Cost Effectiveness of CO2 Mitigation in Transport

Report prepared by CE Netherlands

for ECMT

EUROPEAN CONFERENCE
OF MINISTERS OF TRANSPORT

CE
Solutions for
environment,
economy and
technology

Oude Delft 180
2611 HH Delft
The Netherlands
tel: +31 15 2 150 150
fax: +31 15 2 150 151
e-mail: ce@ce.nl
website: www.ce.nl
KvK 27251086

Cost effectiveness of CO_2 mitigation in transport

An outlook and comparison with measures in other sectors

Report

Delft, April 2006

Author(s): Bettina Kampman
Sander de Bruyn
Eelco den Boer

Publication Data

Bibliographical data:
Bettina Kampman, Sander de Bruyn, Eelco den Boer
Cost effectiveness of CO_2 mitigation in transport
An outlook and comparison to cost effectiveness of measures in other sectors
Delft, CE, January 2006

Transport / Carbon dioxide / Emissions / Reduction / Measures / Costs / Effects / Fuels / Technology / Analysis

Publication number: 06.4184.20

CE-publications are available from www.ce.nl

Commissioned by: European Conference of Ministers of Transport.
Further information on this study can be obtained from the contact person Bettina Kampman.

CE

Solutions for environment, economy and technology

CE is an independent research and consultancy organisation specialised in developing structural and innovative solutions to environmental problems. CE's solutions are characterised in being politically feasible, technologically sound, economically prudent and socially equitable.

CE Transform

Visions for sustainable development

The business unit CE Transform provides advice and support to business and government in implementing changes towards sustainable development.

For the latest information on CE check out our website: www.ce.nl.

This report is printed on 100% recycled paper.

Contents

Summary 1

1 Introduction 5
  1.1 Introduction 5
  1.2 Project aim 5
  1.3 Reading guide 6

2 CO_2 mitigation measures 7
  2.1 Introduction 7
  2.2 Measures in the transport sector 7
  2.3 Measures in other sectors 9

3 Cost effectiveness: some background information 11
  3.1 Introduction 11
  3.2 The definition, methods and interpretation of cost effectiveness analysis 11
    3.2.1 Definition 11
    3.2.2 Purpose and use of CEA 11
    3.2.3 Methods to arrive at CEA 12
    3.2.4 Interpretation of the results of CEA in this study 15
  3.3 Drivers for the development of cost effectiveness over time 15
    3.3.1 Technological development and learning 16
    3.3.2 Effect of experience and economies of scale 17

4 Cost effectiveness of transport measures 19
  4.1 Introduction 19
  4.2 Fuel economy and energy savings 19
    4.2.1 Fuel economy typology 19
    4.2.2 Costs of fuel economy 19
    4.2.3 Costs in relation to other sectors for efficiency measures 21
    4.2.4 Effectiveness of fuel economy measures compared to other sectors 23
    4.2.5 Fuel economy: some preliminary conclusions 25
  4.3 Comparison of biofuels with biomass use in the electricity sector 25
    4.3.1 Comparison of the various biomass applications 26
    4.3.2 Results 28
  4.4 Hydrogen for transport? 31
    4.4.1 Comparison of hydrogen use in transport and power generation 32
    4.4.2 Renewable (or nuclear) energy: for hydrogen transport or power generation? 35
  4.5 Comparison of the various CO_2 mitigation options in transport 35

5 The role of government policies 37
    5.1 Introduction 37
    5.2 Policies for new technologies 37
    5.3 Improving the effectiveness of fuel economy as a policy option in combating climate change 39

6 Conclusions 41
    6.1 Cost effectiveness of CO_2 mitigation in transport 41
    6.2 The role of government policies 42

References 43

Summary

Background
In climate policies, CO_2 emissions of the transport sector are getting increasing attention. Emissions are rising continuously due to increases in passenger and freight transport demand, and the question how this trend can be reversed has not yet been answered.

In the EU 25, the share of the transport sector in total CO_2 emissions has increased over the past years, from 21% in 1990 to 26% in 2000. Also, absolute emissions are increasing, from 795 Mt in 1990 to 968 Mt in 2002. Scenario studies predict that these emissions will continue to rise. Road transport has the largest share in these emissions, and is expected to be responsible for more than 80% of transport final energy consumption in 2030.

ECMT is currently working on a report on carbon emission reductions in the transport sector. Since cost effectiveness of mitigation measures is an important issue in this analysis, ECMT has asked CE Delft to write a background report on cost effectiveness of technical measures to reduce CO_2 emissions in the transport sector.

Aim of this report
The report analyzes the cost-effectiveness of CO_2 mitigation options in the transport sector and compares these with similar options in other sectors. The cost-effectiveness of an environmental measure is a comparison of the effects of a measure with the costs of implementing it. A more cost-effective measure will have achieved the desired results for less money or more results for the same amount of money.

The mitigation options in the transport sector analyzed in this report are:
- Improved fuel economy of cars.
- Biofuels.
- Hydrogen.

Hence, the report focuses on the cost effectiveness of technological improvements, i.e. on fuel efficient vehicle technologies and fuels. Measures that, for example, affect the demand for transport or modal split have not been examined.

In each of these mitigation options, the following questions are addressed:
- How does the cost effectiveness of CO_2 mitigation options in the transport sector compare with the cost effectiveness of measures in other sectors?
- How will this relationship evolve in the future, in the time frame up to 2030?
- How do costs of technology reduce over time?

The report concentrates on the main developments that can be expected, and on the order-of-magnitude of cost effectiveness of certain types of measures. Detailed cost curves for measures are not derived.

Main findings: cost effectiveness

Several, ex-ante and ex-post, studies conclude that efficiency measures in the transport sector can be more cost effective than some measures in other sectors. These conclusions are supported by recent estimates of cost effectiveness of fuel efficiency improvements in passenger cars. Fuel savings typically compensate part of, or even all, additional costs.

However, a recent EEA study concludes that if CO_2 prices are implemented throughout the economy, the power sector would be the most promising and cost-effective way to achieve emission reductions, mainly through fuel shifts (an increase of wind power and biomass, and combined heat and power). Fuel economy measures in the transport sector are less attractive in that study, since the cheap and easy options have already been exploited and the transport sector seems to a certain extent unresponsive to price changes. We notice, however, that a low price elasticity is assumed in the transport sector in this study and that empirical evidence on this is mixed.

When comparing the use of biofuels in the transport sector with its use in power stations, the latter is more favourable from a cost effectiveness point of view. This is especially valid for most of the current, 1st generation biofuels, even at current high oil prices. The 2nd generation biofuels that are currently being developed are expected to achieve more favourable cost effectiveness, due to both reduced costs and higher unit greenhouse gas emissions abatement. At current oil and coal prices, the 2nd generation biofuels may be able to achieve a cost effectiveness comparable to that of coal replacement by biomass in power stations. There is currently no indication, however, that biofuels become more cost effective than biobased electricity generation in the future.

In the longer term (from 2025 onwards), hydrogen might come on the market as an option for reducing CO_2 emissions in transport, when produced from climate neutral energy sources. However, a comparison with other potential applications of hydrogen and with a more direct use of the climate neutral energy sources leads to the conclusion that the cost effectiveness of its use in transport can not compete with more direct uses of the energy sources, for example in electricity generation, in the timeframe under investigation.

Main findings: Cost effectiveness may improve over time

Most future CO_2 emission reductions, both in the transport sector and elsewhere, are expected to come from new technologies, and improvements of currently available technologies. Experience with technological development in the past shows that the cost of new technologies can reduce significantly over time, as a result of learning, optimisation and scaling up of production.

Both the costs and cost effectiveness of new technologies are generally unattractive as long as the technologies are immature. However, if the R&D is successful, the new technologies may become more competitive and even outperform more conventional technology once they are developed further, and large scale market access has been achieved. Deriving a long term strategy for CO_2 reduction in the transport sector thus requires insight into the potential development of costs and cost effectiveness of the various mitigation options.

Even though the different stages and mechanisms of technological development are well understood, predicting the cost curve over time for a specific new technology is very difficult. Ex-post analysis of cost developments in renewable energy technologies has shown that the costs typically decline by 15-25% for every doubling of production.

Before new technologies and fuels enter the market, they usually encounter a number of financial, technical and non-technical barriers. High costs, teething problems, lack of (financial) support by the established industry, an undeveloped distribution system, etc. all hamper large scale market introduction. Government policies such as R&D funding, pricing incentives and standards may help to remove these barriers and create market opportunities for the new technologies. Governments can thus be crucial to successful development of the technologies needed to reduce CO_2 emissions in transport.

Main findings: Comparability between studies is limited

Many cost effectiveness analyses are carried out to assess both technological and policy measures but unfortunately, most are hardly comparable due to substantial differences in methodology. For example, different cost categories are included, different perspectives are taken or different methods to discount costs and benefits are applied. In this report, the welfare-economic perspective is chosen, which implies that costs of environmental measures to society as a whole are included.

We must furthermore conclude that there are only very few studies that address the issue of cost effectiveness of measures across sectors. Even data on the cost effectiveness of measures within the transport sector is scarce. Individual measures are often only assessed ex-ante, but different cost effectiveness studies can not generally be combined and compared because assumptions and methodologies differ so much. Choosing the most cost-effective pathway for society to combat global warming is therefore difficult with present knowledge.

1 Introduction

1.1 Introduction

In climate policies, CO_2 emissions of the transport sector are getting increasing attention. Emissions are rising continuously due to increases in passenger and freight transport demand, and the question how this trend can be reversed has not yet been answered.

In the EU 25, the share of the transport sector in total CO_2 emissions has increased over the past years, from 21% in 1990 to 26% in 2000. Also, absolute emissions are increasing, from 795 Mt in 1990 to 968 Mt in 2002. Scenario studies for CO_2 emission reductions in the next decades predict that these emissions will continue to rise, even if more stringent climate policies are implemented (IEA, 2005). Road transport currently has the largest share in these emissions, and this will remain in the future: This subsector is expected to be responsible for more than 80% of transport final energy consumption in 2030.

ECMT is currently working on a report on carbon emission reductions in the transport sector. The report assesses the effectiveness of the ECMT Member and Associate Member governments in developing policies to reduce transport sector CO_2 emissions, and recommends constructive ways forward for further policy development. Focus is on 2010 and 2030 time frames.

Since cost effectiveness of CO_2 mitigation measures in an important issue in this analysis, ECMT has asked CE Delft to write a background report on cost effectiveness of technical measures to reduce CO_2 emissions in the transport sector.

The report does not contain detailed cost effectiveness calculations of measures. Rather, the cost effectiveness of measures in the transport sector is compared with that of comparable measures in other sectors. The same time frames as in the ECMT study are used, so that potential developments in cost effectiveness of the various types of measures are addressed.

1.2 Project aim

The report addresses the following questions:
- How does the cost effectiveness of CO_2 mitigation options in the transport sector compare with the cost effectiveness of measures in other sectors?
- How will this relationship evolve in the future, in the time frame up to 2030?
- How do costs of technology reduce over time?

The report concentrates on the main developments that can be expected, and on the order-of-magnitude of cost effectiveness of certain types of measures. Detailed cost curves for measures are not derived. All transport modes are covered, although the main focus will be road transport.

Furthermore, the study focuses on the cost effectiveness of technological improvements. In the transport sector, these concern fuel efficient vehicle technologies and fuels. These will be compared with technological measures in other sectors such as in industry and power stations. Measures that, for example, affect the demand of transport or the modal split are therefore not assessed.

