries

IS	Iceland
N	Norway
CH	Switzerland

European Candidate Countries

BG	Bulgaria
CY	Cyprus
CZ	Czech Republic
EE	Estonia
HU	Hungary
LV	Latvia
LT	Lithuania
MT	Malta
PL	Poland
RO	Romania
SK	Slovak Republic
SI	Slovenia
TR	Turkey

Other Countries

USA	United States of America
J	Japan

1 Summary

The transport sector accounts for a growing share of greenhouse gas emissions and is highly dependent on mineral oil imports from outside the European Union. In order to contribute to the solution of these problems, the Directive on the promotion of the use of biofuels or other renewable fuels for transport[1] sets the objective of 5.75 % substitution of conventional fuels by 2010. Moreover, several research projects have been carried out dealing with the introduction and dissemination of renewable fuels in the transport sector. However, most of the projects focused on single technologies or a specific field in the range of fuels and transportation.

The objective of this study is to elaborate the aspects of a Europe-wide introduction of renewable fuels in a comprehensive way. Against the backdrop of the enlargement of the European Union, the study includes all modes of transport[2] and considers the whole chain from primary energy to its final use. As the underlying objective is a self-sufficient energy supply, only sources of energy within Europe are addressed.

The main focus is the long term perspective (about 2030) and the cross border aspect in terms of an area-wide fuel provision. Consequently, local, small-scaled solutions are not discussed. Due to the focus upon the transport sector, comparisons with stationary applications of renewable energy are not given.

Design of the study

A stepwise procedure was chosen, starting with a broad basic survey of primary energy carriers, transformation technologies, fuel distribution and final use in vehicles. A selection of certain fuel chains on the basis of the broad survey follows, which are analysed in depth by a life cycle assessment. Economic considerations are described for the major options of renewable fuels.

Based on the first survey and the more detailed analyses, several scenarios are worked out that lead to appropriate implementation strategies. They illustrate limits and options of a renewable fuel system in the future on a Europe-wide scale.

Basic survey

The provision and use of renewable fuels in the transport sector requires the establishment of new technologies as well as the revision of existing technologies in several fields, ranging from the generation of primary energy to the final use in vehicles. To give an overview of these technologies, a classification is established, including the primary energy supply, the transformation into fuel, the fuels' distribution and its final use in vehicles. For all four classes a certain number of technologies are described by using standardised module sheets (see annexes).

This basic survey provides a summary in terms of CO_2 emissions, output price and potential for a number of renewable fuels, shown in Table 1. All figures presented in the table are related only to the production of the fuel. The distribution and final use in vehicles is not considered. In contrast to renewable fuel emissions, most of the emissions from fossil fuel use arise by combustion in cars. For energy crops, the technical potential is calculated by assuming that 10 % of the arable land is available. The potential of residues and renewable electricity generation is recorded without any subtraction for competing utilisations.

[1] Directive 2003/30/EC of the European Parliament and of the Council, 2003
[2] Except electric railways

Table 1: Results of the basic survey of renewable energy sources, containing primary energy provision and transformation into fuel

Note: Figures in this table are based on different sources as registered in the module sheets of the annexes. Therefore the table intends to show differences and orders of magnitude in principle and is not suitable for detailed comparisons of selected single data.

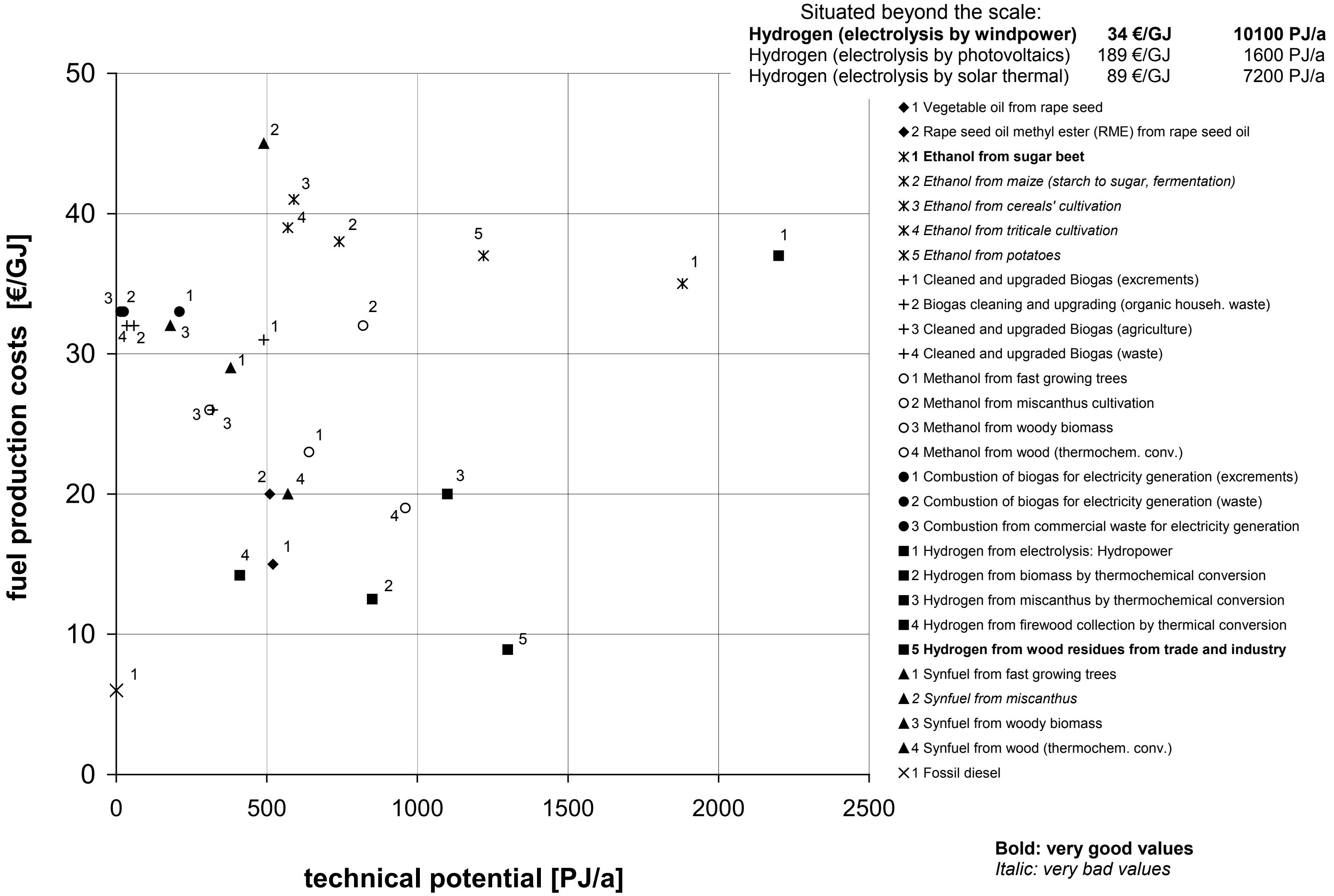
Technical potentials are calculated by assuming that 10 % of the arable land is available; residues and renewable electricity generation is recorded without any subtraction for competing utilisations.

primary energy (class 1 module)	module id class 1	**transformation** (class 2 module)	module id class 2	**CO_2-emissions class 1+2, (i.e. final use is excluded)**	**total output costs for fuel production**	**technical fuel potential for EU 15**	**technical fuel potential for EU 30**
Biodiesel							
Rape cultivation (rape seed)	C1-P1	Vegetable oil from rape seed	C2-O1	20 kg/GJ	15 €/GJ	260 PJ/a	520 PJ/a
		Rape seed oil methyl ester (RME) from rape seed oil	C2-S1	24 kg/GJ	20 €/GJ	250 PJ/a	510 PJ/a
Ethanol							
Sugar beet cultivation	C1-P5	Ethanol from sugar beet	C2-F1	24 kg/GJ	35 €/GJ	1000 PJ/a	1880 PJ/a
Maize cultivation	C1-P11	Ethanol from maize (starch to sugar, fermentation)	C2-F2	65 kg/GJ	38 €/GJ	380 PJ/a	740 PJ/a
Cereals' cultivation (grains, e. g. winter wheat)	C1-P6	Ethanol from cereals' cultivation	C2-F3	60 kg/GJ	41 €/GJ	330 PJ/a	590 PJ/a
Triticale cultivation	C1-P7	Ethanol from triticale cultivation	C2-F3	59 kg/GJ	39 €/GJ	320 PJ/a	570 PJ/a
Potato cultivation	C1-P12	Ethanol from potatoes	C2-F4	69 kg/GJ	37 €/GJ	680 PJ/a	1220 PJ/a
Methanol							
Fast growing trees (short rotation plantations)	C1-P9	Methanol from fast growing trees	C2-T1	43 kg/GJ	23 €/GJ	330 PJ/a	640 PJ/a
Miscanthus cultivation (perennial grass)	C1-P10	Methanol from miscanthus cultivation	C2-T1	77 kg/GJ	32 €/GJ	410 PJ/a	820 PJ/a
Logging residues	C1-R2	Methanol from woody biomass	C2-T1	37 kg/GJ	26 €/GJ	210 PJ/a	310 PJ/a
Collection of wood residues from trade and industry	C1-R8	Methanol from wood (thermochem. conv.)	C2-T1	37 kg/GJ	19 €/GJ	650 PJ/a	960 PJ/a
Synthetic fuel							
Fast growing trees (short rotation plantations)	C1-P9	Synfuel from fast growing trees	C2-T3	42 kg/GJ	29 €/GJ	200 PJ/a	380 PJ/a
Miscanthus cultivation (perennial grass)	C1-P10	Synfuel from miscanthus	C2-T3	105 kg/GJ	45 €/GJ	240 PJ/a	490 PJ/a
Logging residues	C1-R2	Synfuel from woody biomass	C2-T3	32 kg/GJ	32 €/GJ	125 PJ/a	180 PJ/a
Collection of wood residues from trade and industry	C1-R8	Synfuel from wood (thermochem. conv.)	C2-T3	32 kg/GJ	20 €/GJ	390 PJ/a	570 PJ/a

Biogas							
Collection of animal excrements	C1-R4	Cleaned and upgraded Biogas (excrements)	C2-S3	14,5 kg/GJ	31 €/GJ	360 PJ/a	490 PJ/a
Collection of organic waste from households	C1-R5	Biogas cleaning and upgrading from organic waste	C2-S3	14,8 kg/GJ	32 €/GJ	40 PJ/a	59 PJ/a
Collection of vegetable residues from agriculture	C1-R6	Cleaned and upgraded Biogas (excrements)	C2-S3	14,8 kg/GJ	26 €/GJ	200 PJ/a	320 PJ/a
Collection of organic commercial waste	C1-R7	Cleaned and upgraded Biogas (waste)	C2-S3	14,8 kg/GJ	32 €/GJ	20 PJ/a	35 PJ/a
Electricity Generation							
Collection of animal excrements	C1-R4	Combustion of biogas for electricity generation (excrements)	C2-E3	27 kg/GJ	33 €/GJ	150 PJ/a	210 PJ/a
Collection of organic waste from households	C1-R5	Combustion of biogas for electricity generation (waste)	C2-E3	28 kg/GJ	33 €/GJ	17 PJ/a	25 PJ/a
Collection of organic commercial waste	C1-R7	Combustion from commercial waste for electricity generation	C2-E3	28 kg/GJ	33 €/GJ	10 PJ/a	15 PJ/a
Hydrogen by electrolysis							
Hydropower	C1-E1	Hydrogen from electrolysis: Hydropower	C2-H1	2,9 kg/GJ	37 €/GJ	1300 PJ/a	2200 PJ/a
Wind power (onshore + EU 12 offshore)	C1-E2	Hydrogen from electrolysis: Windpower	C2-H1	12,9 kg/GJ	34 €/GJ	9000 PJ/a	10100 PJ/a
Solar energy (Photovoltaics)	C1-E3	Hydrogen from electrolysis: Photovoltaics	C2-H1	43 kg/GJ	189 €/GJ	1040 PJ/a	1600 PJ/a
Solar thermal electricity	C1-E4	Hydrogen from electrolysis: Solar thermal	C2-H1	7,0 kg/GJ	89 €/GJ	3600 PJ/a	7200 PJ/a
Nuclear energy	C1-E5	Hydrogen from electrolysis: Nuclear power	C2-H1	0 kg/GJ	19 €/GJ	0 PJ/a	0 PJ/a
Hydrogen by thermochemical conversion							
Fast growing trees (short rotation plantations)	C1-P9	Hydrogen from biomass by thermochemical conversion	C2-H2	23 kg/GJ	12,5 €/GJ	450 PJ/a	850 PJ/a
Miscanthus cultivation (perennial grass)	C1-P10	Hydrogen from miscanthus by thermochemical conversion	C2-H2	51 kg/GJ	20 €/GJ	540 PJ/a	1100 PJ/a
Logging residues	C1-R2	Hydrogen from firewood collection by thermical conversion	C2-H2	18 kg/GJ	14,2 €/GJ	280 PJ/a	410 PJ/a
Collection of wood residues from trade and industry	C1-R8	Hydrogen from wood residues from trade and industry	C2-H2	18 kg/GJ	8,9 €/GJ	870 PJ/a	1300 PJ/a
Fossil fuel							
Mineral oil	C1-F1	Refinery of Crude Oil	C2-R1	11,7 kg/GJ	6 €/GJ (without taxes)	0 PJ/a (fossil)	0 PJ/a (fossil)

Figure 1 depicts the potential data related to the calculated fuel price. It is seen that ethanol from sugar beet and hydrogen based on thermochemical processing of wood residues as well as hydrogen from wind power based electrolysis offer high potentials and comparatively low costs.

Figure 1: Technical potentials and production costs of various fuel chains for the enlarged European Union (EU 30)



Options for advanced and new powertrain technologies for all modes of transport are included in the basic survey as well. There is no doubt that the conventional combustion technology will continue to dominate in the future. The reasons for this are twofold: on the one hand, such technology can be run by most renewable fuels with only small modifications, and on the other hand, there is a lack of appropriate alternatives. Given the 2030 time horizon, this applies for all transport modes except passenger cars.

Renewable fuels, which have suitable potentials and therefore should be included in considerations of the future transportation system in Europe, are biodiesel, synfuels and blends of fossil based fuels with ethanol and methanol. One of the main advantages of these options is that they do not require large alterations of the conventional combustion powertrain.

In the case of passenger cars, the fuel cell power train appears technically feasible and in position to power vehicles in an adequate way to meet customer demand. The major challenge lies in the build-up of the necessary hydrogen industry, including renewable electricity generation, hydrogen production and distribution.

In principle, new powertrain concepts are not only possible for road vehicles but also for all other means of transportation. Due to their low share of the whole transportation system, however, there have been until now only a few experiences with such alternative technologies. Accordingly, this study does not recommend such technologies for other means of transport beyond road vehicles. This is also true for airplanes, where some concepts for the usage of hydrogen already exist.

Detailed analysis

The detailed analysis of renewable fuel chains provides the basis for the selection and elaboration of scenarios and implementation strategies in the last part of the study. Firstly, the detailed analysis contains a **life cycle assessments** for a selected number of fuel chains.

Using the criteria of availability, CO_2 emission, and costs as identified in the basic survey, the following fuels chains are chosen:

- ethanol from sugar beets
- methanol from wood residues and fast growing trees
- rape methyl esther
- synthetic fuel (by Fischer-Tropsch) from wood residues and fast growing trees
- hydrogen from logging residues
- hydrogen by electrolysis using renewable electricity

All fuels are linked with the final use in passenger cars, lorries, ships, trains and airplanes. Specific emissions and fuel consumption figures have been projected for reference vehicles in 2030. The anthropogenic greenhouse gas effect, acidification of soil and waters, nutrification and the cumulated fossil energy demand are taken into account as impact categories of the LCA.

Hydrogen based on electrolysis using renewable electricity shows the least environmental impacts in general, especially by using a fuel cell. When renewable electricity powers all processes, the environmental impacts of some chains can be lessened, e.g. fuel cell cars using liquid hydrogen based on wood residues. Production of hydrogen by renewable electricity and electrolysis (including emissions from the production of wind energy installations) is similar to the thermo-chemical production of hydrogen from wood residues.

For fuels based on energy crops, the environmental effects depend mainly on the agricultural method of cultivation and the energy consumption for transformation, especially for RME and ethanol from sugar beet and methanol from poplar wood. Concerning acidification and nutrification, these chains, which have a high demand of secondary energy inputs, exceed the emissions of diesel driven vehicles. If coal and heavy fuel are avoided for transformation, ethanol from sugar beet has an advantage compared with biodiesel from rape seed. The production of agricultural annual energy crops poses a particular threat to biodiversity.

The environmental effects of fuel from residues are quite small because only transformation and transportation play a relevant role for the global warming potential. For the other impact categories, the direct emissions are dominant. Thus, the transformation technology has the highest influence on the LCA result because the emissions of combustion engines using different fuels were assumed to be equal (corresponding to expected standards).

Biofuels based on residues cause less emissions than those based on cultivated energy crops because in this approach the environmental effects of cultivation are completely assigned to the main product.

The detailed analysis additionally addresses **economic considerations**. This analysis concludes that the successful incorporation of renewable fuels into the European energy portfolio will require a sustained commitment on the part of the public sector, industry, and consumers in order to overcome cost and market diffusion barriers over the medium term. With respect to the economic effects of renewable energy consumption, a main finding is that the net employment impacts are expected to be positive, with most job creation occurring in the agricultural and manufacturing sectors.

Trade effects are also expected to be positive for most Member States, primarily due to decreased dependency on imported fuel. Moreover, several countries are well positioned to establish a comparative advantage in renewable technologies on world markets, particularly in the wind and biomass sectors. While increased biofuel consumption in automobiles will not necessitate major technical medications, the establishment of hydrogen-based vehicles poses several technological challenges.

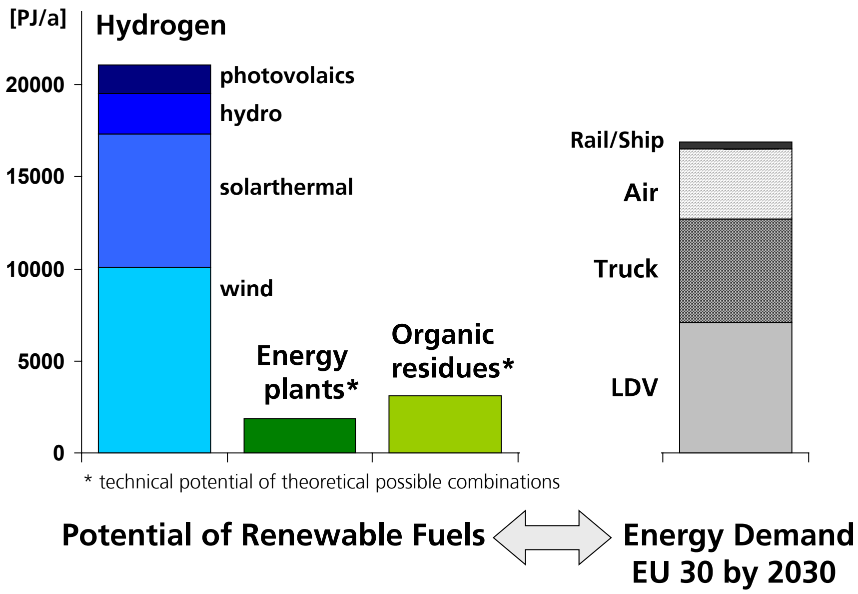
Over the medium term, consumers will contend with higher fuel and car prices. Impacts on the prices for final goods from increased fuel costs, however, are expected to be negligible.

In conclusion, to facilitate greater renewable energy reliance will require coordinated action at the community level. In this regard, the integration of environmental and energy policy across the Member States, with a particular emphasis on legislative instruments that unify fuel tax systems and foster trade, are among the most pressing challenges.

Scenarios and their implementation

A crucial point for the design of scenarios and implementation strategies towards the introduction of renewable fuel in the future is the proportion of the energy potential of fuels and the forecasted demand in the transport sector. Although the transport energy demand is projected to be moderate and efficiencies of vehicles are assumed to be high, the potential of the observed biofuels from plants or residues is not sufficient to serve a major proportion of energy demand of transport in Europe, as it is illustrated in Figure 2. In contrast, the technical potential of hydrogen based on renewable energy is expected to even exceed the energy demand of the transport sector. Here, the potential of renewable generated electricity is figured out in principle, so the influence of competing utilisations in other sectors apart from transport is not considered.

Figure 2: Technical overall potential of renewable fuels in comparison to projected energy demand for transportation for EU 30 in 2030

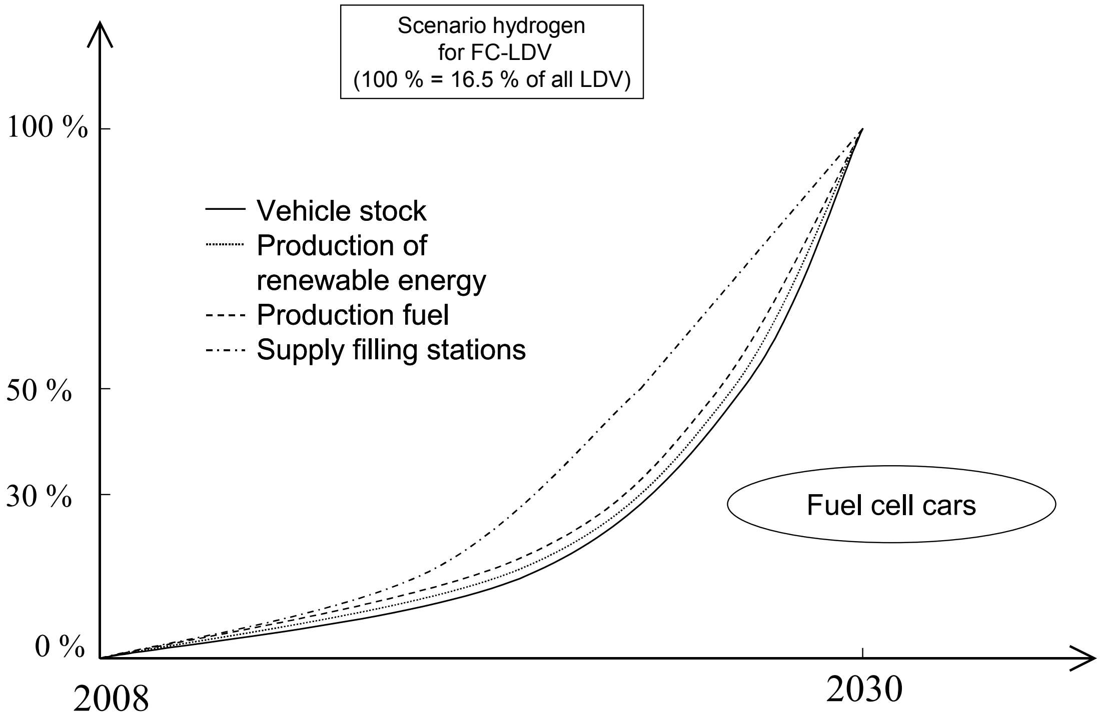


Given this situation, and taking into account the life cycle assessment and the economic considerations, the study does not recommend a single fuel option, but rather a mixed solution for certain kinds of applications.

As a key point, **hydrogen** is foreseen for a long-term strategy on renewable fuels for passenger cars. Within the next three decades, passenger cars appear able to enter a transition period to use hydrogen, potentially reaching a share of nearly 17 % of all cars.

As shown in Figure 3, the suggested implementation process starts in 2008 with a trial phase of only a few vehicles. Thereafter, the share of implementation must gradually increase until the objective of the scenario is reached in 2030. This minimum path must be regulated by a prescription to the automakers. The price of hydrogen powered cars will initially be much higher than those of conventional cars. Sales must generally be promoted by incentives like tax reduction or direct subsidies to enable competitive prices of the vehicles.

Figure 3: Implementation of hydrogen for light duty vehicles

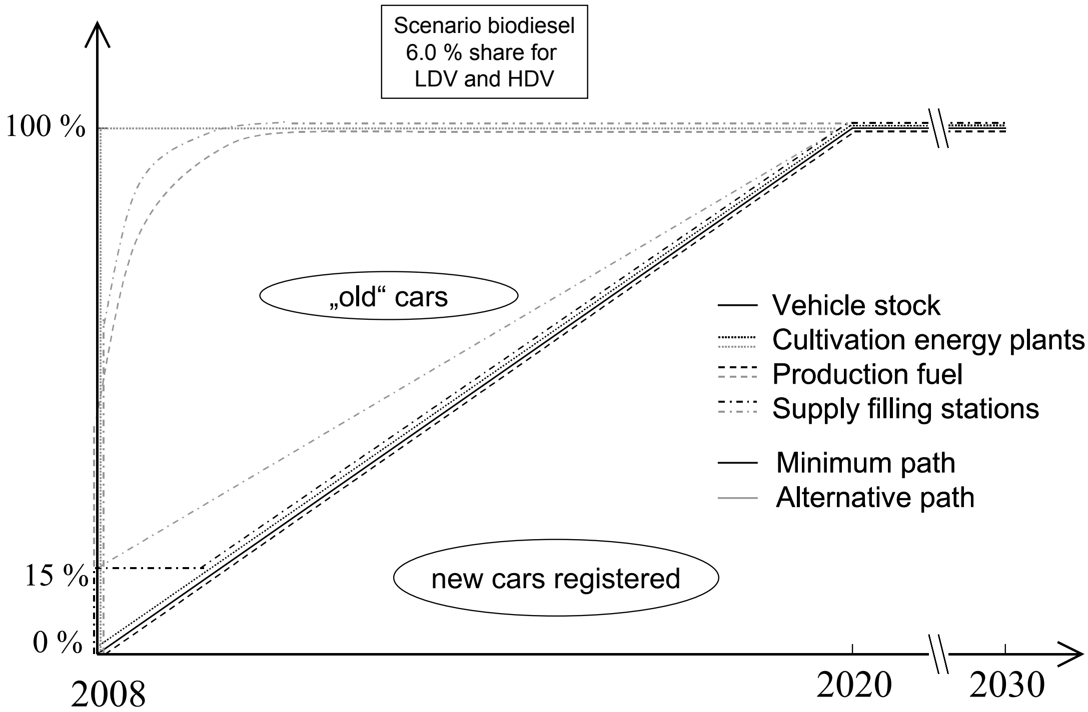


The renewable energy generation must be built up according to the vehicle path. The scenario makes clear that the required hydrogen for the implemented cars (1,092 PJ/a in 2030) is small (5.2 %) compared to the overall technical potential of a renewable hydrogen production. Nevertheless, it requires the construction of new power generation stations with accordingly large capital investments. For example, the installation of offshore wind power plants for the production of 523 PJ Hydrogen per year will require 7 billion €. The power generation and the production capacities for hydrogen must be built-up simultaneously. A major problem to be solved is the distribution of the energy or the fuel. Taking into account the present state of research in this field, it is not possible to recommend a definite distribution system.

An area-wide infrastructure of filling stations is another precondition for the implementation of hydrogen cars. The substitution of only 5 % of the European vehicle fuel requires a full area coverage of refuelling stations, which is given by a share of 15 % of all stations. To reach the target of the conversion of 30 % in 2030, investments of 78 billion € will be necessary (assuming two million € per filling station).

For lorries and the conventional powered passenger cars, the continuation and extension of the use of **rape methyl ester** (biodiesel) is recommended as an admixture to fossil diesel. The scenario worked out results in a biodiesel potential of almost 500 PJ/a in the EU-30 in 2030, assuming the availability of 10 % of the arable land for energy plant production. This potential can cover 6.0 % of the diesel demand of road transportation. Figure 4 indicates the implementation of the scenario “Biodiesel for road transportation” from 2008 on. The annual rate of new vehicles registered, which fulfil specific technical requirements related to the usage of biodiesel, is constant. This assumption leads to a total shift of the vehicles within 12 years. The extended cultivation of energy plants and the fuel production have to run in parallel, whereas the build-up of the filling stations supply needs a lead-time. The bold lines in the figure represent the minimum path, which must be guided by regulations. The slight lines show alternatives, which can be achieved by providing incentives or by harnessing free market forces.

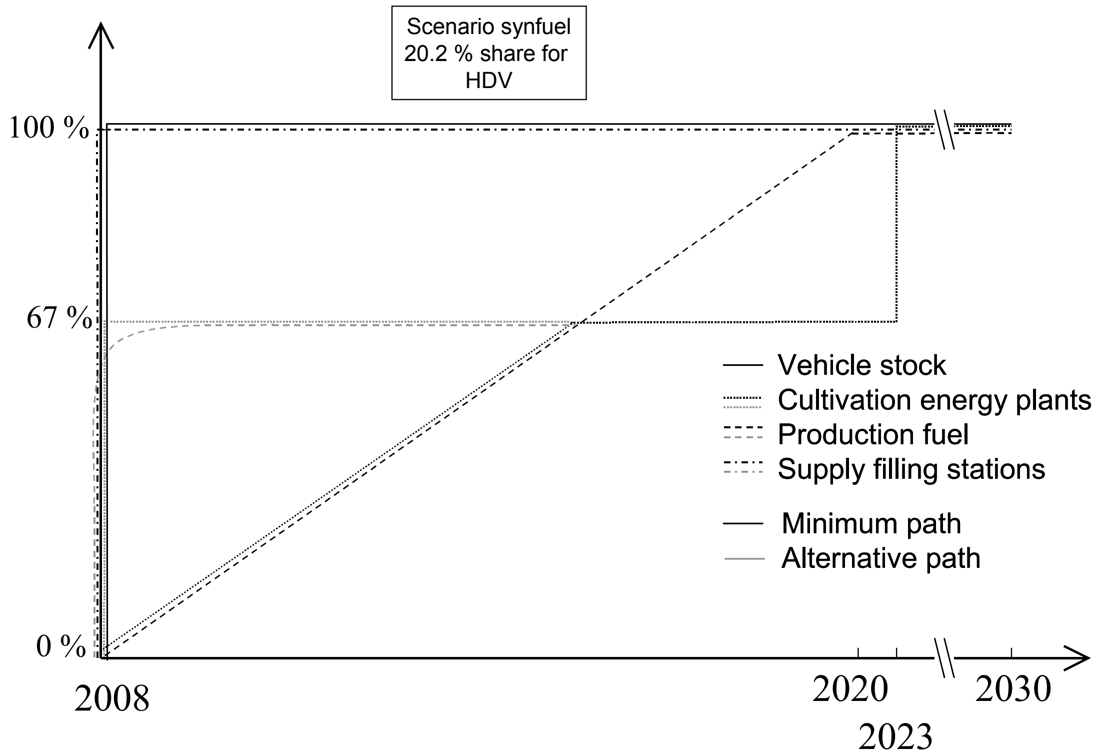
Figure 4: Implementation of biodiesel for road transportation



Another recommendation is the use of RME for inland navigation. In this case, the energy demand can be completely covered by pure biodiesel. Ship engines can be operated with this fuel with only a few modifications. Due to the limited number of required distribution and filling facilities, infrastructure costs are also not a major concern.

Alternatively, the introduction of **synthetic fuel** by Fischer-Tropsch processing as an admixture to diesel for heavy duty vehicles offers advantages due to its similar characteristics to diesel. Therefore, an adjustment of vehicles and filling stations is not necessary. Figure 5 shows that the limiting path for an introduction is the build-up of production capacities to process the wood residues, which are available over the short term in a first period and the cultivation of energy plants (fast growing trees) in a second period. 1,144 PJ per year is the overall potential found out for synfuel, resulting in a coverage of almost 20 % of the demand of HDV.

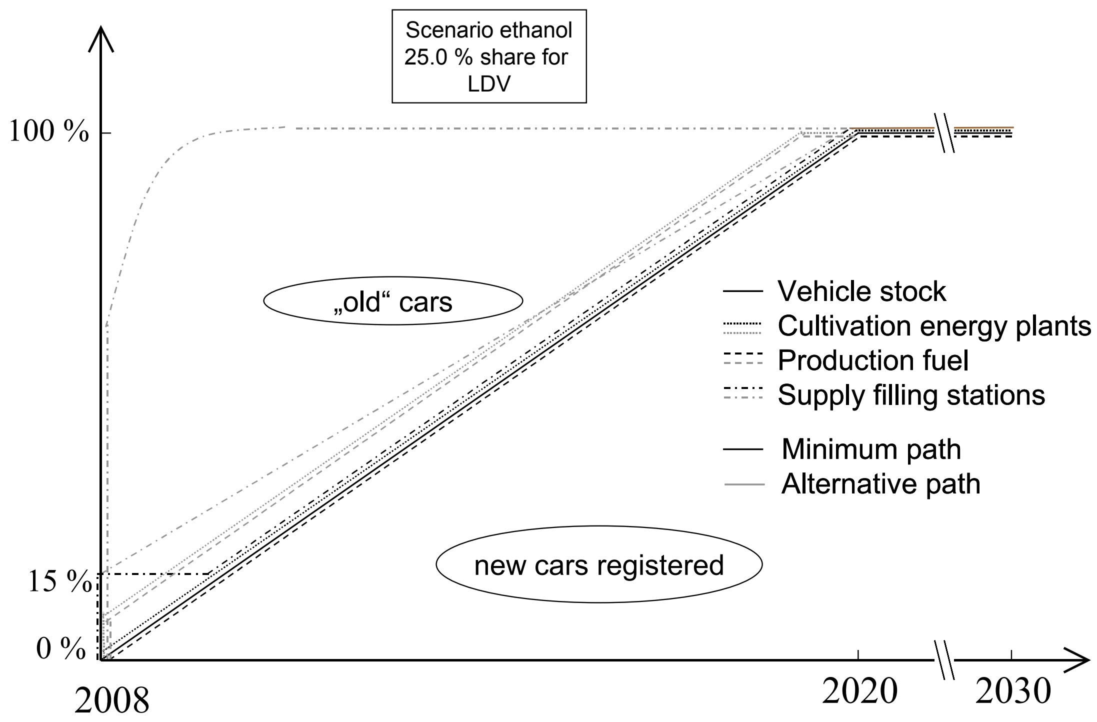
Figure 5: Implementation of synthetic fuel for heavy duty vehicles



In order to give every region in Europe the best opportunities with respect to potential, costs or facilities already available, the **blending fuel scenario** aims at establishing various blends. For this purpose, standardisations of the renewable admixtures or the blends in total are essential. Furthermore, a Europe-wide compatibility of vehicle technologies and fuels is required for this scenario. Two types of blended fuels are considered: An ethanol-petrol blend out of sugar beets and a methanol-diesel blend out of logging residues and fast growing trees. The overall potential of ethanol in the EU-30 amounts to 1,838 PJ/a; the potential of methanol is 332 PJ/a. The scenario suggests an ethanol share of 25 % of the ethanol-petrol blend and a methanol share of 3 % of the methanol-diesel blend.

Figure 6 shows the time flow of the implementation of the ethanol-petrol blend. The annual rate of registered new cars is constant. The lines of the cultivation of energy plants and the fuel production must run in parallel, whereas the build-up of a supply of filling stations needs a lead-time. As in Figure 4, the bold lines represent the minimum path, which must be guided by regulations. The slight lines show alternatives, which can be achieved by giving incentives or by the free market.

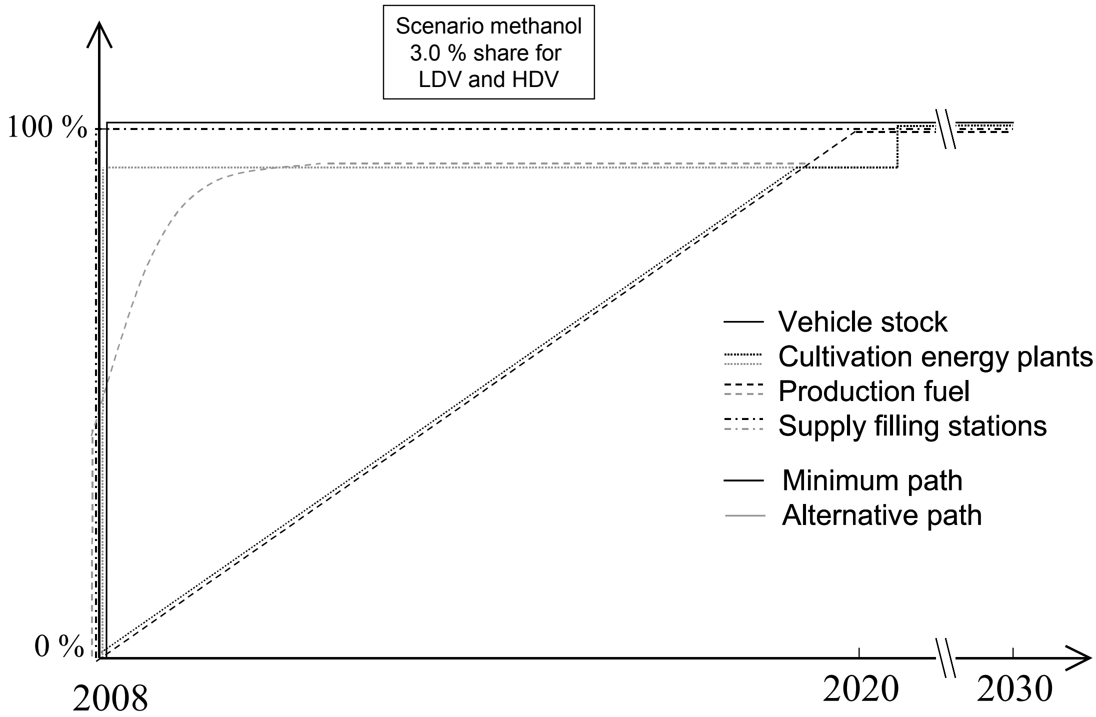
Figure 6: Implementation of ethanol-petrol blend



Blends with an ethanol share below 5 % can be used in cars that are not adapted, therefore an alternative path is considered in this figure. However, it is necessary to offer both ethanol-blend and conventional petrol during the transition time anyway, which makes the distribution of this option more expensive. Fuel companies must be committed by regulations to offer the ethanol-petrol blend at a minimum of 15 % of filling stations. From 2020 there is only ethanol-blend available.

Figure 7 illustrates the implementation of the methanol-diesel blend, which is different from the ethanol-petrol introduction. The scenario suggests the production of methanol mainly out of logging residues, which are available over the short term and cover 93 % of the overall methanol potential foreseen in this scenario. Additional potential for methanol is provided by the cultivation of fast growing trees, especially in the Scandinavian countries. Because of the suggested share of only 3.0 % methanol, there is no need for any conversion of vehicles and filling stations.

Figure 7: Implementation of methanol-diesel blend



In air transportation, there are currently no substantial efforts to power aircrafts by renewable fuels. In view of the steadily increasing energy demand of this transport mode, the intensification of research and development activities in this field is recommended.