1.3 Reading guide

In the next chapter, a brief overview is provided of the CO_2 mitigation measures that are expected to be able to contribute to CO_2 mitigation in the period until 2030. This is followed by some background information on cost effectiveness in chapter 3. In this chapter, the definition and methodology for the assessment of cost effectiveness are described, and the development of cost effectiveness for new technologies is discussed. In chapter 4, the cost effectiveness of technical CO_2 mitigation measures in transport are compared to that of technical measures in other sectors. Since policies may have a large impact on the development, market implementation and, therefore, cost effectiveness of new technologies, the role of government policies is discussed in chapter 5. The conclusions and recommendations of this report are given in chapter 6.

2 CO_2 mitigation measures

2.1 Introduction

In this chapter, we briefly describe the type of technical CO_2 mitigation measures that can be taken in both the transport sector and in other sectors. We will not describe these measures in detail, but rather try to give an impression of what can be done in the various sectors.

2.2 Measures in the transport sector

CO_2 emissions of the transport sector can be reduced by various technical and operational measures. The technical measures, subject of this study, can be broadly categorised according to whether they influence *fuel efficiency* of the vehicles, or whether they affect the *CO_2 emissions of the fuel* (over the whole fuel chain). The main exception is the case that hydrogen with fuel cells replaces both fossil fuels and combustion engines. Then, both the emissions of the fuel as the fuel efficiency of the vehicle can be affected significantly.

The potential of technical CO_2 reduction measures in the passenger car sector is getting increasing attention, due to its large share in total transport emissions and because the EU has set clear targets for passenger cars (140 g/km in 2008/9, according to the type approval test, under agreements with car manufacturers with Environment Ministers proposing 120 g/km in 2012). A recent report by IEEP (2005) therefore assessed for the European Commission the potential and costs of technical measures to reach a 120 g/km target[1]. Less is known for heavy duty vehicles and other motorised modes of transport. Furthermore, only few studies have aimed to identify the technology that is necessary to achieve further CO_2 reduction, in the longer term.

The following table gives a broad overview of new technologies and technological improvements that have the potential to reduce CO_2 emissions most, for the various modes and the categories mentioned above. More detailed information about these technologies and more CO_2 reduction options (with less potential) can be found in the literature given in the last column of Table 1.

---

[1] Note that the automobile industry has criticized the cost figures used in that report. A follow up study is currently being carried out.

Table 1 List of technological improvements and new technologies that are expected to have the highest potential to reduce CO_2 in the transport sector, until 2030

Transport mode	**Technology**		**Literature (selection)**
	Fuel efficiency	**Fuel**	
Passenger cars and light duty vehicles	Engine downsizing	Biofuels (1st and 2nd generation, various types)	(IEEP, 2005) (Ricardo, 2003) (Concawe, 2005)
	Cylinder deactivation	Hydrogen	
	Hybrid drive		
	Vehicle body weight reduction		
Heavy duty road vehicles	Hybrid drive trains	Biofuels (1st and 2nd generation, various types)	
		Hydrogen	
Trains	Weight reduction, improved aero-dynamics, decreasing friction	Biofuels	(CE, 2005)
	Regenerative braking with energy recovery	Hydrogen	
		Renewable electricity for electric trains	
Aircraft	Airframe design improvements, such as wingtip devices, increased application of light weight materials, etc.	Biofuels	(IPCC, 1999) (CE Delft, 2000) (CE Delft, 2005)
	Engine improvements and increased use of fuel efficient engines (such as turboprop engines)	Hydrogen	
Maritime ships	Optimisation of hull and propeller design	Biofuels	(IMO, 2000)
	Efficiency optimisation	Hydrogen	
	Choice of fuel (heavy fuel oil to marine diesel oil)		

Some of the technologies listed in this table are already on the market, albeit only in limited numbers or volumes. Examples are the hybrid drive trains in passenger cars, 1st generation biofuels in road transport and optimisation of ship hulls and airframe design. Others are still in a research stage, such as the 2nd generation biofuels and hydrogen.

2.3 Measures in other sectors

CO_2 mitigation measures in other sectors can also be divided in two routes: fuel efficiency improvements and increasing the share of renewable fuels (and developing the use of coal with CO_2 sequestration). A brief overview is given in Table 2.

Table 2 List of technological improvements and new technologies that have the highest potential to reduce CO_2 in other sectors, until 2030

Efficiency measures	**Fuel shifts**
Thousands of specific measures to save energy during production processes	Expansion of cogeneration
Isolation of buildings and other measures to save energy in buildings	Coal-fired cogeneration
Energy savings in households through improved isolation of houses	Cogeneration in dwellings
Energy savings through improved design of electrical appliances	Solar heating, heat pumps
Improved heat exchange efficiency in power stations and improved gas turbine design	Expansion of wind turbines
	CO_2-sequestration
	Biomass

3 Cost effectiveness: some background information

3.1 Introduction

The cost-effectiveness of an environmental measure is a comparison of the effects of a measure with the costs of implementing it. A more cost-effective measure will have achieved desired results for less money or more results for the same amount of money.

In this chapter, we will first focus on the definition of cost effectiveness and on the methods to estimate it. How to interpret the results of a cost effectiveness analysis is then described. Finally, we will go into the drivers of cost effectiveness developments over time. These are particularly relevant for new technologies, whose cost effectiveness is typically not competitive when it enters the market, but may improve strongly from increased scale of production, learning effects, etc.

3.2 The definition, methods and interpretation of cost effectiveness analysis

3.2.1 Definition

The cost-effectiveness of an environmental measure is a comparison of the effects of a measure with the costs of implementing it. A more cost-effective measure will have achieved desired results for less money or more results for the same amount of money.

Cost-effectiveness analysis (CEA) is similar to the well known concept of cost-benefit analysis (CBA; cf. Mishan, 1981) except that:
a The benefits are not specified, the costs are instead linked to the effects.
b Social costs (e.g. environmental deterioration) are normally not included in CEA. CEA handles only private costs.

By linking the costs to the effects, CEA becomes a kind of efficiency criterion.

3.2.2 Purpose and use of CEA

Cost-effectiveness analysis (CEA) is a tool used for assessing the efficiency of certain technologies, programs or policies and to compare alternatives. With the use of cost-effectiveness analysis decision makers can more rationally choose between alternatives and assure that goals will be met at least possible costs[2].

---

[2] Unlike CBA, the goals themselves are not subject to economic analysis in CEA, which some economists consider as an important advantage of CEA over CBA (Oka, 2003). In the environmental sphere, CEA has been more popular than CBA because the use of CBA is limited as benefits of environmental improvements are difficult to determine in monetary terms.

In the use of CEA, one distinguishes between *ex-post* and *ex-ante* CEA. Ex-post CEA is normally used to evaluate certain policies and programs in the past. It answers questions like: Have policies resulted in the desired outcomes? How much did these policies cost? Who has born those costs? Ex-post CEA can be useful to give account of existing policies and to further improve the effectiveness or efficiency of existing policies by learning lessons from the past (OECD, 1997). Furthermore, various ex-post CEA of individual instruments might teach us which instruments perform better under which conditions (EEA, 2001).

Ex-ante CEA is normally used to evaluate policy plans and technologies. Normal question here is which policy plans or technologies are desirable from a cost perspective.

Some studies have pointed at the divergence between ex-post and ex-ante CEA. Ex-ante CEA tends to overestimate the costs to a certain extent. For cases where both CEAs were available, the international literature reports a difference of a factor 2-5 between ex-ante CEA and ex-post CEA (Harrington, 2000; Burtraw, 1996; Stockholm Environmental Institute, 1999). The main reasons are that learning effects tend to be underestimated ex-ante and that some cost-studies are conducted for strategic reasons, for example to obstruct more stringent environmental policies. In paragraph (3.2.4) we will go deeper into the learning effects.

Although CEA is useful for designing cost-effective environmental policies, one must bear in mind that cost-effectiveness is never the sole criterion in designing policies. Considerations of equity, amongst other things, are not encompassed in CEA.

3.2.3 Methods to arrive at CEA

Although the concept of CEA is crystal clear to most policy makers and scientists, the methodological guidelines to calculate cost-effectiveness are more obscure. When correctly applied, CEA takes into account the full stream of project costs, including construction, maintenance, and monitoring costs, as well as the time-value of money. However, in reality, results differ to a certain extent as CEAs vary according to:

1. Perspective.
2. Cost categories covered.
3. Effects considered.
4. Corrections on the CEA.
5. The techniques applied to convert past and future costs into monetary values of today.

Due to these differences, results between different CEA studies are often hardly comparable.

Perspective of CEA

CEA may take different perspectives. Clearly, a CEA for a private investor may be totally different than a CEA for society as a whole. In the environmental sphere, most CEA take a welfare-economic perspective, in the sense that all net costs to society are taken into account. A tax in this perspective is not a cost, but only a transfer of money from one agent to the other. For a private investor, however, a tax is a cost which should be included in the CEA.

In the remaining part of this study we take the welfare-economic perspective and hence only determine the costs to society as a whole from environmental measures.

Cost categories

The cost concept in CEA relates to *net additional costs*: the private additional costs minus the private additional benefits. Private implies here the cost categories which are tangible[3]. Social costs (e.g. environmental pollution) are normally not included in CEA. “Additional” implies here that one only looks at the *extra* costs associated with the technology. A CEA of the voluntary commitment by the car manufacturers would, therefore, only look at the additional costs that have to be made in order to comply with this commitment.

Even though the orientation on private costs is evident from most CEA-studies, the studies themselves differ in the type of private cost categories that are taken into account.

The most detailed studies take into account the following costs:

- Investment costs (e.g. costs of the equipment, labour costs in order to learn to use the equipment and costs of retrofit).
- Costs of operation and maintenance.
- Administrative costs for the government (e.g. costs of monitoring and execution of the policies).
- Administrative costs for the users of the equipment.
- Intangible (i.e., non financial) consumer benefits and costs, for example because the new equipment has lowered/raised comfort.
- Indirect dynamic costs, for example by including long-term welfare benefits such as employment in the CEA. .
- Energy savings.

Most studies do take into account the investment costs, the costs of operation and maintenance and the direct benefits. Other cost categories are not always taken into account. Empirical results therefore depend to a large extent on the cost categories that have been investigated, and studies covering different sets of cost-categories cannot easily be compared to each other. Especially the

---

[3] Note that the various cost categories may be spread over different actors. For example, car manufacturers need to invest in the R&D and production of more fuel efficient cars, whereas it will be the owners of these cars that will benefit from lower fuel costs. Of course, car manufacturers will pass on (at least part of) the additional costs to the people that buy these cars.

intangible consumer benefits and costs may make a big difference in some practical examples (see Box 1).

The effect

Effects can be difficult to measure. One fundamental question is how emissions would develop in absence of the policy instrument (baseline-discussion). There are no uniform methods to assess the additional effect from policies and studies will differ in the way how they have calculated the *Business as Usual (BaU)* scenario.

To complicate things, the effects calculation should correct for certain auxiliary effects, such as free-riders (who would have made the targeted investment anyway)[4]. This is not always done in studies.

BOX 1: Do smaller cars imply lower welfare?

One of the difficulties with CEA comes when addressing the potential welfare effects from a policy stimulating the use of smaller vehicles. Clearly, a shift towards smaller vehicles would be environmentally desirable for the lower fuel consumption (and also in relation to the demand for parking space). However, most economists have tended to argue that bigger cars generate more welfare as consumers are willing to spend much more on a bigger car than on a smaller car. The price differential between big and small cars can be perceived as the revealed welfare preference for size in vehicle purchases. Hence a policy stimulating smaller cars would entail welfare losses to society and therefore be undesirable as long as the monetarized environmental effects of bigger cars are lower than the price difference between big and small cars. Other economists (cf. Easterling, 1974), however have pointed at the importance of relative welfare in economics. To a certain extent, consumers of cars include status components in their purchase decisions (“*Keeping up with the Jones”).* As Mishan (1981) points out, this component of private benefits does not generate a net welfare benefit because although the buyer of, for example, a SUV has the pleasure of feeling himself better than the neighbours, the neighbours might suffer the discomfort of feeling *worse* as a result. Mishan proposes to cancel such effects out as ‘perverse welfare effects’. If we accept Mishan’s way of thinking, the main question is to what extent the buyer of big cars is affected by aspects like social status and prestige. If this were his sole motivation for buying a bigger car, one might conclude that there is no welfare differential between smaller and bigger cars and that hence a policy oriented stimulating smaller cars would entail welfare gains to society due to the lower environmental effects of smaller cars. Clearly this extreme case does not apply to all purchase decisions and comfort is a factor of equal or more importance. But some discounting of the benefits measured simply according to price difference does appear appropriate.