2 Introduction

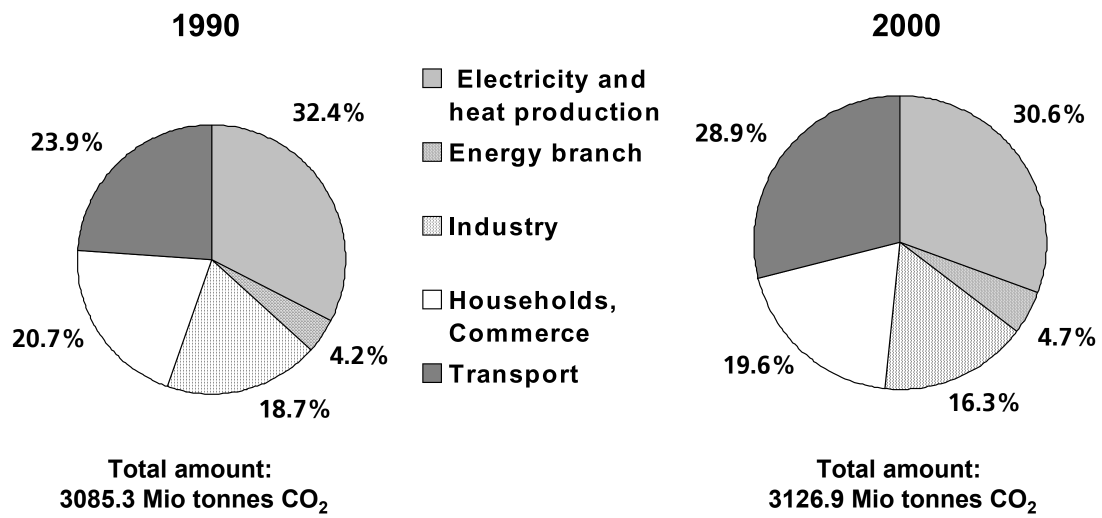
2.1 Purpose of the study

Passenger and freight transport volume has doubled over the last 25 years, with major increase rates in road and air transport for the passenger transport sector and in road and sea transport for the freight sector. A further tremendous increase in passenger and freight transport is expected for the next 10 to 20 years, again with the highest rates in road and air traffic.

Transport of passengers and freight is responsible for a large amount of greenhouse gas emissions (GHG) and especially of CO_2 due to its nearly exclusive use of fossil fuels such as petrol and diesel. While other sectors have increased their use of renewable energy in recent years this task remains a major challenge for the transport sector in the near future, especially in terms of the fuel supply and fuel prices.

The European Union greenhouse gas emissions have to be reduced and brought down to 8 % below the year 1990 emission levels (EU Kyoto Protocol target for 2008-2012). On the European level, CO_2 emissions account with almost 80 % (given as CO_2 equivalent) for the biggest part of the GHG emissions. Between 1990 and 2000 the CO_2 emissions from fossil fuels increased by 22 % in the transport sector (EU 15) while the total emissions were nearly constant (+ 1 %). Besides transportation only the energy branch recorded an emission rise, however only half of the increase rate of transport and on a much lower level.

Figure 8: CO_2 emissions in EU 15 by sector (1990 and 2000)



[Source: European Commission, Directorate General for Energy and Transport (Ed.): Transport in figures, 2002]

In order to contribute to objectives such as meeting climate change commitments, environmentally friendly security of supply and promoting renewable energy sources the European Parliament and the Council adopted the Directive on the promotion of biofuels or other renewable fuels for transport on 8 May 2003[3]. The Directive sets indicative targets aiming at a minimum proportion of biofuels of 2 % by the end of 2005 and 5.75 % by 2010.

In this context, the overall intention of this study is to investigate fuel provision options in the transport sector on a renewable base and to investigate the appropriate future vehicle technologies. The study compares the renewable fuels among themselves in order to derive recommendations for the most promising options. However, the study does not deal with the question whether renewable fuels should be favoured against equivalent fossil fuels. The long-term question is not, if they have to be substituted, but how this substitution may be done. The environmental, economic and other consequences of different renewable fuel options are compiled and described. This results into long term and intermediate strategies for the implementation of such renewable based options.

A large number of local and regional projects also deal with the use of renewable fuels in transportation. They consider a fuel supply and distribution system that can be handled within reasonable resources. This study concentrates on cross boarder transportation, i.e. in the sense of European area-wide provision of fuels, and is basically leaving small captive fleets outside. This makes the main differences from local studies.

The main focus of the study lies on the long term solution (25 – 30 years) for the introduction of fuels from renewable energy sources. Intermediate solutions (5 – 10 years) are also taken into account if they fit into the long term concept and do not constitute the best first step for today.

The approach of the study is very broad. It covers all main options but without any pre-selection initiated by the policy or the industry. All modes of transport are considered but due to its high relevance road transport is a main part of the study. Electric railways are excluded because of their general differing characteristics. The candidate countries are involved in the most important sections of the study since it is induced by the time perspective of 25 to 30 years.

A large scale introduction of a new kind of fuel will have impacts on a large variety of fields, from the agricultural sector especially facing the EU enlargement over the competitiveness of the vehicle manufacturers to the dependencies of the EU caused by oil imports. In this context the study describes possible tendencies of the future development, showing risks and opportunities and pointing out important criteria for future decisions. For this reason discussions on very detailed problems or technical approaches are avoided.

2.2 Structure of the final report

The structure of this report reflects the procedure of the study as it has actually been carried out.

Within the introducing chapter 2 the description of the purpose of the study can be found. The procedure and the approach, which has been used for the compilation of the study, follow in section 2.3.

The first main analysis of the study is a broad survey of basic technologies necessary to know when working on renewable fuels for the transportation sector. This survey is summarised in chapter 3, considering vehicle concepts, and in chapter 4, considering renewable energy sources. The annexes 1 to 4 include very detailed information on this topic.

Chapter 5 of the final report presents the selection of certain fuel chains and the detailed analysis of their environmental consequences.

[3] Directive 2003/30/EC of the European Parliament and of the Council, 2003

Chapter 6 deals with economic considerations and other consequences caused by the introduction of a new fuel system.

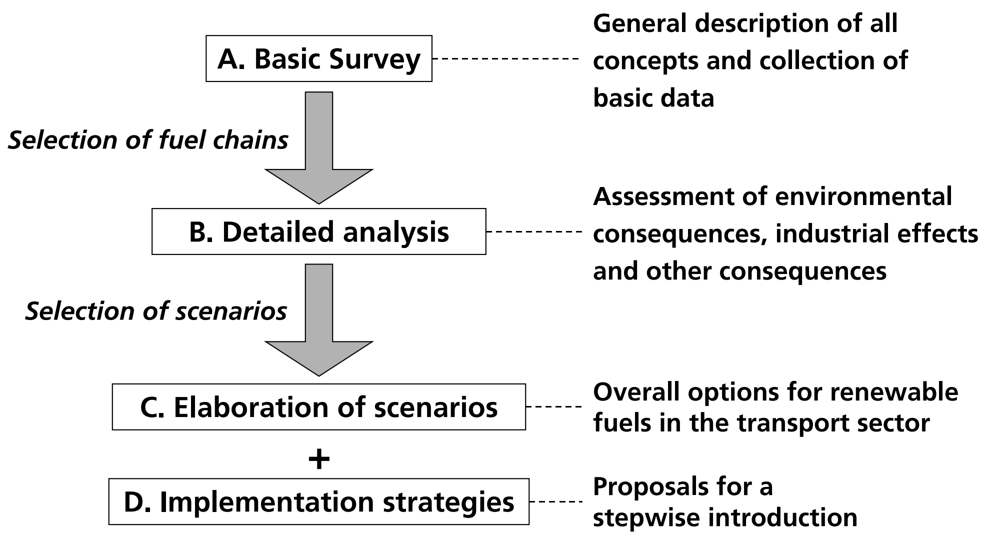
Chapter 7 presents firstly the selection of scenarios, i.e. fuel supply and vehicle options. Secondly it continues with the description of these scenarios. The implementation strategies for the selected scenarios are carried out in chapter 8.

Chapter 9 summarises major findings and presents the conclusions of the study.

2.3 Approach and methodology

For the elaboration of the study a stepwise procedure was chosen (see Figure 9): Starting with a broad basic survey of technical concepts and fuel provision options, followed by two stages of selections, first the selection of fuel chains for a detailed analysis and second the selection of scenarios for the fuel supply for the transportation sector. Lastly implementation strategies are worked out for these scenarios.

Figure 9: Procedure of the study



A. Basic survey

The first step of the study is a basic survey of all possible technical concepts in connection with transportation powered by renewable fuels. For getting a better structured view on the wide range of energy sources and technologies a classification was established as follows (see Figure 10):

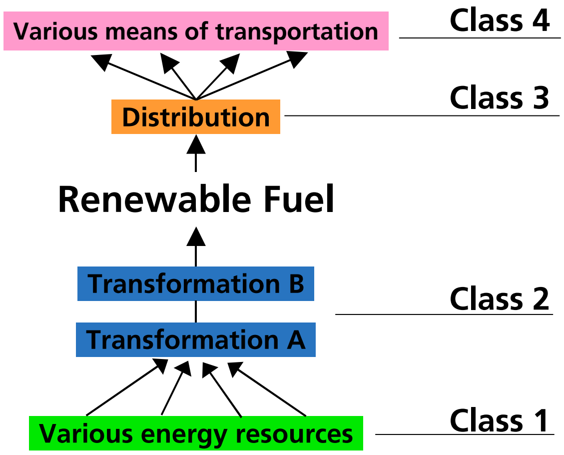
Class 1: Provision of primary energy sources or electricity generation (comprises energy plants, organic residues and renewable or nuclear electric energy)

Class 2: Transformation of the primary energy sources of class 1 into secondary energy sources
(comprises crushing of oil plants, thermochemical conversion, fermentation, electricity from biomass, production of hydrogen and secondary processing)

Class 3: Distribution of the fuel resulting from class 2 to the user
(comprises tank lorries and trains, pipelines and shipping)

Class 4: Vehicle propulsion technologies for the final energy use
(comprises combustion engines and electric propulsion for all modes of transport)

Figure 10: Classification of energy sources and technologies



Each of the four classes consists of several elements, here called modules. For example class 1 includes modules of various oil and woody energy plants, class 4 includes various propulsion technologies like piston engines or fuel cells. These elements represent a sub-category of the classes and were compiled in a common form, the module sheet (see Figure 11). These module sheets are the result of the broad basic survey for which relevant publications and literature was used, conferences were visited and meetings with important industrial and scientific representatives were arranged by the consultant.

The module sheets include a general description of the state of art of the issue. Some quantitative figures concerning CO_2 emissions, efficiency and costs are recorded. Finally a qualitative assessment of some other aspects is mentioned. The module sheets were modified for each class.

Figure 11: Module sheet for the description of the classes´ elements (see annex)

No.:	(module number)	**(Module Title)**

Class:	(number)	Input from:	(Module number)
Category:	(subtype of class)	Output to:	(Module number)

General description of the process
(description)
Regional specifications in the EU
(description)
Foreseeable intermediate (5-10 years) and long-term (25-30 years) development
(description)
Internal and external resources
(list of sources)

Description of the calculation to obtain the quantitative figures
(description)
Description of the calculation to obtain the availability data
(description)
Description of the finding of some qualitative evaluations
(description)

Quantitative assessment of the module for the present state	
Output unit:	[output unit]
Economy:	
costs (€) per output unit	(number)
Ecology:	
emission of CO_2 (kg) per output unit	(number)
Efficiency:	
GJ output energy per GJ input energy	(number)

Availability (especially for primary energy)																
Quantitative potential (PJ/a)																
Country / primary energy origin	A	B	DK	FIN	F	D	EL	IRL	I	L	NL	P	E	S	UK	EU 15
actual use																
technical potential																
Country / primary energy origin	CY	CZ	EE	HU	PL	SI	BG	LT	LV	MT	RO	SK	TR	CH	N	EU 30
actual use																
technical potential																

Qualitative assessment of the module					
	very bad	bad	medium	good	very good
Ecology					
(various parameters)			(X)		
Availability					
(various parameters)			(X)		
Other indicators					
(various parameters)			(X)		

B. Selection of fuel chains and detailed analyses

The modules of the four classes can be linked together in many different variations in order to create a technically feasible fuel chain from the primary energy to the final energy use. Starting from the results of the basic survey the most promising chains are chosen for the detailed analysis. The selection is done by considering the best figures of the basic survey as well as some further criteria, which have not been considered in the basic survey but could become relevant in the future.

The selected fuel chains undergo a **Life Cycle Assessment (LCA)** which elaborates the environmental consequences using available future data of the process steps and assumptions where necessary. The LCA provides information about

- Global warming potential
- Acidification
- Nutrification
- Cumulated fossil energy demand
- Biodiversity
- Others

On the base of the selected fuel chains **economic considerations** are presented as well. A qualitative description of all relevant aspects is given including some calculations for certain aspects. Results of several studies dealing with economic aspects of renewable energy, the building up of the necessary infrastructure and the vehicle market are outlined.

The following economic indicators are taken into account: Effects on employment are discussed and a comparative overview of employment changes in the automotive sector, agriculture sector, and the economy at large provided. Furthermore implications for trade are examined, noting in particular the impact of distributional effects across EU Member States as determined by their import dependency on fossil fuels. Changes in production and infrastructure costs are covered and the role of the public sector in overcoming barriers to market entry resulting from the high fixed costs of renewable fuels is described. A discussion of private demand and the behaviour of consumers completes this part of the study.

C. Selection and elaboration of scenarios

After analysing nearly the whole range of impacts and consequences, which can be caused by the introduction of renewable fuels, options for a Europe-wide renewable fuel supply, here called scenarios, are worked out.

Several criteria, mainly the outcomes of step B are considered. As a further aspect the future energy demand of the transportation sector becomes relevant at this phase of the study. For the assessment of the potentials of renewable fuels and for establishing scenarios the future energy demand by transportation mode is forecasted. Since the available studies in this field have different purposes and consider different countries, some assumptions have been made. The aim is to get a rough overview on tendencies and proportions of the supply-demand ratio in the long term perspective.

The approach of the scenario selection is a qualitative one. It takes into account that (beside the consideration of step B and the energy demand forecast) a concrete and consequent quantitative assessment would not lead to a satisfying result because uncertainties are to high and assumptions too numerous.

The scenarios themselves describe several future options for the usage of renewable fuels in the transport sector with regard to the long term perspective. They provide information about coverage proportions for different transport modes and elaborate blending opportunities. Overall environmental effects are figured out.

D. Implementation strategies

Implementation strategies refer to the scenarios and attach importance to the implementation steps, which are necessary to introduce renewable fuels successfully. Based on the introduction of new technologies in the past as well as on new insights of the study the possible developments for the next decades are illustrated.

The implementation strategies include technical measures to achieve renewable fuels in transportation and also some regulative and fiscal instruments, which can support the fuel introduction or are even indispensable.

3 Survey of promising technical vehicle concepts

3.1 Technical concepts for road traffic

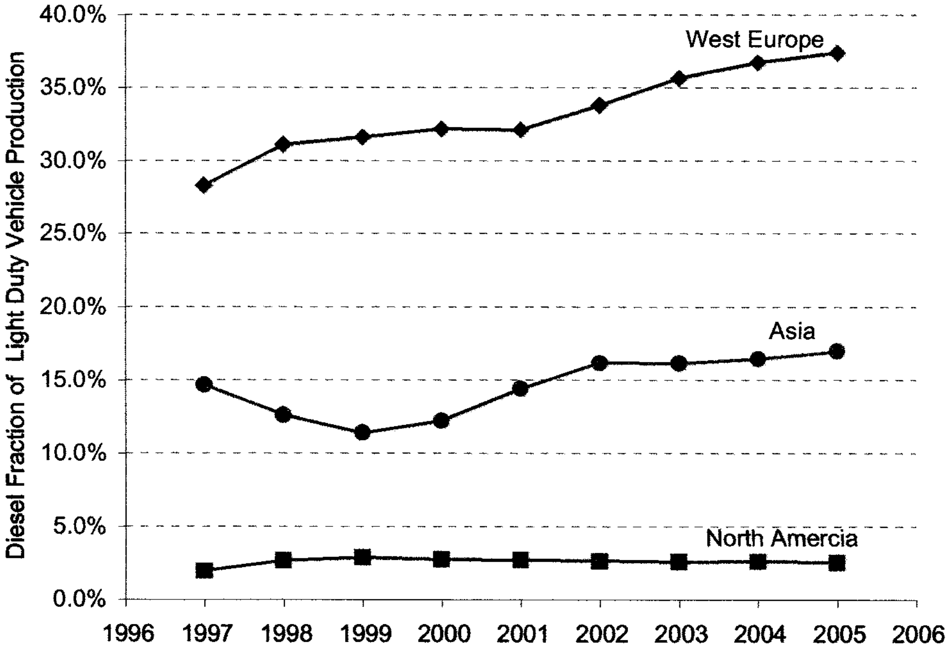
3.1.1 Combustion engines

In road traffic mostly conventional combustion engines are used. These technologies are standardised and well engineered.

There are two different types of drives in use - the petrol engine and the diesel engine, which operate on petrol and diesel respectively.

Today around two third of all LDV run on petrol while the last third is running on diesel. This share differs widely by the different countries in Europe due to the differences in the price per litre for petrol and diesel. Those prices are to a large extend dependent on the fuel taxes for both fuels and especially for diesel those taxes reflect different opinions on the health hazard of the exhaust fumes of a diesel engine. Today throughout Europe the use of diesel engines in LDV is growing. (see Figure 12)

Figure 12: Diesel Fraction of Light-Duty Vehicle Production by Region[4]



[Source: DRI-WEFA, 2001]

Lorries and buses run more or less only with diesel all over the EU.

The reasons why these conventional engine concepts are so widely spread are the easy handling, the range, the supply guarantee, and the relatively low costs for the vehicles, the fuel and the infrastructure.

[4] DRI·WEFA and Arthur D. Little: Future Powertrain Technologies: The next Generation, Position Paper Advanced Combustion Engine Technology, Outlook, 2008 – 2020, 2001.

But the conventional combustion engines have two big disadvantages, the emission of pollutants and the release of CO_2 as the main substance causing the so called greenhouse effect. The emissions arise during the burning process in the engine. The most important pollutants are CO, VOC, NO_x and benzene. Mainly with diesel engines but also with the modern direct-injection petrol engines particles are another critical compound of the exhaust fumes. The release of CO_2 is due to the effect that fossil fuels contain carbon.

To tackle the problem of the pollutant emissions which was top on the agenda in the last two decades in Europe´s transportation related environmental discussion the EU has settled the so called Euro-Norms which lead to a tremendous reduction of the emissions (see Table 2).

Table 2: Mandatory tailpipe emission limits[5]

			Euro 0 (1988/90)	Euro 1 (1992/93)	Euro 2 (1996)	Euro 3 (2000)	Euro 4 (2005)	Euro 5 (2008)
LDV [g/km]	petrol	NO_X		1,13	0,5	0,15	0,08	
		VOC				0,20	0,10	
		CO		3,16	2,2	2,3	1,0	
	diesel	NO_X		1,13	0,7	0,56	0,30	
		VOC						
		CO		3,16	1,0	0,64	0,5	
		parti-cles		0,18	0,08	0,05	0,025	
HDV [g/kWh]	diesel	NO_X	15,8	9,0	7,0	5,0	3,5	2,0
		VOC	2,6	1,23	1,1	0,66	0,46	0,46
		CO	12,3	4,9	4,0	2,1	1,5	1,5
		parti-cles	-	0,4	0,15	0,1	0,02	0,02

For LDV the most important technology to fulfil the needs of the limits shown in table 3-1 is the three-way-catalytic-converter. But there are also some measures concerning improvements in the technology of the combustion engine itself, like the introduction of the petrol driven direct injection engine or the improvement of the fuels.

According to the timegap in the general awareness of the problem the discussion to reduce the fuel consumption in road transportation came up later than the discussion on the road transport related emissions, mainly based on the need to reduce the road transport related release of CO_2. 1998 it came to a commitment between the European car manufacturers, organised in the ACEA, and the European Union dealing with a self commitment of the car manufactures to reduce the release of $C0_2$ of new vehicles sold in Europe until 2008 by 25 % compared with the situation in 1997. This reduction leads to the target of an average release of CO_2 of 140 g/km (corresponding to a fuel consumption of 5.7 l/100km) compared with 187 g/km (corresponding to 7.6 l/100km) in 1997. Furthermore the ACEA committed itself to review the situation in 2003 to evaluate the prospects for further reduction towards the Community's objective for new cars sold of an average release of CO_2 of 120 g/km (corresponding to 4.9 l/100km) by 2012. Due to this self commitments of ACEA there are still no regulations on the maximum value for fuel consumption of LDV.

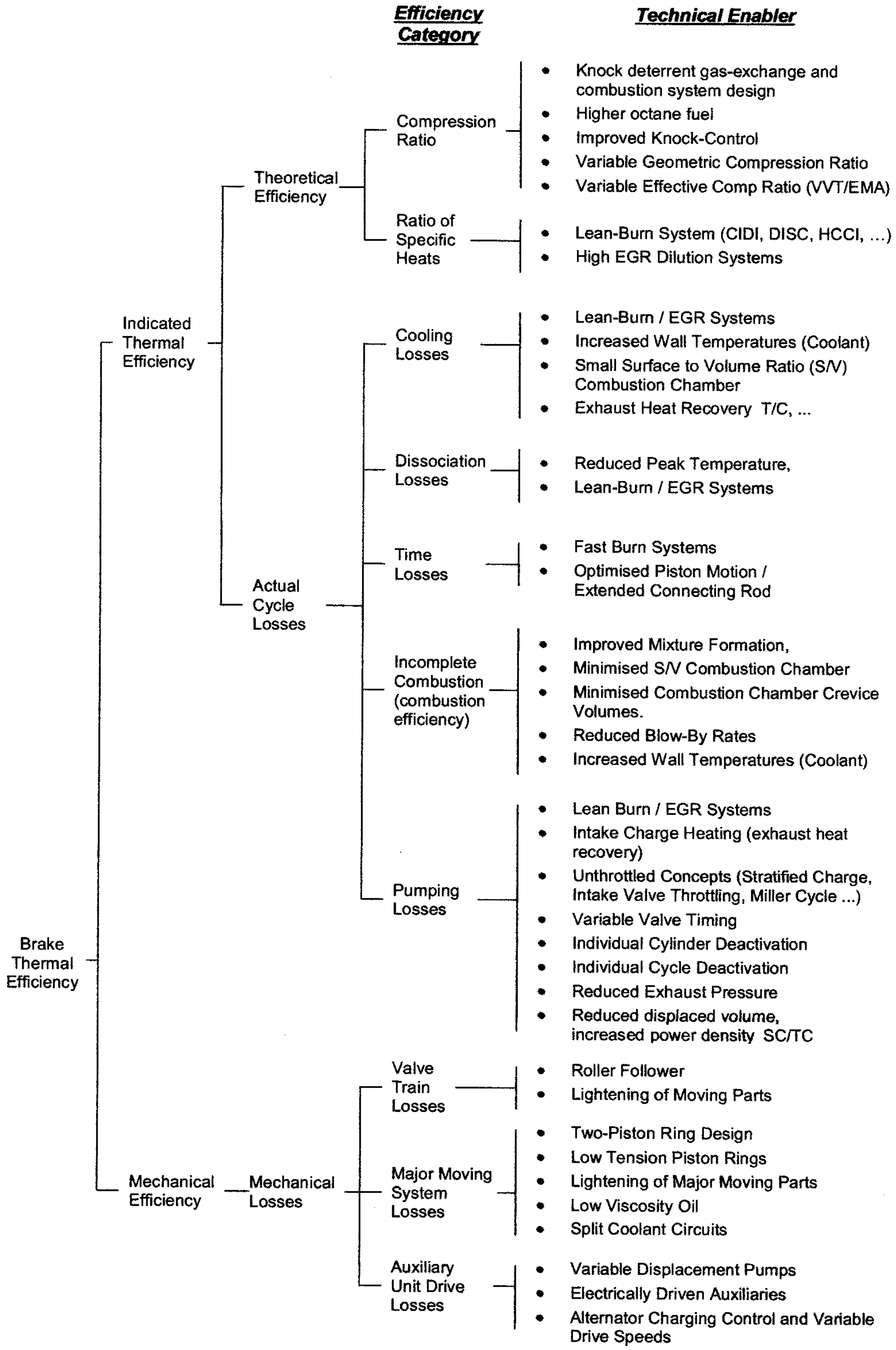
For LDV there are neither additional regulations for the reduction of the exhaust fume emissions after EURO4 nor for further improvements in the fuel consumption after the year 2012. But DRI·WEFA and Arthur D. Little describe in their report "Position Paper Advanced Com-

[5] Several EU-Directives on mandatory tailpipe emission limits.

bustion Engine Technology, Outlook, 2008 - 2020"[6] a lot of possibilities to improve combustion engines which are driven by fossil fuels. Those measures lead them to some forecasts for further reductions. Figure 13 summarises for example some technical enablers for an increased internal combustion engine efficiency. It's not the task of this study to describe all this measures in detail but the variety of these measures show that there is a large potential to be expected to improve the efficiency of the combustion engine leading to a reduced fuel consumption.

[6] DRI·WEFA and Arthur D. Little: Future Powertrain Technologies: The next Generation, 2001.

Figure 13: Technical enablers for an increased internal combustion engine efficiency (incomplete listing)[7]



[Source: DRI-WEFA, 2001]

[7] DRI·WEFA and Arthur D. Little: Future Powertrain Technologies: The next Generation, Position Paper Advanced Combustion Engine Technology, Outlook, 2008 – 2020, 2001.

Taking into account the measures shown in Figure 13 and some other measures DRI·WEFA and Arthur D. Little build up some scenarios for a possible future development until 2020 in Europe as a main part of their reports "Future Powertrain Technologies - The Next Generation". This is the most far-reaching concept in respect to the potentials of combustion engines to reduce emissions and energy consumption. Part of this scenarios are scenarios on future regulations in the EU with regard on the exhaust emissions, the fuel quality and the fuel consumption resp. the release of CO_2. Table 3 shows the supposed regulations for Europe.

Table 3: Supposed European regulations until 2020[8]

Regulated Criteria	***Europe***		
	No Surprises	***No Smoking***	***No Solace***
HC, CO, NOx	• Euro-V (50% of Euro-IV) by 2012 • Euro-VI (50% of Euro-V) by 2018 • Diesel and gasoline standards the same		
Toxic Compounds	Legislation similar to US mandates introduced		
EVAP	Approach near-zero (75% reduction from current 2g/test standards)		
OBD	Legislation similar to US mandates		
Fuel Sulfur	Gasoline: By 2000, 150 ppm Diesel: By 2000, 350 ppm Both: In 2005, 50 ppm mandatory but <10ppm will be available; by 2011, <10 ppm mandatory		
Fuel Economy / CO_2	• 140 g CO_2/km (2008) (6.0 L/100km, 39.1 mpg) • 120 g CO_2/km (2012) (5.5 L/100km, 43 mpg) [Down from industry average 170 g/km (6.9 L/100km, 34.3 mpg) in 2000]		• 120 g CO_2/km (2008) (5.5 L/100km, *43 mpg*) • 90 g CO_2/km (2012) (4.6 L/100km *50.7 mpg*) [Down from industry average 170 g/km *(6.9 L/100km, 34.3 mpg)* in 2000]
PM	• 0.05 g/km (2000) (diesel only) • 0.025 g/km (2005) (diesel only) • 0.013 g/km (2010) (all LDV) • 0.010 g/km (2015) (all LDV)	• 0.05 g/km (2000) (diesel only) • 0.025 g/km (2005) (diesel only) • 0.010 g/km (2010) (all LDV) • 0.002 g/km (2015) (all LDV)	
ZEV	No ZEV mandates	ZEV fraction of new fleet sales mandated – • 2% in 2016 • 6% in 2020	

[Source: DRI-WEFA, 2001]

The different scenarios are defined as follows:

- "No surprises: a "business as usual" baseline scenario.
- No smoking: a scenario where PM emissions are declared highly carcinogenic and the health effects of emissions gain increased public attention, and
- No Solace: a scenario where global warming and PM emissions become the highest priority."[9]

Each of the scenarios is part of a whole group of scenarios describing not only the legislation but also the availability and prices of oil and energy and the economic and business framework.

Even if the authors of this study figure out that "the European Rough Ride Scenario < *comment: The regulation related scenario "No Solace" is part of the " Rough Ride Scenario".* > is on the borderline of what is technically achievable, even with very aggressive

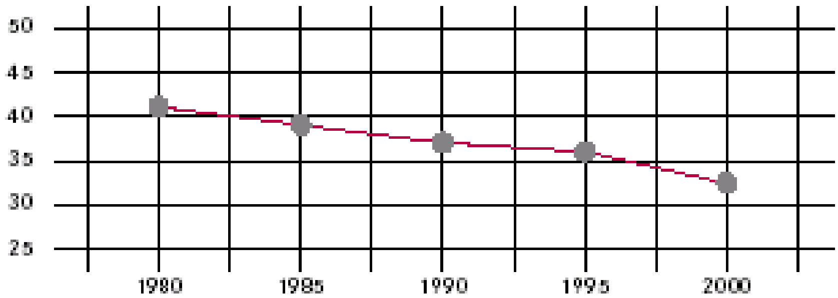
[8] DRI·WEFA and Arthur D. Little: Future Powertrain Technologies: The next Generation, Final Report Alternative Scenarios, 2001.
[9] DRI·WEFA and Arthur D. Little: Future Powertrain Technologies: The next Generation, Final Report Alternative Scenarios, 2001.

ramp-up rates for new technologies"[10] it indicates which potentials for future developments the combustion engine still has, without reflecting for one specific technology for the pathway in the future.

Compared with LDVs busses and trucks (HDV) in Europe already have a relatively low fuel consumption and low release of CO_2. This is due to the fact that they are running more or less only for commercial needs with a high mileage and that a reduced fuel consumption leads to reduced operation costs. In the past this lead to a continuous reduction in the fuel consumption as

Figure 14 shows for a 40-ton truck-trailer combination which can be assumed as typical for European long distance transportation.

Figure 14: Fuel consumption of a 40-ton truck-trailer combination 1980 - 2000 in litres / 100km[11]



[Source: DaimlerChrysler, 2001]

On the opposite HDV are still the main contributors to the road transport related air pollution. But as shown in Table 2 they are now part of the emission related legislation in Europe and have to fulfil severe standards leading from EURO1 in 1992/3 to EURO5 in 2008. Due to the optimisation of the engines of HDVs the compliance with the emission standards leads to a slight increase of the fuel consumption which will be between one and three litres per 100 Kilometres.

In general there are more or less the same measures to improve the efficiency of HDVs engines as for diesel driven passenger cars. But as already mentioned with respect to the requirements of the improvement of the air quality these measures can't develop their full potentials. On the other hand there are some improvements possible in the fields of the energy demand of the auxiliary instruments (e.g. air conditioning), of the weight and of the aerodynamics.

Overlying all this aspects we can expect until 2020 a fuel consumption of a 40-t-HDV of around 30 litres / 100km.

Beside the technical optimisation the pollutant emissions as well as the release of CO_2 of the combustion engine can be diminished with the use of alternative fuels instead of conventional ones.

One alternative which is already relatively wide spread is the use of Biodiesel. Most new built diesel engines can drive with the methyl ester produced from rape or sunflower without big modifications. The big advantage is the vegetable basis of the fuel. This leads to a significant reduction of the release of CO_2 compared with diesel produced on a fossil basis since the

[10] DRI·WEFA and Arthur D. Little: Future Powertrain Technologies: The next Generation, 2001.
[11] DaimlerChrysler, 2001.

same quantity of carbon which will be released during the combustion was stored in advance in the plant during the growth of the plant. The emissions of the other exhaust gases are predominantly lower than those of fossil diesel. Biodiesel can be used pure or as a blend. In Europe there are different developments. So run vehicles in Austria, Germany and Sweden with pure Biodiesel, while in France Biodiesel is added to the fossil diesel with a share from 5 to 30 % and Italy uses a 5 % - blend.

Alcohols are a further possibility to run vehicles. The most common alcohol to be used as a fuel in Europe is methanol. There are two ways to obtain methanol: It can be easily extracted from fossil energy carriers such as coal and natural gas and it can also be produced from wood or waste. The calorific value of methanol of 20 MJ/kg is about half the calorific value of conventional fuels. Vehicles operating on methanol have considerably lower emissions of NO_x, CO and VOC than vehicles powered by petrol. In addition methanol engines generate only a small quantity of aromatic compounds. This is leading to a reduction of the impact to the ozone production. If methanol is produced from biomass the CO_2-balance is a fairly good one. The same quantity of carbon that will be released during the combustion was stored in advance in the plant during the growth of the plant.

Ethanol is also a possible alcohol alternative to fossil fuels. The properties of ethanol are quite similar to methanol. Ethanol is usually made of biomass, crop, starch or cellulose material. The emissions of NO_X, CO and VOC are lower than those of a petrol engine. Ethanol from biomass has also a good CO_2-balance since again the same quantity of carbon which will be released during the combustion was stored in advance in the plant during the growth of the plant.

Methanol and ethanol can be used pure but it is more common to blend conventional fuels with those alcohols. This procedure improves the exhaust gas emissions without large investment in infrastructure or modification of engines.

Gas is an other alternative to fossil fuels. A vehicle running on natural gas (over 80 % CH_4) reaches performances comparable to those of a vehicle running on conventional fuels. Natural gas is stored in two states of aggregation: in liquid form (LNG = Liquefied Natural Gas) or as a gas under a pressure of 200 bar (CNG = Compressed Natural Gas). At present the CNG is the preferred storage alternative in Europe. A CNG-vehicle has up to 90% lower NMVOC emissions but high NO_X emissions. Vehicles running on natural gas emit 20 % less specific CO_2 emissions than vehicles running on diesel. For the climate protection gas-vehicles are better than conventional petrol or diesel vehicles. The limited range and also the fact that the dimension of the network of filling stations for natural gas is far away from the dimension of the network for conventional fuels lead to the bivalent operation. For this kind of operation the vehicle is equipped with two kinds of storage devices and the engine can run alternatively both on natural gas and petrol.

But natural gas is not a renewable source of energy. There are some possibilities to produce biogases, e.g. using sewer gases from organic waste or from waste water treatment plants, which can be addressed as renewable. Since those applications can't reach potentials to that extent that would be necessary to fulfil the needs of Europeans long distance transportation the usage of those biogases should be left to local applications.

An alternative fuel to be used in conventional combustion engines is also hydrogen. In the past there already were some field tests using liquid hydrogen. Today in this market the German car producer BMW sets the pace by operating a test fleet of several cars of its upper class. Those cars are bivalent. This means they can be operated by petrol or liquid hydrogen. The cars have with both fuels nearly the same driving performances. BMW is operating this test fleet since 2001 and intends to start the mass production in a few years.

In January 2003 Ford presented the new model Ford U to the public. The Ford U also uses an internal combustion engine but now in combination with an electric hybrid transmission. As fuel only gaseous hydrogen is used which is stored under a pressure of 700 bar. The electric motor serves also as a generator to recover the brake energy.

Both technical concepts, from the technical point of view, seem to be promising for the future, combining well known technology from the traditional actuation concepts with the "new" fuel hydrogen. From the present point of view both types of storage, liquid or gaseous under a pressure of 700 bar, are possible, both showing specific advantages and disadvantages. The main disadvantage of the liquid hydrogen is the high energy demand to cool it down to the liquid state of aggregation, while gaseous hydrogen can be stored under ambient temperatures. The main disadvantage of the gaseous hydrogen is the low energy content per volume. That's why it has to be compressed and stored in heavy and voluminous tanks. Both, the weight and size of the tanks and the low energy content, reduce the range of the vehicles considerable.

When burning hydrogen in a combustion engine there occur only very low NO_x-emissions resulting from the nitrogen in the air. That's why this propulsion concept is very environmental friendly. But with respect to the reduction of the release of CO_2 only hydrogen from renewable sources fulfils the necessary requirements. So the availability of hydrogen in general but especially of renewable produced hydrogen is the bottleneck for the implementation of this actuation concept in the near future. Nevertheless it makes some sense to start already with non-renewable produced hydrogen to bring the cars to the market.

Besides conventional piston engines there exist some other concepts for combustion engines. One of them is the gas turbine. The basic difference between a gas turbine and a conventional combustion engine lies in the fact that the ignition of the combustion is not done via an explosion but in a continuous mode. Gas turbines are already used in many applications that require a low unit weight. The implementation of this engine in passenger cars and trucks would lead to reduced emission of pollutants. The main advantage against the background of the introduction of renewable fuels is the multifuel performance of this engine which allows using all liquid or gaseous combustible substances like petrol, diesel, methanol/ethanol, natural gas or hydrogen. Several technical difficulties have kept the gas turbine from being implemented on a broad basis into road vehicles by now. The high operating temperatures put enormous stress on the implemented components, reducing the life span of the entire device and leading to a very costly series production. Besides the efficiency of 30 %, that is state of the art by now, is also rather low. In case of part load operation the efficiency even falls down to 10 to 15 %. Further disadvantages are the high noise generation and a delayed reaction behaviour in comparison with the piston engine.

The steam engine is an other drive technology. Potentially steam engines can operate at a very high efficiency. Test constructions lead to engines with an efficiency almost as high as the efficiency of diesel engines. But to put these engines into practice still a series of technical difficulties has to be overcome. For instance at present the construction volume is rather high, that means that the performance density is rather low. Even if the concept of the steam engine is still in a very initial stage of development a considerable improvement potential can be expected. Within the framework of the research on regenerative energies in transportation this concept could be of importance as it features the multifuel capability.

Like the gas turbine the Stirling-engine is operating on a drive concept based upon continuous combustion. This engine type also features a multifuel capability. In contradiction to the piston engine the combustion of the fuel does not take place in but outside the cylinder (external combustion). Major advantages of the engine construction are the continuous combustion leading to a very low emission of pollutants, to reduced noise generation and to the multifuel capability. Decisive disadvantages are the conceptual and technical difficulties at the implementation of this principle into a vehicle engine. As the major part of the thermal energy is conveyed to the cooling water a big energetic loss occurs here and as a result the efficiency of the engine is low. Via a so-called regenerator with a high heat accumulation capability part of the energy is recuperated.

3.1.2 Fuel Cells

Beside the conventional combustion engines there exists an other technology for vehicle drive, which is just shortly before the introduction to the market - the fuel cell.

The fuel cell technology intends to profit from the advantages of the electric drive (no emissions of pollutants, low noise emission) avoiding the constraints of the battery technology. The components of the drive (electric engine) are the same as for the battery powered electric vehicle and therefore do not represent any technical or economic problem.

The fuel cell makes it possible to obtain electricity directly via the transformation of hydrogen and oxygen into water. This method has the advantage that it does not generate in place any CO_2, pollutant emissions or noise. Furthermore this process can be operated with a very high efficiency compared to the operation of an internal combustion engine.

Of all different types of fuel cells special attention is given to the application of the PEM-fuel cell in road traffic. The advantages of this type of fuel cell are as follows. It can be operated at ambient temperature, the power density is very high and the electrolyte doesn't consist of any critical toxic substances. Most developers consider the PEM to be the most suitable fuel cell for vehicles. Only some are focusing on alkaline fuel cells or solid oxide fuel cells (SOFC). At the moment the disadvantages of all fuel cells are the high price and the lack of long term stability.

The storage of hydrogen and the transformation into electric energy are the difficulties that arise. The storage of hydrogen in gaseous or liquid form represents two completely different situations for the application and the infrastructure.

For gaseous hydrogen the problems that have to be dealt with are the very low specific energy content per volume and the safety aspect (explosion hazard). The storage of gaseous hydrogen can be done with pressurised hydrogen or with the help of the hybrid storage. For pressures of 250 bar or 350 bar which are state of the art by now the specific energy of the hydrogen related to the volume is relatively low and therefore efforts are made to achieve pressures up to 700 bar using new materials.

As a further possibility to store gaseous hydrogen the metal hybrid storage is taken into consideration. In this case atomic hydrogen is stored this leading to an advantage with respect to safety.

The liquid storage offers by far the highest specific energy with respect to mass and volume and therefore it is particularly suited for the implementation in road vehicles. However the technological requirements are extreme as hydrogen liquefies only at extremely low temperatures. That's why the liquefaction is a very energy-intensive process and the storage requires costly installations.

As basins for liquefied hydrogen highly isolated tanks can be used. Due to the fact that heat penetration cannot be avoided the hydrogen in the tank will vaporise to a certain extent and this will lead to an increase of the pressure in the tank. The gaseous hydrogen generated this way must be let off. The tanks for the storage of liquid hydrogen are costly and sophisticated constructions. Besides the fuelling unit has to be invested with complicated appliances in order to ensure a high isolation of the refuelling adapter. Nevertheless initial applications of automatic fuel stations for liquid hydrogen show that the refilling is possible in less than ten minutes.