Techniques

The techniques to arrive at CEA differ widely. For example, the cost-effectiveness of taxes has been assessed by a number of techniques using linear programming, general equilibrium models, accounting of costs and benefits and econometric estimations (University of Westminster, 2004). There is no uniform principle, but as a general rule one may say that cost accounting is the prime technique and only if data do not allow for direct cost accounting one should try to use other methods.

---

[4] Other effects include the rebound-effect (Greening et al., 2000) which imply that the savings in energy result in higher incomes and hence in an increase in energy consumption and the Baumol effect (Baumol and Oates, 1988) which imply that subsidies alter the optimal production levels of producers.

A significant issue is whether and how to apply discounting. Discounting is used to bring all future costs and benefits to a common denominator. Clearly, people have a time-preference for money in the sense that they prefer benefits now and costs later. This would be an argument for discounting. The appropriate rate of discounting is, however, a matter for discussion and no common guidelines have been established. While some prefer to discount with the internal rate of return of private companies (which would be between 9 and 15%), others prefer a social discount rate, which would be similar to the yields on long-term government bonds (i.e. around 4-5%). One solution would be to use internal rate of returns if CEA is conducted for private investors and social discount rates if a societal and welfare-economic perspective has been chosen.

Governments are primarily concerned with the welfare of society as a whole, and ought therefore to employ a social discount rate. It should be noted that consumers may employ even higher implicit discount rates than private firms in factoring future fuel savings into choices over the type of car they buy. Correcting for this divergence of appreciation can be a reason for government intervention.

3.2.4 Interpretation of the results of CEA in this study

As outlined in paragraph 3.2.2., CEA can be interpreted as an efficiency criterion and can be helpful in identifying cost-effective environmental policies. The discussion in paragraph 3.2.3 made it clear that results from different studies are not fully comparable to each other. Hence one cannot say that technique A is preferable to technique B because study X has calculated a cost-effectiveness of A of € 20 per tonne CO_2 and study Y has estimated the cost-effectiveness of technique B to € 30 per tonne CO_2.

In order to make results comparable, one has either to recalculate the results (CE, 2005) or to apply statistical techniques like meta-analysis (Bergh, 1997). Both are time-consuming efforts that fall outside the scope of the present study. For these reasons, we will focus in the remaining part of this study only on comparable results within studies, without comparing results from different studies. If study X has shown that A is more cost-effective than B, this is probably true *for the range of cost-categories that were taken into account in study X*. If study X has only taken a few cost-categories into account, the outcomes are partial at best.

3.3 Drivers for the development of cost effectiveness over time

Most future CO_2 emission reductions, both in the transport sector and elsewhere, are expected to come from new technologies, and improvements of currently available technologies. Some of these technological options are already on the shelf, but not in the market on a large scale. Others are still in the R&D stage, not yet ready for market introduction.

Experience with technological development in the past shows that the cost of new technologies follows a learning curve, and reduces over time. If the technological development is successful, costs reduce over time due to, for example, optimisation of the technology, efficiency gains in production and economies of scale in the production process.

Therefore, both cost and cost effectiveness of new technologies are generally unattractive as long as the technologies are immature. They may, however, become more competitive and even outperform more conventional technology once they are developed further, and large scale market access has been achieved. Deriving a long term strategy for CO_2 reduction in the transport sector thus requires insight into the potential development of cost and cost effectiveness of the various mitigation options. Constraints on the improvement of cost effectiveness that are not likely to change over time have to be separated from factors that are susceptible to improvement over time.

3.3.1 Technological development and learning

Various stages can be identified in the life-cycle of a technology. Different schemes and stage definitions have been derived in literature, one of these is shown in Table 3. Each stage typically takes several decades, however, they are not always well defined, and tend to overlap. Clearly, not all technologies will reach all stages, only the successful ones.

Table 3 Stages of technological development, and typical characteristics (from (Junginger, 2005))

Stage	Mechanism	Cost	Commercial market share
1 Invention	Seeking new ideas, breakthroughs, basic research	High	0%
2 Research, development and demonstration (RD&D)	Applied research, research development, demonstration projects	(Very) high	0%
3 Niche market commercialization	Identification of niche applications, investment in field projects, learning by doing	High, but declining	0-5%
4 Pervasive diffusion	Standardization and mass production, economies of scale, building of network effects	Rapidly declining	Rapidly rising (5-50%)
5 Saturation	Exhaustion of improvement potentials and scale economies, arrival of more efficient competitors on the market	Low, sometimes declining	Maximum (up to 10%)
6 Senescence	Domination by superior competitors	Low, sometimes declining	Declining

In each of these stages, different learning mechanisms and scale effects apply, that both may reduce cost. Utrecht University (2005) identifies the following mechanisms behind technological change and cost reduction:

- Learning-by-searching.
- Learning-by-doing.
- Learning-by-using.
- Learning-by-interacting.
- Upsizing (or downsizing).
- Economies of scale.

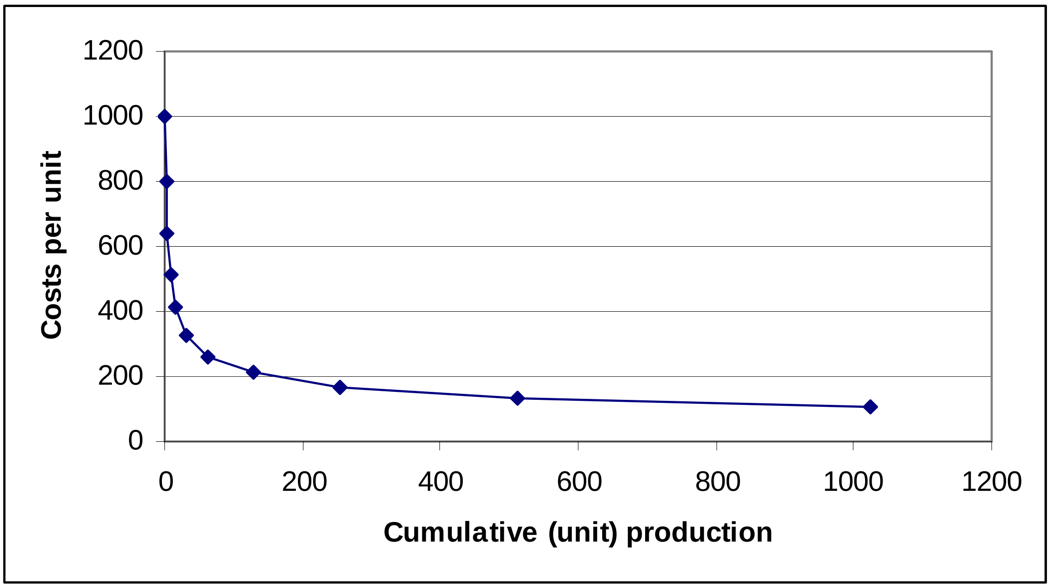
Often, combinations of these factors occur in each stage, although not all may apply for all technologies. Competition between manufacturers eventually brings the price of new technologies down sharply.

It should be noted that these learning and scale effects are not limited to technological development and production itself, but also occur at the user level (Sandén, 2005). For example, the increasing adoption of a technology will decrease the uncertainty of its merits and service costs will decrease with user experience. Furthermore, it may become more attractive to use a good once its market share is increasing because complementary goods, services and spare parts will be available on an increasing scale and lower cost.

3.3.2 Effect of experience and economies of scale

Clearly, cost reduction can be achieved both by experience (learning) and by increasing the scale of production. However, even though the different stages and mechanisms are known, predicting the cost curve over time for a specific new technology is very difficult. In order to learn from the past, these cost curves have been derived for various technologies with hindsight. Often, a relationship is found between the cost development of a product or a technology and its cumulative production. In literature, the parameter progress ratio (PR) is often used to describe this relationship. PR describes the rate at which costs decline for every doubling of production. For example, a PR of 0.8, or 80%, equals a 20% cost decrease for each doubling of the cumulative capacity. To illustrate this effects, a typical cost curve is shown in Figure 1, for PR = 80%. In this example, the cost of one unit starts at 1,000, but reduces sharply once production and sales volumes increase.

Figure 1 A typical cost reduction curve, with PR=0,8: costs per unit reduce sharply with increasing (cumulative) production volumes



Utrecht University (2005) analysed the cost developments of various renewable technologies in the past decades. For onshore wind farms, PR values were found to lie between 77-85%. For electricity from biomass-fuelled CHR plants, PR values of 91-92% were found. For biogas production costs, the PR was 85% from 1984 to the beginning of the 90s. In the period between the early 90s and 2002, cost reductions were insignificant, leading to a PR level of approximately 100%. (Goldemberg, 2004) analysed the cost development of ethanol production in Brasil. They found a PR of 93% in the timeframe 1980-1985, and of 71% in 1985-2002.

For each technology, the cost reductions were found to be due to different types of learning. For example, in the case of biogas plants, a local, small scale technology, learning-by-using and learning-by-interacting were found to be the most important learning mechanisms. For CHP plants, up scaling was probably the main mechanism behind cost reduction.

4 Cost effectiveness of transport measures

4.1 Introduction

In the following paragraphs, cost effectiveness of technical CO_2 mitigation measures in the transport sector are compared to technical measures in other sectors. Firstly, measures that improve fuel economy of vehicles are compared to energy savings in other sectors. Then, in section 4.3, biofuels are compared to the use of biomass for CO_2 mitigation in other sectors. In section 4.4, a similar assessment is made for hydrogen.

4.2 Fuel economy and energy savings

This section discusses expectations for the cost effectiveness of measures related to vehicle fuel economy and compares them with the results for similar measures in other sectors.

4.2.1 Fuel economy typology

Fuel economy measures cover a range of approaches including engine optimization, hybride drives and lowering the weight of cars. Fuel economy can be stimulated by three distinct types of measures:

Type 1 Technical adaptations in vehicle design, such as downsizing, port injection, direct injection, hybrid drives, etc.
Type 2 Behavioral changes in driving, i.e. fuel efficient driving.
Type 3 Behavioral changes in purchasing automobiles (consumers switch to smaller or lighter or more fuel efficient vehicles such as diesel engines).

Aspects like modal shift or less transport are not considered to be part of fuel economy as these include substitution and volume aspects and not strictly efficiency-aspects.

Many governments around the world have adopted polices to improve the fuel economy of road transport. Official arguments differ from a reduction of greenhouse gas emissions in Europe to security of energy supply in the US and China (An and Sauer, 2004).

4.2.2 Costs of fuel economy

There is a vast body of literature estimating costs of fuel economy measures, especially for light vehicles. Yet there is remarkably little consensus on the actual costs of these measures. In particular, there is debate whether the benefits of fuel economy measures (i.e. saved fuel) outweigh the costs. While some studies (i.e. Greene and Schafer, 2003; NRC, 2002; Department for Transport, 2003; T&E, 2005) indicate that costs would be negative (i.e. measures for fuel economy would generate benefits), other studies indicate moderate to substantial costs for fuel economy measures (EC, 2004; ACEA, 2006).

So how do we evaluate such contradictionairy results? As remarked earlier in this study, results from various Cost-Effectiveness Analyses are hardly comparable due to differences in methodology. In paragraph 3.2.3 we identified five reasons why results from different studies should not be compared with each other. For fuel economy measures, there is an additional sixth reason: studies generally compare different type of measures within the set of fuel economy measures and take only a partial view at the types of measures available. Studies that tend to orient on Type 1 measures (see above) calculate in general higher costs than studies that orient on Type 2 or 3 measures. There is, to our knowledge, not a single study which has investigated the cost-effectiveness of all types of fuel economy measures in a single methodological framework[5].

Therefore, results from these studies may each be valid within the cost-accounting framework that has been developed in these studies. As the scope and time-frame of the present study does not allow us to do an in-depth analysis on the relative strengths and weaknesses of the dozens studies on fuel economy measures, we will try to develop below some general findings in the literature.

Finding 1: Technical adaptations in the engine design tend to generate net costs while behavioral changes tend to generate net benefits.
IEEP/TNO (2005) has investigated cost-curves for fuel efficiency improvements of new passenger cars, meeting the EU target of 120 g CO_2/km in 2012. They focus only on Type 1 measures differentiated for six car types. Cost estimates differ widely and depend on the methodologies used, but as a general conclusion, the authors state that “For the most cost-effective scenarios the average CO_2 abatement costs are between 34 and 71 €/tonne…”. (p78)[6]. Note that in this study, the average oil price of 2002 was used. Abatement costs will be lower at higher oil prices, since this will increase the fuel savings benefits.

The results by IEEP/TNO are echoed by EC (2004) that gives an overview of various technical measures in engine design that can be taken in order to lower CO_2-emissions of consumer vehicles. They estimate that the total average costs to society can be as high as 50 €/tonne CO_2 in 2015 if all measures are implemented resulting in a net reduction of almost 25% in 2015 compared to autonomous developments. However, they also define a more rational package of measures which would lower costs to 15 €/tonne and still result in a net reduction of nearly 20%.

Such results are –at first sight- contradicted by other studies (Capros, 1998; Greene and Schafer, 2003; NRC, 2002) that concluded that net benefits can be expected from fuel economy measures. However, closer inspection of the results from these studies teaches us that they mainly focus on Type 3 measures; i.e. smaller cars and a switch to diesel engines. We must notice, however, that these

---

[5] Also, none of the studies have seriously investigated potential rebound effects. If transport measures result in net benefits, rebound effects could be potentially high.

[6] These are societal costs presented as average costs to meet the targets (not marginal costs). Costs for manufacturers are even higher according to the authors. This leads them to conclude that if automobile industry were to be included in ETS (CO_2-emission trading scheme), they would probably be net buyers of rights instead of applying measures to their engines.

latter studies are considerably less detailed in their cost calculations which cast some doubts on the reliability of the results.
Type 2 measures also tend to generate net benefits. An ex-post evaluation of Dutch climate change policies by CE (Bruyn, 2005) showed that information campaigns aiming at improving driving behaviour have been very cost-effective, even though the total effect has been small.

Although there is no study that compares the various types of fuel efficiency measures, we suggest that the existing studies point at the fact that policies oriented at Type 2 and 3 measures tend to be more cost-effective than policies oriented at Type 1 measures. Whilst Type 1 measures can potentially deliver more abatement.

Finding 2: Steep marginal increases in cost-functions for Type 1 measures exist
Both IEEP/TNO (2005) and EC (2004) show that there exists a range of technical measures that can be implemented at costs below the 20 €/tonne CO_2. However, further reductions seem to be expensive at present. The IEEP/TNO study concludes that the marginal costs of meeting the 120 g CO_2/km target for new passenger cars can be as high as 140-180 €/tonne.

From IEEP/TNO (2005), EC (2004) and TNO/IEEP (2004) we conclude that policies should be carefully targetted in order to minimize costs. TNO/IEEP (2004) also concludes that a policy setting intermediate targets (i.e. linear targetting) is more cost-effective than policies setting targets somewhere distinct in the future.

It is unclear whether costs can be expected to decline in the long run due to technological developments. Some expect that due to developments of alternative propulsion techniques cost curves may in the end shift downwards again (ACEEE, 1998) and (US-DOE, 2000). We note here that technological breakthroughs are difficult to include in cost-effectiveness analysis and, as outlined in Chapter 3, there is a general trend to overestimate costs ex-ante.

Finally, we notice that the cost effectiveness data for heavy duty vehicles and other modes are very scarce, even though feasible CO_2 reduction measures have been identified. For example, in the maritime sector (Marintek, 2000) has shown that there is significant potential to reduce emissions of CO_2 with technical and operational measures. However, this study did not calculate cost effectiveness of these measures. There is in general a need to compare the costs of fuel efficiency measures for consumer vehicles with fuel efficiency measures for other transport modes.

4.2.3 Costs in relation to other sectors for efficiency measures

It is difficult to assess the cost-effectiveness of measures in the transport sector with other sectors due to a lack of studies that integrate a detailed account of fuel economy measures in the transport sector with similar types of energy savings in other sectors in the economy.

Ex-ante estimations of average cost effectiveness of energy saving measures in buildings range from about 40 to 120 €/tonne CO_2 (IPPC, 2001; DEPA, 2005), industrial savings are in general more cost-effective. From the ICARUS-4 database (Alsema en Nieuwlaar, 2001), an ex-ante modelling result into the costs of energy saving measures in industry and dwellings, more than 700 options to reduce energy demand have been identified. Some measures do generate net benefits to society, yet, they have not been implemented so far.

The studies that do present an overview of cost-effectiveness between sectors are hampered by their limited account of fuel economy measures. For example, Capros (1998) documents how, initially, cost-curves for the transport sector have been modelled in the influential PRIMES model and compares this with other sectors. Table 4 gives the average costs of a 9.8% cut in CO_2 emissions in the EU according to the PRIMES model (National Technical University of Atens, 1998) to meet the Kyoto targets.

Table 4 Average costs of CO_2 reduction in 2010 compared to 1998, in €/tonne (1990 prices) according to PRIMES

	Industry	Service	Transports	Power sector	Households
EU (8 countries)	73	26	-105	25	142

The measures in the transport sector are solely built up from improvements in the fuel economy of cars resulting in new, lighter, car models with downsized engines. As the additional capital costs of developing such cars (+15%) are relatively low in comparison with the average fuel savings (35%), the resultant is negative costs per tonne CO_2. It should be noted that eventual losses in comfort or safety are not taken into account in the PRIMES model. Hence, Table 4 is only valid if Type 3 measures have been taken into account. Measures for the other sectors reflect mainly energy savings measures.

Another example is the recent ex-post evaluation of climate change policies in the Netherlands, where the costs of climate change policies have been evaluated between 1999 and 2004 (ECN, 2005; CE, 2005). Table 1 gives an overview of the outcome of the Dutch evaluation (CE, 2005).

Table 5 National average costs of climate policy measures, 1999-2003, €/tonne CO_2 (2004 prices)

	Built environment	Agriculture	Transport	Industry	Renewable Energy	Non-CO_2	National total
Cost effectiveness	20 to 70	2 to 20	-30 to -25	15 to 30	100 to 300	10	40 to 90

Of course, these values depend on the type of policy that has been conducted. For transport, this has been mainly information measures related to altering behaviour in driving (so-called as ecodriving) – in our scheme this refers to Type

2 measures. Only very few technological measures were promoted in the period investigated.

For the future, several studies have indicated a large potential for carbon capture and storage. The costs for new power plants may range between 30 and 50 €/tonne CO_2 (Rao and Rubin, 2002). Costs of retrofitting existing power plants may be a factor 1.5 to 2 times higher. Hence these costs may be competitive to especially renewable energy but energy savings measures are in general still more cost-effective than CO_2 capture and storage.

4.2.4 Effectiveness of fuel economy measures compared to other sectors

The analysis so far has oriented on costs of measures to raise the fuel economy of cars. There is quite some evidence that altering driving behaviour or a switch to lighter vehicles will generate net benefits to society, and that measures intended to improve engine design tend to generate costs. This would indicate that cost-effective climate change policies in the transport sector should orient on behavioral changes instead of technological changes.

However, the ex-post evaluation in the Netherlands (see above) showed that, though the costs are negative for the transport sector, the effect of policy measures to alter driving behaviour in the transport sector have been marginal. Also the ex-ante policy evaluation in New Zealand (Ministry of the Environment, 2005) concludes that that there are substantial and cost-effective gains available from energy-efficiency improvements in the residential, commercial and industrial sectors. Options to capitalize benefits in the transport sector are considered to be minimal (for Type 2 or Type 3 measures), or very expensive (for several Type 1 measures).

This makes the most promising fuel economy measures in the transport sector paradoxical: cheap but hard to get. This is emphasized by the various studies that have calculated the impacts of a genuine CO_2-tax or tradeable permit system for all sectors in the economy. For example, the EEA (2005) has investigated the possibilities of policies and technologies for a transition to a European low-carbon energy system in the year 2030. They investigate a low carbon energy pathway (LCEP) scenarios in which carbon prices determine the development of the energy system to illustrate the development of energy demand The study concludes that in the case of reasonable development of CO_2 prices (tradeable permits), the power sector would be the most promising and cost-effective way to achieve emission reductions, mainly through fuel shifts. The share of the contribution of end-use sectors' (i.e. transport, households, services and industry) in overall emission reduction would fall from 43% in 2010 to 28% in 2030. In the LCEP scenario, renewable energies show the largest increase compared with the baseline, driven by a significant increase in wind power and biomass. Combined heat and power contributes to improving efficiency and increases its share in electricity production to 17–28 % in 2030.

Hence, the EEA study concludes that in case CO_2 has a genuine price in the economy, the main shifts take place on the supply side through fuel mix changes, and that energy efficiency improvements on the demand side are becoming less important, partly because the easy options to save energy have already been exploited.

In the EEA study, the choice between supply and demand options to reduce the emissions of GHGs is made on the basis of cost-effectiveness only, in line with the introduction of a uniform carbon tax. The analysis therefore provides an indicator of the 'elasticity' of a particular sector, i.e. how much it is flexible and can shift to low or zero-carbon fuels and more efficient technologies, or even reduce its energy demand given the cost of options. One conclusion from the EEA study is therefore that the transport sector is rather irresponsive to price changes. Such results are repeated in other studies. Mantzos (2004) concludes that the tertiary and household sectors are the most responsive sectors to price changes whereas both industry and the transport sector exhibit only a limited reaction to price increases, certainly in a time span of 20-25 years.

For transport, the main reason why a carbon tax would have limited effects is that price elasticities tend to be substantially smaller than the income elasticities of demand. From Goodwin (2004) we conclude that the price-elasticity of total transport demand can be 0.6 in the long run and the income-elasticity of demand is a factor 1.5-3 higher[7]. This implies that price of fuels must rise faster than incomes to curb CO_2 transport emissions if the price mechanism is used as the principal policy tool.

One reason for the low price elasticity is that environmentally motivated price increases are largely invisible within the overall movement in fuel prices caused by volatility in international oil markets. Another reason for a relatively low price elasticity is that buyers of new cars generally only consider the first three years of fuel savings, and not the fuel savings over the life of the car (NRC, 2002; RIVM, 2001). This results in behaviour at the moment of car purchase that although rational for the consumer does not maximize welfare – which, in general, takes a longer time horizon into account. Furthermore, potential benefits for consumers over the car's life time are small, while risks for producers are high (Greene, 2005). The benefits for most technological measures stimulating fuel economy accrue to the consumers, while the costs are located at the manufacturers. Manufacturers are not able to pass these costs entirely to the consumers because they discount future savings heavily at the moment of purchase. This is clearly a kind of market-failure and correcting it requires economic instruments that provide incentives at the moment of purchase.