The liquefaction of hydrogen requires a high input of both technology and energy. Hydrogen is available at first always as a gas and therefore liquefaction will always be an additional process. Nevertheless this sophisticated procedure is worthwhile as the volume related energy content of liquid hydrogen is considerably higher even than that of gaseous pressurised hydrogen at 700 bar. Liquid hydrogen represents a very attractive solution for road vehicles. The range of a fuel cell vehicle powered by LH_2 will be higher than that of a vehicle with GH_2. Ranges of 500 km or even more seem achievable. Or the other way round in case of a moderate range the size of the tanks can be kept comparably small.

However the usage of liquid hydrogen is connected to serious technical and economic difficulties. The enormous difficulties arising in connection with the handling of hydrogen lead to the idea to produce hydrogen onboard during the operation of the vehicle from an energy carrier that can be handled more easily. Methanol can be used in two different ways. One way is to obtain hydrogen from methanol on-board by using a reformer and to operate the fuel cell with hydrogen (Indirect Methanol Fuel Cell, IMFC), the second possibility is to operate the fuel cell directly with methanol (Direct Methanol Fuel Cell, DMFC).

Compared to hydrogen methanol is a very cost-efficient fuel when both with respect to handling and to the specific energy. The handling is a lot easier as methanol is in liquid form at ambient temperature and therefore the safety problems are smaller.

To obtain hydrogen from methanol a reformer is used. To save the reforming process intense efforts are made to develop a possibility to achieve a direct conversion of the methanol in the fuel cell. This Direct-Methanol-Fuel-Cell (DMFC) is very attractive for vehicles as it requires less space and is cheaper than a combination of fuel cell and reformer. However the DMFC is still in the stage of research. There still exist serious technological problems which need to be clarified before this procedure can be used on an industrial scale.

The refilling of the vehicles can be done in analogy to the refilling with conventional fuels.

As changeover from petrol to methanol or hydrogen economy a further kind of technology is under research: a petrol fueled system consisting of a fuel cell and a specific reformer. Vehicles driven with this technology run with conventional petrol that is converted into hydrogen on-board with the help of a reformer. The fuel cell works with the hydrogen produced and operates an electric engine. Compared with a conventional piston engine it has not much impact on emissions but the fuel cell has a higher efficiency than a conventional combustion engine.

For road vehicles the fuel cell technology is in the transition stage between research and test phase. There are already numerous passenger cars and buses under operation in various field tests. For large lorries operated on long distances (e.g. a 40-ton truck-trailer combination) today no application of fuel cells is foreseeable.

Of course the pollutant emissions depend on the used fuel. Hdrogen will lead really to a zero emission vehicle, at least for the direct emissions while operating the vehicle. Some higher direct emissions occur by using methanol, the highest by using petrol. Since emissions not only occur while just operating a car but also in the processes before a careful analysis of the fuels considered is necessary. The optimal solution seems to be the usage of renewable produced hydrogen. Considerations with repect to the release of CO_2 lead to similar results.

3.2 Technical concepts for other modes of transportation

3.2.1 Railways

For railways the range of application of modern internal combustion piston engines running on diesel is universal. In the sector of rail traffic locomotives and motor rail coaches with diesel engines are used for high-speed travel, for regional part load traffic but also for heavy freight trains or for shunting. Diesel engines are very effective in rail transport due to their high part-load, loading and acceleration behaviour. Besides diesel engines have high total lives of up to 80,000 hours of operation, low maintenance rates and an efficiency of 30 to 45 %. Diesel engines could be used as primary drive (diesel hydraulic) or as driving component (diesel electric) for power generation.

Today modern diesel motor rail coaches comply with the exhaust emission standard EURO2 for lorries.

Engines for new motor rail trains and new high-speed trains have to comply with the exhaust emission standard ERRI (European Rail Services). To cover a distance of 100 km the maximum of 6 kg CO_2/person is allowed to be generated.

One alternative for the drive of diesel engines is the usage of Biodiesel. Internal combustion engines operating on Biodiesel have to comply with the same requirements as a conventional diesel engine. By using Biodiesel of the standard E DIN 51606 the exhaust of soot, carbon monoxide and hydrocarbons is reduced drastically and there is no emission of sulphur. If Biodiesel is used in combination with an oxidation catalyst these emissions reduce even more. As the exhaust emissions of the Biodiesel do not contain any sulphur, the exhaust cleaning device will have a lasting and appropriate function. There will be a considerable reduction of the release of CO_2 since the carbon which will be released during the combustion was stored in the plant during the growth of the plant. In rail traffic there exists the possibility to operate on pure Biodiesel or on a blend of Biodiesel and conventional diesel.

As alternative fuel in railway transport also natural gas (over 80% methane) can be used. The advantages of natural gas as a fuel are the extremely clean burning process and the low content of carbon and this way the exhaust emissions lie clearly considerably below those of the diesel engine. Another advantage is the low noise level. First tests with the natural gas drive have been made in rail traffic. The natural gas needed is transported in a LNG (= liquid natural gas) tank at a temperature of -138° Celsius and a pressure of 5 bar. The advantage of the LNG tank is that it is designated to economise space within the vehicle and at the same time to improve the range of the vehicle in comparison with the conventional storage technologies of natural gas. The range of the tested locomotive operating on natural gas lies between 250 to 300 km. The implementation of natural gas on rail motor coaches in regional tranportation requires an engine power of 472 kW and again the usage of a LNG tank.

But natural gas is not a renewable source of energy. There are some possibilities to produce biogases, e.g. using sewer gases from organic waste or from waste water treatment plants, which can be addressed as renewable. Since those applications can't reach potentials to that extent that would be necessary to fulfil the needs of Europeans long distance transportation the usage of those biogases should be left to local applications.

An alternative drive concept to conventional piston engines is the gas turbine. In gas turbines the energy conversion is done continuously. A compressor heats the air intake and compresses it to 5 bar. A part of the air pre-heated in heat exchangers will be burned along with the fuel in the gas turbine and the combustion products together with the rest of the air will be cooled down to approximately 1300° Celsius at the exit of the turbine. The remaining temperature gradient will be reduced at the connected turbine. The adjustment to the different load demand is done via the regulation of the temperature of the working gases as well as by moving the guiding blades of the compressor and the turbines. The high working temperatures lead to high demands with respect to the components used. Gas turbines achieve efficiencies between 30 to 45 %. Gas turbines can power locomotives, motor rail coaches and motor-coach trains. The advantage of the gas turbines is given by the fact that they are smaller and lighter than common diesel engines with three to four times the power of the diesel engines. The major disadvantage is that the fuel consumption is approximately double the consumption of a conventional diesel engine this leading to a considerably reduced range. Another disadvantage is the high noise level. Fuels that can be used are: natural gas, diesel, kerosene and jet fuel.

In the US there is one application of the gas turbine for long distance transportation on the market. Bombardier Transportation has developed a so called jet train with a maximum speed of 240 km/h, designed for the North-American market. This Bombardier JetTrain is powered by a gas turbine derived from a Pratt & Whitney PW 150, which replaces the traditional diesel engine found in most current rail equipment, but which is also fuelled with diesel. The acceleration is twice compared to an diesel engine whereas the emissions and the release of CO_2 are considerably lower.

Principally gas turbines are suitable for the re-equipment for the operation on hydrogen. The operation with a mixed gas is effected without any problems today as one can rely on experiences on the addition of up to 80 % of H_2. The usage of pure hydrogen however generates considerable problems. Due to higher combustion temperatures as in case of the operation on natural gas the operation on pure hydrogen will lead to increased emissions of NO_x that can be reduced via water injection but cannot be brought under the required limiting values.

Instead of combustion engines for the drive of trains there are also imaginable fuel cells coupled with electric engines. Such a solution would follow the extensive experience about electric traction already available. But up to now there are no applications known dealing with the usage of fuel cells in long distance rail transportation. There are some ideas for the usage in light rails in regional traffic and one test locomotive was presented in the United States operating on a small scale on a private industry ground.

Taking into account the stage of development of the different alternative technologies in railway transportation only the usage of biodiesel in combustion engines could serve as a promising alternative to diesel driven combustion engines.

3.2.2 Inland Navigation

Inland navigation and coasting require engines with a high performance and broad application spectre. Furthermore vessel engines need to have a very high reliability. Fuel injection is done under normal or high pressure. The engines have a high specific output, a low noise level, a soft and smooth run, a reduced fuel consumption in the entire load sector and long life in connection with a reduced demand for maintenance.

Principally all conventional vessel engines can operate on diesel oil or heavy fuel. The heavy fuel must be brought to a temperature of 125 degrees Celsius before combustion. Only after this heating procedure it can be injected into the combustion engine. Heavy oil is formed of the residues of the refinery process of crude oil to petrol, diesel and other light heat oils. 80 % of the vessels worldwide operate on heavy oil. The ISO 8217 standard refers to the fact that the vessel fuels must consist of mixtures of hydrocarbons resulting from the oil refinery process. According to this standard fuels should not contain any other additives or chemical residues. For this reason the vessel engine manufacturer recommend a quick test of the quality of the bunker oil in order to avoid engine damage. The exhaust emissions dealt with are NO_x and SO_x, whereas the percentage of sulphur is continuously reduced in the fuel.

Engines running on Biodiesel nowadays have to fulfil the same requirements as the conventional vessel diesel engines. The combustion of Biodiesel according to the standard E DIN 51606 produces less sooth, CO and hydrocarbons and is free of sulphur. These emissions can be reduced even more if Biodiesel is used in combination with an oxidation catalyst. The fact that Biodiesel does not contain any sulphur ensures the optimal and durable functioning of this exhaust cleaning device. Biodiesel also leads to a significant reduction of the release of CO_2 compared with diesel produced on a fossil basis since the same quantity of carbon which will be released during the combustion was stored in advance in the plant during the growth of the plant.

Ship engines can use both pure Biodiesel and a blend of conventional diesel and Biodiesel. Biodiesel features considerable advantages with respect to hydrocarbons, carbon monoxide and particles when compared to conventional diesel. Whereas in case of mineral diesel the share of sulphur has to be reduced by way of an energy-intense process leading also to an increase of the emission of CO_2 and to a loss of the oiliness of the fuel Biodiesel can be considered as sulfur-free (max. concentration of sulfur: 0,001 %) and despite of this fact it has excellent lubricating properties and this way the wear of the engine is reduced. In case of accident biodiesel does not harm the water life likewise conventional fuel does.

Natural gas can be an alternative energy for ships. The advantages of natural gas as a fuel in comparison to diesel are the very clean combustion and the low carbon content obviously leading to an obvious reduction of the emission of pollutants. The convincing aspects of a gas engine are the smoothness of running and smoothness of combustion as a result of the fact that they operate on an externally supplied ignition. The typical composition of natural gas is 90 % methane and 10 % ethane. Another alternative that can be used as a drive in vessels is the diesel-gas-engine. This engine can operate both on diesel and on natural gas. The change from liquid to the gaseous fuel is possible without an engine stop. The natural gas needed is stored on board the ship under high pressure (200 bar) in gas cylinders. The special features of these gas engines invested with a controlled three-way catalytic converter are the extremely low emissions of gaseous pollutants like NO_X, HC lying clearly below the limiting values of the Euro 3 standard.

Another advantage of gas engines is an almost residue-free combustion and this way the emission of particles lies also below the limiting value.

But natural gas is not a renewable source of energy. There are some possibilities to produce biogases, e.g. using sewer gases from organic waste or from waste water treatment plants, which can be addressed as renewable. Since those applications can't reach potentials to that extent that would be necessary to fulfil the needs of Europeans long distance transportation the usage of those biogases should be left to local applications.

Hydrogen is one of the most promising energy carriers for the future. The usage of hydrogen as fuel for diesel engines combines a high efficiency with low emissions illustrating a meaningful stage of development on the way towards a hydrogen industry. As actuation for ships a direct injecting hydrogen diesel engine with high power density and low emissions could be used. When using hydrogen instead of diesel respectively heavy oil for fuel in big-size diesel engines the characteristic features of hydrogen have to be taken into consideration by implementation of an adjusted combustion concept.

Following theoretical concepts in principle also the usage of the fuel cell for inland shipping is possible. But up to now there are no concepts under discussion.

Taking into account the stage of development of the different alternative technologies in inland navigation and coasting only the usage of biodiesel in combustion engines could serve as a promising alternative to diesel driven combustion engines.

3.2.3 Aviation

Since air transportation has increased significantly during the last years, this mode can not be neglected in this study. The dominant role is taken by jet airplanes as they are used for the vast majority of air traffic and generate the major amount of pollution. Smaller piston-engine airplanes have by far a smaller impact since they do not fly at that high altitudes as jet airplanes do and usually operate only on short distances. For these smaller airplanes there are some thoughts to implement the fuel-cell technology as there is a project by NASA and EPA in the USA where a small turbopiston engine shall be modified to function with a fuel cell that shall provide enough energy for ranges of 500 to 800 miles.

Several opportunities improving the aircraft technology are to mention as there are a better aerodynamic, new materials that provide a weight reduction, improved engines and better avionics. Summarizing these measures e.g. the Lufthansa Airline expects a total fuel reduction potential of optimistic 40 % for the next 20 years. Most of these improvements could be achieved independent of the fuel type.

As a renewable fuel for airplanes there exist only hydrogen as a serious option. In principle hydrogen can be used easily as a fuel for turbines. It completely avoids direct emissions of greenhouse effecting gases, the most important one being CO_2. Moreover CO, hydrocarbons (HC), sulfur oxides (SO_x) and particles are avoided as well. Because of the presence of nitrogen in the air a very small amount of nitrogen oxides (NO_x) is emitted. However, compared to the combustion of kerosene the emission of water is 2.6 times greater for the use of hydrogen. The resulting water vapour creates a serious greenhouse effect if the flight altitude is above 10 km.

Because hydrogen is an extremely clean fuel, it will lead to about 25 % longer lifetime of the jet turbines. Maintenance will be reduced accordingly. Through its high calorific value (120.000 KJ/kg compared to 42.800 KJ/kg for kerosene) the fuel weight is reduced by a factor of 2.8, which enables smaller engines with less noise.

On the other hand, the low density of hydrogen (even for liquid hydrogen which is the only opportunity for airplanes) creates a crucial problem because it requires fuel tanks which are 4 times larger than for an equivalent mass of kerosene. Apart from the cryogenic fuel system major structural modifications comprising reinforcements of the fuselage and wings are necessary for the backfitting of a conventional airplane. However, because of the voluminous tanks, liquid hydrogen airplanes in the long term perspective will require a completely new designed airplane concept.

The intention to demonstrate the liquid hydrogen technology by a regional jet aircraft (type DO 328) was abandoned. Current plans are to substitute the kerosene operated auxiliary power unit (APU) with a fuel cell.

3.3 Conclusion

The analysis of the different technical vehicle concepts shows that over all different means of transport a lot of measures are possible to be taken to reduce the transportation related impact on the environment, esp. to reduce the release of CO_2. But the scope of this study which is dealing with renewable fuels for cross border transportation in Europe reduces the variety of the different measures to only a few really realistic options. Those options are mainly for road transportation. In detail for road transportation the following measures are promising:

- usage of Biodiesel (pure or as a blend),
- usage of Methanol as a blend,

- usage of Ethanol as a blend,
- usage of hydrogen (liquid or gaseous) in a combustion engine and
- usage of hydrogen (liquid or gaseous) in a fuel cell.

Besides the road transportation only the usage of pure Biodiesel in inland navigation and coasting seems to be realistic.

4 Survey of renewable energy sources

4.1 Introduction

The second main pillar of this study is the survey of renewable energy resources. The aim is to compile a survey of energy resources, especially resources of bioenergy and renewable electricity production combined with options for hydrogen production, to supply cross border transportation in Europe with fuel for different technical concepts. The results comprise a lot of existing studies concerning this broad variety of options. The compilation aims at giving a common base for all these results to carry out comparisons and assessments for the following steps of the study.

To a certain extent the results have obviously to rely on estimations rather than exact figures because the conditions of agriculture, different technical approaches for the conversion and some other indicators vary broadly within Europe. Even among different sorts of biogas plants there are large differences for instance. Several estimations were necessary when available sources included no information about certain parameters.

The information for each primary energy source and for each conversion technology is collected in the module sheets of class 1 and class 2 that can be found in the annex.

4.2 Primary energy sources

The primary energy sources considered within this study can be divided into three main groups and one fossil reference group:

1. Plants cultivated for energy production
2. Organic residues
3. Renewable electricity sources and nuclear energy
4. Fossil fuels: Crude oil, the dominant primary energy carrier of the transport sector and natural gas (considered for comparison reasons).

The first group can be split into oil plants, woody plants and other plants:

- Oil plants are cultivated to produce an oil seed that serves as fuel or as the base of a fuel.
- The woody plants (fast growing trees or Miscanthus) can be used in different forms. Wood is the most used biomass today and can be transformed into various fuels.
- Other plants can be cultivated for transforming them to alcohol (methanol or ethanol) or for producing biogas in a biogas reactor.

The number of plants that can provide biomass is by far higher than considered in this study because any plant can theoretically be taken. In order to have a realistic overview over the range of possibilities, representative plants with existing cultivation experience for each group were taken. These plants represent the range of possibilities, i.e. the cultivation of other plants is assumed to be comparable.

The second group (organic residues) comprises residues from agriculture, from forestry and organic residues from trade, industry and households, like wood residues, straw and humid organic residues. From an economic point of view, the residues can be grouped into three types:

a) Residues which can be used for different purposes with an already existing demand and an existing price higher than zero (e.g. industrial wood residues, straw in some regions), these other purposes can be in the energy sector (heating systems) or in the material sector (chipboards).

b) Residues currently left to nature where they are decomposed slowly by bacteria. Here, the technical potential is considered as the part that can be removed from the ecological cycles without damage. The procurement price is not a price for the material but only the price for the removal and transport to a collection point. In some cases, prices were estimated negligible.

c) Residues which occur as waste to dispose. Those who want to dispose them are often paying prices for the waste disposal. It was assumed that this price corresponds mainly to the collection system. So the collection of these residues is free for the users and the procurement price was assumed to be zero.

The third group of primary energy resources comprises the renewable forms for electricity production as well as nuclear energy production for comparison purposes.

Normally, electricity is not a primary energy source, but in this study, it is used as a base for producing a fuel (hydrogen) and not as a final energy carrier. Investigations refer to hydropower (both storage and run-of-river hydropower systems), wind power, photovoltaic solar energy and to solar thermal electricity generation.

In fact, more options of renewable energy production exist, e.g. waves, geothermal energy and tidal energy, but an estimation of the potentials would be very difficult. The current use of these forms of power production is limited to some pilot plants in specific countries, e. g. geothermal energy in Italy or tidal energy in France.

The production of electricity based on biomass is considered as a conversion step of biomass and therefore considered in class 2 “transformation into fuels”, see chapter 4.3.

As a result of discussions with the European Commission and several stakeholders the option of nuclear energy is included in this survey, knowing that it is not a renewable energy source like the others mentioned in this section. Nuclear power would be interesting especially for comparisons of prices for energy production.

4.3 Transformation into fuels

Transformation processes represent class 2 of the study classification and can be divided into five main groups:

1. Pressing of oil plants: It includes conventional technologies that have been used in the food industry for a long time and that lead to vegetable oils.
2. Thermochemical conversion: It includes several technologies that have been developed in the past for the conversion of coal or other fossil fuels into methanol or synthetic fuels, the well known “Fischer-Tropsch” process or the methanol synthesis. Normally, the technologies can use any kind of biomass, however, the use of woody biomass is most common.
3. Fermentation: It describes natural processes. The production of ethanol by fermentation is a traditional technology for producing alcoholic drinks, but for producing fuels it is necessary to obtain pure ethanol from various sources (sugar, starch or lignocellulose). In the same group, the process of anaerobic digestion is included that transforms humid biomass into biogas.

4. Electricity from biomass: It includes combustion technologies that transform wood, straw or biogas into electricity (or into electricity plus heat if combined heat and power plants are used).
5. Production of hydrogen: It includes all technologies leading to hydrogen. One of these technologies is a thermochemical conversion (corresponding also to the second group). The other technologies are electrolysis and the transformation of natural gas into hydrogen. The latter is not renewable but the most-used path to produce hydrogen today.

Some of these processes do not produce a fuel which can be readily used in vehicles. Therefore a sixth group contains

6. all forms of secondary processing (refinement) necessary to obtain the desired fuels. The esterification of vegetable oils, the upgrading of biogas, the etherification of ethanol into ETBE and the compression or liquefaction of hydrogen are considered here. The transformation of biogas into electricity is not treated here because it is considered as a part of the group "electricity from biomass".

The number of the fuels that can be produced for the transport sector is by far more limited than the number of technologies to produce them.

Resulting fuels are:

- Vegetable oil (pure plant oil)
- Biodiesel (fatty acid methyl ester based on vegetable oils)
- Methanol
- Ethanol (or ETBE)
- Synfuel (based on thermochemical Fischer-Tropsch conversion of biomass)
- Hydrogen (liquid or gaseous, based on electrolysis or on thermochemical conversion)
- Biogas

The fossil chains needed for comparison form an eighth group. In this group, only the refinery of crude oil into diesel and kerosene for the final use is considered. Natural gas is not considered because it needs no special transformation before transporting it to the user.

Diesel has been chosen as fossil reference because it can be used in most vehicles such as passenger cars, lorries, trains and ships. The field of application for petrol is by far more restricted. Furthermore the diesel fuel chain is taken as the general purpose of the study is to compare renewable options against each other and not to discuss whether renewable fuels are better than fossil fuels. Moreover differences between petrol and diesel, for which engine technologies will assimilate anyway until 2030, are less important compared to the renewable options, especially when regarding the uncertainty of the data for the renewable technologies.

4.4 Parameters and methods used for the broad basic survey

4.4.1 Estimation of the technical potential

Most of the renewable primary energy sources accrue in solid forms: Either as plants (or parts from plants) cultivated for energy purposes or as residues from forestry or agriculture or as organic waste.

For energy crops, the technical potential has been calculated from the available arable land. As 10 % of these agricultural areas of all European countries are currently set aside, it was assumed that this share of the arable land of each country can be used for energy crop production. The assumption of taking 10 % of the surface is not linked to current decisions of the common agricultural policy but only a technical assumption. In each module, the assumption was made that all the area can be used for each plant described in the module, suitable conditions provided (e. g. exceptions in special cases like Finland, where is no chance to grow sunflowers).

It is important to know that potentials for energy crop production can not be added because the same free arable land is seen as a potential area for each plant.

The 10-%-assumption does not mean that a certain area of each country will be reserved for energy production while the rest of the agriculture will continue to produce food and plants. Crop rotation between energy crops and other plants is always necessary (perennial plants like trees are the only exception). If any boundary condition changes and leads to an enlargement of the area available for energy purposes, the necessary crop rotation will become a restricting factor for most of the plantations. Hence the potential may be doubled if the set-aside of agricultural land will be 20 % instead of 10 %. But for most of the plants it will not be possible to cover 50 % of the arable land or more.

The potential energy supply depends not only on the arable land but also on the expected yield. Here, the European statistics have been used: The specific yield in tons per hectare for each country and most of the plants in the year 2000 was given. For some plants (e. g. Miscanthus), such data were not available. In these cases, typical values have been found in literature or have been estimated for one country and transferred to similar countries. In countries with other climatic conditions, the typical yield was estimated higher or lower, following the environmental requirements as described in the general description.

Within these yields, only the components that can be transformed into fuels were included in the calculated technical potential. The energy content of some residues, e. g. straw, is calculated separately. So the technical potential is always referring to one fuel chain, any possible splits (e. g. using rape seed for RME and rape straw for methanol) were not considered, including them would increase the technical potential.

Estimations for the future were not made. In fact, there is a long term tendency towards higher yields, especially in those countries where technological gaps in comparison to other European countries exist. So the technical potential for most of the Southern European countries and all candidate countries will be higher than a prediction based on today's yields. On the other hand, any form of intensive, integrated, ecological or other agriculture needs investments and their financing. The common agricultural policy for the future (2030) is not clear today (2003). So the potential was estimated from existing yields (in EU 15) and similar yields for candidate countries in corresponding climate zones.

For residues, the technical potential means the occurring quantities under current conditions. So the quantity of animal excrements is deduced from the number of existing animals in animal housing systems. This number can vary in future but indicates the current potential.

The influence of utilisations competing for the same residue or the actual profitability are not analysed. This question corresponds rather to the "available amount" Figure. In order to estimate this figure under real (commercial, legal, practical and other) frame conditions, the analysis must go more in-depth in the different European countries. In fact, the technical potential for each residue is not completely available: A certain quantity may already be used for energy purposes, another quantity may be used for material recycling purposes and for the remaining quantity which has actually no use, some share can not be gathered under actual economic conditions. For the remaining available share of the technical potential there are often other interests, e.g. replacing fossil electricity by renewable electricity for the other sectors (households, industry, etc.). This question is leading to an analysis of a future energy economy based on renewable sources in general, what leaves the transport sector focused in this study.

For wind energy, solar energy and hydropower, the assumptions are mentioned in the module texts. They are derived from literature.

4.4.2 Estimation of the fossil CO_2-emissions

The fossil CO_2-emissions are estimated for each module. A module comprises the current process but excludes the building of the factory or the construction of the means of transport. Hence the CO_2-emission is mostly deduced from the input of electricity, heat and transport (including tractors). In consequence CO_2-emissions for a processing module can be very low when the process is very simple (e.g. for an oil mill). Data are taken from [Frischknecht et al. 1996][12]. This database comprises typical CO_2-output values for different energy carriers, among them the typical EU15 electricity mix. In some cases, a supplementary CO_2-output is generated by the processing itself (e.g. thermochemical processing of wood, see annex, module C2-T1).

4.4.3 Estimation of the energetic efficiency

The efficiency of each process can be considered in two different ways.

The first indicated efficiency figure is related to the technical potential after conversion steps: It means the ratio between the energy content of the output (secondary) energy source in GJ and the energy content of the input (mostly primary) energy source. So it is possible to calculate the potential supply for fuels as a function of the potential supply of primary energy sources described in class 1. The value can never be higher than 1, in most cases it is between 50 % and 70 %. The rest of the energy content of the input energy source is lost during the process.

The second indicated efficiency figure includes the cumulated energy demand necessary to produce 1 GJ of output energy. Here the conventional electricity and heat input appear as well as indirect effects (energy necessary for planning and constructing the factory etc.). This approach is important for the life cycle analysis (see chapter 5). The result will be a lower percentage than described above because losses of the input energy source and needs for auxiliary power are involved in the efficiency quota.

In the modules of class 1, the second Figure is the only efficiency recorded in the data sheet. Values higher than 1 correspond to the fact that the energy output is higher than all auxiliary energies together (this indicates that the considered energy is really renewable). For fossil energy sources like crude oil or natural gas, the value is lower than 1 because the initial energy content of the fossil fuel is a part of the energy input, so the auxiliary energy for transportation will reduce the 1:1 ratio between input and output in any case.

In the module sheets of class 2 and 3 both efficiency values have been indicated if they were available.

4.4.4 Cost estimation

The cost estimations normally refer to market prices of the module output. These market prices can vary within the EU, in this case a typical price or an average was taken. Prices don't include VAT because VAT differs between the member countries and is not the subject of this project.

[12] Frischknecht et al., 1996.

When prices vary from one year to another, the last available data were taken. For some modules, a market price was not found because today no stabilised market exists. This concerns especially new technologies that have not been disseminated so far. In these cases, the “cost per output unit” was estimated as a function of the initial cost that comprises the raw material and the processing costs. Possible profits for the seller were not included.

This method seems not very consistent, but it was the most realistic approach to find data that can be compared at all. Finally, there are two trends that can compensate each other: On the one hand, the price for new technologies will decrease when the market penetration leads to more applications. On the other hand, the providers of the new technologies will look for profits, i. e. not all price reductions will be transferred to the customers.

Within the module descriptions, sources of the indicated prices or calculation schemes for these prices are generally explained.

4.4.5 Qualitative indicators

Supplementary information about impacts can be assessed by qualitative indicators.

- The need of space (the more space the worse) is more important for plantations with low energy contents or for big engines.
- The readiness for marketing (the more introduced into the market the better) is an important indicator for describing the state of the art: Good technologies that are still in the research phase will only contribute in the long term to important market shares. Technologies that are already broadly implemented can help in making short term changes.
- The hazardousness (the more hazard the worse) describes concrete health risks for people operating with the technology or for nature if accidents occur. It doesn’t comprise the emissions in general such as CO_2 because these are described above.
- The complexity of technique (the more complex the worse) indicates if the system is easy to handle for all people or only specially educated professionals can understand and handle the system. It is expected that less complex systems will have less operating troubles than complex systems.
- The output standardisation (the more clear standards the better) is helpful for the cross-border interoperability. E.g. electricity is a very well standardised energy, while biogas can occur with very different properties such as higher or lower methane contents.

Some of these indicators have not been evaluated for every technology. For example, the demand of space has no importance for some conversion technologies or for the collection of certain residues.

4.5 Composition of possible chains

Within the class 1 modules, supply processes of renewable primary energy are described. These energy sources have to be transformed into final energy which can be used for the transport sector. This transformation is described by the class 2 modules. For some specific fuel supplies it is necessary to add a secondary conversion step; e.g. rape seed → rape seed oil → RME.

Not all combinations of the class 1 and 2 modules being possible are technically feasible.

Table 4 is restricted to the reasonable fuel chains for which experiences and data exist.

The energy potential "after class 2" is calculated by the potential of the corresponding class 1 module and the transformation efficiency of the following conversion step or steps. The total output price "after class 2" is given as far as possible by market prices. If no market prices exist, the production costs are used (as described in chapter 4.4.1). The total CO_2-emissions "after class 2" are derived from the CO_2-emissions of all necessary conversion processes. This leads to results shown in Table 3.

The highest and the lowest data per row are written in bold letters. Given the inherent uncertainty, all data have been truncated.

Table 4: Results of the basic survey of renewable energy sources, containing primary energy provision and transformation into fuel

Note: Figures in this table are based on different sources as registered in the module sheets of the annexes. Therefore the table intends to show differences and orders of magnitude in principle and is not suitable for detailed comparisons of selected single data.

Technical potentials are calculated by assuming that 10 % of the arable land is available; residues and renewable electricity generation is recorded without any subtraction for competing utilisations.

primary energy (class 1 module)	module id class 1	**transformation** (class 2 module)	module id class 2	**CO_2-emissions class 1+2, (i.e. final use is excluded)**	**total output costs for fuel production**	**technical fuel potential for EU 15**	**technical fuel potential for EU 30**
Biodiesel							
Rape cultivation (rape seed)	C1-P1	Vegetable oil from rape seed	C2-O1	20 kg/GJ	15 €/GJ	260 PJ/a	520 PJ/a
		Rape seed oil methyl ester (RME) from rape seed oil	C2-S1	24 kg/GJ	20 €/GJ	250 PJ/a	510 PJ/a
Ethanol							
Sugar beet cultivation	C1-P5	Ethanol from sugar beet	C2-F1	24 kg/GJ	35 €/GJ	1000 PJ/a	1880 PJ/a
Maize cultivation	C1-P11	Ethanol from maize (starch to sugar, fermentation)	C2-F2	65 kg/GJ	38 €/GJ	380 PJ/a	740 PJ/a
Cereals' cultivation (grains, e. g. winter wheat)	C1-P6	Ethanol from cereals' cultivation	C2-F3	60 kg/GJ	41 €/GJ	330 PJ/a	590 PJ/a
Triticale cultivation	C1-P7	Ethanol from triticale cultivation	C2-F3	59 kg/GJ	39 €/GJ	320 PJ/a	570 PJ/a
Potato cultivation	C1-P12	Ethanol from potatoes	C2-F4	69 kg/GJ	37 €/GJ	680 PJ/a	1220 PJ/a
Methanol							
Fast growing trees (short rotation plantations)	C1-P9	Methanol from fast growing trees	C2-T1	43 kg/GJ	23 €/GJ	330 PJ/a	640 PJ/a
Miscanthus cultivation (perennial grass)	C1-P10	Methanol from miscanthus cultivation	C2-T1	**77 kg/GJ**	32 €/GJ	410 PJ/a	820 PJ/a
Logging residues	C1-R2	Methanol from woody biomass	C2-T1	37 kg/GJ	26 €/GJ	210 PJ/a	310 PJ/a
Collection of wood residues from trade and industry	C1-R8	Methanol from wood (thermochem. conv.)	C2-T1	37 kg/GJ	19 €/GJ	650 PJ/a	960 PJ/a
Synthetic fuel							
Fast growing trees (short rotation plantations)	C1-P9	Synfuel from fast growing trees	C2-T3	42 kg/GJ	29 €/GJ	200 PJ/a	380 PJ/a
Miscanthus cultivation (perennial grass)	C1-P10	Synfuel from miscanthus	C2-T3	105 kg/GJ	45 €/GJ	240 PJ/a	490 PJ/a

Logging residues	C1-R2	Synfuel from woody biomass	C2-T3	32 kg/GJ	32 €/GJ	125 PJ/a	180 PJ/a
Collection of wood residues from trade and industry	C1-R8	Synfuel from wood (thermochem. conv.)	C2-T3	32 kg/GJ	20 €/GJ	390 PJ/a	570 PJ/a
Biogas							
Collection of animal excrements	C1-R4	Cleaned and upgraded Biogas (excrements)	C2-S3	14,5 kg/GJ	31 €/GJ	360 PJ/a	490 PJ/a
Collection of organic waste from house-holds	C1-R5	Biogas cleaning and upgrading from or-ganic waste	C2-S3	14,8 kg/GJ	32 €/GJ	40 PJ/a	59 PJ/a
Collection of vegeta-ble residues from agriculture	C1-R6	Cleaned and upgraded Biogas (excrements)	C2-S3	14,8 kg/GJ	26 €/GJ	200 PJ/a	320 PJ/a
Collection of organic commercial waste	C1-R7	Cleaned and upgraded Biogas (waste)	C2-S3	14,8 kg/GJ	32 €/GJ	20 PJ/a	35 PJ/a
Electricity Generation							
Collection of animal excrements	C1-R4	Combustion of biogas for electricity genera-tion (excrements)	C2-E3	27 kg/GJ	33 €/GJ	150 PJ/a	210 PJ/a
Collection of organic waste from house-holds	C1-R5	Combustion of biogas for electricity genera-tion (waste)	C2-E3	28 kg/GJ	33 €/GJ	17 PJ/a	25 PJ/a
Collection of organic commercial waste	C1-R7	Combustion from commercial waste for electricity generation	C2-E3	28 kg/GJ	33 €/GJ	**10 PJ/a**	**15 PJ/a**
Hydrogen by electrolysis							
Hydropower	C1-E1	Hydrogen from elec-trolysis: Hydropower	C2-H1	**2,9 kg/GJ**	37 €/GJ	1300 PJ/a	2200 PJ/a
Wind power (onshore + EU 12 offshore)	C1-E2	Hydrogen from elec-trolysis: Windpower	C2-H1	12,9 kg/GJ	34 €/GJ	**9000 PJ/a**	**10100 PJ/a**
Solar energy (Photo-voltaics)	C1-E3	Hydrogen from elec-trolysis: Photovoltaics	C2-H1	43 kg/GJ	**189 €/GJ**	1040 PJ/a	1600 PJ/a
Solar thermal electric-ity	C1-E4	Hydrogen from elec-trolysis: Solar thermal	C2-H1	7,0 kg/GJ	89 €/GJ	3600 PJ/a	7200 PJ/a
Nuclear energy	C1-E5	Hydrogen from elec-trolysis: Nuclear power	C2-H1	0 kg/GJ	19 €/GJ	0 PJ/a	0 PJ/a
Hydrogen by thermochemical conversion							
Fast growing trees (short rotation planta-tions)	C1-P9	Hydrogen from bio-mass by thermo-chemical conversion	C2-H2	23 kg/GJ	**12,5 €/GJ**	450 PJ/a	850 PJ/a
Miscanthus cultivation (perennial grass)	C1-P10	Hydrogen from mis-canthus by thermo-chemical conversion	C2-H2	51 kg/GJ	20 €/GJ	540 PJ/a	1100 PJ/a
Logging residues	C1-R2	Hydrogen from fire-wood collection by thermical conversion	C2-H2	18 kg/GJ	14,2 €/GJ	280 PJ/a	410 PJ/a
Collection of wood residues from trade and industry	C1-R8	Hydrogen from wood residues from trade and industry	C2-H2	18 kg/GJ	8,9 €/GJ	870 PJ/a	1300 PJ/a
Fossil fuel							
Mineral oil	C1-F1	Refinery of Crude Oil	C2-R1	11,7 kg/GJ	6 €/GJ (without taxes)	0 PJ/a (fossil)	0 PJ/a (fossil)

4.6 Evaluation of chains

In this chapter the different fuel chains, including class 1 (energy sources) and class 2 (transformation), are evaluated concerning CO_2-emissions, costs and availability (potential). This assessment does not take into account the following steps (distribution and use in vehicles), which might have different efficiencies. This is very important if compared with the emissions of fossil fuels because most of the fossil fuel CO_2-emissions occur by their final use in motors and not by their production.

In fact, the production of renewable fuels often leads to more CO_2-emissions (due to agriculture, multiple conversion steps) than importing the crude oil and the running of an oil refinery. This is over-compensated by the fact that fossil fuels induce CO_2-emissions and renewable fuels do not. The CO_2-emissions of the combustion of biofuels are not considered because they are compensated by the production of the bio-energy carriers.

For costs and potentials, the relations between the different fuel chains are considered in Figure 15. Fuel chains located in the upper left of the diagram represent "bad", in the lower right "good" fuel supply chains, i.e. low costs and high potentials and vice versa. Fuel chains, which are situated in extreme positions in comparison to the others, are marked in bold ("good") and in italic ("bad") in the legend.

The dashed lines within the diagram indicate the arithmetic mean of all considered chains (without loadings), except the fossil reference chain. The values of the arithmetic means are caused especially by three fuel chains, which are situated beyond the chosen scale. These are the chains of electrolysis hydrogen from photovoltaic, solar energy or solar thermal electricity. They show extreme values in respect of high costs for photovoltaic-based hydrogen, high potential for wind power based hydrogen and relatively high potential and high cost for solar thermal electricity. In the legend, these chains are underlined. These three options have a high influence on the dashed lines (arithmetic means).