---

[7] The 0.6 figure includes less transport and modal shift. Based on the results by Goodwin (2003), the specific elasticity for fuel economy alone can be determined as being around 0.3. in the long run, fairly low.

4.2.5 Fuel economy: some preliminary conclusions

The investigation into the costs and effects from fuel economy measures showed that for a comprehensive analysis technological measures should be distinguished from behavioral measures. While technological measures tend to result in net costs to society, behavioral measures tend to generate net benefits. The main problem is, however, that behavioral measures are difficult to enforce by environmental policies. Consumers tend to be rather irresponsive to price changes and altering behaviour is more difficult than a policy oriented on setting standards for car manufacturers.

At the same time we notice that policies oriented towards persuading consumers to buy smaller cars have not been fully exploited. As prices of fuel have been risen less than incomes, one should not be surprised for the growing demand for larger and heavier consumer vehicles. A rethinking of the use of the price mechanism may be required for policies to be more effective.

This results in the following observation for the costs and opportunities for policies stimulating fuel economy differentiated between the various types of measures.

Table 6 General classification of costs and political effectiveness of various fuel economy type of measures compared to energy savings in industry and service sectors[8]

Type of measure	Costs	Political effectiveness
Type 1: Technological measures	Average to very high (steep marginal increase in cost-curves)	High
Type 2: Driving behaviour	Very low (benefits only)	Low
Type 3: Purchasing behaviour	Low	Average (not yet fully exploited)

4.3 Comparison of biofuels with biomass use in the electricity sector

In recent years biomass has become one of the fastest growing renewable energy sources in the EU. Biofuels are promoted in the transport sector, and biomass is used in power stations, where it replaces coal. More and more biomass residue streams are used for energy applications, and an increasing amount of crops are cultivated for energy and biofuel applications, but biomass supply can be expected to be limited in the future. Biomass cultivation requires large areas of agricultural land (although ideal characteristics may differ between different types of biomass), which means that it will have to compete with other functions, such as food production, nature reserves, etc. Furthermore, large scale biomass cultivation (especially in monoculture) may have a negative impact on biodiversity of an area, and it may have impacts on surrounding areas, for example on the water management.

---

[8] We use the term political effectiveness to illustrate whether the reduction potential can be influenced by political measures. It is closely connected but yet quite distinct from political feasibility which deals with the practical realms of policy making. For example, tightening CO_2 emission standards may not be political feasible given the large interests of car manufacturing in the EU, but in theory the instrument could be quite effective though.

When looking at GHG reduction and energy diversification policies, it thus makes sense to assess:

a In what sector the available biomass can be used best.

b How biofuels compare to other CO_2 mitigation options in the transport sector.

In the following paragraphs, these two issues will be addressed from a cost effectiveness point of view.

4.3.1 Comparison of the various biomass applications

In this assessment, various different types of biofuels should be distinguished since both cost and GHG emission reduction depend on the biomass used and conversion process applied. In addition, as was discussed in chapter 3.3, costs of biofuels (in fact, of any technology) can be expected to reduce once the production increases, due to for example scale effects, network effects and learning.

An overview of the various types is given in Table 7. Note that bioethanol from sugarcane, as produced in Brazil, is already a relatively mature technology with large production volumes since the 1990s (Goldemberg, 2004). The so-called second generation biofuels, on the other hand, are still in the R&D stage. Biodiesel from rapeseed oil and bioethanol from grains or sugar beet are biofuels with mature technologies that are currently gaining market access fast, with rapidly increasing production volumes over the past years.

Table 7 The various types of current and potential future biofuels, and the biomass that is used as feedstock

Biofuel	Mainly produced from	Comments
Currently available		
Fisher Tropsch diesel	Woody biomass (e.g., forest residues, straw, fast growing woody crops such as miscanthus, …)	
Bioethanol	Woody biomass (e.g., forest residues, straw, fast growing woody crops such as miscanthus, …)	Various technologies are being developed
HTU diesel	Dry and wet organic biomass (such as organic waste)	HTU = Hydro Thermal Upgrading

When biomass is used for electricity production, several potentially attractive options exist (CE, 2003, 2005):

1 In coal-fired power plants with:
  a Indirect co-combustion of biomass.
  b Gasification-based co-firing.
2 As a substitute for heavy fuel oil in refineries.
3 As a substitute for natural gas in other combustion plants.
4 Combined gasification and electricity production, using pressurised circulating fluidised-bed gasification in combination with syngas utilisation in a combined cycle.

5 Combined combustion and electricity production, using large-scale circulating fluidized bed gasification with a high-pressure steam cycle and steam heating.

The first three are based on currently commercially available and proven technology, the latter two are state-of-the-art and currently under development.

Recently, several studies looked at the comparison of biomass for transport fuels or for the electricity sector. In (CE, 2003), a comparison is made between biofuels and electricity based on biomass for the timeframe 2005-2010. In (CE, 2005), the two applications of biomass were assessed for the timeframe 2010-2020.

In (Concawe, 2005), the GHG reduction potential of a number of biofuels and electricity routes were compared, assuming equal land use for the biomass cultivation. The result of this assessment is thus crop land efficiency, a comparison of Mtonne CO_2-eq avoided, per hectare per annum[9].

The cost effectiveness of a biofuel is defined as the additional cost of the biofuel, compared with the conventional fuel it replaces, divided by the GHG reduction that is achieved with this replacement. A similar definition holds for the use of biomass in the electricity sector. Cost effectiveness of both routes thus depends on quite a number of variables, as shown in Table 8. Some of these variables are related to the biofuel or bioelectricity technology, some are related to the fossil fuel that is replaced.

Table 8 The various items that affect the cost effectiveness of biomass use for biofuels and electricity generation

Biofuels	**Electricity**
Items that affect additional cost of biofuels	
Costs in the biofuel chain: • The biomass feedstock. • The conversion process. • Transport and distribution of the biomass feedstock and the biofuel. • Revenues from by products.	Costs in the biomass-to-electricity chain: • The biomass feedstock. • Transport of the biomass. • Processing cost.
Costs of the fossil fuel it replaces • The oil price. • Transport, refinery and distribution costs.	Costs of the fossil fuel it replaces: • The coal or natural gas price. • Transport costs.
Items that affect GHG emissions	
GHG emissions from the biofuel chain due to: • Biomass cultivation. • Process emissions and energy use. • Transport and distribution. GHG benefits might occur due to the production of by products.	GHG emissions from the biomass-to-electricity chain, due to: • Biomass cultivation and transport. • Process emissions and energy use.
GHG emissions of the fossil fuel chain: • Oil production and refining. • Transport and distribution.	GHG emissions of the fossil fuel chain: • Gas production and coal mining. • Transport and distribution.

---

[9] Unfortunately, bio-ethanol from Brazil was not included in these studies.

In both the biofuel and the electricity routes, various options are available and new, more efficient processes are being developed. In this study, it will not be attempted to quantify the costs and GHG of each of these routes. Rather, a more general analysis will be performed, based on the literature cited above.

4.3.2 Results

The results of (CE, 2003) and (CE, 2005) are shown in Figure 2 to Figure 4, for two different oil prices: \$30 and \$60/barrel[10][11].

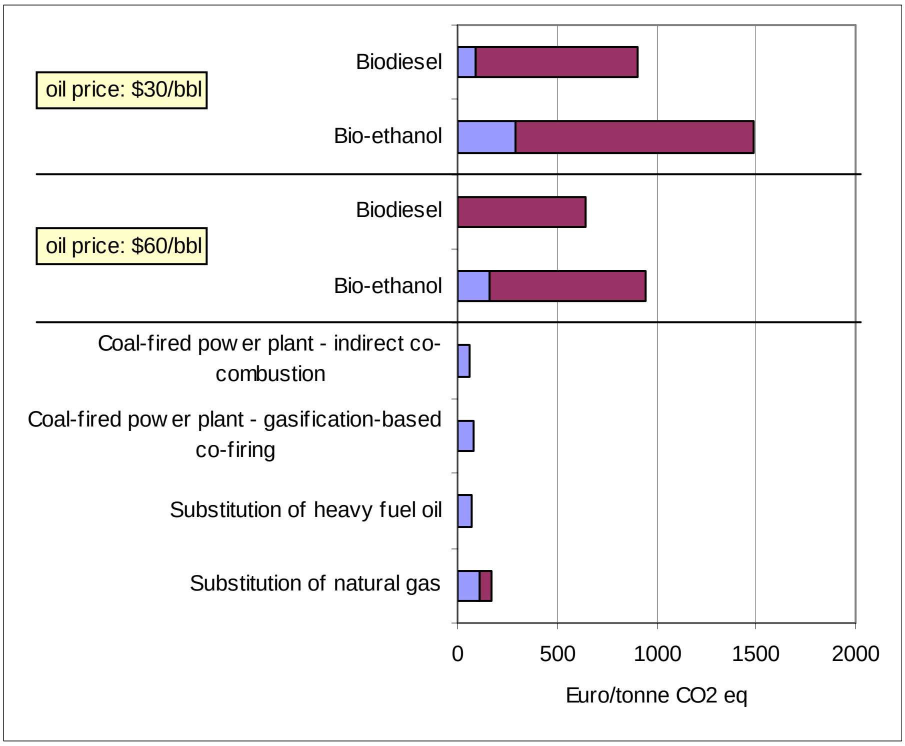
Figure 2 shows the cost effectiveness of the biofuels investigated for the timeframe 2005-2010, at these two oil prices. The results show that the average cost effectiveness of these biofuels is much less favourable than that of biomass use in the electricity sector. In the latter route, the biomass can best be used to replace coal, rather than natural gas or heavy fuel oil. These higher oil prices reduce the additional cost of biofuels, which leads to a significant improvement of the cost effectiveness figures. Nevertheless, the average cost effectiveness is still less favourable than that of the electricity routes. It is also worth noting that the ranges are very large in the biofuel cases, due to ranges in both cost and greenhouse gas emissions. In the best case, the cost effectiveness of the biofuels can be comparable to that of the electricity routes, but on average, the biofuels perform much worse.

---

[10] The CO_2 abatement costs of the various current and future biofuels are also calculated in Concawe, 2005. Results are comparable to the ones shown here. We use the CE studies in this report because they specifically compare biofuels with the use of biomass in the electricity sector.

[11] These represent the average oil price of oil imports into the EU during 2002-2004 and the average oil price of oil imports into the EU in August/September 2005 respectively.

Figure 2 Estimates for cost effectiveness of greenhouse gas abatement with biomass, comparison of current biofuels with the use of biomass in the electricity sector, at two different oil prices, in the timeframe 2005-2010 (CE, 2003, 2005)

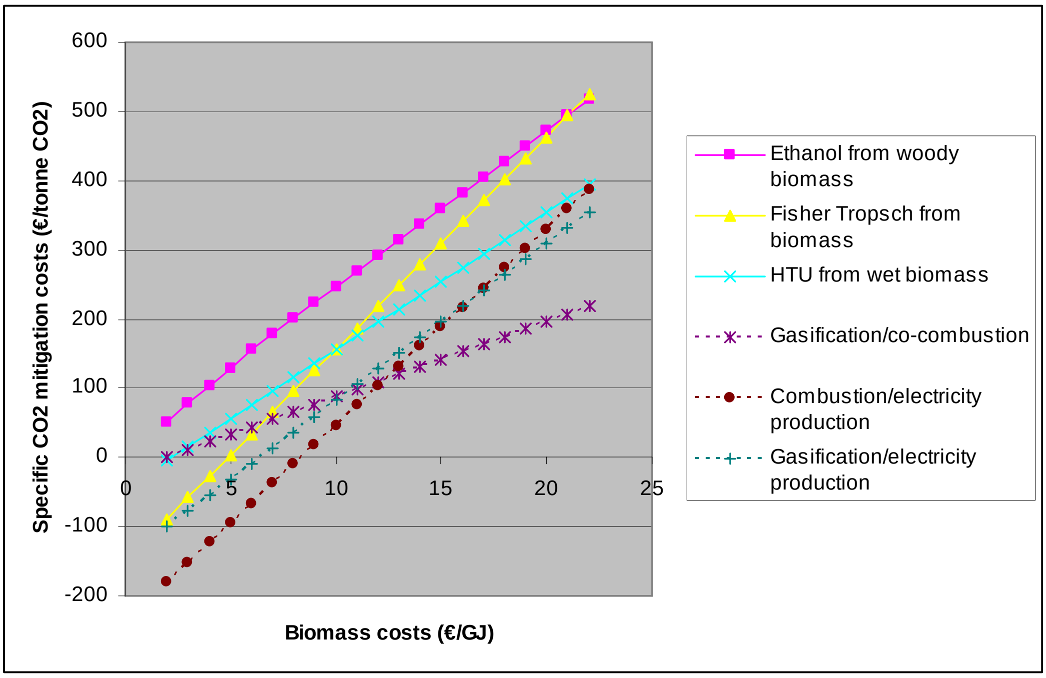


NB. The red bars indicate the ranges in the data.