As it is indicated in bold the following fuel chains have low costs and a high potential (better than both arithmetic means):

- Ethanol from sugar beet
- Hydrogen based on thermochemical processing of wood residues from trade and industry
- Hydrogen from wind-power based electrolysis (outside the diagram because of its high potential - the costs of this process are moderate)

The following fuel chains (italic legend) have relatively high costs and a low potential (worse than both arithmetic means):

- all other forms of ethanol production (based on maize, cereals including triticale and potatoes)
- Synfuel from miscanthus

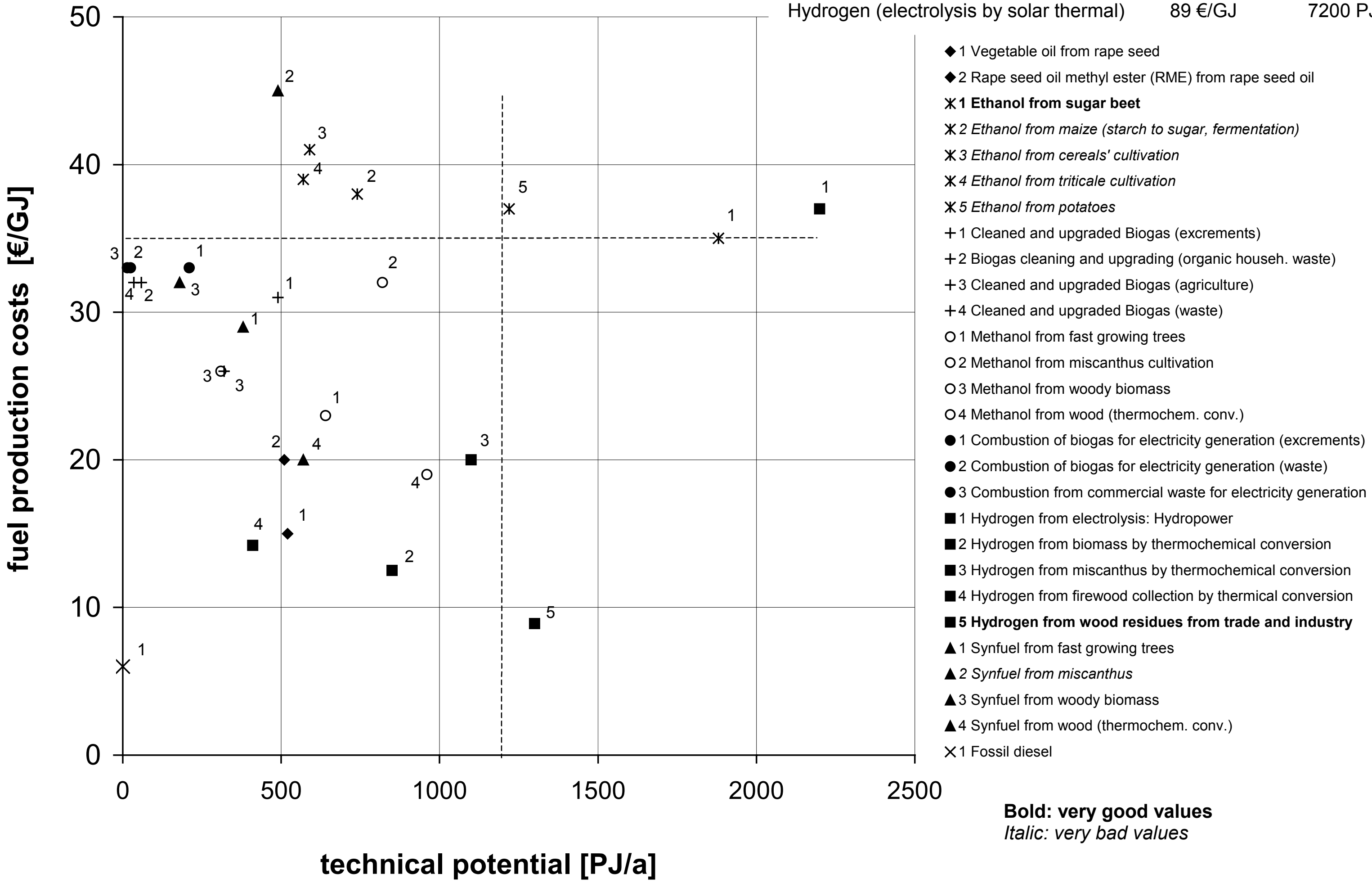
For comparison, the position of fossil diesel fuel is marked: Currently it is by far the cheapest fuel (about 6 €/GJ), but there is no renewable potential (given as a yearly value).

The evaluation of the CO_2-emissions of the fuel provision chain makes only sense for the renewable fuels, not for the unburned fossil fuel because of the different CO_2-output during the vehicle use.

Figure 15: Technical potentials and production costs of various fuel chains for the enlarged European Union (EU 30)

Situated beyond the scale:

Hydrogen (electrolysis by windpower)	**34 €/GJ**	**10100 PJ/a**
Hydrogen (electrolysis by photovoltaics)	189 €/GJ	1600 PJ/a
Hydrogen (electrolysis by solar thermal)	89 €/GJ	7200 PJ/a



Bold: very good values
Italic: very bad values

Table 4 in chapter 4.5 gives information about the CO_2-emissions of different fuel provision chains. The best values are found for hydrogen from electrolysis based on hydropower or solar thermal electricity. For hydropower-based hydrogen, the cost and the potential are not far from the means, the solar thermal option is more expensive than the others. In general, low CO_2-emissions can be found for renewable electricity and for fuels based on organic residues, whereas all options with agriculture or forestry have higher emissions due to the energy demand for the cultivation of the energy crops.

This corresponds to the fact that fuels based on residues are cheaper than those based on energy crops. So the economical and environmental advantages show in the same direction. The main problem is the lower availability of residues compared with renewable electricity and some energy crops.

5 Fuel chains and their environmental consequences

In order to assess the possibilities of renewable fuels in the transport sector, the single modules or classes can not be investigated separately. It is necessary to compile and analyse fuel chains which include all four classes of modules from the primary energy to the final energy use. Thus, it is possible to work out an overall assessment of technologies and energy sources. This is of high importance because origins of emissions, for example, have great differences when comparing such wide spread future options.

The previous chapters 3 and 4 represent the broad basic survey of energy sources, transformation processes and vehicle technologies. In the following sections of chapter 5 a selection of fuel chains undergoes a detailed environmental analysis .

In general, many of the modules can be combined in order to create a technically feasible renewable fuel supply and utilisation option. Summing them up would lead to an abundance of options for the use of renewable energy. Therefore, a selection of these chains has to be made for the further analysis.

5.1 Selection of fuel chains

For a reduction of the number of fuel chains several criteria have been taken into acount. Firstly, the findings of the basic survey of primary energy and transformation are considered. The following fuels result as preferable:

In respect of the **technical potential**:

- Hydrogen from electrolysis using renewable generated power (wind power, hydro and solar thermal electricity)
- Ethanol form sugar beet cultivation
- Hydrogen from wood residues

In respect of the **CO_2-emissions:**

- Hydrogen from electrolysis using renewable generated power (wind power, hydro and solar thermal electricity)
- Biogas from organic waste and residues
- Hydrogen from wood residues

In respect of the **estimated costs**:

- Hydrogen from wood residues and fast growing trees
- Methanol from wood residues (and fast growing trees)
- Synfuel (by Fischer-Tropsch) from wood residues
- Pure vegetable oil (rape seed oil)
- Rape seed oil methyl ester (RME)

Further criteria for the compilation of the fuel chains are the results of the vehicle technology survey. Due to the state of the art of **propulsion technologies** and their foreseeable further development only the piston engine and electric drive by fuel cell are taken into account. The fuel cell is only considered in passenger cars since an application in lorries, rail and ships seems not to be realistic. In respect of air traffic there are no reasons to take other technologies in consideration than jet propulsion.

Some additional criteria can not be neglected when discussing about a long term change of the fuel system within the broad approach of this study. Therefore, the **suitability for cross border application** has to be considered as well as **current experience with technologies.** Furthermore, attention has to be paid to generating **exemplary fuel chains** which do not exclude main fuel chains because of a too strict selection method.

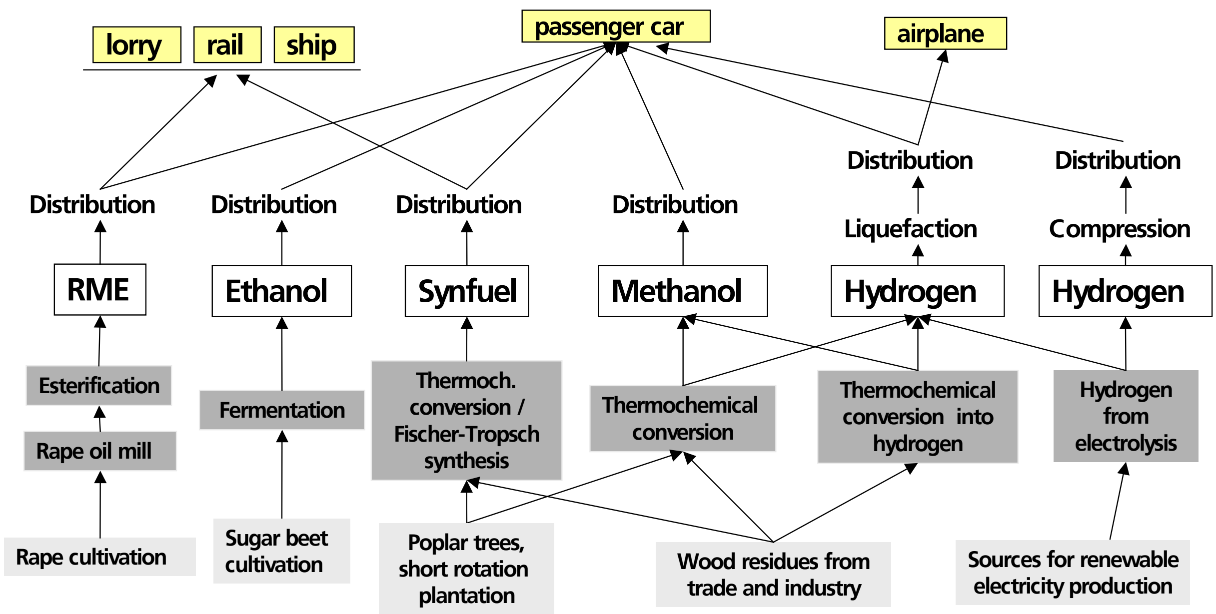
In view of this discussion and resulting from consultations and meetings with the Commission as well as several stakeholders, it is reasonable to emphasise the selection of

- RME
- Synfuel (by Fischer-Tropsch)
- Ethanol
- Methanol

Biogas as a gaseous energy carrier is not taken into account because it seems to be appropriate especially for regional solutions, e. g. garbage trucks etc.. Biogas can be used as a blend for natural gas but the potential (availability) of biogas is not in position to justify a long term change from petrol/diesel vehicles to natural/biogas vehicles. The opportunity to use gas as a transition technology in order to utilise the infrastructure in the long term perspective for hydrogen is not a promising one. Hydrogen requires a completely new infrastructure and can not use a modified natural gas infrastructure.

For all the above mentioned reasons the fuel chains are chosen as illustrated in Figure 16.

Figure 16: Fuel chains selected for the detailed analysis



These fuel chains are analysed in depth in respect of their environmental consequences (see the following sections of this chapter). As reference a fossil fuel chain is included for all vehicles.

5.2 The life cycle assessment

In the following the method “life cycle assessment” (LCA) is described. This method serves to quantify the environmental effects of the renewable fuel production. Afterwards the investigation’s basic assumptions on the system are pointed out, and the reviewed effective influences will be fixed.

5.2.1 Method of the LCA

For an analysis of the ecological effects of the fuel production based on renewable energies, it has to be considered that fuels are not environmental benign per se although they have been produced from renewable sources. All energy sources, fossil and renewable must be made available, provided, and transported to the final user. Furthermore the conversion plants have to be built and operated, a certain quantity of by-products that are used within the fuel production process have to be produced and transported themselves to the conversion plants. All these processes are connected with environmental effects, such as air pollution and waste disposal. These effects have to be taken into account for a life cycle assessment of the fuel provision. To quantify all the environmental effects of the renewable fuel provision, the whole provision chain has to be investigated including all the efforts for transport, infrastructure and all the preliminary products. The method to realise this is the life cycle assessment (LCA). A LCA doesn’t only take into consideration the direct environmental effects caused by the energy conversion itself, but also the preliminary and – if there are any – the following process steps (fuel exploitation, transport, disposal) as far as possible. Even such processes which are only indirectly part of the energy provision (production of raw materials, or the establishing of a necessary infrastructure).

A life cycle assessment consists - according to the international standard ISO 14040 - of the following four steps:

- Goal and scope definition,
- inventory analysis,
- impact assessment,
- interpretation.

Therefore, after the assignment of the boundary conditions for the investigation, an inventory has to be established in the second step. This inventory regards all accumulated input and output flows that occur within the provision chain of the product or the service that has to be investigated. Based on this inventory, values on indicators of effects are determined in the following impact assessment. For this purpose all materials flows that influence a certain impact category (e.g. green house effect, acidification) will be – according to their weight - aggregated to a single indicator as far as possible. The results of the single steps will be finally interpreted, discussed and evaluated.

Within a life cycle assessment it is impossible to take all the environmental effects into consideration because the high number of energy and material flows requires methodology restraints. The result of a LCA applies therefore only to the environmental areas that have been defined and enumerated within the first step of the LCA. Additionally the basic assumptions influence the result of an analysis very strongly. Thus the results have to be discussed only in tight connection with the basic assumptions. With regard to processes that have a high electricity consumption the choice of the power mix, for example, is of very important concern and influences the result strongly.[13]

5.2.2 Impact categories taken into consideration

The anthropogenic green house effect, the acidification of soil and waters, the nutrification and the accumulated fossil primary energy demand (i.e. consumption of exhaustible energy sources) are selected to compare the life cycles of the fuel provision based on different renewable energies (see Table 5). CO_2 that is bound within the biomass will not be enumerated, because the CO_2 that will be released by using biomass for energy purposes has formerly - during plant growing - be taken off the atmosphere. Thus, those emissions are climate neutral. Only airborne acidification and nutrification emissions are considered when computing the indicators for acidification and nutrification. The single fossil energy sources are aggregated by their weighted calorific value. Electricity from nuclear energy is converted to primary energy with an efficiency of 33 %.

The impact categories chosen for this LCA are restricted to direct effects. Indirect effects, e.g. health effects that need epidemiological statistics, are not included.

Table 5: Survey of the analysed impact categories

Impact category	Impact indicator	Main Substances
Anthropogenic green house effect	CO_2 equivalents	Carbon dioxide[a], methane, N_2O, SF_6, CF_4, C_2F_6 etc.
Acidification of soil and waters	SO_2 equivalents	sulphur dioxide, nitrogen oxides, hydrogen chloride, ammonia etc.
Nutrification	PO_4^{3-} equivalents	nitrogen oxides, ammonia
Accumulated fossil energy demand	primary energy	oil, mineral coal, brown coal, natural gas, uranium[b]

[a] the biomass bound CO_2 will not be enumerated
[b] electricity from nuclear energy will be converted to primary energy by using an efficiency of 33 %

These impact categories reflect not all impact categories listed in DIN EN ISO 14040. They were chosen as the most relevant ones and as those with existing data bases. The relevance depends on the ecological danger linked to the impact (in general), to the distance from the political target (distance between the need and the reality) and to the contribution of the transport sector to the impact as a whole.

- The “anthropogenic green house effect” corresponds to the global warming potential. Its reduction is an international political target to minimise the global climate change.
- Acidification is an important environmental problem, especially for soils and waters. Therefore the European Commission published a strategy to combat acidification in 1997.[14] Sulphur dioxide, nitrogen oxides and ammonia are the main air pollutants leading to acidification. In 1990, the transport sector was the main source for nitrogen oxides (63 %) and agriculture was the main source for ammonia (94 %). Sulphur dioxide was mainly emitted from combustion plants (87 %).

[13] DIN EN ISO 14040, 1997.
[14] European Commission (Ed.), COM(97) 88 final.

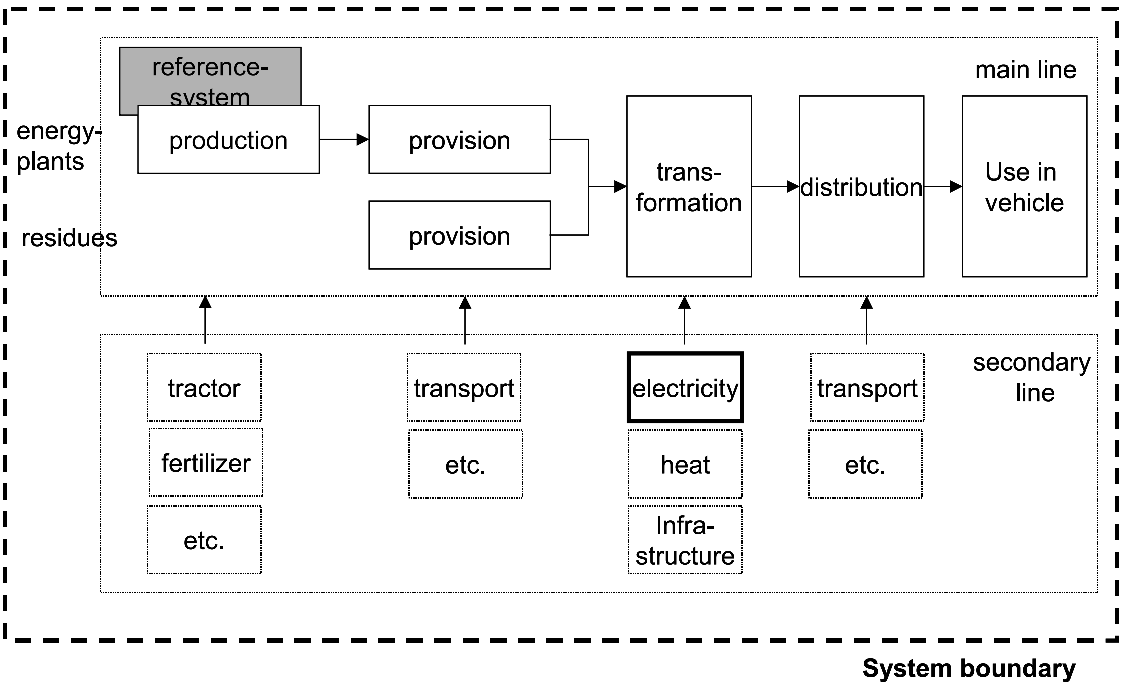
- Nutrification is a water pollution problem, but pollutants that cause the problem can be carried in the air or in the water.
- In a LCA, generally the "cumulated energy demand" is used. It was decided to consider only the "cumulated fossil energy demand" for illustrating the energy demand that is not covered by renewable fuels (which are the main interest of this study). The cumulated fossil energy demand is a general indicator on the consumption of fossil fuels and its environmental effects. Besides, this indicator is useful to describe the dependency on imported fuels because domestic fossil fuels within the EU (mainly coal) don't play a relevant role in the transport sector.

Besides the effects listed in Table 5, other environmental effects have to be described, such as biodiversity. It is an important environmental and ecological issue, but it can not be calculated by the LCA instrument that is based on the airborne emissions of the fuel production and consumption processes. Some qualitative evaluations are given in chapter 5.3.5. For further effects outside the calculated LCA, some remarks are made in chapter 5.3.6.

5.2.3 Basic assumptions

The life cycle that is balanced within a LCA on renewable fuel provision, reaches from the growing respectively the provision of the energy sources, the transport of the primary energy sources to the conversion plant, the conversion process, the transport of the fuel ready to use to the petrol station up to the final use in the vehicle. Within the analysis all the relevant materials are taken into account that are used within the life cycle, including their production, all necessary transports and needed infrastructure (Figure 17). Particularly the erection of the conversion plants is regarded. No difference is made between existing infrastructure and future infrastructure: All infrastructure is taken into account if it exists only for the purposes of the (renewable) fuel production. The services (planning, maintenance, etc.) are out of the chosen system boundary and therefore not considered within this analysis.

Figure 17: System boundary of the LCA on bio-energy chains



The following assumptions were made additionally on the life cycle assessment:

- With regard to the production of energy crops, agricultural reference systems have to be taken into account. These systems help to determine the emissions occurring due the life cycle of the relevant fuel exploitation from biomass. Only the difference in emissions of production and non-production of the investigated biomass has to be taken into account. Thus, to consider correctly the emissions of gaseous pollutants from the growing of energy crops, the emissions of the grassed over fallow cultivation on the same ground have to be deducted from the emissions of energy crops grown.[15]
- If manure is used as fertiliser for the growing of energy crops, any emissions are not charged. In this case it is supposed that the emissions would happen in any case, therefore they are not to be charged to the biofuel chain.
- Agricultural and forestry residues are regarded as "wastes to disposal" according to the actual practice. Thus, all environmental effects of their production are not taken into consideration because they are assigned to the main product whose residues were taken. The transport between the "yard gate" (or forest or collecting point) and the transformation plant is included in the description of the transformation technology. It was assumed that there are no relevant differences between the transport of residues and energy crops (e.g. for methanol production: the transformation step includes the transport from the forest, the same distance is assumed for poplar wood (energy crops) and for logging residues.)
- With regard to processes that provide a number of by-products (joint products, e.g. glycerine in rapeseed oil methyl ester (RME) production) beside the main product, the material and energy flows have to be split and charged in a definite procedure to the different products. A method called allocation by energy will be used to charge the emissions correctly. All outputs will be valued according to their energy content. At last the environmental impacts will be divided to the outputs according to their share at the total energy output. The use of credits is another method to charge emissions to different joint products. In this case the result depends very much on the process that would be used to produce the avoided product. In the actual analysis the allocation by energy is chosen to make the assessment procedure and the results more transparent.
- For the time being renewable energies are only poorly used in the traffic sector. An investigation of the ecological effects of different fuel provision chains must therefore be related to the future (the reference year is 2030). For the time being, many of the regarded technologies are still in the state of demonstration and testing; they will be usable at large scale only in the future. It is very difficult to carry out a LCA on future systems, because a great number of processes occur within the system boundaries that have not been analysed for the time being. Therefore, forecasts which can be used within the LCA are not available. For the actual LCA the following attempt is chosen to represent future techniques: Processes of the main line (see Figure 17) are considered by assuming a future large scale application with a higher efficiency than the process has in present. The processes of the secondary line will be considered according to the present state of the art in European countries. An exception is made for the power mix. Due to the supposed great influence of the power mix on the balance results, the future power mix is considered according to the baseline projection of the "European Union Energy Outlook to 2020"[16].
- The vehicle production is outside of the investigation boundary and will therefore not be considered. It is supposed that the efforts on vehicle production will not change significantly if the vehicles will use renewable fuels.

[15] Kaltschmitt and Reinhardt, 1997.
[16] European Commission (Ed.): European Energy Outlook to 2020, 1999.

5.2.4 Input data

Every LCA depends mainly on the quality of input data. The collection of the input data requires the most work within a LCA. The broad range of technologies and preliminary steps of this study must rely on existing data bases. The most important data base was [Frischknecht et al., 2001][17] as well as the internal data of the Institute for Energy and Environment, Leipzig.

For this study it has been necessary to define reference vehicles with comparable properties. All figures are worked out for the unit "vehicle-km". This is sufficient for comparing the different fuel types within the scope of this study. The general approach is based on future exhaust emission standards, modified against the background of several vehicle research studies and of discussions with vehicle manufacturers. All figures intend to represent the long term perspective (approximately 2030). Differences of the vehicle emission powered by petrol, ethanol or other fuel can be neglected because emission standards are assumed to be much stronger in the future for most of the transport modes. All the vehicles have to keep the limits. CO_2-emissions are calculated for each fuel separately.

- Passenger car: Base is a middle class passenger car with an assumed fuel consumption of 4,0 litres diesel per 100 kilometres. Assumption of emission standards: According to DRI·WEFA and Arthur D. Little[18]. Assumptions are equivalent to 25 % of the EURO-IV standard.

  Based on this, emissions were figured out assumed to be as high as the future limit.

- Lorry: A typical heavy long distance lorry is taken (gross weight 40 t). The diesel consumption is projected to be 30 litres diesel per 100 kilometres. Emission standards are compiled on the base of Directive 1999/96/EC, EEV and projected exhaust emission standards in the California Code of Regulation.

  Based on this, emissions were figured out assumed to be as high as the future limit.

- Train: Since electrified railways are not included in this study, the attributes of a modern long distance diesel train are taken (Siemens ICE-TD, 195 seats, 2240 KW, 200 km/h). Future emission limits are projected to be half of the limits expected in 2008 (UIC 624, ERRI). The fuel consumption is assumed to be 200 litres diesel per 100 kilometres.

  Based on this, emissions were figured out assumed to be as high as the future limit.

- Inland navigation vessel: An average vessel is taken (net load: 3000 t, 1000 KW). The emission limits of the Central Commission for the Navigation on the Rhine (2001) are assumed to be constant, the fuel consumption is projected to be 2000 litres diesel per 100 kilometres.

  Based on this, emissions were figured out, assumed to be as high as the future limit.

- Airplane: The Airbus A 320 is taken (net load 19 t) assuming an energy consumption of 16,4 MJ per ton kilometre. Source of emission data: Borken, Patyk, Reinhardt[19].

  The energy consumption of the hydrogen airplane is assumed to be the same as for the conventional airplane.

[17] Frischknecht et al., 1996.
[18] DRI·WEFA, Arthur D. Little: Future Powertrain Technologies, Lexington; Cambridge, 2001.
[19] Borken, Patyk and Reinhardt: Basisdaten für ökologische Bilanzierung, Heidelberg, 1999.

Table 6: Specific input data of reference vehicles for final use in the long term perspective

		energy consumption	CO_2	NO_x	CO	HC	H_2O (water vapour)	Particles
		[MJ / vehicle km]	[gram per vehicle kilometre]					
Passenger car								
piston engine	diesel	1.15	90	0.04	0.125	0.04	0	0.006
piston engine	RME	1.15	80.4	0.04	0.125	0.04	0	0.006
piston engine	methanol	1.15	78.4	0.04	0.125	0.04	0	0.006
piston engine	ethanol	1.15	81.5	0.04	0.125	0.04	0	0.006
piston engine	hydrogen	1.15	0	0.038	0	0	100.6	0
fuel cell	GH_2	0.57	0	0	0	0	43	0
fuel cell	LH_2	0.57	0	0	0	0	43	0
fuel cell	methanol	0.8	57	0	0	0	43	0
Lorry								
piston engine	Diesel	10.58	800	0.0588	45.57	0.41	0	0.0294
piston engine	RME	10.58	740	0.0588	45.57	0.41	0	0.0294
Train								
piston engine	diesel	70.56	5340	58.8	19.6	4.9	0	1.47
piston engine	RME	70.56	4932	58.8	19.6	4.9	0	1.47
Inland navigation vessel								
piston engine	diesel	705.6	53400	2175.6	980	254.8	0	105.84
piston engine	RME	705.6	49320	2175.6	980	254.8	0	105.84
Airplane*								
jet propulsion	kerosene	311.6	23085	115.14	39.14	9.69	9784	0
jet propulsion	hydrogen	311.6	0	7.0	0	0	23152	0

* additional for kerosene: SO_2: 4.37 g/vehicle kilometre, CH_4: 0.513 g/vehicle kilometre

5.3 Results of the life cycle assessment

5.3.1 Global warming potential

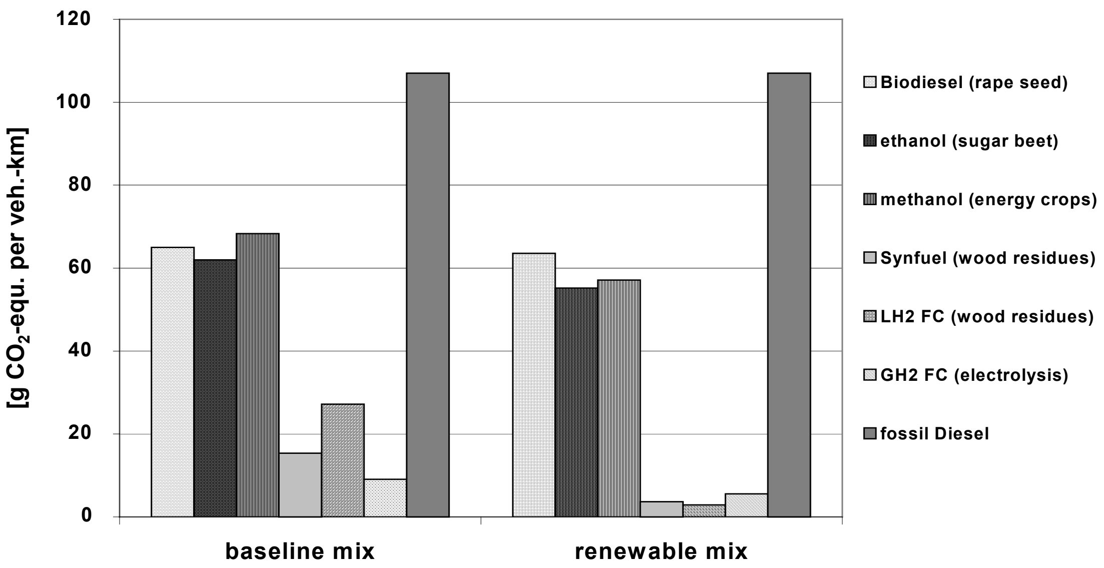
The global warming potential (GWP) corresponds to the described additional anthropogenic green house effect in chapter 5.2.2. It is calculated at the base of the projected energy mix of the European Union in 2020 and (as a sensitivity analysis) for a completely renewable electricity supply. In that case the portions of hydro-, wind and solar energy correspond to the potentials described in chapter 4. Within the renewable mix, a natural gas based ethanol plant is assumed because sugar processing plants are currently using a high percentage of heavy fuel oil.

Figure 18 shows the result of calculating fuel chains in respect of passenger cars. All renewable fuel applications reduce the GWP if compared with conventional fossil diesel. The influence of changing the electricity mix from the baseline projection to the renewable mix is highest for liquid hydrogen because the liquefaction is based on substantial quantities of electric power.

Generally, the influence of changing the power mix is high where transformation processes need a lot of electricity. As example related to the projected baseline electricity mix the production of methanol from fast growing trees is explained: It needs considerable amounts of electricity, not only for the methanol processing itself, but also because the input needs oxygen that is taken by electricity from oxygen in the air. These two inputs correspond to 50 % of the cumulated fossil energy demand of the total chain, another 25 % is needed by the poplar tree plantation itself. In contrast, for the biodiesel production electricity accounts only for less than 7 % of the cumulated fossil energy demand (oil mill and transesterification plant), the agriculture (mainly based on diesel tractors) needs the biggest fossil energy share of about 50 %.

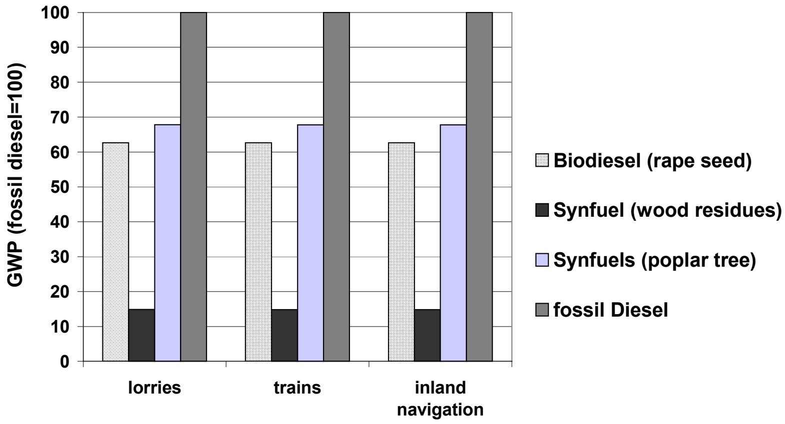
The influence of agriculture and forestry on the GWP is important for all fuels based on energy plants. Using fuels based on residues or hydrogen from renewable electricity reduces the GWP more significantly than using fuels based on energy crops.

Figure 18: Impact on global warming potential (passenger cars)



For lorries, trains and ships, the number of fuels that can substitute fossil diesel is more limited than for passenger cars. Figure 19 shows the impact ratio on the GWP of lorries, trains and ships, which is the same of all transport modes because the greenhouse gas emissions are directly linked to the energy demand. Here only figures assuming the baseline electricity mix are included.

Figure 19: Impact on global warming potential by baseline electricity mix (lorries, trains, ships)

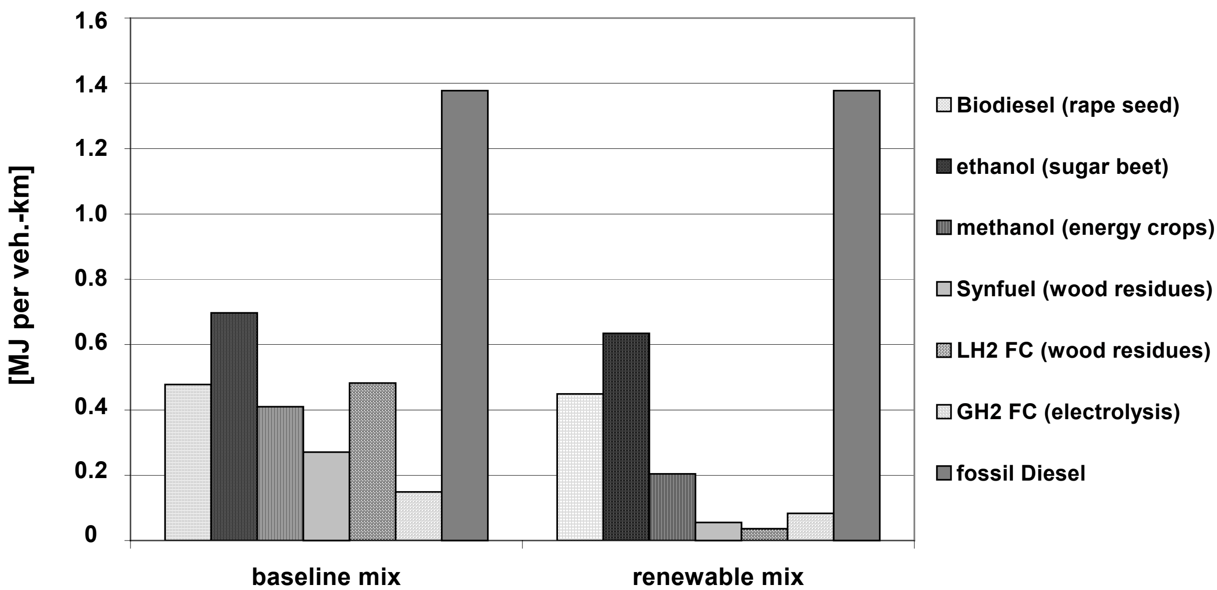


The energy demand per vehicle-km was assumed to be the same within each transport mode for each fuel. Absolute values between lorries, trains and ships are very different, so for each transport mode the GWP-value for fossil engines was set as 100 per cent in the figure above. So the relations reflect only the different chains for renewable fuel production, for the fossil chain, the direct emission is added.

5.3.2 Cumulated fossil energy demand

The LCA results for fossil energy demand correspond mostly with the results for the global warming potential.

Figure 20: Cumulated fossil energy demand for passenger cars



A relation of the fossil energy demand to the GWP is given for fuels based on electricity and on residues. Differences appear for fuels from agriculture, that indicates that not only the burning of fossil fuels leads to the global warming. If the baseline electricity mix is assumed, the methanol based on fast growing trees shows good values, even better than the liquid hydrogen option that is based on the same type of wood residues.

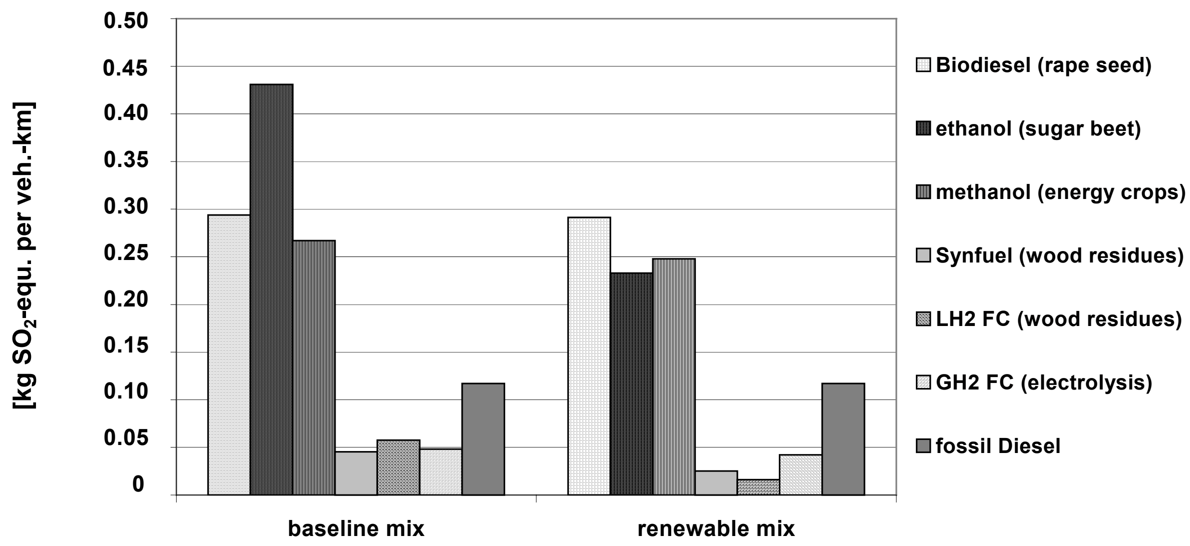
5.3.3 Acidification

Due to uncertainties in the sector of sewage plants, the following results refer only to air-borne pollution, the direct pollution of water is not considered. Agriculture and combustion engines play the most important role for pollution within this study. Direct emissions of biofuel combustion are supposed to be the same as those from fossil fuels because they have to keep the same limits. So renewable fuels show the same impact on acidification as fossil fuels – whereas the CO_2-emissions of biofuels are neglected because they are compensated by the biomass production.

The acidification effects of agriculture (and processing plants) are added so that fuels based on energy crops show worse acidification values than fossil diesel does. Hydrogen and syn-fuel based on wood residues show better values in comparison with both fossil and energy-crop-based fuels.

The better values for synfuel compared to fossil diesel are due to the supply chain and not to the direct emission during the combustion. For ethanol, the changed heat mix within the sugar processing plant becomes obvious (see Figure 21). The change of fuel within the plant leads to a reduction of more than 80 % of all SO_2-emissions and thus brings a lower acidification potential than the use of RME or poplar-based methanol.

Figure 21: Impact on acidification (passenger cars)

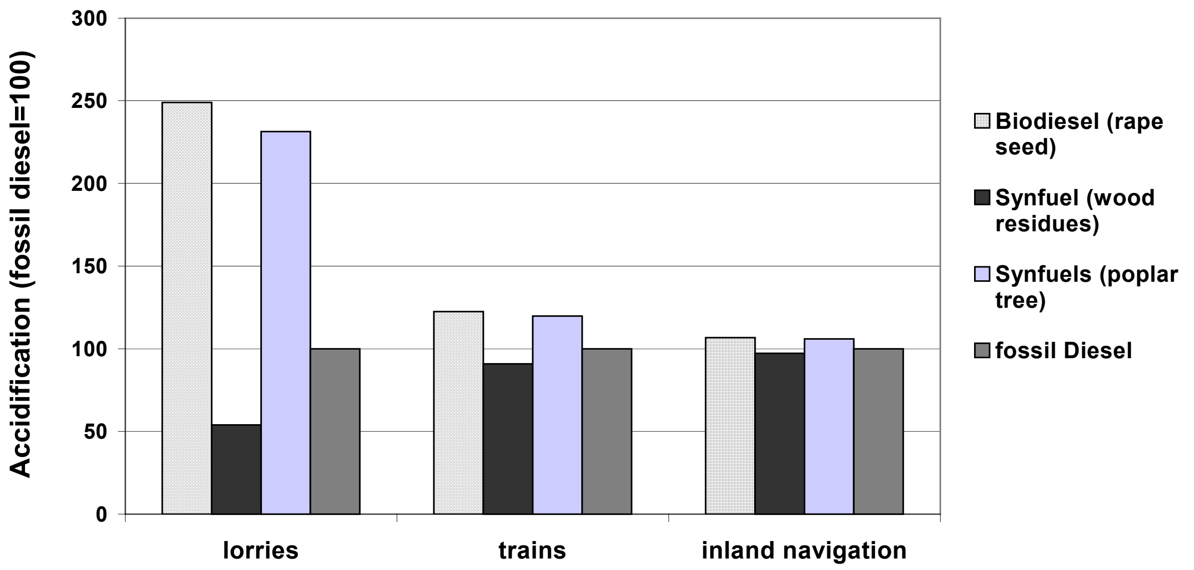


For lorries, trains and ships, Figure 22 shows the same fuel options like for the global warm-ing effect. The results base on the baseline electricity mix.