Figure 3 and 4 show the results of (CE, 2005), in which the longer term (2010-2020) was analysed. Clearly, as the 2nd generation biofuels technologies and some of the electricity routes are still in the R&D stage, these data can only be estimates, using best estimates from literature regarding likely processes, efficiencies and cost. In the calculations, it is assumed that the technologies are applied in large-scale production facilities.

Again, results are shown for two different oil prices, $ 30 and $ 60 per barrel. Since future biomass costs are also uncertain, these are varied in the graphs. Uncertainty ranges are also significant, but are not shown for readability reasons. These figures illustrate that biobased electricity generation is likely to remain a more cost effective application for biomass in the future (at least until 2020), even compared to the more cost effective 2nd generation biofuels. However, these future biofuels may achieve comparable performance in case of high oil prices, stable (i.e., low) coal prices and low biomass prices. The graphs furthermore show that in both routes, cost effectiveness strongly depends on the biomass cost. Future biomass costs are currently anticipated at 6 €/GJ for 2010 and beyond (CE, 2005).

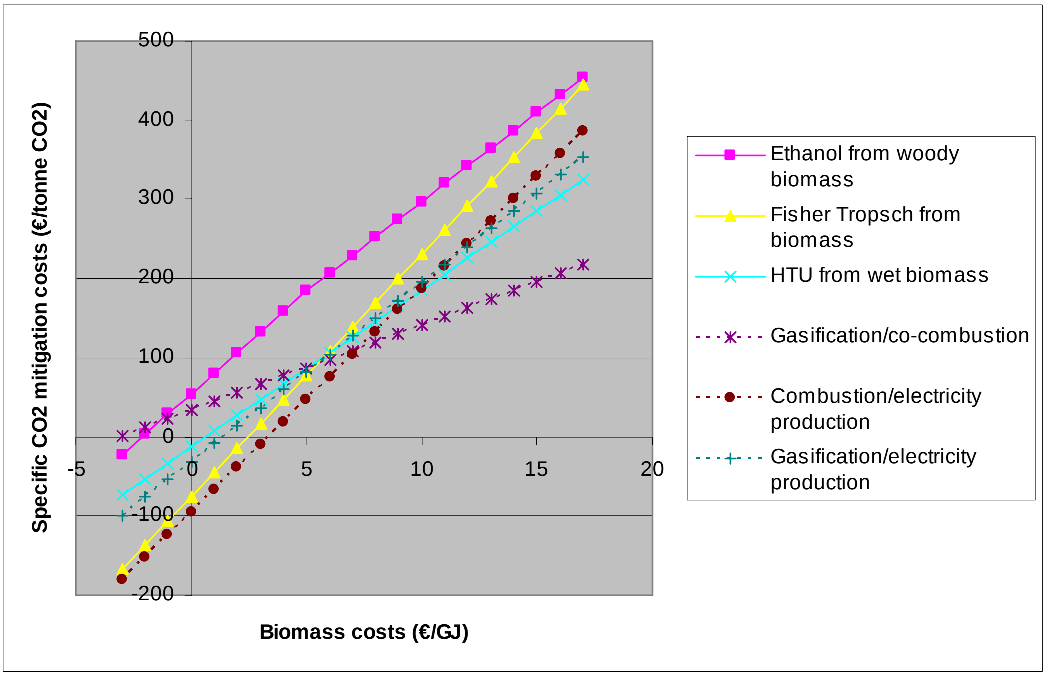
Figure 3 Estimates for cost effectiveness of greenhouse gas abatement with biomass, comparison of various 2nd generation biofuels with biomass use in the electricity sector, *at oil prices of appr. 30 $/bbl*, in the timeframe 2010-2020



NB. Uncertainty ranges are not shown in these graphs for readability reasons. HTU stands for Hydro Thermal Upgrading process, which can convert dry or wet biomass into diesel.

Source: CE, 2005.

Figure 4 Estimates for cost effectiveness of greenhouse gas abatement with biomass, comparison of various 2nd generation biofuels with biomass use in the electricity sector, *at oil prices of appr. 60 $/bbl,* in the timeframe 2010-2020



NB. Uncertainty ranges are not shown in these graphs for readability reasons. HTU stands for Hydro Thermal Upgrading process, which can convert dry or wet biomass into diesel.

Source: CE, 2005.

In the short term, the main reasons for the less favourable cost effectiveness of biofuels are the additional cost and processing energy of the processing steps required to convert the biomass to a high-quality transport fuel[12]. Cost effectiveness is highest when the biomass is used to replace coal-based electricity generation.

In the longer term, the most cost efficient electricity production process is determined by the biomass cost. Gasification and co-combustion of raw syngas in a coal-fired power plant scores well for high biomass costs, whereas combustion and electricity production in a large-scale circulating fluidized bed gasification with a high-pressure steam cycle and steam heating is most cost efficient when biomass costs are relatively low.

In (CE, 2005) it is shown that in the future, advanced biofuel processes might achieve similar efficiencies to biomass use in power stations, and require comparable investment costs (in €/$GJ_{biomass}$), but only if the more optimistic predictions in relation to the production technologies prove to be right. The main differences in cost effectiveness then stem from the higher market value of electricity, compared with fuels. There is no indication, however, that the cost effectiveness of these biofuels will become better than the specific greenhouse gas mitigation costs related to biobased electricity generation.

In conclusion, from a cost effectiveness point of view, biomass can better be used in the electricity sector to replace coal, than in the transport sector as a replacement of petrol or diesel. In the longer term, the differences in cost effectiveness are expected to become smaller. To achieve this, however, biofuels need to be developed that perform much better than current biofuels, both regarding GHG reduction and cost. Bio-ethanol and Fisher-Tropsch diesel, both from woody crops, are likely candidates, but perhaps also other 2nd generation biofuels such as HTU diesel can meet these criteria.

4.4 Hydrogen for transport?

Hydrogen and fuel cell technologies offer potentially significant reduction in emissions of transport and other power applications in the future, but their use will remain at very low levels in the next 20 to 50 years (EEA, 2005). At the moment the use of hydrogen as a (transport) fuel is limited to research and demonstration programmes. Examples for this are the EU CUTE project, the HyChain project and several demonstration programmes of vehicle manufacturers, governments and NGO's[13]. It is expected that market penetration will be driven initially mainly by small portable fuel cell applications for handheld electronic devices, followed by stationary combined heat and power plants (CHP, first for individual houses and small commercial premises, later as large CHP

---

[12] Costs of biofuel transport distribution to petrol stations might also be higher than of fossil fuels. However, it is assumed here that logistics will be optimised, and associated costs and GHG emissions will be comparable to that of fossil fuels.

[13] For more information, see www.hfpeurope.org.

systems) (EC, 2005). Commercial application in transport is not expected to happen before 2020 at the very earliest. The main bottlenecks are (CRS, 2004; EC, 2005):

- Technological bottlenecks (Storage, durability and mass production techniques).
- High costs (fuel and vehicle).

There are many hydrogen production pathways, but since CO_2 mitigation is the central theme in this report we neglect fossil pathways as e.g. onboard generation of H_2 from e.g. gasoline. We thus assume that H_2 is produced by either renewable electricity, coal with CO_2 sequestration or biomass.

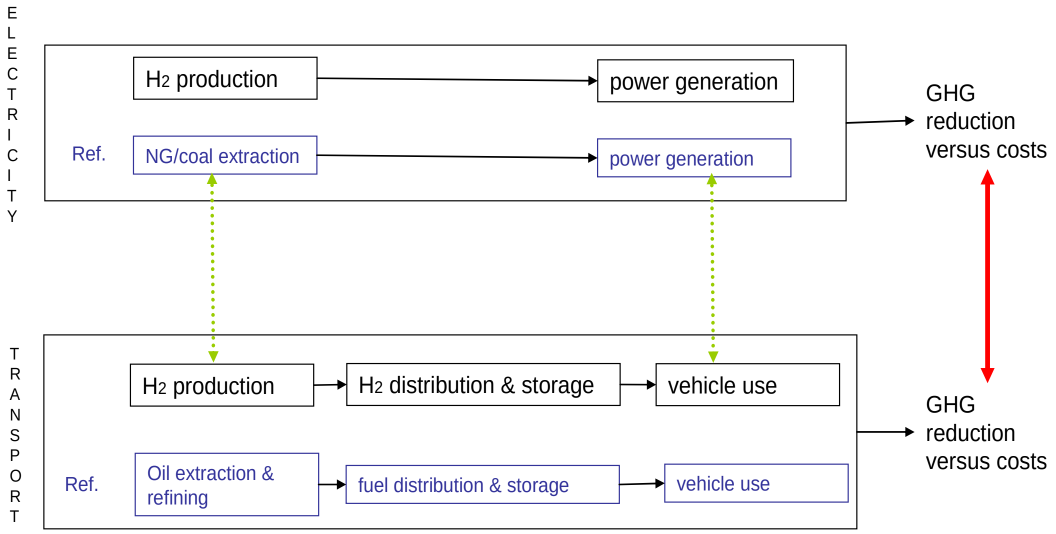
When comparing the (future) cost effectiveness of hydrogen in transport with that of other sectors, two approaches can be taken. First, the application of hydrogen in transport can be compared with the use of hydrogen in other sectors. In the second approach it is assumed that the hydrogen is produced from renewable energy. Then, the use of this hydrogen in transport can be compared to the direct use of this renewable energy in other sectors. In the following paragraphs, both routes are analysed.

4.4.1 Comparison of hydrogen use in transport and power generation

In this section we deal with the question what the most cost-effective application of using hydrogen is: transport or large scale power application?

In Figure 5 we depict the two H_2 fuel cycles that can be compared and their fossil reference technologies. To asses the pathway with the highest cost effectiveness, we compare both possible H_2 routes on costs and GHG emissions with their fossil counterpart. By determining by step the impacts on costs and CO_2 of a change from the reference fuel to H_2 an overall qualitative conclusion can be drawn.

Figure 5 Schematic overview of H_2 production pathways and their fossil reference technologies



Efficiency (CO_2)
The efficiency of current internal combustion engines (ICE) – either a gas turbine, a diesel engine or a petrol engine - is around 25%-35%[14]. The efficiencies of the engine parts are generally comparable. A power generation plant has a somewhat higher efficiency than a vehicle, but this is due to the excess steam condensation. The replacement of an ICE by a fuel cell (50% efficiency on average) delivers therefore an equal efficiency gain for the engine part of the fuel chain.
The same is more or less true for the fuel extraction phase and the carbon content of the fuels used. The efficiency of oil exploration and refining is comparable with natural gas/coal extraction (University of Technology, 2002).