For the acidification, all direct emissions from the combustion engines were supposed to be equal per transport mode, so the figure reflects the added effects of the fuel provision chains and of the direct emissions for each fuel and for each transport mode.

In general, Biodiesel causes the highest acidification potential, synfuel based on fast growing trees is not far from this value, and only synfuel based on wood residues shows better values than fossil diesel.

Figure 22: Impact on acidification by baseline electricity mix (lorries, trains, ships)



In fact, the differences are by far more important for lorries than for trains and ships. Considering the LCA in detail, it becomes clear that strong emission limits for road transport that are planned for Europe are limiting the direct emissions that are supposed to be equal for all combustion engines. So the remaining emissions are dominated by the fuel provision chain (only 4 % of the emissions are direct emissions). For inland navigation, such emission limits don’t exist. Thus, almost 96 % of the acidification potential is caused by direct emissions (where no differences for all combustion ship engines are supposed), the fuel chain differences can hardly influence the total result. For trains, the share of direct emissions is 85 %.

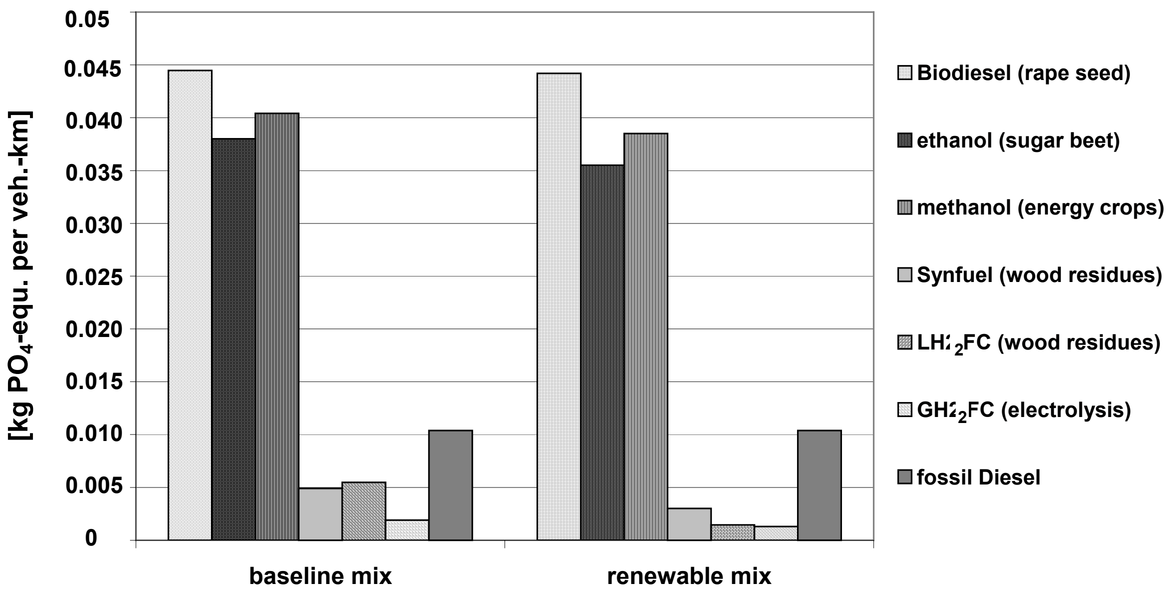
5.3.4 Nutrification

Due to uncertainties in the sector of sewage plants, the following results refer only to airborne pollution, the direct pollution of water is not considered.

The results in Figure 23 show the high influence of agriculture and short rotation forestry on the phosphate emissions of the corresponding fuel chains.

For lorries, trains and ships, the tendencies correspond to those described in chapter 5.3.3.

Figure 23: Impact on nutrification (passenger cars)



5.3.5 Biodiversity

For biodiversity, the most known indicator is the number of bird species in agricultural areas. The development of other indicators has begun for establishing an international data base COM (00) 20 final.[20] The possible influences of the renewable fuel provision chains on biodiversity are:

1. Agriculture with large areas of monoculture can oust other species (plants and animals) and so reduce their habitat. The set aside land can be a better habitat for wild species than areas with agriculture, especially with intensive agriculture.

   This influence has the most important consequences. The influence is different for different crops because the energy content that is available per surface is different (corresponds to the question “need of space” in the module sheets of class 1). In fact, the potential for all fuels has been calculated based on the same available area, but if the necessary area is considered as a specific value per fuel, the differences appear again.

2. Invasive alien species can threaten ecosystems if these species are introduced as (or linked to) energy crops.

   The only new species that was considered is Miscanthus, but there is no information that leads to the supposition of invasive expansion behaviour of the plants.

3. Agriculture or forestry has more negative consequences for biodiversity if fertilisers, pesticides, weed-killers or irrigation are used in higher amounts because these impacts of intensive agriculture lead to the tolerance of less species than if these chemicals are not used. This is mainly different between agriculture and forestry because wood plantations are generally less intensive than agriculture.

4. The removal of logging residues from the forests can change forest ecosystems.

[20] European Commission (Ed.), COM (00) 20 final.

Due to sustainable forestry systems there is not a high importance of this aspect. The removed wood is replaced normally by new plantations and the removal of the logging residues needs not more space than the removal of the logged trees.

5. If transportation demand of a fuel provision system is higher, this contributes to the global transportation demand. Transportation demand generates transport infrastructure demand and infrastructure (roads and railroads) often cuts habitats and thus threats species.
6. The lower the total price of a fuel will be for the end user, the more traffic and transport demand will be generated (market reaction). Transportation demand generates transport infrastructure demand, and infrastructure (roads and railroads) often cuts habitats and thus threats species.

Table 7 shows the evaluation considering the importance of the first and the third influence.

Table 7: Influence on biodiversity of the chains selected for LCA

fuel chain (for passenger cars)	need of agricultural (forestry) area	intensity of agricultural production	total evaluation: negative influence on biodiversity
RME (base: rape)	high	high	high
ethanol (base: sugar beet)	low	high	medium
methanol (base: poplar wood)	medium	low	low to medium
synfuel (base: wood residues)	no need	no agriculture	no influence
liquid H_2 in fuel cells (base: wood residues)	no need	no agriculture	no influence
gaseous H_2 in fuel cells (base: electrolysis, renewable power)	no need	no agriculture	no influence
fossil diesel	no need	no agriculture	no influence

The communication from the commission on alternative fuels for road transportation and on a set of measures to promote the use of biofuels[21] [COM (01) 547 final] sees the same main influences on biodiversity. Some effects mentioned in the communication like the importance of co-products were not taken into consideration within this study. It is recommended to undertake some more in-depth-going studies for those energy crops that will play an important role within the strategy of the EU. Further valuable information on this issue are to find by the Convention on Biological Diversity (and the conferences of parties)[22].

5.3.6 Others impacts

Two additional aspects which could also be of relevance in the case of a renewable fuel introduction are the influence on water pollution and the consequences of biotechnology.

The influence on water pollution depends mainly on two factors:

- Utilisation of chemicals within the agriculture for energy crops
- Effectivity of sewage plants that treat waste waters from fertiliser factories (if the waste waters of these factories are not treated, the importance of nutrification and acidification of agriculture-based fuel chains will sharply rise, following the LCA model).

[21] European Commission (Ed.), COM (01) 547 final.
[22] Convention on Biological Diversity.

Biotechnology or genetic engineering can lead to higher yields for special energy crops but it causes other risks for the environment (invasive alien species that can threat existing ecosystems). Within the framework of this study, the existing yields of existing crops were assumed and the LCA was based on conventional plants (without genetic engineering). So the question of genetic engineering has some relevance for energy crops but it is not taken into consideration within this study.

5.4 Sensitivity analysis and interpretation

Sensitivity analysis

The results in chapter 5.3 include the sensitivity analysis concerning the electricity mix: One case corresponds to the predicted EU baseline electricity mix for 2020, the other corresponds to a complete renewable electricity mix. At the same time, the heat supply for the ethanol production was changed from mainly heavy fuel oil into natural gas because the heat supply of the factory was the main emitting source of the whole chain.

Some of the provision chains can be exchanged between the different fuels: The methanol, synfuel or hydrogen production can be based on a thermo-chemical treatment of woody biomass in general. So it was found out how the wood provision chain influences the result: wood residues (example: logging residues) accrue without supplementary emissions, fast growing trees (example: poplar) need cultivating and harvesting measures.
As an example,

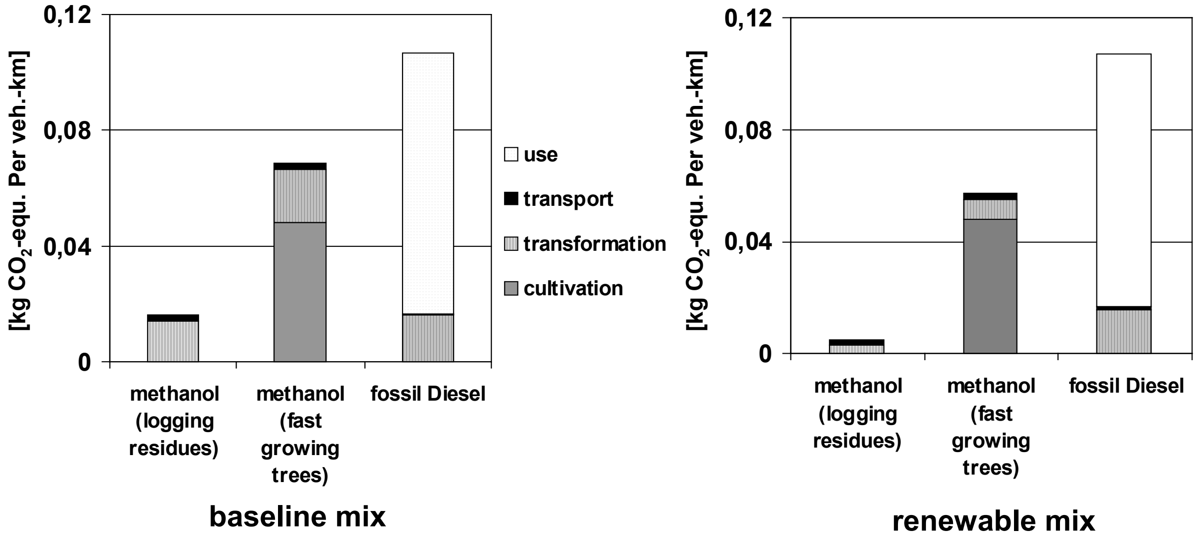
Table 8 shows the results for methanol provision for passenger cars.

Table 8: Sensitivity analysis by methanol driven passenger car

Impact category	global warming potential	acidification (airborne emission)	nutrification (airborne emission)	cumulated fossil energy demand
dimension	kg CO_2-equ. per veh.-km	g SO_2-equ. per veh.-km	kg PO_4-equ. per veh.-km	MJ prim. energy per veh.-km
cars driven with methanol from fast growing trees	0.068	0.267	0.040	0.410
cars driven with methanol from logging residues	0.016	0.050	0.006	0.275

The advantage of both chains compared with fossil diesel occurs because direct CO_2-emissions for renewable fuels are not considered. Figure 24 shows the contribution of different steps to the GWP for the considered fuels and the fossil diesel chain as a reference. Electricity influences mainly the transformation processes of the renewable fuels, so differences between the right and the left graph can be explained.

Figure 24: GWP caused by cars using different fuels



Interpretation:

All renewable fuel chains considered here contribute to a reduction of greenhouse gas emissions and of the consumption of fossil energy carriers.

Concerning acidification and nutrification the chains using energy plants and having a high demand of secondary energy inputs (biodiesel, ethanol from sugar beet, methanol from poplar wood) exceed the emissions of diesel driven vehicles. The global warming potential of these chains is higher than of chains based on renewable electricity or biomass residues as well.

Three groups of fuels should be distinguished:

1. Fuels based on energy crops

- The environmental effects of fuels from energy crops depend mainly on agriculture and the type of cultivation (which fertilisers, which energy demand). This is especially important for biodiesel from rape seed oil and for ethanol from sugar beet (or other annual plants).
- The production of agricultural annual energy crops causes the most problems for biodiversity.
- For the production of ethanol, there is also a high influence of the energy consumed by the transformation plant. If coal and heavy fuel are avoided, ethanol from sugar beet has an advantage compared with biodiesel from rape seed. This advantage doesn't include a transformation into ETBE because additional energy will be necessary for this transformation.

2. Fuels based on residues

- The environmental effects of fuel from residues are quite small because only transformation and transportation play a relevant role for the global warming potential, for the other impact categories, the direct emissions are dominating. Thus, the transformation technology has the highest influence on the LCA result because the emissions of engines using different fuels were assumed to be equal (corresponding to expected standards).

- Biofuels based on residues (logging residues from forestry, wood residues from trade and industry, straw, ...) cause less emissions than those based on cultivated energy crops because the environmental effects of cultivation are completely assigned to the main product (e. g. furniture from wood). Example: Methanol based on wood residues: 77 % less GWP.
- The global warming potential of synfuels (based on wood residues) is similar to that of hydrogen, the acidification potential is higher.
- There are no important differences between methanol and synfuel if both are based on residues because the thermo-chemical processes are similar.

3. Hydrogen based on electrolysis, using renewable electricity

- The chains ending with hydrogen use generate the least environmental impacts in general.
- The use of fuel cells leads to better results than using hydrogen in a combustion engine.
- Using renewable electricity in all processes, the environmental impacts of some chains can be lessened, the most important decrease (more than 89%) is found for fuel cell cars using liquid hydrogen based on wood residues.
- Production of hydrogen by renewable electricity and electrolysis (including emissions from the production of wind energy installations) is similar to the thermo-chemical production of hydrogen from wood residues.
- Liquefaction of hydrogen leads to more emissions due to the high energy consumption of this process.

6 Economic Considerations

6.1 Introduction

Energy diversification, security of supply, and environmental stewardship are among the principle economic justifications for renewable energy technologies. Yet despite affording these competitive advantages, the success of such technologies in emerging as a prominent component of the European energy infrastructure has been uneven. As of 1997, the share of renewables in total energy consumption was roughly 6%, a figure that the European Commission aims to double by 2010.[23] Focussing specifically on the transport sector, the purpose of the present chapter is to assess the economic implications of increased renewable energy use against the backdrop of two questions: 1) What are the potential economic impacts that would result? 2) What are the associated implications for aggregate social welfare and real resource costs to the economy?

In addressing these questions, it was not possible to conduct a comprehensive analysis of industrial concerns for each of the fuel chains selected in chapter 5 due to a paucity of both economic data and literature on the subject. Instead, the chapter is organized with the aim of highlighting important economic indicators that are likely to be directly affected by the introduction of renewable fuels. Section 6.2 discusses effects on employment, and provides a comparative overview of employment changes in the automotive sector, agriculture sector, and the economy at large. Section 6.3 examines implications for trade, noting in particular the impact of distributional effects across EU Member States as determined by their import dependency on fossil fuels. Section 6.4 covers changes in production and infrastructure costs. This section includes a brief discussion of biofuel use, but the emphasis is placed on hydrogen given the significant promise and challenge of this source in meeting future energy needs. Section 6.5 analyzes the role of the public sector in overcoming barriers to market entry resulting from the high fixed costs of renewable fuels. This is followed in section 6.6 by a discussion of private demand and the behaviour of consumers. Finally, section 6.7 concludes the chapter by providing an overview of the most salient findings.

6.2 Employment

A central question that concerns policy makers and the public is whether the net employment effects of environmental policies are positive. With respect to renewable energies, there appears to be a growing consensus among governmental and intergovernmental agencies of the European Union that synergies exist between support of such energies and employment generation. Several studies have identified positive, albeit in some cases relatively insubstantial, effects on jobs creation associated with renewable energy consumption. Moreover, projections vary markedly across different sectors of the economy.

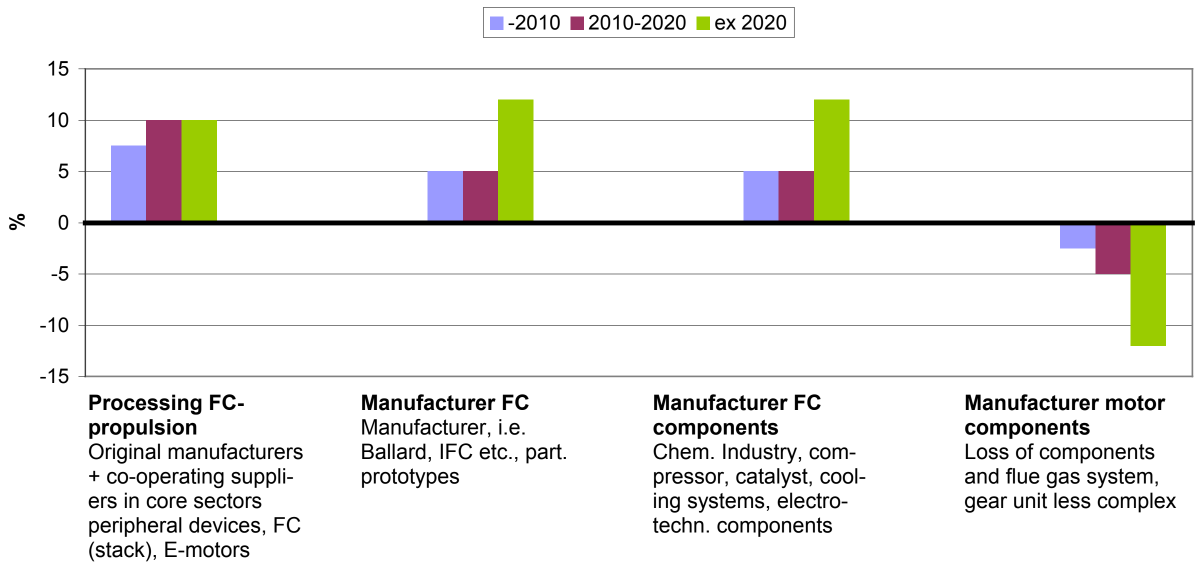
6.2.1 Hydrogen and the automotive sector

Within the automobile industry and related sectors, for example, research undertaken by the Fraunhofer Institut [1999] suggests modest impacts on employment from the introduction of fuel cell cars. Drawing on data from the state of Baden-Württemberg in Southwest Germany, the site of several car manufacturers and suppliers (DaimlerChrysler, Porsche, Bosch, etc.), the study estimates net employment effects ranging between +1500 jobs and -800 jobs depending on the competitive position of that state's fuel cell industry. Figure 25, adapted from

[23] COM(97) 599 of 26.11.1997. Energy for the Furture: Renwable Sources of Energy – White Paper for a Community Strategy and Action Plan.

a review of the study by Jürgens, Meißner, and Bochum [2002], provides a decomposition of these effects. Whereas manufacturers of the fuel cells and their components will require more employees, manufacturers of (conventional) motor components will reduce their staff.

Figure 25: Production of fuel cell cars – expected effects on employment in the processing chain (related region: Baden-Württemberg, D)



[Source: Jürgens; Meißner and Bochum, 2002]

Although the results from the study are limited in their geographical scope, they can be conservatively assigned as an estimate for other European automobile manufacturing countries (e.g. France, Spain) given that Germany is the biggest vehicle manufacturing country in the EU.

6.2.2 Biofuels and the agricultural sector

While no major industrial restructuring is required for biofuel use in the automotive sector, positive employment effects from increased production of biofuels are anticipated for the agricultural sector. This is one rationale underlying the European Commission’s initiative to promote this class of renewables, with the goal being to increase the portion of biofuels in total fuel consumption stepwise from 2 % in 2005 up to 5.75 % in 2010. The technical potentials for producing renewable fuels based on agricultural cultivation vary by countries, as described in annex 1. The most relevant impacts on agriculture are expected in countries like France, Germany, Italy and Spain, primarily because of their large available areas. With respect to the Central and Eastern European Countries, the highest potential (e.g. for rapeseed or sugar beets) is located in Poland, Romania, Turkey and partially in Hungary due to their large rural populations and high percentage of workers employed in the agricultural sector. The farm size in these countries, however, tends to be small relative to western European standards, meaning that farmers could face significant competitive pressures with integration into the EU [Missfeldt, 2003]. Consequently, biomass production offers one means to diversify production and facilitate the integration of the agricultural sector into the EU economy.

Germany is another country that is well-positioned to further develop its capacity for biomass production. Based on a macroeconomic evaluation of projected increased rape cultivation for biodiesal production, Schöpe and Britschkat [2002] calculate additional employment of approximately 19,720 people based on a projected rape cultivation of 700,000 ha (350,00 ha of non-food area and 350,000 ha of food area).[24] They point out, however, that some portion of this job increase may result from the employment of formerly idle family labour.

The European Commission [2001a] cites corroborative evidence of these positive employment effects, estimating that a biofuel contribution of around 1% to total EU fossil consumption would create between 45,000 and 75,000 new jobs. Other sources, for instance the Office of Technological Assessment at the German Parliament [1997], published net-effects of additional jobs[25] by the production of biofuels (RME and ethanol) between 13 and 20 jobs per 1,000 t biofuels, which are of the same order of magnitude of the underlying figures used in the European Commission's calculation.

6.2.3 Aggregate employment effects

A more comprehensive picture of employment effects from renewable energies is provided by a multisector study commissioned under the auspices of the European Commission's ALTENER Programme [EUFORES, 2000]. Using the SAFIRE (Strategic Assessment Framework for Rational Use of Energy) model and data on policies in support of renewable energy development in the Member States, the study predicts a140% increase in the energy produced by renewable sources between 1995 and 2020 in the EU15.

Based on the cultivation of energy plants, the use of organic residues, as well as the use of wind, sun and water energy, the study calculates the output of 3838 PJ of renewable energy in the year 2020 in the form of electricity and fuel. The largest overall increases come from biomass sources, which grow 122% from 1422 PJ in 1995 to 3153 PJ in 2020. This partly reflects the fact that biomass covers a wide spectrum of uses, including heat, electricity, and, increasingly, as transport fuels in some EU countries

The study estimated the employment impact of the market changes using the RIOT (Renewables enhance Input-Output Tables) model, the outputs from which represent net impacts, i.e. taking account of employment displaced in conventional energy sectors. As indicated in Table 9, the creation of over 900,000 new jobs are predicted by 2020, slightly over 500,000 of which are created in the agricultural and forestry sectors through the provision of fuel from energy crops, forestry, or agricultural wastes. As these sources represent primary energy carriers, the predicted employment effects on the agricultural sector can be used as an upper-bound reference value for consideration of effects in the transport sector.

[24] This projection takes into account instruments for creating set asides for the reduction of food production and conditions for such set asides as specified under the Blair House Agreement. It further assumes 350,000 ha of rape will be cultivated on traditional food fields due to increasing demand for biofuel.

[25] This effect – and the employment effect presented at RME production – is **not a real additional effect**. It is more a preservation effect: If RME or Ethanol are not produced, these jobs will be dropped out.

Table 9: Impacts on employment from the major industrial sectors

(new full time equivalents relative to base in 1995)

Industrial Sectors	1995 (base)	2005	2010	2020
Agric	7,663,157	288,453	407,421	512,874
Fuel	2,071,698	-21,188	-30,485	-34,444
Renewable Energy Manufacturing	38,555	92,610	135,890	193,572
Metals, Mine, Chem	4,369,960	13,850	21,437	33,937
MetProd	2,826,240	19,151	22,285	26,436
AgMach	3,124,353	22,049	32,173	43,393
OffMach	738,776	84	196	401
ElecGood	3001,134	10,384	14,849	24,399
TranspEq	2,857,927	8,557	12,640	17,167
Food	4,330,754	701	1,865	3,611
Textile, Paper, Plast	7,143,658	974	1,519	5,816
OthMan	3,283,655	323	1,383	3,238
Constr	9,807,506	5,231	9,055	14,979
Distrib	22,132,257	7,330	15,422	26,411
Cater	6,587,631	-58	408	1,707
Transp, Communic	8,613,961	1,436	5,777	10,440
BankIns	4,702,649	10,119	15,064	20,579
OthMrk	25,402,640	8,250	14,359	22,497
NonMkt	28,730,936	-14,838	-23,146	-29,270
Total Industry	**147,427,447**	**453,418**	**660,812**	**900,546**

[Source: European Forum for Renewable Energy Sources, 2000]

Two caveats of the study bear noting. First, the analysis assumes no displacement of employment in conventional agriculture and forestry from the expansion of biological fuel sources, the rationale being that there is still widespread overproduction of many agricultural products from consumer and export subsidies. Second, the results cannot be extrapolated to the countries of Central and Eastern Europe given that the productivity of the agricultural economy in these countries is likely to be considerably lower.

6.2.4 On employment as an economic indicator

While the evidence presented above offers an optimistic assessment of employment gains from increased renewable energy reliance, some caution is warranted in placing excessive emphasis on employment generation as an economic policy objective. From the perspective of aggregate social welfare, it bears noting that each job created has some associated opportunity cost, as measured by the next highest value to which labor could be allocated. Although renewable energy sectors may be more labor intensive [e.g. see EUFORES, 2000], labor productivity, and hence wages, may be lower in these sectors relative to traditional energies. To the extent that low wage jobs displace higher wage jobs, the merits of employment generation as a singular gauge of policy success becomes more questionable. Thus, in addition to measuring the distributional effects via the number of jobs lost and jobs gained, it is also important to consider the criterion of economic efficiency, as measured by whether those who are employed in the renewables sector could hypothetically compensate those who are displaced from the traditional energy sector and still be at least as well off. This is an issue that to date has received little analytical treatment.

6.3 Trade

Reducing dependency on fossil fuel imports and fostering a comparative advantage in the production of renewable energy technologies for export are two trade-based justifications for the increasing use of renewable energy. While the EU as a whole stands to benefit from greater reliance on renewables, as discussed below there are likely to be distributional effects that weaken the trade position of some Member States.

EU companies are already firmly anchored in international markets for several renewable technologies, and their influence stands to increase as expanding domestic markets provide a platform for further innovation. According to a recent study by ECOTEC [2002], wind and biomass are two sectors that show particularly great promise. The study notes that the EU has established itself as the largest market for wind energy developments, with 75% of the total world installed capacity of 18.5 GW. The study further predicts that the EU's wind energy capacity will grow from 12 GW in 2000 to 60 GW by 2010, while at the same time international wind energy markets are predicted to grow at an average of 25% per year to at least 2006. Danish companies are currently the market leaders in the EU, with a market share of 40-50%, but German and Spanish companies are increasing their prominence as a result of expanding domestic markets.

Biomass resources comprise the largest share of renewables production in the EU. These resources currently contribute more than half of the total renewable energy production, a share that is expected to increase. According to a European Commission White Paper [1997], biomass sources are proposed to produce more than 80% of the total additional contribution of renewables by 2010 in EU countries. Finland and Sweden have particularly strong export-oriented biomass industries based on combustion technologies for heat and power production, while France has positioned itself as the leading EU producer of biofuels [ECOTEC, 2002].

As the EU pursues the goal of becoming more energy independent through reduced imports of fossil fuel sources, there will be different regional impacts resulting from the transition to a renewable based fuel technology. Although the majority of EU countries are dependent on oil imports from non-EU countries (see Table 10), there are several countries that benefit from their regional fossil resources, e.g. Denmark, United Kingdom, and Norway. For the dependent countries, an introduction of a renewable fuel will improve their trade balance, while the effect on energy exporting countries is more ambiguous.

Table 10: Import dependency on fuels of EU 15 (2000) and CE Countries (1999)

2000, %	B	DK	D	EL	E	F	IRL	I	L	NL	A	P	FIN	S	UK	EU15
Solid Fuels	92.3	94.2	23.2	84.9	9.8	86.9	61.4	104.2	100.0	102.4	85.8	102.9	70.0	90.3	40.6	50.5
Oil	100.1	-78.2	95.4	100.2	101.0	99.0	104.1	96.7	102.1	99.8	89.9	98.8	113.1	101.8	-55.7	75.1
Natur. Gas	99.3	-64.8	79.1	99.1	101.4	100.0	72.1	81.1	100.0	-49.5	80.6	100.3	100.0	100.0	-10.6	45.7
All Fuels	**77.7**	**-33.9**	**59.5**	**69.5**	**76.5**	**51.1**	**86.5**	**85.6**	**99.8**	**38.5**	**66.4**	**87.1**	**55.7**	**39.6**	**-17.1**	**49.4**

1999, %	BG	CY	CZ	EE	HU	LT	LV	MT	PL	RO	SK	SI	TR	CE	EU	Aver.
Solid Fuels	31.3	85.7	-28.9	10.5	25.3	69.9	67.0	-	-25.8	25.5	77.4	22.5	33.3	-3.7	47.0	27.6
Oil	94.4	102.5	95.1	92.9	75.1	86.0	83.5	100.0	95.5	36.2	97.3	100.4	89.0	85.2	72.0	73.7
Natur. Gas	102.6	-	96.3	100.0	73.9	100.0	103.5	-	67.2	18.5	91.4	99.4	95.0	72.9	44.7	49.2
All Fuels	**48.5**	**100.5**	**25.0**	**38.2**	**54.3**	**53.5**	**57.8**	**100.0**	**9.9**	**21.9**	**68.7**	**55.5**	**61.4**	**36.9**	**48.9**	**45.7**

Import Dependency = Net import / (Bunkers + Gross Inland Consumption); values over 100% are possible due to changes in stocks. [Source: EC, Transport in figures, 2002]

In the long-term perspective, it is instructive to examine European countries that are currently energy exporters for the European Union. Among these, the **Netherlands** is a country that could be adversely affected by a reduction of conventional fuels. Although the Netherlands are a small country, they have a high deposit of natural gas (3% of world-wide natural gas production). The Netherlands export more than 7% (50,000 Mm^3) of the world's total export volume of natural gas. Roughly 70% of the crude oil and natural gas industry turnover are gained by exports. Furthermore, the Netherlands have a high capacity for refining and producing chemical products. In 2000, the Netherlands exported the biggest volume of refined petroleum products in the world (63 Mt). The chemical industry employs only 10% of the total number of employees in industry sector, but these 10% earn (in addition with the turnover of oil industry) 34,500 million € (equal to 23% of total turnover in the industry sector)[26]. Another aspect is the share of more than 10% of cars driven by LPG in the Netherlands. By a forced reduction of these production capacities (given the market penetration of alternative fuels as hydrogen), the LPG strategy of the Netherlands may falter and the market for LPG (and the refinery pre-stage) will weaken.

Norway[27], which has a heavily resource-based economy**,** is another country that may be negatively impacted from increased renewable fuel reliance. Norway is not only the biggest supplier of oil and gas for the EU (22.4% of total EU imports), but it is also the second biggest exporter in the world (146 Mt/a in 2000) after Saudi Arabia.[28] In case of a successive build-up of a renewable fuel infrastructure in Europe, Norway's oil outlets would contract because of the lower dependency of the previous net-importer countries. Lower oil revenues would in turn undermine the country's ability to maintain budget surpluses. Considering employment, only 0.7% (about 16,500 persons) of total employees obtain about 15-20% of Norway's GDP, which amounts to 60% of the export volume depending on current oil prices. Given an implementation of renewable fuels linked with the reduction of fossil fuels, a comparatively small segment of the labor market would be affected, but the country could stand to see a decrease of 15-20% of its GDP (equal to 25,000 to 32,000 million US$). A substitution of this loss by expanding hydropower electricity, which is the biggest resource for cheap electricity in Norway, has met with opposition from environmental interests[29].

6.4 Production and infrastructure costs

The single most important factor hindering greater commercial penetration of renewable energies is their costs relative to traditional sources, both with respect to their direct processing costs and the attendant technical modifications required for energy-using technologies. There are several dimensions to cost that merit consideration when assessing the financial implications of renewable energy use. This section reviews the cost changes resulting from biofuel consumption, as well as the electricity generation and infrastructure costs incurred from hydrogen use. Section 6.6 examines changes in the prices of automobiles resulting from technical modifications.

6.4.1 Biofuels

Depending on the course of implementing renewable based fuels, the vehicle industry may need to undergo extensive restructuring in development, production processes and supply structures. Not every fuel, however, will lead to the same serious consequences in production and/or market outlets. For example, as a result of technological advances, most vehicles in circulation in the European Union can function on biodiesel or ethanol blends of up to a

[26] The Netherlands Foreign Trade Agency (NFTA), 2002; Statistics Netherlands (CBS), 2003.
[27] As member of the European Economic Area.
[28] European Union (Ed.): The EU's relations with Norway, 2001; International Energy Agency (IEA), 2002.
[29] German Embassy in Norway.

certain share without mechanical modifications. The main factor hindering more widespread production of these fuels is their costs relative to traditional petrol.[30] For example, using figures from the European Commission [2001a], biodiesel has a production cost of approximately 500 €/1000 litres as compared with 200-250 €/1000 litre for traditional petroleum-based diesel assuming current oil prices. Given that it takes 1100 litres of biodiesel to replace 1000 litres of traditional diesel, this implies a minimum cost differential of 300 € for each 1000 litres of diesel replaced [European Commission, 2001a]. Ethanol is another renewable source that is mainly used mixed with gasoline and diesel. Although ethanol has lower production costs than biodiesel, it requires 1500 litres of ethanol – an additional 400 compared with biodiesel – to replace 1000 litres of gasoline [European Commission, 2001a].

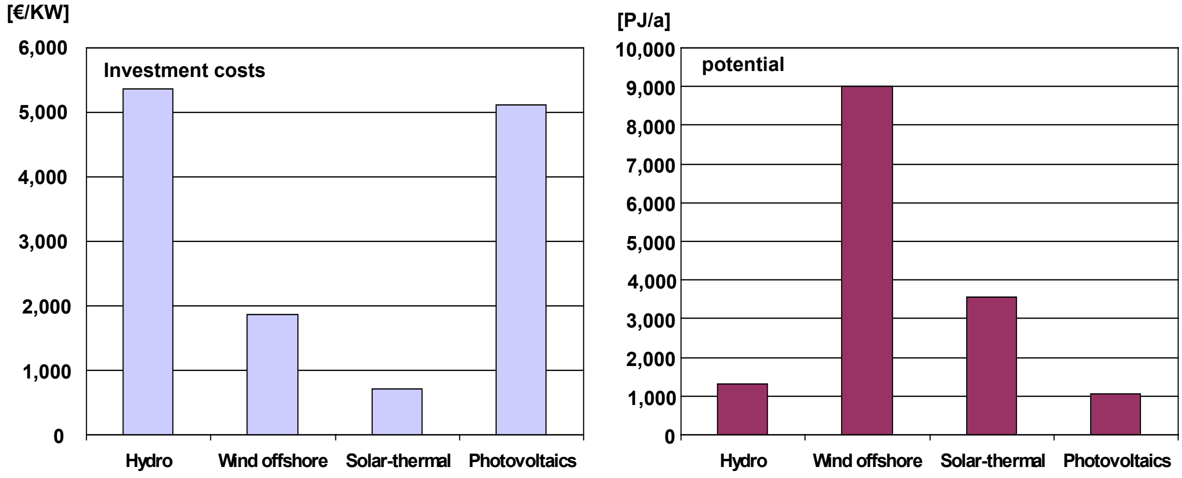
6.4.2 Hydrogen

Hydrogen represents the most challenging alternative to conventional gasoline because of several technical hurdles relating to production and distribution. With respect to production, it is important to recognize that hydrogen is an energy carrier – as opposed to an energy source – meaning that any consideration of its cost-effectiveness must take into account how it is produced. While a main benefit of hydrogen is that it can be produced from almost any source of energy, including both renewables and nonrenewables, the production process is relatively energy intensive. For example, using electrolysis – a fully developed process with little scope for significant technological cost reductions – the amount of renewable sources required to produce and process the hydrogen is at least double that needed to produce petrol from crude oil [Federal Environmental Agency, 2000].

Energy production costs
Given that electricity offers one of the primary means for producing hydrogen, an assessment of electricity generation costs using renewable sources is instructive in gauging the feasibility of using hydrogen as an energy carrier. Figure 26 indicates the necessary investment costs for the installation of 1KW renewable energy. These data represent the actual prices for an installation; a “learning” effect for the long-term perspective is not calculated. It is noted that hydro power and photovoltaics are very costly, whereas wind offshore and solar-thermal power are comparatively low priced. The prices correlate to the technical potential of the sources. Consequently, an expansion of a high price technology with a low future energy potential does not appear to be suitable.

[30] These costs consist of cultivation of energy plants, their transformation into fuel, and their distribution to fuel stations.

Figure 26: Investment costs per KW installed in relation to potential (EU 15) per year



[Sources: Investment costs: Stiftung Energieforschung Baden-Württemberg (Ed.), 2001, Potential: own calculation]

On the basis of these data and the technical potential investigated in this study, a rough calculation of investment costs is given in Table 11. Assuming the usage of 25 % of the technical potential of each renewable energy source, investment costs will amount to more than 2,000 billion €[31] (neglecting a possible "learning potential"). The amount of energy thereby generated, which is equal to roughly 5350 PJ, can then be used to produce 3745 PJ of hydrogen using electrolysis.

Table 11: Cumulated investment costs for energy production by renewable sources[32]

	Overall Potential [PJ/a]	Used Potential (25%) [PJ/a]	Required invest for used potential [Mio. €]
Hydro	1,890	472.5	124,560
Wind offshore	12,899	3,224.8	450,925
Solar-thermal	5,119	1,279.8	823,519
Photovoltaics	1,493	373.3	604,665

For wind power generation, a detailed and adjusted long-term (2020) investment cost framework was done by TES.[33] Using the figures from that study, investment costs show a reduction of approximately one third relative to the 450,925 figure listed in the table, for a total of 302 billion €.

Similarly, solar cell production has followed a steep learning curve during the last 20 years [Willeke, 2001], such that a duplication of the cumulated production volume was correlated with a price reduction of 20 %. Although costs are still high, the potential for cost reduction is evident.

[31] Costs are based on today's prices. The power stations will not be constructed once but successively. By this process, a dynamic decrease of production costs can be expected.
[32] See Annex 5 for detailed calculation.
[33] Transport Energy Strategy (TES), 2001; (see [40])

In comparison to renewable energies, nuclear power plants provide a much cheaper source of energy and therefore represent a conceivable intermediate alternative. Generating the same amount of electricity as is assumed in Table 11 (used potential), the financial requirement would amount to almost 869 billion €[34]. By subtracting the generated power of nuclear power plants (EU15) in 1999, the additional costs would be reduced to 350 billion €. External costs would have to be additionally considered, which could be significantly higher for nuclear energy generation than for renewable energy production. Quantification of these costs, however, is problematic, particularly given methodological challenges in valuing the impact of low-probability, high-damage events as characterize nuclear power accidents.

Distribution

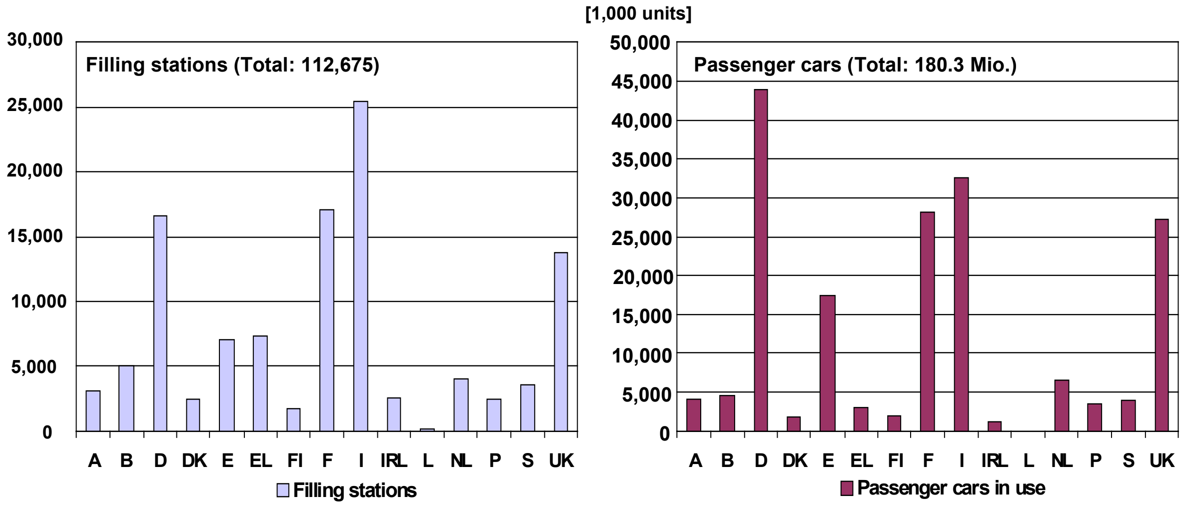
Beyond difficulties in efficiently harnessing energy from hydrogen, there are additional challenges in establishing the requisite infrastructure to support widespread use of fuel cell vehicles. In contrast to biofuels, which can be distributed with only minor modifications to the existing fuel infrastructure, the build-up of an adequate transportation and filling station infrastructure is critical to the successful introduction of hydrogen. The primary methods for the transportation of hydrogen fuel are pipeline, rail, marine shipping and trucking, all of which are also used for the transportation of conventional fuels, but which would require modification to support hydrogen distribution. Ogden et al. (1997) estimate the capital cost of a pipeline to be roughly 83,000 €/km. Amos (1998) calculated pipeline transmission costs for different ranges and energy delivery rates. For a distance of 100 km, the author estimates the cost of transmission to be 0.45-0.53€/GJ for energy delivery rates of 1.5 GW and 0.15 GW, respectively, while at 300 km, these costs are 0.68-1.97€/GJ for 1.5GW and .5 GW, respectively.[35]

Another critical aspect regarding a competitive implementation of hydrogen as automotive fuel is the build-up of an adequate filling station infrastructure. The projected number of required filling stations in Europe depends on the number of cars operating on hydrogen. Assuming that future hydrogen cars have the same range as conventional cars, an extrapolation of the required hydrogen stations can be done on the basis of the actual structure of filling stations and the passenger cars in use. Figure 27 shows the relation between these two indicators.

[34] see Annex 5 for details of the calculation.

[35] The references to Ogden et al. (1997) and Amos (1998) are taken from Padro and Putsche (1999), who present cost figures in dollars. Currency conversions are based on the 1997/98 ECU/dollar exchange rate.

Figure 27: Number of filling stations and number of total passenger cars in EU 15 by 2002



[Source: European Automobile Manufacturing Association (ACEA), 2002b; International Energy Agency (IEA), 2002]

In general, a highly linear relationship is evident between the number of cars in use and the installed stations. The average number of cars accounting for one station in EU 15 amounts to 1,600.

In order to install about 60,000 H_2-stations, L-B-Systemtechnik [2002] calculated about 75 billion € in 2020 based on expected costs of about 1.25 million € per filling station.

Assuming a conversion of 20 % of the European filling stations (EU 15) to hydrogen filling stations until 2030, investments of approximately 28.2 billion € would be necessary based on a calculation using the figures above.

6.5 The role of the public sector

While the costs of renewable energy production from most sources has been decreasing over the last 30 years [Mc Veigh et al., 1999], significant barriers to investment still remain. Support from the public sector through tax relief, subsidized raw material production and favourable loans is therefore critical to establishing long-term stable income streams for ensuring financial viability. In the energy industry, for example, a major obstacle preventing installation of a distribution system for fuel cell vehicles is the still negligible share of hydrogen cars. This same consideration applies to the automobile industry: Without a hydrogen filling system in Europe, manufacturers will not start mass production. And a production of small numbers is not cost effective.

In recent years, a stream of studies have emerged that examine the effects of technical change and learning effects on the adoption of renewable energies. Isoard and Soria [2001], for example, emphasize the importance of institutional commitments to foster learning effects and overcome diseconomies of scale resulting from high fixed costs or market diffusion barriers. The authors accordingly recommend that public support be provided to reach the production threshold at which economies of scale take effect. In this regard, fossil fuel technologies are generally seen to have smaller potential for learning-by-doing and consequently smaller potential for cost reductions given that these sectors are already mature relative to renewable energies [Rasmussen, 2001]. To the extent that learning-by doing effects are present, then demand for renewable energies will induce technological progress. There thus may be positive externalities associated with endogenous technological change, implying that the market outcome is less than the socially optimal outcome of production in the affected renewable energy sectors.

These considerations suggest that it is incumbent on public authorities to develop policies for channelling financial support to the renewable energy sector. Major challenges exist, however, in raising the necessary funding, particularly given the reduced taxed revenues that would accompany a reduction in oil sales. Additionally, no adequate compensation can be expected by the taxation of renewable fuels because these fuels are recommended to be taxed at low rates during the phase of introduction. For example, the Sweedish Bioalcohol Fuel Foundation stresses the importance of long-term tax reduction (circa 10 years) for bioethanol, with comparable rates for bioethanol fuels and bioethanol blends [European Parliament, 2001]. As indicated in Table 12, Sweden is simultaneously a country in which the revenues from taxation on fuels and lubricants are of high importance for the total public revenues.

Table 12: Revenues from taxation on fuel and lubricants (2000 and 2001), relation to public revenues (public authorities, 2000)

	S	DK	I	P	E	IRL	F	FIN	D	B	UK	NL	EL	A	EU
fuel & lubricants	40.0	16.1	29.3	2.6	11.8	1.7	30.6	3.0	37.9	4.7	22.5	6.2	2.1	2.6	211.1
share in total revenues	26.2	16.4	5.4	5.3	4.9	4.5	4.2	4.1	4.0	3.8	3.5	3.3	3.1	2.5	5.3

[Source: European Automobile Manufacturing Association (ACEA), 2002a, and Federal Statistical Office, Germany (Ed.), 2002]

In order to compensate the future reduction of these revenues caused by the lower oil sales, a rising rate of taxation on fossil fuels is advisable. While an excessively high rate of taxation on oil can theoretically cause a cut in revenues from decreased consumption, this is an unlikely outcome given that demand for oil is inelastic over a wide band of prices (see below). Hence, it can be expected that the consumption of fuel, and by extension tax revenue, will not decrease markedly until a very high rate of taxation is reached, leaving considerable scope for raising taxes on fuel.

Member States have experimented with several other mechanisms for financing the renewables sector using public funds. For example, Germany's Feed-In-Law, expanded in 2000, provides support for renewable energy electricity by providing a guaranteed market and fixed price for electricity from renewable energy sources. Denmark has catapulted its wind energy industry to world leader status through a combination of premium tariffs for electricity from wind power and subsidies toward R&D in the early 1990s. In Finland, there has been extensive R&D support into the biomass technology.

As increasingly ambitious targets are set for the share of renewables in total energy consumption, a fundamental question regards whether the political commitment will be forthcoming to finance similar programs. This will depend in large part on the extent to which efforts to promote renewables reflect the real impact of these energy sources on the economy. While biofuels are currently more expensive than fossil fuels, it is not possible to conclude that biofuels are less economical without taking into account the positive and negative externalities associated with consumption of the two fuel sources. For example, the positive externalities of bioethanol in France have been estimated to be roughly 0.17 € per liter, with additional benefits achieved through scale economies, leading French officials to assume that biofuels could close the price gap with fossil fuels within the next 10 years [European Commission, 2001b].

6.6 Private demand

Ultimately, renewable fuels can only be established when consumers do not have the alternative of fossil fuels with lower costs. Thus, the following section considers a) the development of initial vehicle costs, b) the shift of fuel prices, and c) the effects of increased costs for mobility (represented by higher fuel and vehicle costs) on the demand response of private households.

6.6.1 Vehicle costs

With respect to fuel cell cars, cost disadvantages are expected compared with the mature production of conventional cars, especially during the introduction phase when production levels are low. There are varying estimations regarding the future additional costs for fuel cell vehicles. For example, realising the target costs for fuel cell vehicles, the future additional costs for cars driven by fuel cells are expected between 3,000 € and 4,000 € [Erdmann, 2000]. Furthermore Oertel and Fleischer [2001] estimate that the additional purchase charge for a fuel cell vehicle (referred to as a mid-class vehicle with combustion engine) range between 15 € and 25 € per KW (absolute: between 770 € and 1,280 €). It is assumed that the petrol prices will be about 1.15 € within the next ten years and the energy consumption will be reduced by 25-30%.

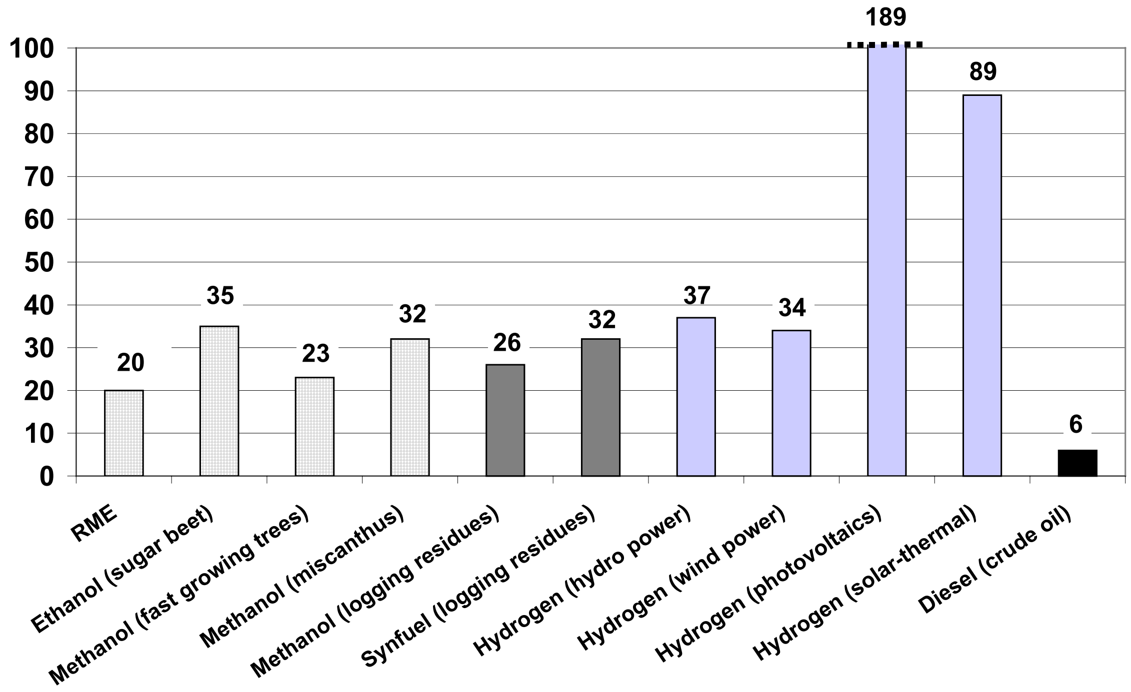
These exemplary estimations are compatible with calculations of TES [2001]. It points out additional costs for fuel cell cars of about 2,200 € in the period 2010 to 2020 (whereby a conventional car will cost approximately 18,000 €). Nevertheless, these cost structures can only be achieved by a competitive mass production. Hence, incentives must be implemented[36] to stimulate both suppliers and buyers of renewable fuel operated cars.

6.6.2 Shift of fuel prices

The introduction of alternative fuels based on renewable resources will lead to an increase of net-prices for fuels. According to the findings presented in Chapter 4, the production costs of renewable fuels will be considerably higher than for fossil fuels (see Figure 27).

[36] In general by the government/EU for the industry and/or the buyers of hydrogen driven cars. Possible monetary subsidies for the mentioned groups can be financed by a higher taxation (gradually) of fossil fuel driven cars (reasoned by their higher negative environmental impact by emissions etc.).

Figure 27: Fuel production costs in €/GJ



[Source: internal calculation, see chapter 4]

Two kinds of effects caused by higher fuel prices (and higher car prices, respectively) on private households can be expected: a pecuniary effect on the aggregate goods demand, and a consumption effect on the demand for fuel and mobility.

The pecuniary effect is indirect. Given that fuel is an input factor within the supply chain of goods, an increase in the price of this input causes an increased final product price, which in turn determines the aggregate demand for the product. The extent to which an increase in fuel prices changes demand may, however, only be negligible. In the first instance, companies cannot transmit higher production costs (caused by higher transport prices) completely, due to the strong competition (Europe- and world-wide). Secondly, fuel prices are generally of low importance in determining the total product price. For example, the share of transport prices on the Free-on-board-prices (HDV) of exports from Austria to other European countries amounts to 5% [Labour Chamber Vienna, 2002]. Thus, a substantial reduction of the aggregate demand – caused by higher transport costs – is not expected as long as the relation of transport prices to labour costs stays low.

A second effect of higher fuel prices stems from the fact that the demand for fuel is a derived demand according to its many uses. These uses include food, shelter, clothing, and perhaps most importantly, transportation. The demand response of private households for fuel, which is derived from the demand for mobility, can then be further divided into two effects: the income effect, which is caused by a shift of the household's budget constraint as a result of the price-change of one good; and the substitution effect, which is caused by a change in the relative price relationship between two or more goods. The substitution effect results in a decreasing demand for the now more expensive fuel and an increasing demand for cheaper substitutes. The income effect results in a shift in demand for a good as caused by a shift in real income (i.e. from higher fuel prices).

To estimate whether fuel is price sensitive, it is necessary to assess the relative influence of income and substitution effects that comprise a demand response to price changes. Over the short run, the substitution effect for fuel is likely to be relatively low. Given a rise in oil prices, consumers have little time to change their fuel inefficient cars or undertake other actions (e.g. moving from the suburbs to the city center) that would reduce fuel dependency. The resulting small substitution effect will tend to make demand for fuel inelastic.[37] On the other hand, fuel is a normal good, so it is likely that a decrease in real income from higher fuel prices will lead consumers to purchase less fuel. The size of this impact will depend on the proportion of fuel expenditures in the consumer's overall budget. To the extent it is high, it will tend to make demand for fuel more elastic. On the whole, however, since income effects tend to be weaker than substitution effects, the fact that the substitution effect is likely to be small will outweigh the possibility that the income effect is large, making demand for fuel inelastic.

Valid empirical data are not available for a quantification of private household's reaction caused by extremely high fuel prices, though former studies have tried to predict demand reductions for marginal changes of the price. For example, Graham and Glaister [2002] estimate long-run price elasticity of petrol demand for OECD-countries amounting to –0.79 on average. The calculated elasticity was based on moderate petrol price changes during a period from 1960 to 1985 and therefore may have limited applicability for prices changes of more than 500%, which would be necessary in the case of renewable based hydrogen.

Another aspect of higher fuel prices is their impact on the demand for public transport. This case shows parallels to the case mentioned with respect to aggregate goods demand. Within a system of public transport, fuel prices do not comprise a high share of the total costs for transportation[38]. Therefore, the demand for public transport will not decrease to the same extent as for individual transport. To the contrary, due to the relatively higher price increase for individual transport, a modal shift (from passenger cars to public transport) might be motivated. An exact quantification of these effects, also with respect to their impacts on the transport situation (e.g. decrease of congestion by more use of public transport) is beyond the scope of this part of the study.

6.7 Summary

Increasing the share of renewable fuels in energy consumption holds great promise on several fronts: meeting energy needs, contributing to economic growth, and ameliorating the negative environmental consequences that have resulted from heavy reliance on fossil fuels. Nevertheless, the successful incorporation of renewables into the European energy portfolio will require a sustained commitment on the part of the public sector, industry, and consumers in order to overcome cost and market diffusions barriers over the medium term. Based on the overview of this chapter, the following conclusions with respect to the economic effects of renewable energy consumption can be drawn:

- Net employment impacts are expected to be positive, with most job creation occurring in the manufacturing and agricultural sectors. The candidate countries have particularly sizeable endowments of biomass resources, the exploitation of which could generate both environmental and economic benefits.
- Trade effects are also expected to be positive for most Member States, primarily due to decreased dependency on imported fuel. Moreover, several countries are well-positioned to establish a comparative advantage in renewable technologies on world markets, particularly in the wind and biomass sectors. Other countries, most notably Norway, Denmark, and the United Kingdom, may have to contend with decreasing oil export revenues as European importers decrease their fossil fuel dependency.

[37] The elasticity of demand is defined as the percentage change in quantity demanded divided by the percentage change in price. If the absolute value of this term is less than one, demand is said to be inelastic, if greater than one, demand is elastic, and if equal to one, demand is unitary elastic.

[38] More important costs are represented by the over-head, the administration or personnel (i.e. bus drivers) which do not occur in the case of individual traffic/transport.

- While increased biofuel consumption in automobiles will not necessitate major technical medications (for blends up to 10%), the establishment of hydrogen-based vehicles poses several technological challenges. In addition to the setting up the requisite infrastructure, hydrogen will only become environmentally viable once fuel cell vehicles are efficient enough to compensate for the caloric losses incurred in producing the fuel.
- Technological innovations in the renewables sector will require public support in the early stages of their development to overcome high fixed costs and achieve economies of scale. Given a low elasticity of demand for fossil fuel over the short run, there is scope for increasing tax rates to compensate for lost fuel revenues from the overall reduction in consumption.
- Over the medium term, consumers will contend with higher fuel and auto prices, which may induce a modal shift to public transport for some segments of the population. Impacts on the prices for final goods from increased fuel costs are expected to be negligible.

In conclusion, to facilitate greater renewable energy reliance will require coordinated action at the community level. In this regard, the integration of environmental and energy policy across the Member States, with a particular emphasis on legislative instruments that unify fuel tax systems and foster trade, are among the most pressing challenges.

7 Scenarios for renewable fuels for cross border transportation

7.1 Criteria for the selection of scenarios

The selection of appropriate scenarios is based upon different relevant criteria. These are in particular:

- Life cycle assessment: Furnishes information on the environmentally relevant effects of different energy paths. The evaluation criteria are the climatologically relevant effects (CO_2), acidification (SO_2) and nutrification (PO_4^{3-}). Besides the complete energy demand is of importance (CED).
- Economic considerations: Here the issues of the different sectors are of importance as for instance those of the agriculture, the vehicle industry, the transport sector and the energy sector and these concerns however can be antagonistic. The goal is to reach a suitable compromise for the different parties.
- Potentials: The existence of different renewable energetic sources for the transport sector is very important for the selection of scenarios. The potentials are established values that determine a certain pre-selection with respect to the fuels in question.

It has to be stated that not every possible potential drive form is suited for a scenario. The development of the drive in question has to be in a certain stage and the possibility of an actual implementation of this drive must be a realistic one.

The different criteria do not have the same significance and therefore it is necessary to do a balancing of the criteria. For instance in case of the criteria of the life cycle assessment a certain alternative might represent an aggravation in some aspects which will be accepted due to a significant improvement with respect to CO_2 emissions.

Along with the criteria mentioned above also some other criteria are decisive, not to forget the political concerns. The criteria that are of relevance in particular will be listed in connection with the selected scenarios.

Future energy demand

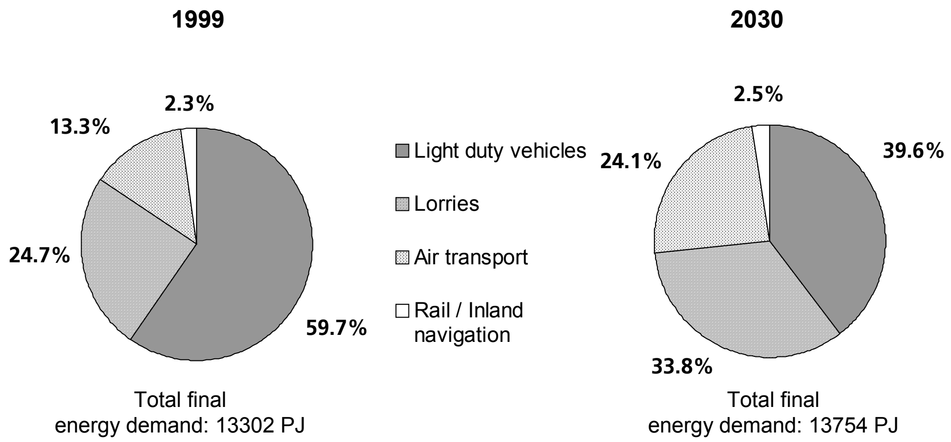
An outstanding criterion for the selection of fuel options for the scenarios is their potential to meet the future energy demand of the transport sector in Europe. Therefore, an outlook on the future energy demand for the long term perspective around 2030 is a fundamental step for establishing future scenarios. The forecast includes the current member states of the European Union as well as the candidate countries. Data of the future fuel consumption have to be split into all transportation modes. To meet all these requirements it is necessary to use different sources and to make some assumptions.

Several sources of data are used: [EU: Transport in Figures (1)] and [World Energy Council: Energy for tomorrows world (2)]. For verification reasons [EU: European Union, Energy Outlook to 2020 (3)] and [Environmentally Sustainable Transport in the CEI Countries in Transition, Final report (4)] are considered.

Western European Countries (EU 15 plus Switzerland and Norway): (1) is used for the base figures and according to (2) the future development is projected. Data are compatible and nearly all the calculation have been comprehended. However, the assumption for the fuel consumption of passenger cars is modified (reduction from 6.5 to 4.0 l/100 km.) This seems to be reasonable considering recent research studies.

The forecast results in a short increase of the energy demand (3.4 %), especially caused by the increases of road goods transport and aviation. So the change of energy consumption by mode will be remarkable.

Figure 28: Final energy consumption in the transportation sector in EU 15 + N + CH

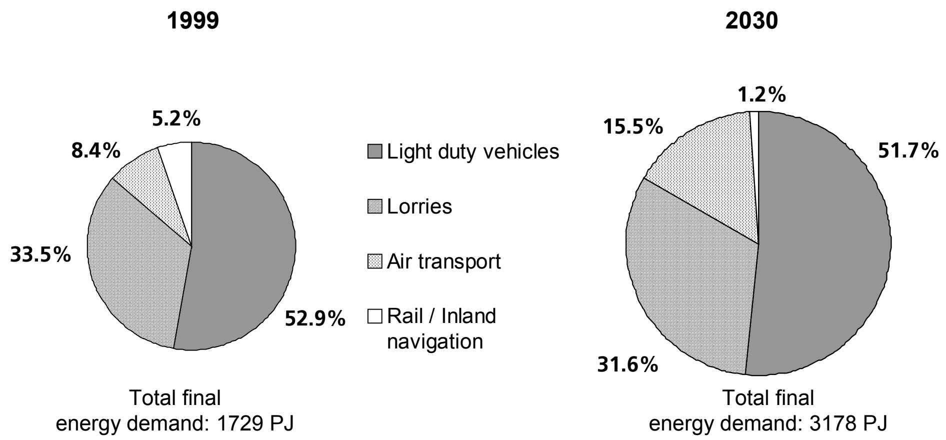


Candidate Countries: In principle the same procedure is taken as for the Western European countries, but some more modifications seem to be necessary. Sources (3) and (4) are considered in this respect.

Basic assumptions regarding light duty vehicle traffic have been approximated to those taken for Western Europe. Future assumptions for the road freight transport differ very much from study to study. Therefore efficiencies and ton-kilometres per capita have been modified by balancing the considered aspects, e.g. the here included countries.

A significant increase of the energy demand of more than 80 % until 2030 is forecasted. It will amount to nearly 3,200 PJ. Changes of the consumption by mode are not as significant as for Western Europe. Figures for passenger car traffic show high increase rates, but they are partly compensated by rapidly growing efficiencies.

Figure 29: Final Energy consumption in the transportation sector in the Candidate Countries



7.2 Selected scenarios

7.2.1 Scenarios by Liquid fuels

7.2.1.1 Biodiesel Scenario

A main reason for establishing the biodiesel scenario is the fact that biodiesel is already in use in several countries with satisfying experiences. Further important reasons that argue for biodiesel are the following:

- Applied technique in Europe.
- Infrastructure is partly available.
- No expensive modification of vehicles: Several diesel engines are suitable for biodiesel and with a comparatively low effort all diesel engines are assumed to be suitable for this fuel in the future.
- Any blends with fossil diesel are possible.
- Environmentally friendly and riskless transport, which is an advantage especially in sensitive areas like waterways.
- Biodiesel is a good compromise between availability and a good eco-balance. In fact the values for nutrification and acidification are rather bad, but this is balanced by good values in CO_2-equivalent data.

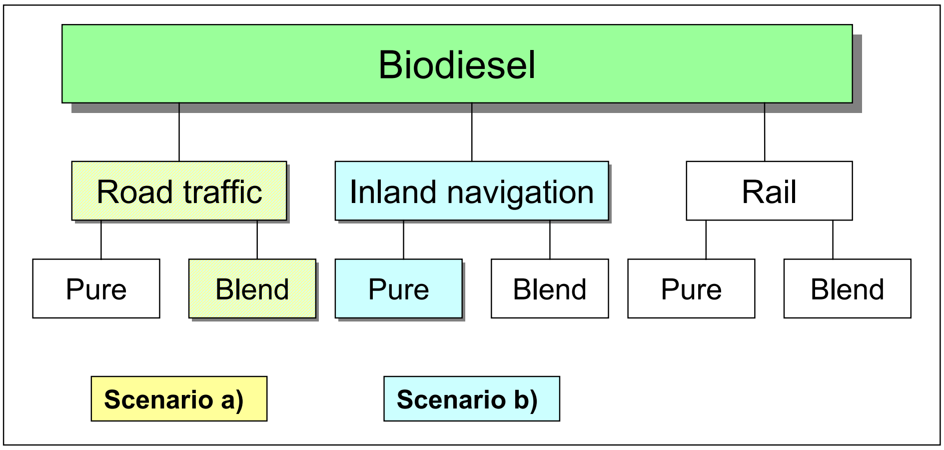
The values for the eco-balancing in comparison to conventional diesel using the baseline energy mix of EU-2020 are listed in Table 13:

Table 13: Values of harmful substances for biodiesel in comparison with diesel

	CO_2-equiv. [kg/veh.-km]		PO_4^{3-}-equiv. [g/veh.-km]		SO_2-equiv. [g/veh.-km]		cum. fossil energy demand [MJ/veh.-km]	
	Diesel	Biodiesel	Diesel	Biodiesel	Diesel	Biodiesel	Diesel	Biodiesel
LDV	0.107	0.065	0.010	0.044	0.117	0.294	1.378	0.478
Lorries	0.956	0.599	0.099	0.412	1.093	2.721	12.673	4.399
Ship	63.813	39.974	288.904	309.802	1593.040	1701.643	845.186	293.409
Rail	6.381	5.352	8.252	10.341	48.172	59.032	84.519	29.341

For the use of Biodiesel two sub scenarios have been established (see Figure 30), scenario a) with biodiesel for road traffic and scenario b) with biodiesel for inland navigation and road traffic.

Figure 30: Illustration of different pathways to introduce biodiesel



The use of biodiesel is not considered for rail transportation. For cross-border transport is used generally electric energy, diesel is mainly used for regional or shunting traffic. This would mean an expensive area-wide supply chain for a small sector, therefore this scenario focuses on road transportation and inland navigation.

a) Biodiesel only for road transportation

Due to the unproblematic application and the compatibility with fossil diesel, biodiesel can easily be used as fuel for passenger cars and trucks, both as a blend or pure. Since several years there are experiences with the use of biodiesel in different countries. There is no impact of biodiesel on the motor-capacity. But there is an increase of the fuel consumption by 10 % when biodiesel is used, the increase is nearly negligible if a blend is used.

Rape seed has in almost every country the biggest biodiesel potential. This potential amounts in the EU-30 in 2030 to 510 PJ/a.

Due to the easy application biodiesel will be used as a diesel blend for light duty vehicles in this scenario. The projected overall energy demand of diesel for road transportation in 2030 amounts to 8489 PJ/a. Biodiesel will cover this demand by 6.0 % of the diesel demand, assumed that the share of diesel is 40 % for light duty vehicle and 100 % for lorries.

As mentioned above there are two ways to use biodiesel, pure or blended with conventional diesel with any proportion. Offering pure means to install a separate supply chain and to convert the filling stations. This is already done in some countries, e.g. in Germany. Also pure biodiesel is subject to market fluctuation. Pure biodiesel could be more expensive under certain circumstances than pure diesel, namely if the price of crude oil decreases and the price of rape seed increases because of a poor harvest.

Biodiesel can be blended with conventional diesel without any problems. By this factor it appears more practical to focus on the blended biodiesel. The possibility of blending with any proportion offers the chance of individual handling in each country.

Since the introduction of biodiesel as pure fuel shows economical disadvantages in this scenario biodiesel will be provided as a blend of fossil diesel.

Considering the single countries it becomes obvious that the coverage will not be equally all over Europe. In fact there can be differentiated between two blocks (see Table 4):

- The EU-15-Countries plus Switzerland and Norway: These countries have a coverage potential, (except Denmark) between 1 % and 6 %.

- The Candidate Countries: They have a coverage potential of 10 % up to 22 % with some single exceptions. The reasons for this considerable difference are both the comparatively low energy demand in transportation in these countries and the large area of available land.

Table 14: Potential of biodiesel in scenario a)

	Potential biodiesel [PJ/a] - rape seed -	**Coverage road transport**
EU-15 countries + CH + N	253	3.7 %
Candidate countries	257	15.5 %
Sum	**510**	**6.0 %**

For this scenario a standardization all over Europe using a given blend of diesel and biodiesel is assumed. The portion of biodiesel is defined to 6.0 %, so in every country the fuel mix can be used by any car and lorry. The standardization requires Europe-wide rules for quotas of minimum admixing. Higher quotas can be achieved by giving financial incentives. Considering the calculated values the minimum is 6.0 % biodiesel in scenario a).

The standardized solution for the whole European Union accounts for an equal distribution of biodiesel all over Europe. Due to the high differences in potential and demand of biodiesel an infrastructure for the distribution is required. To get an idea about the necessary scale of the distribution, some examples are described below.

The countries of eastern Europe will have surpluses of biodiesel with some exceptions. Poland will have a surplus of about 40 PJ biodiesel. Considering the energy density of RME (9.4 KWh/l), almost 1.2 billion litres of biodiesel will have to be exported from Poland to other countries. Other countries with a big surplus are Turkey (almost 2 billion litres) and Romania (more than 700 million litres). A EU-15 country with a big surplus is France (about 230 million litres). On the other hand, the EU-15-Countries plus Swiss and Norway will have an overall deficit of 409 PJ to reach the 6 %-limit. The UK must import more than 1.2 billion litres of biodiesel, Italy just a little less. Altogether the EU-15 countries must import more than 4.5 billion litres of biodiesel.

The overall ecological impact of the biodiesel scenario a) according to the values mentioned above is illustrated in Figure 31 as absolute impact and in Figure 32 in relation to road traffic in total. Reference case is the use of pure diesel.

Figure 31: Potential of quantitative change of harmful substances (6 % biodiesel-blend in comparison to pure diesel for LDV and HDV)[39]

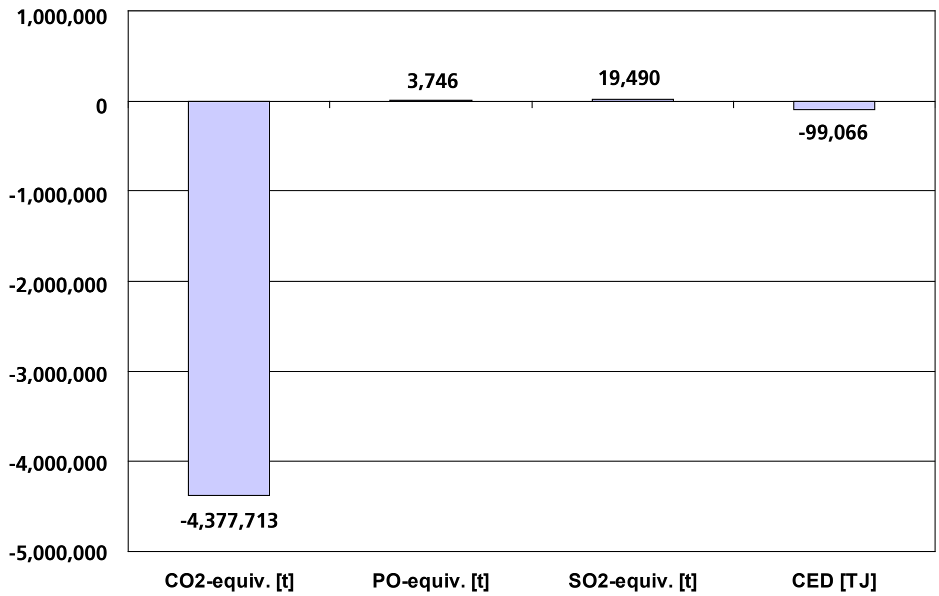
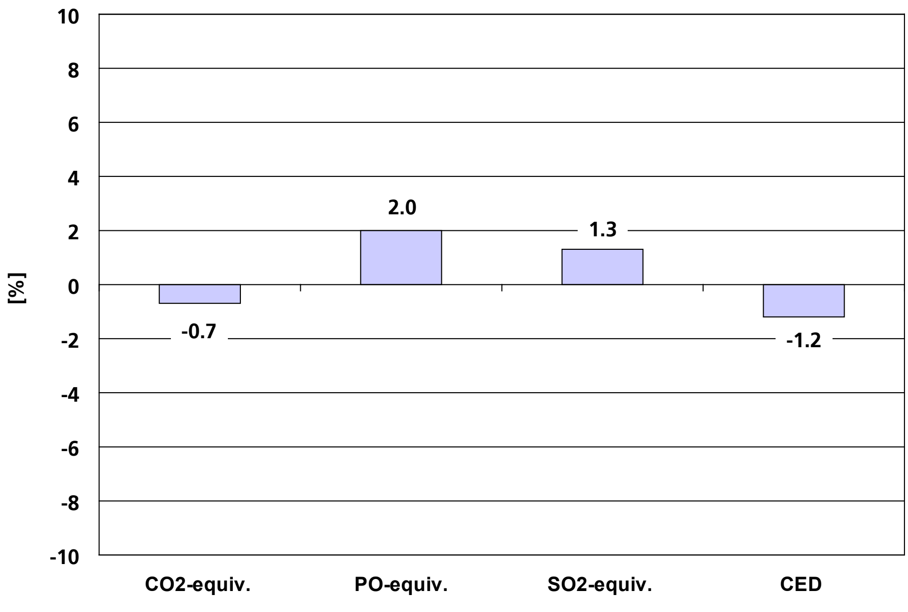


Figure 32: Change of harmful substances related to overall road traffic (6 % biodiesel-blend in comparison to pure diesel for LDV and HDV)



b) Pure biodiesel for inland navigation

Inland navigation shares only a small portion of the transport sector. Therefore this scenario considers the option, to operate the whole European inland navigation with pure biodiesel. Due to the small number of filling stations for ships the supply chain is comparable simple. The use of biodiesel for inland navigation has also the advantage, that this fuel cannot cause such a serious ecological damage like fuel of mineral origin does. Soil and water are able to

[39] CED: Cumulated energy demand (fossil)

regenerate by themselves when it is affected by biodiesel, whereas the affect of fossil fuel makes a special and expensive treatment necessary.

The potential of biodiesel is assumed to satisfy the fuel demand of this sector. The remaining fuel can be used for the road traffic. That would require the installation of another supply chain for an overall rather small amount of fuel. The overall potential of rape seed-based biodiesel in the EU-30 2030 will amount to 510 PJ/a, whereas the diesel demand for inland navigation will be 191 PJ/a. This means a coverage of inland navigation of biodiesel by 267 %.

The remaining available amount of biodiesel (319 PJ/a) is intended to be used as a diesel blend for road transportation. This remaining biodiesel is good for the coverage of 3.8 % of the overall diesel demand, assumed a share of diesel by 40 % of light duty vehicles and 100 % of lorries. Table 15 shows the coverage in the EU-15 countries, Norway and Switzerland, and the larger coverage in the candidate countries.

Table 15: Potential of biodiesel in scenario b)

	Potential biodiesel [PJ/a] - rape seed -	**Coverage ship**	**Coverage road transport with remaining fuel**
EU-15 countries + CH + N	253	147 %	1.2 %
Candidate Countries	257	1353 %	14.3 %
Sum	**510**	**267 %**	**3.8 %**

Besides the advantages described previously there must some disadvantages of biodiesel taken into account. These are mainly:

- Overall potential in Europe comparatively small.
- Distribution of the potential not evenly.
- Possibly technical problems in very cold areas.
- Disadvantages in eco balancing, especially in nutrification.

7.2.1.2 Synthetic-Fuel Scenario

Today the use of synfuel is not very common in Europe und thus there are not that many experiences with these fuels. However there are several reasons that suggest a synfuel scenario:

- The similar characteristics of synfuels and fossil fuels result in a very easy application of synfuels in the current vehicle technology, actually no adjustments are necessary.
- Blending of fossil fuels is not a problem at all.
- The whole distribution and refuelling infrastructure of fossil fuels can be used.

The eco-balancing of synfuels instead of diesel is excellent in the case of residues as primary energy carrier, particularly the global warming potential and the cumulated fossil energy demand decrease. The increase of SO_2-equivalent substances is moderate.

The values for the eco-balancing of synfuels made of fast growing trees and residues in comparison to conventional diesel using the baseline energy mix of EU-2020 are listed in Table 16 and Table 17.

Table 16: Values of harmful substances for synfuel by fast growing trees

	CO_2-equiv. [kg/veh.-km]		PO_4^{3-}-equiv. [g/veh.-km]		SO_2-equiv. [g/veh.-km]		cum. fossil energy demand [MJ/veh.-km]	
	Diesel	Fast grow. trees	Diesel	Fast grow. trees	Diesel	Fast grow. trees	Diesel	Fast grow. trees
Lorries	0.956	0.648	0.099	0.384	1.093	2.529	12.673	3.788

Table 17: Values of harmful substances for synfuel by logging residues

	CO_2-equiv. [kg/veh.-km]		PO_4^{3-}-equiv. [g/veh.-km]		SO_2-equiv. [g/veh.-km]		cum. fossil energy demand [MJ/veh.-km]	
	Diesel	Logging residues	Diesel	Logging residues	Diesel	Logging residues	Diesel	Logging residues
Lorries	0.956	0.142	0.099	0.048	1.093	0.590	12.673	2.490

The transformation of woody biomass by a syn-gas used in the Fischer-Tropsch processing to synthetic diesel or petrol reduces the potential of the renewable fuel, but the advantage of an easy application in the present fuel system is evident and the eco balancing shows good results as well, especially in combination with wood residues.

The technical potential of synthetic fuels is comparatively low in the sense of producing only fuels. If the overall energy output is calculated, i.e. including other products than fuel, efficiency figures will show better results.

Despite of a considerable overall energy quantity the potential of synfuel is limited. Therefore this scenario suggests to restrict the use of synfuel to lorries. The overall potential of synfuel amounts to 1144 PJ/a. Considering that synfuel can easily be blended with diesel, the supply chain already exists and therefore the implementation does not represent any problems.

The overall demand of lorries amounts to 5653 PJ per year. The amount of synfuel is good for a coverage of 20.2 %. The coverage will not be equally all over the European Union. Table 7-6 indicates the coverage of lorries, divided into EU-15 countries, Norway and Switzerland, and the Candidate countries.

Table 18: Potential of synfuel

	Potential synfuel [PJ/a]	**Coverage lorries**
EU-15 countries + CH + N	756	16.3 %
Candidate countries	388	38.7 %
Sum	1144	20.2 %

Overall there is a surplus of synfuel in the candidate countries. The quantity of compensation between the EU-15 and the candidate countries amounts to 5.2 billion litres although there are also EU-15 countries with large surpluses. The largest surplus have Sweden and France, followed by Turkey and Poland. By far the biggest deficit have Germany and the UK with more then 2 billion litres each.