The replacement of the fossil automotive fuel chain by its H_2 counterpart causes considerable additional energy consumption in the distribution and storage phase. Distribution can take place in either the gaseous phase (CH_2 by pipeline) or in the liquid phase (LH_2 by road transport), but in the liquid phase is the most preferable because of the low energy density of gaseous H_2. Available H_2 liquefaction techniques have an energy efficiency of about 60%, future systems could reach an efficiency of around 80% (Bossel, 2003). Road distribution of LH_2 needs around 20 times the amount of energy needed for distribution of liquid fuels, because of the low energy content.

Storage of hydrogen is another energy intensive step. The storage of 1 unit of H_2 in a vehicle costs about 1-1.2 unit of energy, depending on the pressures used. In other words, the efficiency is around 40-50%. Storage may be needed twice: at the refuelling station and in the vehicle. The use of metal hydrides is studied at the moment. This may reduce the energy consumption of storage to around 12% (Heung, 2003), (Bossel, 2003).

We conclude that the large scale power generation would generate the highest yield in the reduction of energy consumption and hence this chain generates the highest CO_2 reduction. This is mainly due to the lack of storage and distribution energy consumption, since H_2 gas can be directly transformed into electricity.

Small scale power generation has similar transportation and storage drawbacks as automotive use.

Costs
Looking at the costs, we see two cost items that play an important role:
- Fuel cell costs.
- Costs for distribution and storage of hydrogen.

Fuel production plays a more limited role. We assume that a change from oil to hydrogen has roughly the same costs associated as a change from natural gas/coal to hydrogen.

---

[14] Marine diesels often have a higher efficiency, they can reach 50% at most.

Distribution and storage of hydrogen in the automotive fuel cycle is an additional cost item compared with the current situation for vehicular use. In the case of power generation, this plays only a marginally role. Additional energy consumption plays a role, but also research and investments in infrastructure and storage techniques.

On the basis of the limited information available we assume that the application of a fuel cell in power generation is cheaper than in transport. The cost increase of a vehicle engine is around factor 10 under mass production of fuel cells (25-35 $/kW versus 195-325 $/kW) (USDOE, 2003). For power plants, investments in a fuel cell power plant have been reported at around 3,000 $/kW. This is around a factor 3 over the current investments that are around 500-1,000 $/kW.

The use of fuel cells in automotive applications is technologically more difficult than stationary application. This is the reason that fuel cell vehicles are not commercially available at the moment. Dealing with worldwide possible ambient conditions, volume and weight reduction and resistance to shock and vibrations need to be solved before the commercial introduction of automotive fuel cells. It may be clear that these issues also have additional costs associated. Marine and rail applications may be somewhat easier than use in road transport, since volume and weight are less important. The same holds for heavy duty vehicles and buses, compared with passenger cars and light duty vehicles.

Conclusion: large scale power application most cost effective

This analysis shows that replacement of the fossil power generation fuel cycle with hydrogen fuelled power generation has a higher cost effectiveness than the replacement of fossil fuel in transport. This conclusion is in line with a recent report by CONCAWE, EUCAR and JRC (Concawe, 2005). In Table 9 an overview of the different steps is shown, with the best performing fuel cycle filled in per step.

Table 9 Costs and CO_2 effects: power generation and vehicle use compared

	Costs	**CO_2 effects**
Fuel exploration		
Transport	Power	Power
Final use	Power	

Note: the best performing fuel cycle is filled in. With empty cells, the differences are small.

Most important drawbacks of transport application are:

- Additional energy consumption and hence CO_2 emissions during distribution and storage.
- Additional costs in distribution and storage.
- Replacement of an ICE by a fuel cell in a vehicle is relatively more expensive than in power generation.

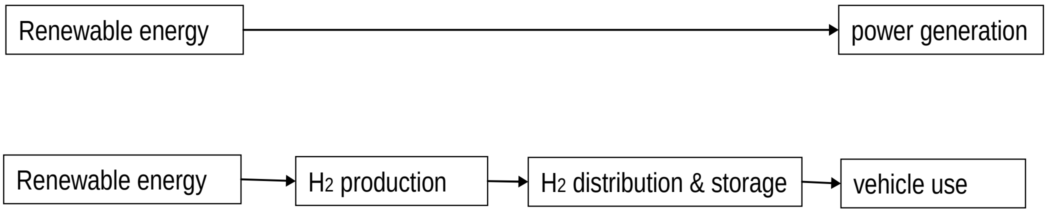
These drawbacks play an important role in the limited expectations of hydrogen for the next decades.

4.4.2 Renewable (or nuclear) energy: for hydrogen transport or power generation?

Currently, the production of electricity from small scale hydropower, biomass and wind are the most cost effective sustainable energy production routes. Climate neutral hydrogen can be produced from any of these renewable energy sources. However, they can also replace fossil sources more directly, by either directly feeding the generated electricity into the network or by replacing coal with biomass in a power station.

In this section we therefore compare the use of hydrogen in transport with power generation from renewable energy. In Figure 6 we depict an overview of these fuel chains.

Figure 6 Schematic overview of fuel chains based on renewable energy



The electricity route is less complex here than in the previous comparison, leading to reduced costs and higher efficiencies. The transport chain is the same as before, and will therefore suffer the same drawbacks of hydrogen in transport mentioned in section 4.4.1. Therefore, compared with electricity production from renewables, the distribution and storage of hydrogen and the use of an automotive fuel cell will always remain more expensive and have additional energy consumption and CO_2 emissions. Therefore optimised power generation from small scale hydropower, wind and biomass will generally remain to be among the most cost-effective options of renewable energy use.

The same conclusion can be drawn for nuclear energy: direct power production is very much more cost effective than using nuclear electricity to produce hydrogen for use in fuel cells. The difference is even more marked than in the case of small scale renewable electricity generation because of the scale of production of nuclear power and the relative efficiency of the electricity grid for distributing power compared to distribution systems for liquid or gaseous fuels.

4.5 Comparison of the various CO_2 mitigation options in transport

The previous sections focussed on the cost effectiveness comparison between technical CO_2 mitigation options in transport versus options in other sectors. In the following, we will compare the various technical options in the transport sector: fuel efficiency improvements, biofuels and, in the longer term, hydrogen.

From the previous paragraphs we can conclude that, at least in the next 5-10 years, fuel efficiency measures in vehicles are more cost effective than biofuels. The only exception might be biofuels produced in tropical regions: Brazilian ethanol can already compete with petrol at oil prices of approximately $ 50-55 per barrel (without import tariffs). Hydrogen is likely to remain a very expensive measure, since it is not expected to enter the market on a significant scale until (at least) 2030. In case of rail transport and (a segment of) passenger cars, renewable electricity might also be a viable option for electric rail traction and for battery powered cars.

Fuel efficiency improvements with currently known technology can be expected to get more expensive as fuel consumption is reduced further (as can be seen in (IEEP, 2005)). At some point in time, these measures have been implemented, and the law of diminishing returns is likely to become valid. The cost of further improvements will then increase, and cost effectiveness of these measures will become less attractive. If the industry is then pushed to improvement fuel efficiency further (e.g., by government policies), new technological solutions are likely to appear that may go through the same cycle of falling costs.

In addition, in the next 10 years, 2nd generation biofuels are expected to enter the market. Once their production volumes are increasing, their cost effectiveness may improve. They are expected to outperform 1st generation biofuels in the longer term. It should be noted, though, that, as mentioned earlier, the potential of biofuels is not unlimited. The availability of biomass residues is limited, as is suitable agricultural land for biomass cultivation. The cost of future biofuels will thus depend on biomass supply and demand. Moreover, unless the oil price rises further (and the coal price remains stable) there will always be more attractive options for using biomass to displace fossil fuel electricity generation as a means to reducing CO_2 emissions instead of using it to produce transport fuels.

In conclusion, we expect that the cost effectiveness of fuel efficiency measures is more attractive than that of alternative fuels, certainly in the short to medium term. In the longer term, fuel economy measures may be still more cost-effective if environmental policies can be designed to alter purchasing behaviour. However, if the scope of environmental policies remains limited to technological adaptations, costs of fuel economy may substantially rise. In that case, costs may approach the level of biofuels. If and when this will occur will depend on the rate with which fuel efficiency improvements are forced in the coming years, on new technological developments in engines and vehicles, on the success of environmental policies to give incentives for more rational purchasing behaviour and on the success of biofuels development. In view of the limitations for both fuel efficiency improvements and biofuel availability, all available options will need to be used if CO_2 mitigation needs to be achieved in the transport sector (without regard to economy-wide cost effectiveness).

5 The role of government policies

5.1 Introduction

Clearly, there is scope for further development of fuel efficient vehicles technologies and climate-neutral fuels. However, this technological potential will not be achieved by itself, due to various reasons:

- Costs of new technologies are often high at first, and can not compete with conventional technologies already on the market, as discussed in section 3.3.
- Large R&D investments are required up front, it may take decades before they are recovered - and that will happen only if the R&D is successful. Companies will only be inclined to make these investments when they are confident that there will be a market for the new product, so that they will be able to get a return on their investment later.
- Technologies that improve fuel efficiency of a vehicle require vehicle buyers to accept higher purchasing costs, which can then be (fully or partially) recovered during the lifetime of the vehicle, by lower fuel costs. Experience shows that consumers often do not take these long-term benefits into account and therefore not base their decision on a realistic cost comparison. Furthermore, fuel costs differ per fuel and transport mode. For example, road transport has higher fuel cost than maritime transport, and petrol cars have higher fuel costs than diesel cars (due to differences in excise duty mainly). The financial return on investments in CO_2 mitigation thus differs per mode and fuel.

Government policies can therefore be crucial to the way new technologies develop, and may thus determine future cost effectiveness and market implementation.

5.2 Policies for new technologies

Even if investments are not profitable for industry or consumers, they may still be justified from a government point of view. For example, incentives for technological developments might be desired in view of achieving CO_2 abatement goals, or to overcome market imperfections as described in the third item of the list above. Also, governments may choose to financially support R&D investments to help industry to pass the initial high cost hurdle that new technology has to face.

Governments may choose from a range of policies. These may be:

- Monetary, for example by adjusting vehicle or fuel tax levels, or by subsidising R&D.
- Regulatory, for example by making biofuels mandatory, or by regulating the maximum CO_2 emissions of cars.
- Communication policies, for example by making consumers aware of the fuel efficiency of passenger cars with a labelling system.

An emission trading system such as the EU ETS can be considered a regulatory policy, since it regulates the maximum amount of emissions allowed by the participants. However, since the scheme creates a price for CO_2 emission credits, it will also result in a financial incentive for emission reductions.

To encourage industry to invest in new technologies, it is important to provide the right boundary conditions with an effective policy mix. What the optimum policy is for a specific technology may depend on the development stage the technology is in, as discussed in section 3.3.1 (Sandén, 2005).

The more mature technologies, that are relatively close to market implementation or that have already entered the market, typically need help to bring their costs down to become competitive on the market. This may be done with pricing incentives (e.g., excise duty reductions for biofuels, subsidies for hybrid cars) or with regulations (e.g., by setting a mandatory percentage of biofuels, or a CO_2 standard for new passenger cars). Also, governments may establish niche markets, in order to gain experience with the new technologies, e.g. through government procurement programs. At first, the incentive required may be relatively high, since the production volumes are still low and thus costs are relatively high. However, as volumes increase, costs will come down. Both the monetary and regulatory policies thus can be adjusted over time.

If a technology is still in its R&D stage, governments may choose to fund R&D, or to provide funds for demonstration projects. This may be very important for technologies that are still far from commercial application, or for companies that do not have sufficient funds themselves. However, industry will not base their R&D investment decisions on these subsidies alone. They will rather base this decision on their assessment of the longer term: do they expect to gain a significant market share with the new technology in the future? Can the new technology reduce their cost in the longer term? For example, if governments can convince industry that biofuels from woody biomass will get more incentives in the future than other biofuels, it will be more attractive to invest in the development of these 2nd generation biofuels.