The overall ecological impact of synfuel is considerable. Particularly there is a large decrease of CO_2 emissions and CED, whereas the increase in nutrification and acidification is moderately. The calculated changes are illustrated in Figure 33 as absolute changes and in Figure 34 in relation to road traffic in total.

Figure 33: Potential of quantitative change of harmful substances (20.2 % synfuel in comparison to diesel)

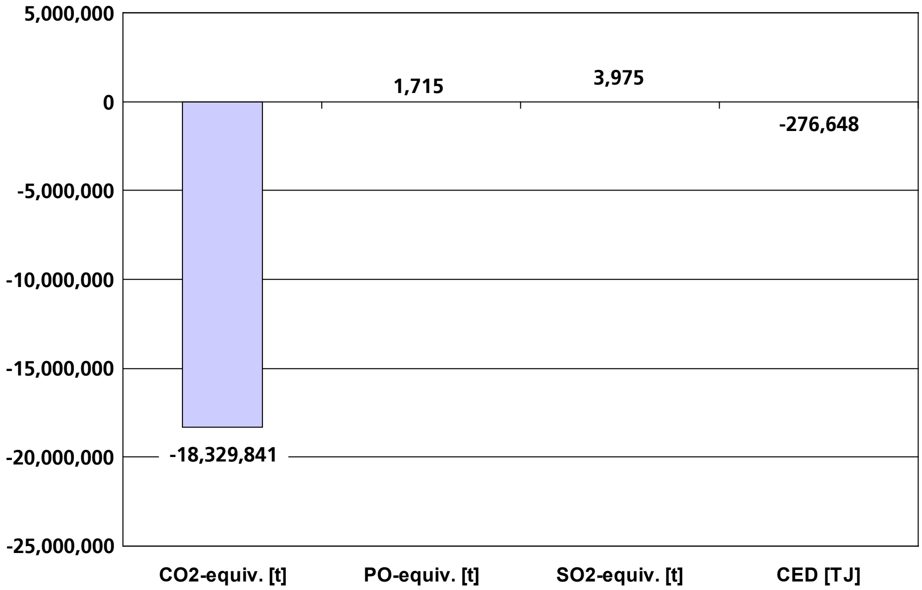
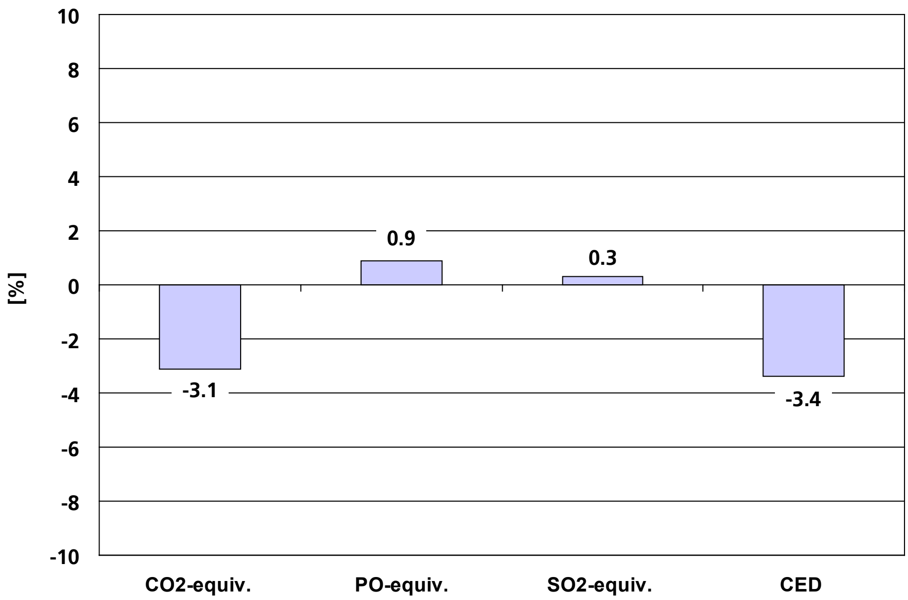


Figure 34: Change of harmful substances related to overall road traffic (20.2 % synfuel in comparison to diesel)



7.2.1.3 Blended fuel Scenario

Blending fuels provides the possibility to combine conventional fossil fuels and renewable fuels without expense in technique and infrastructure of the road transportation sector. To give every region in Europe the best opportunities (in respect to potential, costs or already available facilities), this scenario aims at establishing various blends. For this purpose standardisations of the renewable admixtures or the blends in total are essential. Furthermore a Europe-wide compatibility of vehicle technologies and fuels is required for this scenario.

Ethanol produced of sugar beets shows the highest potential in the most of the EU-30 countries. Due to the given climate conditions the reliability of continuously harvesting sugar beets in Scandinavia is not given. The plantation of fast growing trees seems to be reasonable in these countries. Moreover, all countries have the potential to use logging residues for the production of methanol. That's why the scenario "Blended fuel" has two strands: First, blending of petrol with ethanol and second, blending fossil diesel with methanol.

Overall there are several reasons to establish a blended fuel scenario:

- Infrastructure for distribution is available.
- No expensive modification of vehicles because engines are suitable for blended fuels.
- Immediate changeover is possible.
- Any blends with fossil diesel are possible.

Ethanol of sugar beets is an excellent compromise of availability and eco-balance, apart from the quite high demand of fossil energy for the transformation process. The values for the eco-balancing of ethanol are listed in comparison to conventional petrol in Table 19.

Methanol of logging residues has a very good eco-balance in all relevant criteria, such as CO_2, nutrification and acidification. Indeed the availability is rather poor. The values for the eco-balancing of methanol from logging residues are shown in comparison to conventional diesel in Table 20.

Table 19: Values of harmful substances for ethanol by sugar beet

	CO_2-equiv. [kg/veh.-km]		PO_4^{3-}-equiv. [g/veh.-km]		SO_2-equiv. [g/veh.-km]		cum. fossil energy demand [MJ/veh.-km]	
	Petrol	Ethanol	Petrol	Ethanol	Petrol	Ethanol	Petrol	Ethanol
LDV	0.107	0.062	0.010	0.038	0.117	0.431	1.378	0.697

Table 20: Values of harmful substances for methanol from logging residues

	CO_2-equiv. [kg/veh.-km]		PO_4^{3-}-equiv. [g/veh.-km]		SO_2-equiv. [g/veh.-km]		cum. fossil energy demand [MJ/veh.-km]	
	Diesel	Methanol	Diesel	Methanol	Diesel	Methanol	Diesel	Methanol
LDV	0.107	0.016	0.010	0.006	0.117	0.050	1.378	0.275

Blend petrol-ethanol

The crop growing of sugar beet in order to produce ethanol offers a big potential to use renewable energy in the near future. From that point of view this scenario represents a main pillar of the medium-term energy supply in transportation.

An ordinary internal combustion engine can be operated with an ethanol share by 25 % without modifying the engine. Below this maximum any ethanol share is applicable. If this scenario is considered as a changeover to a long-term energy strategy, the limit of 25 % share should not be exceeded to supply the complete car fleet at any time, even though there is some ethanol left. Nevertheless the fuel has to be offered to the market from the very first beginning with the specific share of 25 % to ensure an optimised operation of the LDV running with this blend.

The overall potential of ethanol in the EU-30 2030 amounts to 1838 PJ/a based on the assumption that in all EU-30 countries, except Scandinavia, the maximum potential of sugar beet plantation is used. Assumed a share of petrol cars of 60 % the demand of petrol in 2030 is 4254 PJ/a. This means a coverage of 43.2 %.

Due to the limitation of 25 % ethanol almost every country has a surplus and is able to cover its own needs. There is a deficit of ethanol in Scandinavia, the Low Countries, Germany and the UK, which can be balanced by imports from some of the candidate countries.

The overall ecological impact of the ethanol-blend strand according to the values mentioned above is illustrated in Figure 35 as absolute changes and in Figure 36 in relation to road traffic in total. They show the overall ecological impact of the use of the described blend.

Figure 35: Potentials of quantitative change of harmful substances (ethanol-blend in comparison to pure petrol)

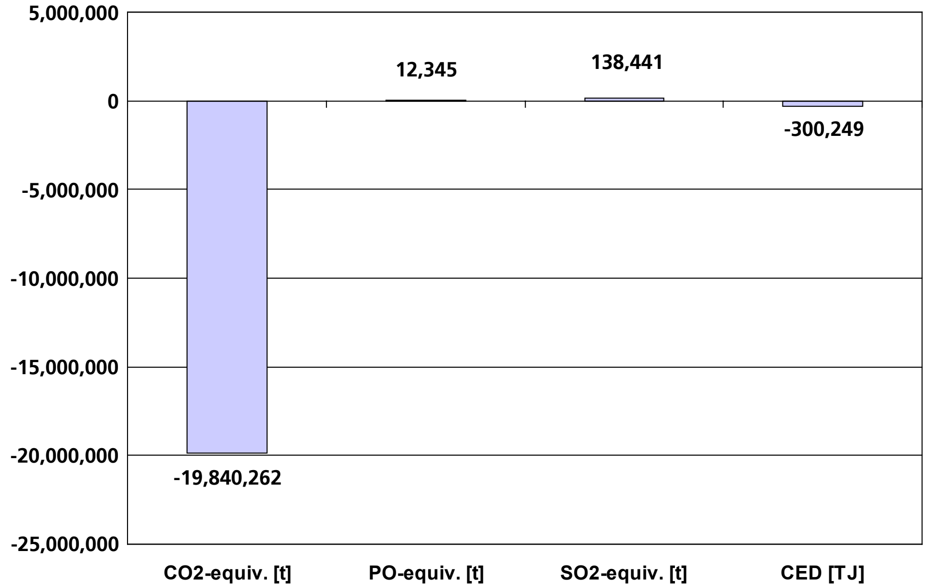
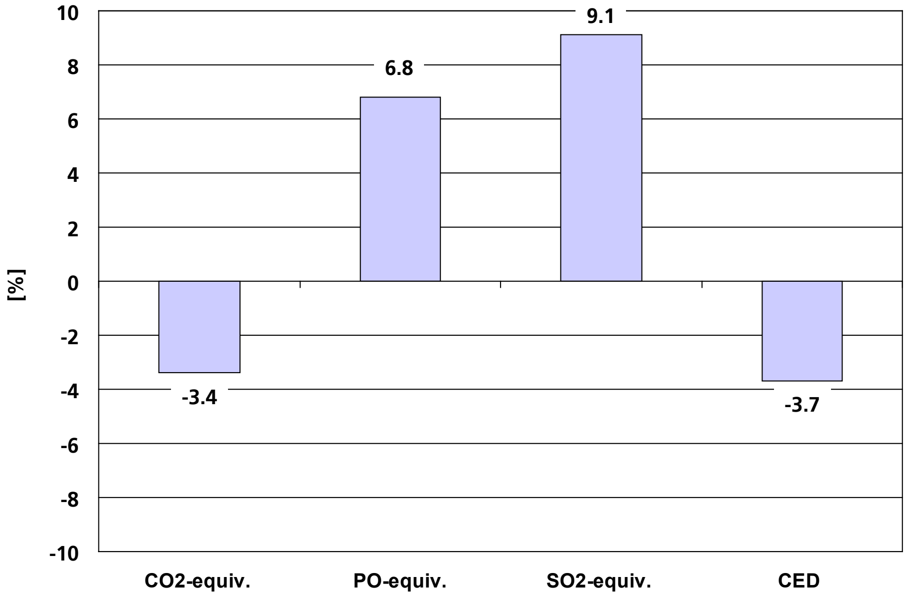


Figure 36: Change of harmful substances related to overall road traffic (ethanol blend in comparison to pure petrol)



Blend diesel-methanol

This strand of the scenario serves as a supplement of the ethanol-strand which is the mainstream in the scenario. The calculated potential is mainly based on the methanol extraction of logging residues. As already mentioned Scandinavia is excluded from cultivating sugar beet. Instead in Scandinavia fast growing trees are considered to provide biomass for the methanol production.

In 2030 the potential of methanol based on logging residues and fast growing trees in Scandinavia is 332 PJ/a. This amount is good for a coverage of 3.9 % of the diesel demand, assumed that the share of diesel is 40 % on LDV and 100 % on HDV.

A compromise of available potential and car-sided technical concerns is a methanol share of 3 %. Due to this limitation most of the countries have a surplus. Therefore the effort for the distribution is moderate. The biggest deficit have the UK (almost 1.7 billion litres) and Germany (more than 770 million litres).

Besides the easy handling and a large potential of CO_2-reduction there are also some disadvantages of using blended fuels, for example the non-area-wide production infrastructure, the uneven distribution of the potential in Europe and the large increase of nutrification and acidification.

7.2.2 Hydrogen Scenario

The usage of hydrogen as an energy carrier in the transport sector is currently still in the stage of development. However it can be assumed that hydrogen will govern the future market. Some of the advantages of hydrogen as energy carrier are:

- Sufficient technical potential of renewable energy to produce Hydrogen (at least for providing energy for all passenger cars in the EU).
- Positive eco-balance in combination with fuel cell, at least for gaseous hydrogen.

- Positive impacts on the research sector and on investments can be assumed.

The values for the eco-balancing of gaseous hydrogen in combination with fuel cell made of renewable power generation in comparison to conventional petrol using the energy-blend of EU-2020 are listed in Table 21.

Table 21: Values of harmful substances for fuel cell cars by gaseous hydrogen

	CO_2-equiv. [kg/veh.-km]		PO_4^{3-}-equiv. [g/veh.-km]		SO_2-equiv. [g/veh.-km]		cum. fossil energy demand [MJ/veh.-km]	
	Petrol	Fuel cell GH_2	Petrol	Fuel cell GH_2	Petrol	Fuel cell GH_2	Petrol	Fuel cell GH_2
LDV	0.107	0.009	0.010	0.002	0.117	0.048	1.378	0.149

The usage of hydrogen requires a completely new design both of vehicles, at least of the powertrains, as well as of the infrastructure. Besides the renewable energy technology for the production of hydrogen is not developed sufficiently yet.

The theoretical technical potential of renewable hydrogen is extremely high and could cover the entire transport sector. But, to use this theoretical technical potential would need an enormous effort both in implementing all the necessary facilities for the power generation, for the extension of the electricity grid and for the hydrogen production and in the building-up of the fuel cell vehicle fleet. It seems not realistic that this could be done in the next three decades. That's why this scenario has to consider some limitations taking into account both the availability of hydrogen, representing the supply, and the size of the hydrogen driven fuel cell vehicle fleet, representing the demand. Both strands can define a critical path.

The critical path in the scenario "Hydrogen" is the expected hydrogen driven fuel cell vehicle fleet in 2030. Although the technology of trucks, trains, ships and airplanes is not expected to be in position to use hydrogen until 2030, current R&D results indicate the opportunity to drive a significant share of light duty vehicles by fuel cells and hydrogen in 2030.

In order to be able to estimate this development the German Transport Energy Strategy (TES)[40] had been set up. The estimation of this task force is considered to be very sophisticated. It is pointing out that in the year 2020 in Germany hydrogen will cover 15 % of the energy which has to be provided in the road transport sector.

The present hydrogen scenario of this study is based on the assumption that these 15 % are valid for the entire EU-30 in 2030.

In the year 2030 the energy demand for road transport will amount in the EU-30 to 12743 PJ/a. 15 % of this energy demand represent 1911 PJ/a. Based on the assumption that the efficiency will increase from 40 % to 70 % due to the implementation of fuel cells, the energy demand will go down to 1092 PJ/a.

Referring to all this considerations **16.5 %** of all LDVs in 2030 will be hydrogen driven fuel cell vehicles. Table 22 shows the results for the EU-15 with Norway and Switzerland as well as for the candidate countries.

[40] TES is an initiative launched by the vehicle manufacturers BMW, DaimlerChrysler, General Motors Europe (Opel), MAN and Volkswagen and the energy suppliers ARAL, BP, RWE, Shell and Total FinaElf, supported by the Federal Government, with the Federal Ministry of Transport, Building and Housing acting as central coordinator.
Transport Energy Strategy (TES), 2001.

Table 22: Share of H_2-vehicles of all LDV in 2030

	Overall road transport [PJ/a]	Assumption 15 % hydrogen [PJ/a]	Increase of efficiency from 40 to 70 % by fuel cell [PJ/a]	Share H_2-vehicles of LDV
EU-15 countries + CH + N	10,095	1,514	865	17.0%
Candidate countries	2,647	397	227	14.8%
Sum	**12,743**	**1,911**	**1,092**	**16.5 %**

The required amount of energy is little compared to the technical potential of renewable energy production. Only 5.2 % of the overall technical potential is needed for transportation purposes. Table 23 shows the contribution of the different energy sources to that amount, assuming that each source contributes to the energy production.

Table 23: Needed shares of technical potential of the different energy sources

	Hydro-power	Wind	Photovoltaic	Solar thermal
Share of overall technical potential	5.2 %			
Contribution of the different sources [PJ/a]	113	523	81	375

The overall ecological impact of hydrogen is enormous. There is a decrease of all relevant substances, particularly in the release of CO_2-equivalents. The calculated changes are illustrated in Figure 37 as absolute changes and in Figure 38 in relation to road traffic in total.

Figure 37: Potential of quantitative change of harmful substances (16.5 % hydrogen in comparison to only petrol)

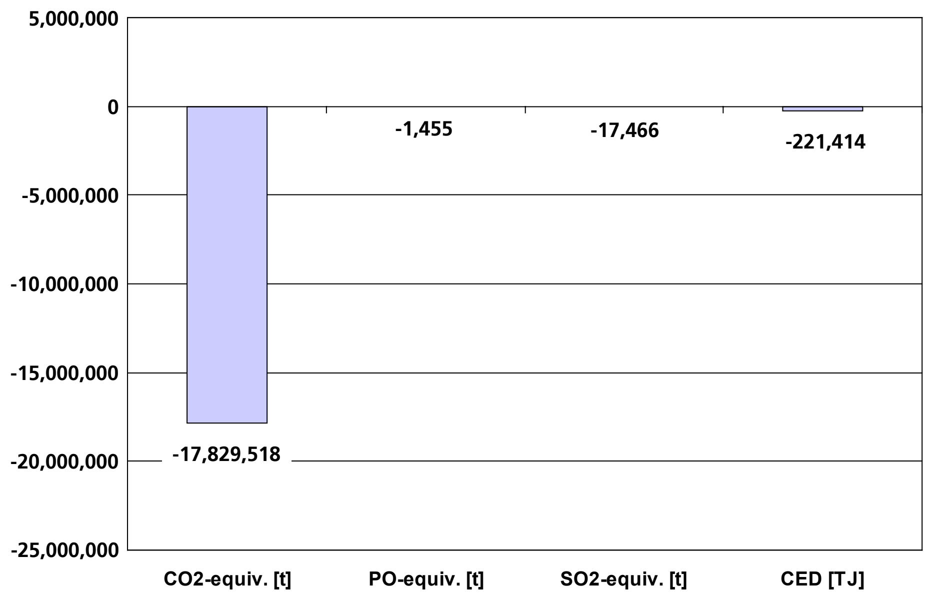
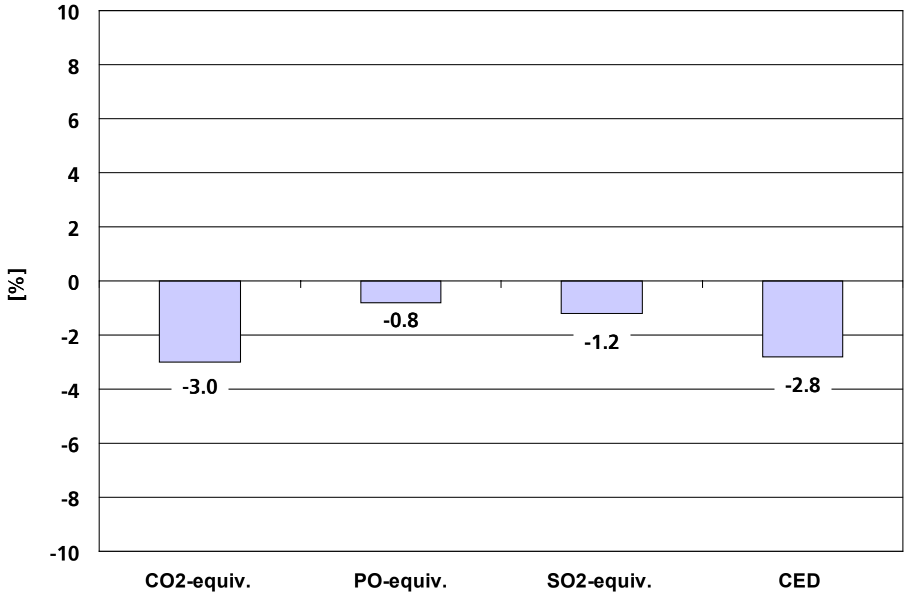


Figure 38: Change of harmful substances related to overall road traffic (16.5 % hydrogen in comparison to only petrol)



Besides the evident advantages of using hydrogen there are several points that have to be taken into account:

- Capital investments are sometimes assumed to be an insuperable barrier.
- The fuel price could be much higher than today.
- Significant incentives, subsidies and other efforts of the public authorities seem to be necessary to initiate the build-up of the infrastructure and the fuel cell-LDV mass production.
- Only little experience in practical daily application.

8 Implementation strategies

8.1 Overview about measures and instruments

In the previous chapter 7 several scenarios where described about the use of renewable fuel for the transportation sector. This chapter 8 describes the process of the implementation and the aspects that are accompanying this process.

The implementation and the establishment of the fuels considered in the scenarios requires the cooperation of the European Union with its member countries and all those parties who are involved in this process. These are mainly:

- Automobile industry
- Agriculture (in the case of biofuels)
- Renewable power generation (in the case of hydrogen)
- Fuel producing industry
- Distribution and logistic industry

The European Union takes care on the time flow and the overall coordination of the implementation and gives admixture quotes as well as environmental and quality standards.

For the implementation it is necessary to define a reference date when the regulations come into effect. Setting the regulation on a European level requires a lead-time of several years. Also the built-up of production capacities, the changeover of crop growing and fuel distribution and the adoption of vehicle technique takes some time. Considering this the reference date is set to 01.01.2008. At that time the introduction of the different scenarios starts, depending on the different scenario path, specific regulations are necessary to ensure the process of the implementation. Depending on the scenarios this takes up to 2023.

The descriptions in this chapter are meant to be “minimum path” which are set by the EU. There are several ways possible to achieve these quotes. One is to make regulations, which rule the needed quote. The free market can accelerate the conversion to renewable fuels. Giving some incentives can support this. One example for a regulation is the Green Paper of the European Commission[41], which sets the objective of blending conventional fuel with biofuels by 2.0 % until 2006 resp. 5.75 % until 2010 and suggests a substitution of 20 % of conventional fuels by alternative fuels, including natural gas, by the year 2020. Having regard to the Green Paper the Directive on the promotion of the use of biofuels or other renewable fuels for transport[42] specifies indicative targets amounting to a minimum proportion of biofuels of 2 % by the end of 2005 and 5.75 % by 2010. Admittedly it must be taken into account that the required biofuel to fulfil these needs can be produced also outside of Europe. Due to the general presumption of this study there are only biofuels considered that can be produced on the area of the European Union. Therefore this study suggests different admixing quotas depending on the assumptions in the illustrated scenarios.

Another way to reach quotas is a self-commitment of all involved industries as it happened at the reduction of CO_2 emissions of passenger cars, which was performed by the ACEA in 1998. The advantage of this is to have a changeover not by force, which can help to find an accord faster than a EU regulation by law. Admittedly there must be a strict adherence by the EU with adapted measures when the targets are missed. The built-up of production capacities can be supported by subsidies and simplified and / or quickened permit procedures.

[41] European Commission (Ed.): Towards a European strategy for the security of energy supply, 2002.
[42] Directive 2003/30/EC of the European Parliament and of the Council, 2003

An important control instrument is the taxation respectively the tax exemption of fuel. Both pure biofuel and blended fuel must be cheaper than conventional fuel. Since the expected costs of the renewable fuels are higher, there must be a reduction or a total exemption of the taxes for the renewable fuel. As the petroleum tax today represents an inherent part of the fiscal system there must be a balance between tax exemption of renewable fuels and tax load of conventional fuel. Therefore the tax-exempted part must be transferred to the conventional fuel. At least at the beginning, the production of biofuel must directly or indirectly be subsidised in order to obtain competitive prices.

8.2 Implementation of the scenarios

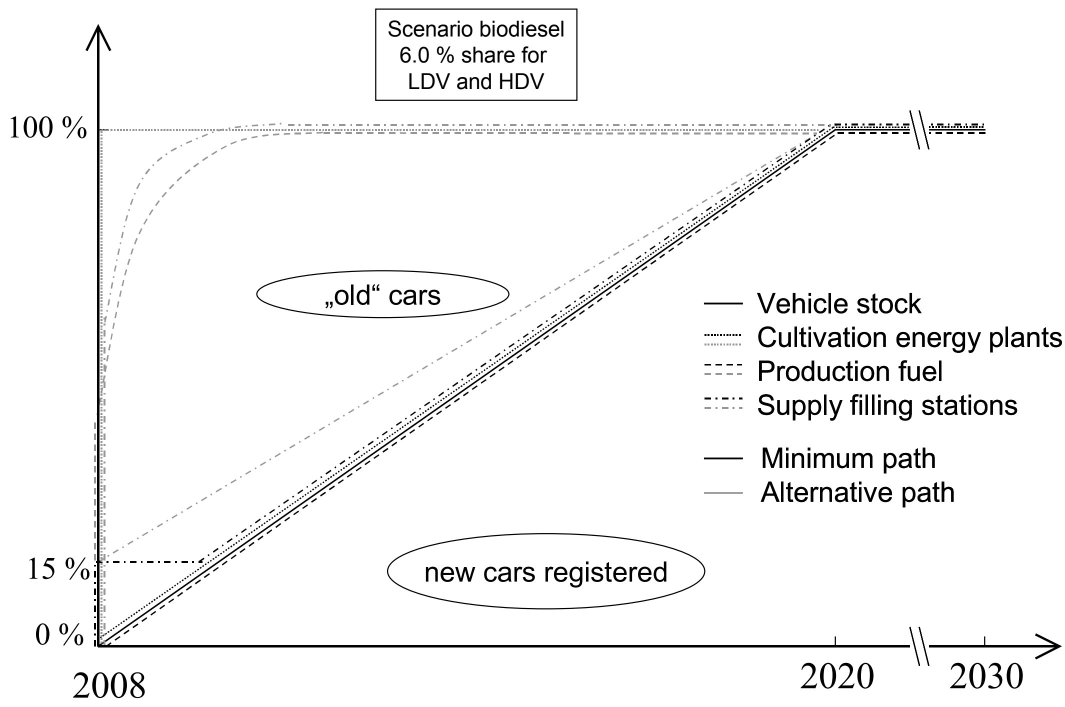
8.2.1 Liquid fuels

Biodiesel for road transportation

According to the biodiesel scenario (see chapter 7.2.1.1) the potential in the EU-30 in 2030 amounts to 508 PJ/a. This potential is good to cover 6.0 % of the diesel demand of road transportation.

Figure 39 indicates the implementation of the scenario "Biodiesel for road transportation" from 2008 on. Constant is the annual rate of new vehicles registered, which fulfil specific requirements related to the usage of biodiesel. The assumed annual rate of replacement leads to a total shift of the vehicles within 12 years. Parallel must run the development of the cultivation of energy plants and the fuel production, whereas the built-up of a supply of filling stations needs a lead-time. The bold drawn lines represent the minimum path, which must be ruled by regulations. The slight drawn lines show alternatives, which can be achieved by giving incentives or which can be regulated by the free market.

Figure 39: Implementation of biodiesel



The vehicle-side aspects for the biodiesel scenario are of secondary relevance. The extra costs for biodiesel concern mainly filters and are negligible. Already today several automakers allow the use of biodiesel. The task is to ensure that all diesel vehicles are equipped with specific filters and tubes, which are capable for biodiesel. Besides this an optimisation of the motor technology regarding the 6 % admixture of biodiesel for the new cars from the year 2008 on is possible. The optimisation must be done with respect to environmental standards, which are given by the EU. From 2008 on all new-registered cars must fulfil the technical conditions for the implemented fuel. If there is more biodiesel produced than required for the new cars registered from 2008 on, it can be sold as pure biodiesel for the adapted cars. After a presumed vehicle life cycle of 12 years the implementation is completed.

For a 6 % quote of biodiesel it is necessary to plant rape seed on 10 % of the agricultural crop land. Since there are experiences in the cultivation of rape seed, the conversion to rape seed can occur shortly. The cultivation of rape seed for the defined amount must be given by regulation and promoted by option money. This can be done in the course of the basic salary for farmers, which is discussed since a while, but take into account that the farmers got already an annual closure bonus of about 60 € per ton of cereal that could be cultivated, which is about 300 – 400 € per hectare[43]. The slight drawn line of cultivation energy plants in Figure 39 shows that it is possible to reap the full potential already in 2008 because of the availability of arable land, if enough seeds exist. Nevertheless the curve of energy plants cultivation should constantly progress below the fuel production curve to avoid an unusable surplus of energy plants.

Due to the scenario conditions from 2008 on the fuel production must be established successive, following a minimum implementation-path according to the development of the vehicle stock. The maximum amount of biodiesel, which has to be reached in 2030, accounts for around 15 billion litres. The production capacity of biodiesel in Europe today accounts to almost 2.5 billion litres. This means, the overall capacity must be increased by the factor 6. Considering the main advantages of biodiesel, which are the already available technology and the possibility to reach the maximum amount much earlier than 2030 allows thinking about pathways with a higher usage of biodiesel than the minimum path. So biodiesel is already in use today both pure, e.g. in Austria and Germany, and as a blend, e.g. in France and Italy. To gain the benefits of this “early usage” the measures to promote this should remain active until the end of 2007. To ensure the minimum path from 2008 on it is necessary to ensure that biodiesel has a lower price per litre than conventional diesel. The price of the biodiesel production accounts for 64 Cent per litre, whereas the production of diesel is about 30 Cent per litre in 2001[44]. Taking this into account there have to be lower taxes for biodiesel. Additionally subsidies for the fuel producing industry are necessary. This regulated market allows an unsolicited higher usage of biodiesel than the minimum path to that amount as advantages for the farmers, the fuel producing industry and the car user occur. The built-up of production capacities must correspond with the cultivation of energy plants for a good utilization of the manufacturing-plants. For an optimised operating of the vehicles and a good environmental impact it is necessary to establish a quality management, which guarantees consistent quality standards of the biodiesel blend.

When a new fuel is implemented it is necessary to have an area-wide distribution. To ensure this minimum distribution, 15 % of all filling stations must offer the biodiesel blend in 2008. This share must be ruled by regulations, which urge each fuel producer to offer the biodiesel blend at 15 % of its filling stations. The bold drawn line in Figure 39 shows the minimum path of the conversion. This time scale of the implementation means a peak of investment in the beginning, followed by a period of no new investments before a longer period of a constant annual investment rate. This is not very realistic. A more equal distribution of investment is

[43] European Commission (Ed.): Council Regulation (EC) No 1251/1999.
[44] State Institute for Environmental Protection Baden-Württemberg (LfU), 2002.

possible by starting already in 2008 with a constant annual investment rate leading to the full equipment in 2020 (see lower slight line in Figure 39).

Besides this, there is a potential for an earlier turnover in the full supply due to the market for biodiesel (see upper slight line in Figure 39). The infrastructure for the supply can easily be adapted. During the transition time it is necessary to offer both biodiesel blend and pure diesel at single filling stations for old vehicles without permission for biodiesel. Because of the uneven availability of biodiesel and the different demand in Europe there is a considerable effort necessary for the distribution. Altogether more than 5 billion litres must be transported from the countries with a surplus into countries with a deficit, mainly from eastern to western Europe.

Actions to be taken by the EU:

- Standards for biodiesel-optimised vehicles
- Regulations for the cultivation of rape seed on 10 % of the arable land, which should be accompanied by financial incentives like basic salary and / or option money
- Tax reduction and / or subsidies for the production of biodiesel to achieve lower fuel prices than conventional fuel
- Quality standards for the biodiesel
- Prescription to the fuel companies for providing a biodiesel distribution at minimum 15 % at its filling stations from 2008 on

Biodiesel for inland navigation

The scenario shows that the demand of inland navigation can completely be covered by pure biodiesel. Nevertheless there is some fuel remaining, which covers 3.7 % of demand of road transportation.

Considering the technical aspects, it is possible to operate the inland navigation with biodiesel today. Due to the robustness of the ship engines there is no need for a major adaption. Little modifications at tubes can be performed in the course of regular services.

The time flow of the implementation depends on the availability of the fuel. The amount of biodiesel that is produced today for the road transportation should not be transferred to the shipping sector when the implementation of biodiesel for inland navigation has begun, but furthermore used for the cars. The realisation requires the cultivation of rape seed like described in the road transportation scenario. Again, the EU must promote this by making regulations, combined with the payment of a basic salary and / or option money.

The production capacities of biodiesel must be built within 5 years from 2008 on by regulation. The needed amount of biodiesel to cover the inland navigation is about 5.6 billion litres. Since the fuel for inland navigation is tax exempted today, the biodiesel must be tax exempted as well. Nevertheless the prices will be considerably higher than today. Therefore the production must be subsidised in order to get fuel prices comparably to those of conventional fuel. Another option is a financial support for the carrier of ships by the EU.

The distribution of the biodiesel does not represent a major problem. Ships can be operated with biodiesel blend with any share. Therefore the fuel consists of diesel blended with the available amount of biodiesel at each time. After a period of 5 years, from 2013 on, this amount is good for the complete biodiesel demand.

The remaining potential can be used for the road transportation sector. The implementation for this case is described previously. The amount of biodiesel is accordingly lower, it accounts for 3.7 % of the diesel.

Actions to be taken by the EU:

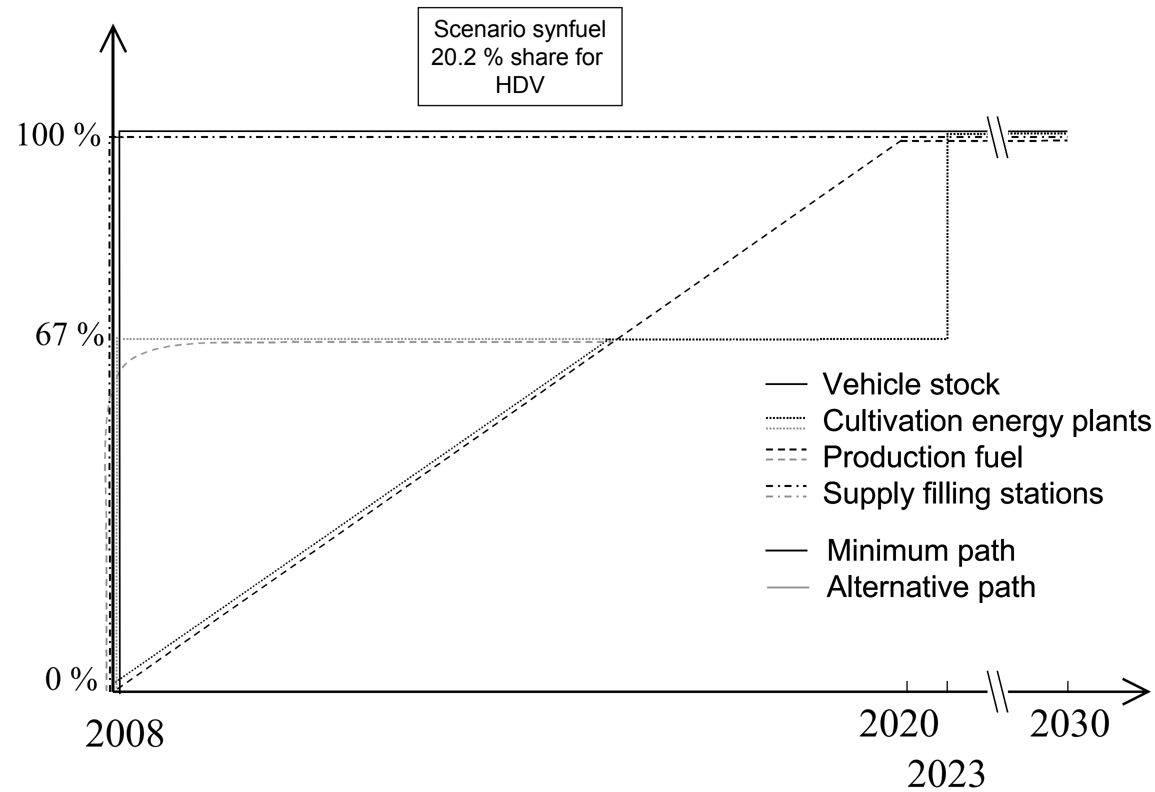
- Regulations for the cultivation of rape seed on 10 % of the arable land, which should be accompanied by financial incentives like basic salary and / or option money
- Tax exemption for biodiesel to achieve lower fuel prices than conventional fuel
- Subsidies for fuel producing industry and / or carriers of ships
- Regulation, that from 2013 on only biodiesel must be used for the inland navigation

Synfuel

The scenario suggests the implementation of synfuel based on the Fischer-Tropsch synthesis as an admixture to diesel for HDV. The overall potential of synfuel amounts to 1,144 PJ/a. The scenario suggests a coverage of 20.2 % of the demand of HDV (see chapter 7.2.1.2).

Since synfuel has the same characteristics as diesel and therefore a conversion of the vehicles is not necessary, the vehicle stock as well as the supply of filling stations is not important for this consideration. Figure 40 shows, that the limiting path is in a first period the built up of production capacity to process the residues, in a second period it is the cultivation of energy plants.

Figure 40: Implementation of synfuel



The scenario suggests the production of synfuel by logging residues, residues from industry and fast growing trees. The residues are available shortly whereas the fast growing trees (i.e. poplars) require a lead-time of 10 to 15 years before the first harvest. Therefore the implementation of this fuel must occur in two steps. As the residues are available immediately, the potential of the fast growing trees, which amounts to one third, can only be used at the very end of the process. The utilisation and recycling of the residues must be supported by subsidies or ruled by regulations. The cultivation of fast growing trees must be given by regulation and promoted by option money. This can be done in the course of the basic salary for farmers.

The production capacity of synfuel by Fischer-Tropsch processing must be established from 2008 on. As there exists no synfuel production in a big scale, it is necessary to built up the complete production capacity. Therefore it is not realistic to follow the leaps of the availability of the basic material. A linear built-up of the synfuel production capacity is suggested, although this means an overcapacity during the period when the potential of residues is taped and the fast growing trees are not available yet. In order to encourage the production, there must be tax exemptions and / or subsidies for the synfuel in order to get lower prices than that for conventional diesel. The needed energy amount is 1,144 PJ/a from 2030 on. Including the fast growing trees the overall potential requires a production capacity of synfuel of more than 32 billion litres per year in 2023 and about 21 billion litres in 2016. The free market makes a faster built-up of the production capacity possible and can be supported by subsidies. But this means, that the overcapacities exist for an even longer period.

Because of the limited quantity of available synfuel the scenario suggests the use of synfuel for lorries. Because of the same characteristic of synfuel and diesel, a conversion of the filling stations and the simultaneous provision of conventional diesel are not necessary. The share of synfuel must be increased according to the availability.

Actions to be taken by the EU:

- Regulations for the collecting and usage of logging residues and residues from industry from 2008 on, which should be accompanied by financial incentives like basic salary and / or option money (logging residues) or subsidies (residues from industry)
- Regulations for the cultivation of fast growing trees on 10 % of the arable land, which should be accompanied by financial incentives like basic salary and / or option money
- Promotion of the production of synfuel by tax exemptions and subsidies

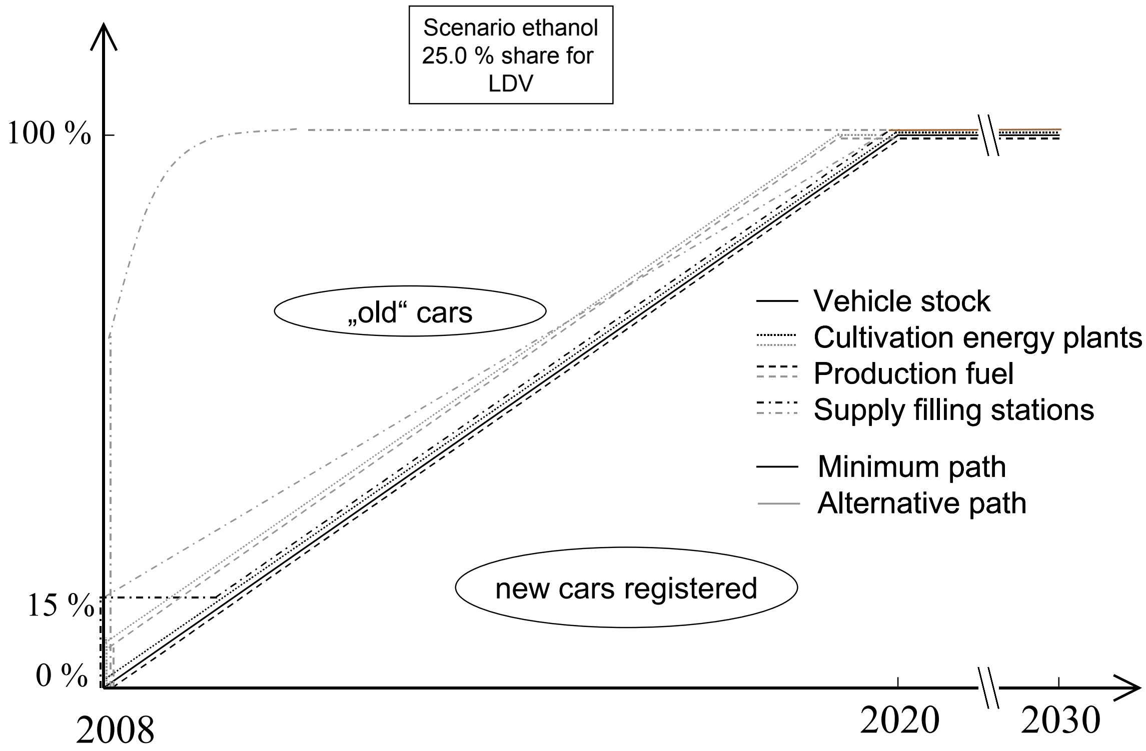
Blended fuels

Due to the different possibilities to produce blended fuels this scenario is considering two types of blended fuels: An ethanol-petrol blend and a methanol-diesel blend. The overall potential of ethanol in the EU-30 amounts to 1,838 PJ/a, the potential of methanol is 332 PJ/a. The scenario suggests an ethanol share of 25 % of the ethanol-petrol blend and a methanol share of 3 % of the methanol-diesel blend.

Ethanol-petrol blend

Figure 41 sows the time flow of the implementation of the ethanol-petrol blend. The annual rate of registered new cars is constant. Parallel must run the lines of the cultivation of energy plants and the fuel production, whereas the built-up of a supply of filling stations needs a lead-time. The bold drawn lines represent the minimum path, which must be ruled by regulations. The slight drawn lines show alternatives, which can be achieved by giving incentives or can be regulated by the free market.

Figure 41: Implementation of ethanol-petrol blend



From a certain share of ethanol in the ethanol-petrol blend it is necessary to adapt the vehicle to the fuel. Therefore from 2008 on every car must fulfil the given guidelines with regard to defined standards of environmental impact and best efficiency. After a presumed vehicle life cycle of 12 years the implementation is completed. This describes the minimum path (see bold drawn line in Figure 41). Blends with an ethanol share below 5 % can be used in cars that are not adapted, which is suggested from 2008 on (see lines “cultivation energy plants, alternative path” and “production fuel, alternative path” in Figure 41). The prices of ethanol-adapted vehicles are not an obstacle for the implementation, because they are comparable to those of vehicles for conventional fuel when they are produced in a big scale.

Ethanol is based on the cultivation of sugar beet on 10 % of the agricultural crop land. Due to the availability of arable land already today, the changeover can occur shortly, presumed that enough seeds exist. Like the rape seed there must be given quotas for the crop growing of sugar beet from 2008 on, which can be achieved by integrating this into a basic salary for farmers or giving option money. The slight drawn line in Figure 41 shows, that it is possible to reap the full potential already in 2008. But the use of the ethanol is hardly possible for the vehicles being on the market before 2008. To avoid unusable energy plants, the line of cultivation must progress below the line of the production capacity.

To reach the final target of a 25 % share of ethanol in the ethanol-petrol blend in 2030, the overall amount of ethanol to be produced is almost 50 billion litres per year. Today the ethanol production in Europe accounts for 400 million litres ethanol per year, which is less than 1 % of the needed capacity. The production capacity for the ethanol must be established from 2008 on, again ruled by regulations and incentives. The minimum implementation path of the production capacity follows the stock of adapted vehicles from 2008 on. To compensate possible higher prices for the production, the share of methanol must be tax reduced and, if necessary, subsidised by the EU. As described previously, there is the possibility to operate vehicles produced before 2008 with an ethanol share of up to 5 %. This share of ethanol can be added to the conventional petrol, which accordingly increases the needed production capacity of ethanol. Following this path, an annual production capacity of more than 4 billion litres has to be established. Taking into account that a big manufacturing plant has an annual production capacity of about 200 million litres per year, this means, that every year 20 – 25 production plants have to be built up.

During the transition time it is necessary to offer both ethanol-blend and conventional petrol, which makes the distribution of this option more expensive. From 2008 on there is an area wide distribution necessary. Thus, the fuel companies must be committed by regulations to offer the ethanol-petrol blend at minimum 15 % of its filling stations. From 2020 there is only ethanol-blend available. Due to the uneven occurrence of the basic materials and the different demand in Europe, almost 6 billion litres of ethanol must be transferred from countries with a surplus to those with a deficit.

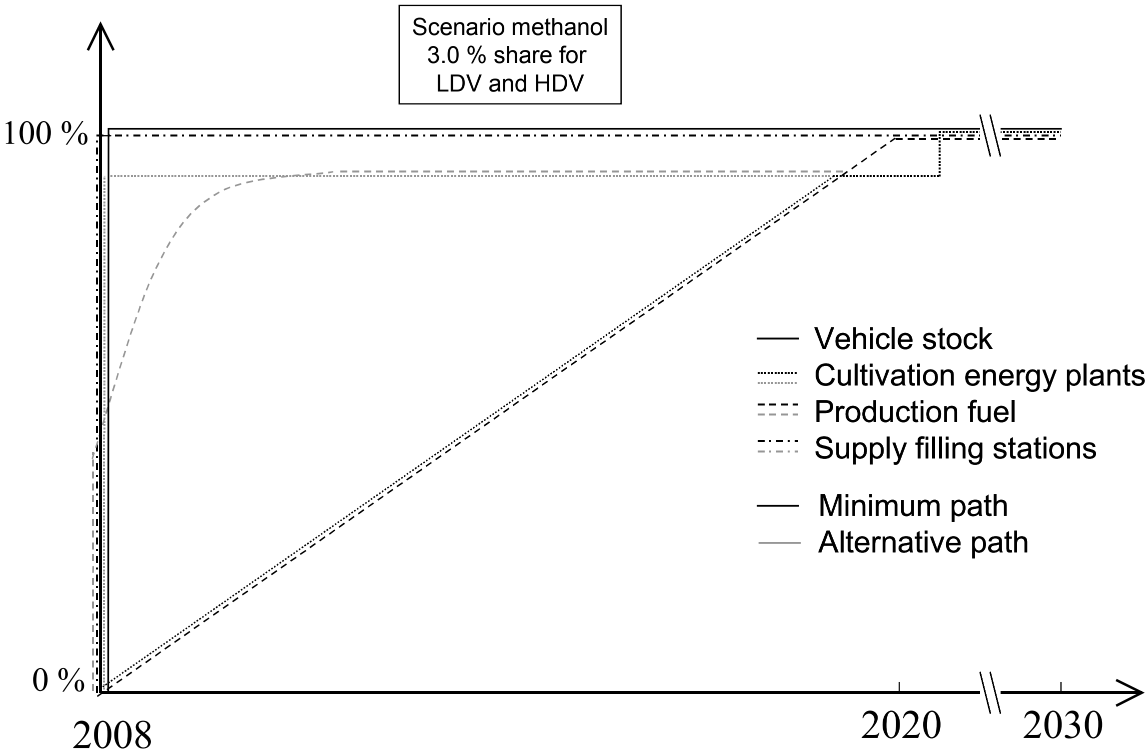
Actions to be taken by the EU:

- Regulations for an 25 % admixing of ethanol to the petrol
- Regulations for the cultivation of sugar beet on 10 % of the arable land, which should be accompanied by financial incentives like basic salary and / or option money
- Tax reduction and / or subsidies for the production of the ethanol-petrol blend to achieve lower fuel prices than conventional fuel
- Prescription to the fuel companies for providing an ethanol-petrol blend distribution at minimum 15 % at its filling stations from 2008 on

Methanol-diesel blend

Figure 42 shows that the time flow of the implementation of a methanol-diesel blend is different to that from the ethanol-petrol blend. The cultivation of energy plants and with that the production of fuel must process in two steps. As a suggested share of 3.0 % methanol does not require any conversions of the vehicles, the vehicle stock as well as the supply filling stations is not important for this consideration. On the other hand, the share of 3.0 % must not be exceeded for some technical reasons.

Figure 42: Implementation of methanol-diesel blend



There is no need for a conversion of the vehicles in a large scale for the methanol-diesel blend because of the low methanol share of 3.0 %. But there can be optimisations of the engines regarding to good efficiency and ecological impact.

The scenario suggests the production of methanol mainly by the biomass of logging residues, which are available shortly. The collection and processing of the residues happens by the demand, which arises from the prediction of the share of admixed methanol. To gain competitive prices subsidies are necessary for the collection and processing of the residues. The potential of the residues is about 93 % of the overall methanol potential. Additional potential for methanol is provided by the cultivation of fast growing trees in specific countries. Sugar beet is not suggested for Scandinavia, as here the cultivation of fast growing trees on 10 % of the agricultural crop land for methanol production is more capable, although this potential is only available after 10 to 15 years. The amount of energy plants must not be above the production capacity. This is particularly important before 2020, when the fast growing trees are not available yet.

The production capacity of methanol by biomass must be established from 2008 on. A linear built-up of the methanol production capacity is suggested, although this means a little overcapacity during the period when the potential of the logging residues is taped and the fast growing trees are not available yet. In order to encourage the production, there must be tax exemptions and / or subsidies for the methanol to get lower prices than that of conventional diesel. Including the fast growing trees the overall potential requires a production capacity of methanol of about 16 billion litres per year. The free market can make a faster built-up of the production capacity possible and can be supported by subsidies. There is a production in a larger scale possible, because a methanol share of up to 3.0 % does not represent an obstacle for the vehicles registered before 2008. Today there exist manufacturing plants for the methanol production by biomass of almost 500 million litres per year in Europe. This means the production capacity must be increased by the factor 32.

Since it replaces the conventional diesel, the methanol-diesel blend does not require a separate supply chain, and a conversion of the filling stations is not necessary. Due to the uneven occurrence of the basic materials and the different demand in Europe, more than 8 billion litres of ethanol must be transferred from countries with a surplus to those with a deficit.

Actions to be taken by the EU:

- Regulations for an 3.0 % admixing of methanol to the diesel
- Regulations for the collecting and usage of logging residues from 2008 on, which should be accompanied by financial incentives like basic salary and / or option money
- Regulations for the cultivation of fast growing trees on 10 % of the arable land in Scandinavia, which should be accompanied by financial incentives like basic salary and / or option money
- Tax reduction and / or subsidies for the production of the ethanol-petrol blend to achieve lower fuel prices than conventional fuel

8.2.2 Hydrogen

Hydrogen for road traffic

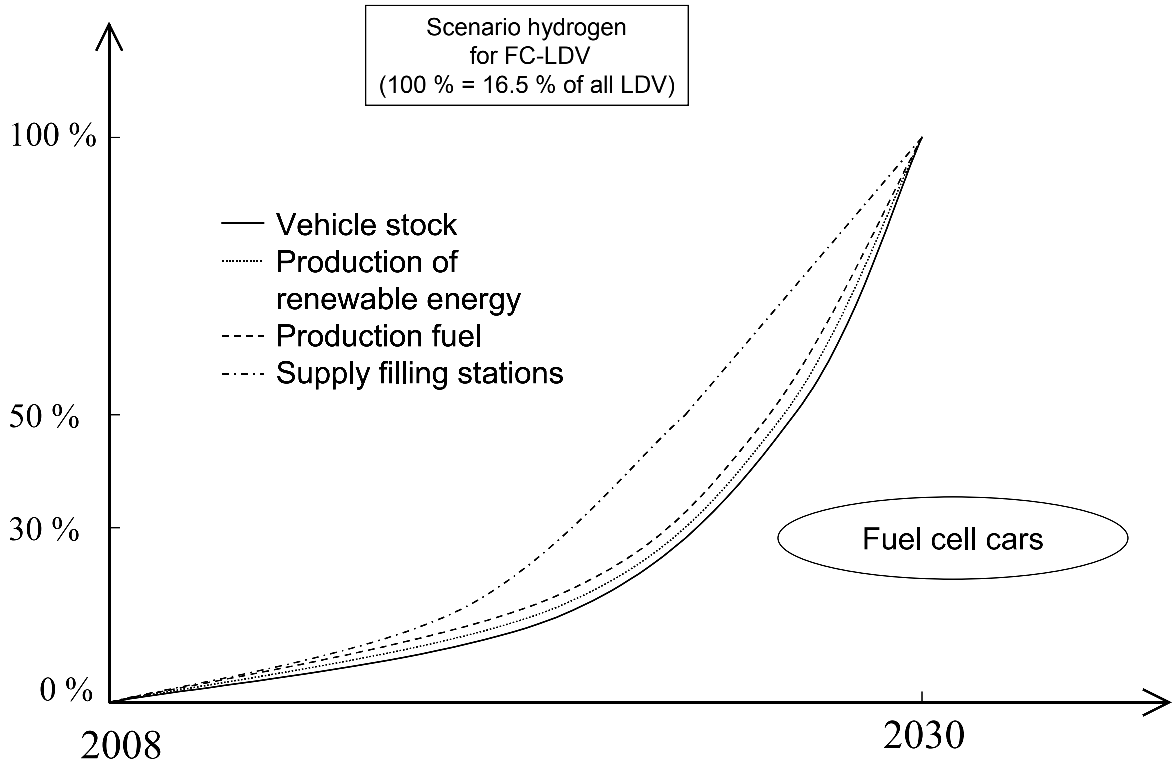
According to the scenario, the share of hydrogen cars in 2030 amounts to 16.5 % of all LDV.

The implementation of hydrogen as a fuel for vehicles must process completely different with several aspects that have to be considered. Today there exists neither vehicles running by hydrogen nor enough hydrogen production capacity nor the infrastructure for a hydrogen distribution.

For this reason first of all the limiting path in the process must be detected. This limiting path is supposed to be the implementation of hydrogen cars (particularly fuel cell cars) in a big scale because of the complexity of technique. The complete changeover will take a long period of time.

Figure 43 shows the time flow of the implementation of hydrogen.

Figure 43: Implementation of Hydrogen



The scenario suggests a share of fuel cell LDV of 16.5 % in 2030. The implementation process starts in 2008 with a phase of proving with only few vehicles. Then the share of implementation must gradually increase until the objective of the scenario is reached in 2030. This minimum path must be regulated by a prescription to the automakers. A faster implementation of fuel cell vehicles is possible and can be reached by the free market or self-commitments of the automobile industry. Due to the technical complexity of fuel cell cars, it is obvious that the price of those cars will firstly be much higher than those of conventional cars. The implementation must start from an upper price class for consumers who are willing to purchase more money for such a car. But experiences show that most of the “average consumer” are not willing to pay such higher prices, therefore the sales must be promoted by incentives like tax reduction or direct subsidies to enable competitive prices of the vehicles.

According to the vehicle path the renewable energy generation must be built up. The scenario makes clear that the required hydrogen for the implemented cars (1,092 PJ/a in 2030) is little compared to the overall technical potential of a renewable hydrogen production. It shows that only 5.2 % of the overall potential of hydropower, wind power, photovoltaic and solar thermal must be used. Nevertheless it requires the construction of new power generation stations with accordingly large capital investments:

- The share of wind power of 523 PJ/a can be covered by the offshore installation of about 14,000 units, which means an overall investment demand of 7 billion €.
- The share of photovoltaic is 81 PJ/a. Under the presumption that the average capacity of a solar cell is around 1,200 kWh/m^2*a, there must be almost 20 million m^2 of solar cells built up until 2030.
- The share of hydropower is 113 PJ/a. Under the presumption that a big run-of-river power station has a capacity of around 2 PJ/a, there must be 50 – 60 new power generation stations built up until 2030.

- The share of solar thermal amounts to 375 PJ/a. Under the presumption that a solar thermal power station has a capacity of around 120 GWh per year, there must be 800 - 900 new power generation stations built up until 2030.

The renewable power generation must be supported by subsidies.

There is the option for a power generation outside of Europe. Particularly the arid areas in northern Africa can be used for power generation by solar thermal and photovoltaic. If the required hydrogen cannot be produced in Europe of any reasons, this option must be taken into account.

At the same time as the power generation, there must be built-up production capacities of hydrogen. Today the hydrogen is nearly exclusively used for industrial application. Therefore the capacities for the transportation sector must be built up completely new. The needed amount of energy corresponds to about 760 million Nm^3 hydrogen. Optimal is the production of hydrogen according to the demand of fuel cell vehicles on the market. In the case that the implementation of hydrogen cars differs from the hydrogen production by any reasons, there must be found measures to compensate this. If the car production hurries ahead the production of hydrogen it is necessary to fill this gap with the production of non-renewable produced hydrogen to avoid a standstill of the technical development. Conversely, if there is more available hydrogen than the demand for fuel cell cars, the hydrogen could be used in combustion engines until the fleet of fuel cell cars exist. The production of hydrogen by renewable energy must be subsidised in order to gain competitive prices.

A major problem to be solved is the distribution of the energy. Basically there exist three ways:

- Transport of electricity and on-site hydrogen production: The advantage of this alternative is the cheap dispersion in the area by already existing power lines. The on-site production of hydrogen could be done at filling stations in 20-feed-containers. On the other hand this makes a transport of the electricity from the places of the power generation by large power lines necessary, which causes in the opinion of experts many problems with permit procedures.
- Transport of gaseous hydrogen: In this alternative the hydrogen is produced at the place of power generation and herewith avoids the new construction of power lines. But the transport of gaseous hydrogen is complicated since the use of lorries is not practical for economical reasons. Therefore a pipeline system has to be built up. Besides all problems of installing a new European wide distribution network this is very expensive, particularly for the dispersion in the area.
- Transport of liquid hydrogen: This system means the cooling of the hydrogen to transform it in a liquid state. The transport can be done via ships and lorries, comparable to the distribution of petrol and diesel. But the effort of the cooling is high, both in terms of energy demand and costs.

Taking into account the mentioned problems it is not possible to give a specific answer today, especially if there is until now more or less none research done in the field of large scale distribution of hydrogen for transportation needs. So the first step of an implementation strategy is to promote research in this specific field.

The infrastructure of filling stations must be built-up new. The conversion of filling stations to gaseous hydrogen is not comparable to the conversion to another liquid fuel. An area-wide infrastructure for fuel supply is a precondition for the implementation of hydrogen cars. A substitution of only 5 % of the European vehicle fuel requires a full area coverage of refuelling stations, which is given by a share of 15 % of all stations. In the beginning of the implementation (first third of the transition period) there is due to some financial and logistic reasons no area wide distribution possible. The target is to have hydrogen at 30 % of all filling stations in 2030. This means also that in this first third of the transition period local and regional applications will have their certain meanings before switching to an area wide application. The 15 % coverage must be reached, when 30 % of the aimed vehicle stock is on the market. For economical reasons the increase in the number of filling stations has to progress consistently, when this point is reached. It can be assumed that there exist about 130,000 filling stations in the EU 30 in 2030[45]. Assumed that there is one hydrogen dispenser per filling station, these filling stations achieve a flow of 23 billion Nm^3 hydrogen per year, whereas the needed amount is less than 1 billion Nm^3 per year. Considering that the conversion of one filling station to hydrogen costs about two million €, the overall conversions of the filling stations to hydrogen accounts to 78 billion € until 2030. The EU must prescribe the conversion of the filling stations. The free market can make a faster conversion possible.

Compared with the other scenarios there are a lot of questions open regarding the implementation of the hydrogen scenario. This is due to the lack of competitive applications in the case of the hydrogen distribution up to now. Therefore, as already mentioned, the first step of implementation is to answer the open questions by additionally investigations. Nevertheless, to reach the scenario objective (16.5 % fuel cell-LDV of the total fleet of LDV), it is necessary to start the process of implementation in 2008, especially with respect to the implementation of hydrogen and fuel cell vehicles in the candidate countries. In general the thoughts on the implementation shows that this implementation is possible if all efforts are bundled in the way described.

Actions to be taken by the EU:

- Regulations for an 16.5 % share of fuel cell LDV in 2030 of all LDV
- Regulations for the renewable energy production, which should be accompanied by financial like subsidies
- Tax reduction and / or subsidies for the production of hydrogen to achieve competitive prices compared with conventional fuel
- Prescription to the fuel companies for providing a hydrogen distribution at minimum 30 % at its filling stations in 2030
- Funding of additional studies on large scale hydrogen supply for transportation needs

Hydrogen for airplanes

The “Cryoplane” project led by Airbus shows that the use of liquid hydrogen as an aircraft fuel is technically feasible. Earlier flight tests in the USA with a B57 that had one engine run by liquid hydrogen and a Tupolew passenger plane in Russia have also proven that the hydrogen technology is applicable.

There is unlike to kerosene no existing large-scale supporting infrastructure for hydrogen. It has to be built up and will require major investments. This comprises the build-up of an airport storage infrastructure, airplane fuelling devices and maintenance.

A NASA study for the airports of San Francisco and Chicago concluded that storage and use of hydrogen fuel is definitely feasible with respect to the airports.

To minimize initial infrastructure problems, the transition from kerosene to hydrogen would start with short- and medium range aircraft that serve the major inner European flight routes. Looking at the timescale required for the transition process, comparably long development periods of at least 10 years for conventional airplanes have to be considered. In case of al-

[45] own calculation, based on L-B-Systemtechnik GmbH, 2002.

ternative fuels, a preceding phase of developing fundamental technologies for fuel storage, fuel system and aero-engine components as well as a demonstrator phase is necessary.

For a hydrogen introduction it is assumed [Pohl/Malychev] [46] that a fleet of 400 to 500 short and medium range aircraft is required to serve the main intra-European routes in the coming decades. The fleet should have access to a hydrogen infrastructure at about 70 European airports. Moreover a yearly production of 2 million tons of liquid hydrogen is required. Replacement of a considerable share of the worldwide aircraft fleet can not be expected until the middle of this century. As a transition step the opportunity of liquid natural gas powered airplanes is taken into consideration.

To limit development costs, the first generation of hydrogen aircrafts is supposed to be a modification of an existing conventional airplane rather than a complete new design, keeping as many components as possible unchanged. However, significant modifications on insulation and pressure resistant tanks can not be avoided. Apart from the cryogenic fuel system major structural modifications comprising reinforcements of the fuselage and wings are necessary for the backfitting of a conventional airplane as well.

Due to the fact, that hydrogen is a very clean fuel the jet turbines life cycle is expected to increase by 25 % and the need for repairs to reduce respectively. Thanks to its high calorific value the fuel weight is lower than for kerosene enabling smaller engines. Therefore lower maintenance costs for the long term cryoplane can be projected.

A fundamental pre-condition for the implementation of a hydrogen fuel system in aviation is seen in a competitive price for hydrogen. Currently hydrogen would not be competitive to kerosene. Political changes will be necessary such as establishing a kerosene tax or CO_2-incentives. Another incentive could be a landing fee in correlation to the amount of emission as practiced in Sweden (for NO_x and VOC) and Switzerland (dependent on engine classes).

8.3 Conclusion

In general, the biodiesel scenario for road transportation seems to be the easiest to implement. It is based on already existing technologies and there are already first applications throughout Europe both using biodiesel pure and as a blend. An additional advantage is the quite high insensitiveness against different shares of biodiesel of the blend. There have to be performed only some slight adaptation at the diesel engines. So the main limitation in the scenario is the built-up of the production facilities. However, also in this aspect there seem to be some chances for a quicker implementation due to market reasons if there are some incentives which promote the usage of biodiesel. On the other hand biodiesel has the smallest potential to reduce the release of transportation related CO_2.

The biodiesel scenario for inland navigation shows that it is possible to come to a total switch from fossil diesel to biodiesel in the European inland navigation and coasting, but on the other hand there are some unanswered questions concerning the introduction of biodiesel in the inland navigation and coasting fleets.

The more promising ways to introduce biofuels for transportation are described in the scenarios "Synfuel" and "Blended Fuels". For the scenario "Synfuel" there are no changes in the vehicles and the distribution network of the fuel necessary. On the other hand, new and large production capacities have to be built up and the potential to reduce the transportation related release of CO_2 is much smaller compared with those of ethanol and methanol.

[46] Pohl and Malychev, 1997.

In general the most suitable scenario to introduce biofuels for transportation seems to be the scenario "Blended Fuels". With both blends (ethanol-petrol up to 5 % and methanol-diesel up to 3 %) there exist already good experiences, and the introduction could start immediately without any changes at the vehicles, if the fuel is available. Besides that the cultivation of the plants and the build-up of production capacity for the fuel could start to reach the goal that in 2020 all LDVs could use either a ethanol-petrol blend with a share of 25 % ethanol or, as well as all HDVs, a methanol-diesel blend with a share of 3 % methanol.

Of course the most challenging task is the implementation of the scenario “Hydrogen”. The scenario shows that it is possible to reach the goal to have in 2030 a share of 16.5 % of all LDVs running with fuel cell and using renewable hydrogen if there are made the efforts described in the scenario. The bottleneck will be the production of renewable hydrogen, from the technical point of view the LDVs will be available. Nevertheless it has to be pointed out that there is some additional research necessary especially in the field of distributing hydrogen or electricity throughout Europe.

In general a stepwise strategy is recommended:

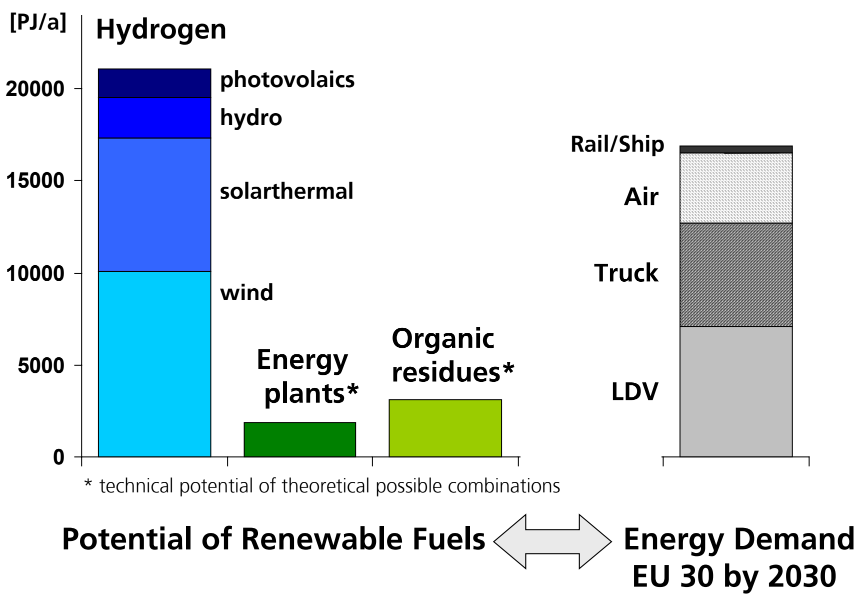
- Continuing the current use of biofuels regulated by the free market. This concerns mainly biodiesel and can be promoted by incentives as it is made in several European countries today.
- Implementation of the scenario blended fuels as a medium-term transient strategy.
- Scenario Hydrogen as a long-term solution.

9 Conclusion

This study on renewable fuels for cross border transportation addresses a wide range of topics on the generation and provision of renewable fuels and their application in a variety of vehicles. In parallel, related industrial concerns are taken into account. The study aims at describing the main tendencies in the shares of renewable energy use across sectors. Major concerns and questions are elaborated based on a Europe-wide, long term perspective (2030). All conclusions are reached by an objective and comprehensive analysis.

From a feasibility perspective, the application of renewable fuels on a large scale implies that their potential supply meets a reasonable proportion of energy demand. The proportion identified in this study is illustrated in Figure 44. It demonstrates the very low share of the energy potential of biofuels from plants or residues relative to the projected future energy demand. In contrast, the technical potential of hydrogen based on renewable energy is expected to even exceed the energy demand of the transport sector.

Figure 44: Technical overall potential of renewable fuels in comparison to projected energy demand for transportation for EU 30 in 2030



Given that biofuels are not currently in a position to provide a large share of energy for the transport sector, it is necessary to distinguish between hydrogen and the other biofuels in order to draw conclusions for an implementation strategy with good prospects.

Although **biofuels** do not show a high energy potential, they can still contribute over the intermediate term to solving energy problems and to reducing greenhouse gas emissions in the transport sector or for other specific purposes. For most of the options, it is possible to introduce them with a short time lag since the technological demands are manageable.

In the case of cultivating energy plants, it would be necessary to proceed carefully with an eye toward maximising the positive ecological effects while minimising negative consequences such as acidification and biodiversity loss. Attention has to be paid to the transformation process, as well, because of its partly high energy demand.

Concerning the use of residues, the assessment depends in some aspects on the applied method and on the boundary conditions assumed. But it can be stated in general that the additional use of residues can promote the positive impacts of biofuels and comprises a remarkable share of the biofuel potential.

However, the results of the study depend to varying degrees on the underlying assumptions. Concerning the **technologies** considered for producing primary energy and for transformation processes, several transformation technologies are still in the pilot phase. Thus, for several parameters, assumptions have been necessary when working out projections over the long term to 2030. A continuous monitoring of the development of these technologies appears to be very useful. This monitoring could provide more actual data on:

- efficiency of all transformation technologies, especially new technologies such as synthetic fuel production,
- real material input and output for all processing steps for improving all LCA data,
- more detailed cost information about these technologies when applied on a larger scale. The furnished price data of this study are partly heterogeneous because of comparing some regulated prices (agriculture), some combined cost data from different production steps (new technologies) and some price examples found in the literature (new energy carriers seldom traded today).

Monitoring the progress of energy supply technologies and fuel transformation processes could lead to a network for innovation that brings together research and fuel producers. The best practices could be identified and the technology transfer, especially between Western and Eastern European countries, could be promoted.

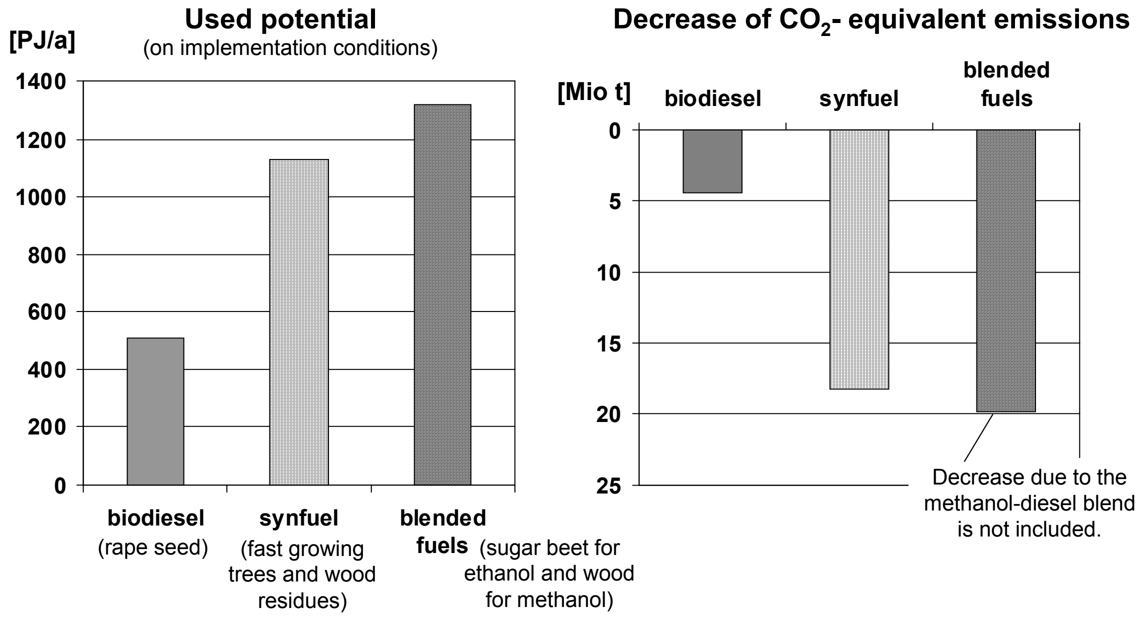
Another question worth further investigation concerns the **potentials** of renewable energy sources. Consideration of multiple purposes for the same energy sources was not included in the study, but it is of high importance as the discussions during the stakeholder meetings showed clearly. For example, logging residues can either be used for producing chipboards, for the production of synfuel or for burning and electricity provision. Furthermore, electricity as input for the hydrogen and fuel cell chain competes against the usage for private households or other purposes. So the question of the concurring demand of different economic sectors for renewable energy supply will greatly influence its potential. Moreover, the European Commission encourages electricity and heat production from renewable sources. The general conditions for competition between using renewable energy sources for electricity, fuel or heat production are different across the European countries. Gauging future development prospects will be facilitated by the availability of more data on renewable fuels.

The main assumption of the availability of 10 % of the arable land for energy crop cultivation for biofuels would be a further issue meriting scrutiny when continuing the work on renewable fuels. This percentage depends on interactions between the Common Agricultural Policy and energy policy because all (food or non-food) crops will only be cultivated if yields and prices are attractive. If prices of crops fall, more food will be imported and a larger area will become free (as fallow land or for energy crops). Price and cost relations in agriculture differ significantly in the European Union, particularly when including the Candidate Countries. Therefore, an in-depth-going analysis of the potentials has also to account for the cost differences.

Further work and analyses in fields mentioned above is recommended and would clearly improve the quality and reliability of information used in this study.

Figure 45 illustrates two key figures from the scenarios carried out for biofuels: the utilised potential and the amount of reduced CO_2-equivalent emissions. As both figures already include technical vehicle restrictions and other concerns (see chapter 6), they do not illustrate a maximum technical potential. The scenario “blended fuels” consists of an ethanol-petrol blend (25 % ethanol) and a methanol-diesel blend (3 % methanol).

Figure 45: Selected results of the study scenarios on biofuels



Among other things, these results support the implementation of the "blended fuel" scenario. Its main challenge can be seen by establishing the agricultural production and the fuel distribution in order to achieve a consistent fuel quality across Europe. Especially for the ethanol-petrol blend, standardisations are required.

There are some further important aspects to address, which show advantages of other scenarios:

- technology and application already exist in the case of biodiesel (vegetable oil methyl ester)
- no changes in vehicles and the distribution network are necessary in the case of synfuel.

It is important to assess whether these aspects rank before the points indicating the mixed blended fuel option mentioned above. For this purpose, economic impacts on the different sectors have to be taken into consideration. The enlargement of the European Union, in particular, requires an in-depth analysis of these aspects because of the much more relevant position of the agricultural sector in the candidate countries in comparison to EU15. As a result of the general analysis of this study, it bears noting that the impact on the agricultural sector (e.g. employment concerns) could be of more importance than on the transport sector itself.

Hydrogen produced using renewable electricity offers potential for meeting a considerable amount of the transportation energy demand. This option is clearly linked with fuel cell powertrains, which indicated very good results for the life cycle assessment of the fuel chains in the framework of this study. Despite current problems concerning the storage of hydrogen and the costs, it is expected that this technology is able to initiate the replacement of the conventional four-stroke combustion engines, especially for light duty vehicles. For other modes of transportation, there are much more crucial obstacles to overcome.

High potentials of electricity from renewable sources (wind power) correspond with moderate specific investment costs. The construction and organisation of appropriate production and distribution facilities for hydrogen seems to require enormous effort. However, by considering a preliminary target of 15 to 20 % hydrogen passenger cars and an introduction period of 20 to 30 years, investments appear to be manageable. In that case, only about 5 % of the hydrogen potential illustrated in Figure 44 has to be utilised. Therefore, the production of the vehicles appears to be the limiting factor.

Although several figures on the prerequisites for a hydrogen introduction are given, it has become obvious that much more research work has to be done to assess consistently and accurately the investments for a hydrogen infrastructure that is positioned to provide fuel for Europe-wide transport. In particular, more detailed calculations and comparisons between the different options for building up the hydrogen infrastructure are recommended for further work in order to confirm and complete the results of this study.

Coping with considerably higher fuel costs could represent a big challenge. Assessments of the effects on the various transportation modes would give some valuable information and criteria for further considerations. Over the intermediate term, the problem of the large price gap between renewables and fossil fuels has to be tackled. In the long run, higher levels of mobility costs in general have to be considered and, finally, a restructuring of the tax system due to the drop of revenues from mineral oil taxes for the public authorities is necessary.

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See "Internal and External Resources" on the module sheets (annex 1 to 4).

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10 Annexes

Annex 1: Module Sheets for primary energy sources **(separate document)**

Annex 2: Module Sheets for transformation technologies **(separate document)**

Annex 3: Module Sheets for fuel distribution **(separate document)**

Annex 4: Module Sheets for vehicle technologies **(separate document)**

Annex 5: Calculation of investment costs

Cumulated investment costs for energy supply by renewable sources:

	Hydro power	Wind offshore	Solar-thermal	Photovoltaics
Nominal power [KW]	1,000	3,000	2,000	100
Full load hours [h/a]	5,500	3,585	300	850
Output [MWh/a]	5,500	10,755	600	85
Investment costs [Mio. €]	5.37	5.57	1.43	0.51
Specific invest [€/KW]	5,370	1,857	715	5,113
Economic life =depreciation [a]	30	20	20	20
Cost of operation [€/a]	134,250	329,937	21,450	-

Source: Stiftung Energieforschung Baden-Württemberg(Ed.), 2001; Data and prices of 2001

Technical potential [PJ/a]	1,890	12,899	5,119	1,493
Usage of potential (25 %) for transport [PJ/a]	472.5	3,224.75	1,279.75	373.25
Potential in [MWh/a]	127,575,000	870,682,500	345,532,500	100,777,500
Required invest [Mio. €]	**124,560**	**450,925**	**823,519**	**604,665**

Assumed parameters for nuclear power generation:

	Nuclear power
Nominal power [KW]	1,530,000
Full load hours [h/a]	2,000
Output [MWh/a]	3,060,000
Investment costs [Mio. €]	1,790.1
Specific invest [€/KW]	1,170
Economic life [a]	30

Source: Technical University Berlin, 2001

Nuclear power generation (EU15) in 1999:	868,400,000 MWh
Prospected power supply for transport:	1,486,100,000 MWh
Difference:	599,600,000 MWh
Costs per 3,060,000 MWh [€]:	1,790,100,000
Total invest for difference [€]:	350,000,000,000