As there are a number of technological measures under development, it is still uncertain which technology will be most successful in achieving cost effective emission reductions in the long term. R&D might lead to a breakthrough in one area, whereas it may prove more difficult than expected in another area. Only generic government policies, i.e. policies that are not aimed at specific technologies, will ensure that the most successful new technologies will come on the market. For example, policies that are directed at reducing CO_2 emissions of new cars or trucks will encourage much more diverse R&D in this field than policies that promote hybrid drives only.

Furthermore, when designing policies for new technology, lock-in effects should be considered. Current fossil fuels and ICE's are very well developed and integrated in modern society, technologies and businesses. New technologies that may require other fuels are at a clear disadvantage. They then need additional, temporary incentives overcome this disadvantage, and to resolve this lock-in effect. Once they have a significant market share, costs have come down and society and businesses have adapted to the new technology, these incentives can be removed.

However, it should be noted that since we do not know yet for sure which technologies will be the most practical and cost effective in the future, there is a risk of promoting a technology in the coming years that is not the optimal technology for the future. This may create a new lock-in that would have to be resolved again in the longer term.

In addition, it should be mentioned that government policies will be most effective when they are predictable. The development of technology may need a long time, and industry needs time to anticipate changes in regulations. For example, in order to achieve a significant market share for 2nd generation biofuels in 2020, R&D efforts are needed now, so that first prototype production facilities can be operational around 2010.

Once a technology is developed and operational but not yet on the market, large scale market introduction may depend on timely market incentives or regulations. This mechanism can be illustrated with the catalytic converter for petrol cars, that was made mandatory in the late 1980s in Europe with the Euro 1 emission standards, and somewhat earlier in the USA. Even though the cost of these catalysts were relatively high at first, all petrol cars were fitted with them within a few years. This reduced their costs significantly, and also improved their performance due to rapidly growing experience with this technology. This made them very cost effective in a relatively short time.

5.3 Improving the effectiveness of fuel economy as a policy option in combating climate change

Although transport in theory offers some of the least cost opportunities for reducing fuel consumption, through behavioral changes, a major obstacle exists in the sense that these benefits are difficult to reap. Emissions reductions may therefore be more cost-effectively exploited in other sectors.

One of the major challenges of policy makers is therefore not to reduce the costs of measures in the transport sector, nor to raise fuel taxes, but to correct the markets in such a way that the decision about the fuel efficiency of a car is placed at the moment of the purchase of the car. This can be in the form of a fiscal incentive in car purchase prices, as has been done with the hybride drive technology in several countries. It is, however, an anomaly that whilst cars with hybrid drives qualify tax deductions at the moment of purchase, lighter cars do not.

The other way is to impose fuel economy standards on the light-duty vehicle fleets. There is some empirical evidence from such standards in the EU, China, US and South Korea. There are several design aspects to take account of when imposing fuel economy standards.

In the first place, standards can be imposed both through mandatory and voluntary agreements. In theory, voluntary agreements may be less effective in the absence of a credible threat of mandatory standards. During the 1980s in Australia, voluntary standards resulted in fuel economy improving significantly from 11.5 liters per 100 km in 1979 to about 9.4 in 1988 but the 8.5 liters per 100 km standard of that year was not met (An and Sauer, 2004). Under the South Korean voluntary system average fuel economy actually decreased due to an increase in the sale of SUVs (An and Sauer, 2004), leading to the announcement of the implementation of mandatory standards in 2004. In the US, Japan, China, Taiwan and South Korea currently mandatory fuel economy standards that can be enforced by either a penalty (US) or public shaming (South Korea).

Another design issue is whether standards should apply to the average car sold by individual manufacturers (US), the average car sold by the industry as a whole (Australia, EU) or to each car sold separately (China). The standards in the US applying to average car sold by each manufacturer are by some regarded as discriminatory or distortionary, because manufactures concentrating on the smaller vehicle market segments can achieve targets with relatively little effort. However, there are generally no administrative obstacles to prevent other car manufacturers focusing on such segments as well. Standards applying to each car sold, however, leave less flexibility to manufacturers. The EU ACEA agreement offers targets applied to the industry as a whole. Manufacturers are able to work out individual targets at an efficient and fair level by setting each firm’s target at the same level of marginal costs per gram of CO_2 per km reduced. Economic efficiency, fairness and minimal competitive impact can be achieved simultaneously. No other system has these three characteristics (Greene, 2005).

It should be noted that fuel efficiency targets may have adverse effects on other policy domains. For example, generally lower fuel excise duties on diesel in the EU has resulted in the market share of new diesel cars steadily increasing from 14% in 1990 to 44% in 2003 (Kageson, 2005) and is expected to reach 52 to 58 percent by 2010 (Deutsche Bank, The drivers, 2004). This shift to diesel cars is estimated to account for 31% of fuel economy progress made by ACEA (T&E, 2005 based on JAMA, 2003). However, diesel cars admit on average more fine particles and NO_x than gasoline cars, thereby increasing the efforts needed to attain local air quality standards in Europe.

6 Conclusions

6.1 Cost effectiveness of CO_2 mitigation in transport

Several ex-ante and ex-post studies conclude that efficiency measures in the transport sector can be more cost effective than some measures in other sectors, if measures altering behaviour of consumers are taken into account. Fuel savings typically compensate part of, or even all, additional costs. There exists a range of cheap technological options to increase fuel efficiency, but these options are limited in scope and their costs tend to increase sharply beyond a certain threshold.

Behavioral changes are, however, difficult to enforce through environmental policies. The role of the price mechanism is limited as price elasticities tend to be a factor 1.5 to 3 lower than the income elasticities of demand. A recent EEA study concludes that if CO_2 prices are implemented throughout the economy, the power sector would be the most promising and cost-effective way to achieve emission reductions, mainly through fuel shifts (an increase of wind power and biomass, and combined heat and power). Fuel efficiency improvements alone will not stop the continuing growth of CO_2 emissions in both passenger and freight transport due to the high income elasticities of demand for transport services.

When comparing the use of biofuels in the transport sector with its use in power stations, the latter is more favourable from a cost effectiveness point of view. This is especially valid for most of the current, 1st generation biofuels, even at the higher oil prices. The 2nd generation biofuels that are currently being developed are expected to achieve more favourable cost effectiveness, due to both reduced costs and higher unit greenhouse gas emissions abatement. However, the technology for biomass use in power stations will also develop further in the coming decades, improving cost effectiveness of that route as well. Since the cost effectiveness of biofuels improves with increasing oil price, the 2nd generation biofuels may be able to achieve a cost effectiveness comparable to that of coal replacement by biomass in power stations. When coal or biomass prices increase or oil prices decrease, the power station route will again have a clear advantage to the biofuel route. There is currently no indication, however, that biofuels will become more cost effective than biobased electricity generation in the future.

In the longer term (from 2025 onwards), hydrogen produced from climate neutral energy sources may come on the market as an option for reducing CO_2 emissions in transport. However, a comparison with other potential applications of hydrogen and with a more direct use of the climate neutral energy sources, leads to the conclusion that the cost effectiveness of its use in transport can not compete with more direct uses of the energy sources, for example in electricity generation, in the timeframe under investigation. Hydrogen production, distribution and storage all reduce efficiency (and thus the CO_2 gains) and increase costs – even when the technological bottlenecks are solved.

We must furthermore conclude that there are only few studies that address the issue of cost effectiveness of measures across sectors. Specific measures are sometimes assessed ex-ante, but different cost effectiveness studies can, in general, not be combined and compared because assumptions and methodologies differ.

6.2 The role of government policies

Experience shows that the costs of a technology can reduce significantly with increasing production volumes. New technologies are therefore relatively expensive when they are still in the R&D stage, or when they only just start to enter the market. Government policies may then help to overcome the financial barriers, and can thus be crucial to a successful development of the new technologies needed to reduce CO_2 emissions in transport. These policies may be either financial or regulatory. R&D efforts can be subsidized, and, even more important, market incentives can be provided. The latter is probably the most powerful, since industry will only consider investing in new technology when they expect to find a significant enough market (and thus return on their investment) for the new product in the future.

References

ACEA, 2006
European Automobile Manufacturers Association
An Integrated Approach to reducing passenger car-related CO_2 emissions
Brussels : ACEA, 2006

Alsema en Nieuwlaar, 2001
Alsema, Nieuwlaar
Icarus 4: a database of energy efficiënt measures for the Netherlands,1995-2020, final report, Rapport nr. NWS-E-2001-21
Universiteit Utrecht, sectie Natuurwetenschappen en Samenleving, 2001

An and Sauer, 2004
F. An, A. Sauer
Comparison of passenger vehicle fuel economy and GHG emission standards around the world
Pew center on Global climate change, December 2004

Baumol and Oates, 1988
W.J. Baumol and W.E. Oates
The Theory of Environmental Policy.
Cambridge: Cambridge University Press, 1988

Bossel, 2003
U. Bossel, B. Eliasson, G. Taylor
The Future of the hydrogen economy : bright or bleak?
http://www.efcf.com/reports/E08.pdf

Burtraw, 1996
Burtraw, D.
The SO_2-emission trading programme : cost savings without allowance trades
In: Contemporary Economic Policy XIV, p. 79-94, 1996

CE, 2003
B.E. Kampman, H.J. Croezen, I. de Keizer, O. Bello
Biomass : for vehicle fuels or power generation? A comparative analysis to 2010
Delft : CE, 2003

CE, 2005
B.E. Kampman, L.C. den Boer, H.J. Croezen
Biofuels under Development : An analysis of currently available and future biofuels, and a comparison with biomass application in other sectors
Delft : CE, 2005

CE, 2005
S.M. de Bruyn, M.J. Blom, R.C.N. Wit, H.J. Croezen, G.E.A. Warringa, B.E. Kampman
Evaluatie doelmatigheid binnenlands klimaatbeleid : Kosten en effecten, 1999-2004
Delft : CE, 2005

Concawe, 2005
Well-to-wheels analysis of future automotive fuels and Powertrains in the European context
CONCAWE, EUCAR and JRC
S.I. : S.n., 2005

CRS, 2004
Congressional Research Service
A hydrogen economy and fuel cells : an overview
January 2004
http://www.ncseonline.org/NLE/CRSreports/04Jan/RL32196.pdf

Department for Transport, 2003
N.J. Owen, R.L. Gordon
‘Carbon to hydrogen’ roadmaps for passenger cars : update of the study for the Department for Transport and the Department of Trade and Industry
Ricardo UK Ltd
Shoreham by Sea : Department for Transport, 2003

Easterling
R.A. Easterling
Does Economic Growth Improve the Human Lot? in P.A.
David and R.M. Weber (eds), Nations.
S.I. : S.n., 1974

EC, 2004
Implementing the Community Strategy to Reduce CO_2 Emissions from Cars: Fourth annual report on the effectiveness of the strategy (Reporting year 2002)
Brussels : 11.02.2004, COM(2004) 78 final

EC, 2005
Hydrogen: a solution to our energy problem?
Presentation by Marc Steen, Institute for Energy, DG-JRC, June 2005
S.I. : S.n., 2005

ECN, 2005
P. Boonekamp, et al.
Indicators of domestic efforts to reduce CO_2-emission in The Netherlands
Petten : ECN, februari 2005

EEA, 2001
EEA (European Environment Agency)
Reporting on environmental measures - are we being effective?
Copenhagen : EEA, 2001

EEA, 2005
EEA (European Environment Agency)
Climate change and a European low-carbon energy system
EEA report 1/2005
Copenhagen : EEA, 2005

Ellerman, 2003
A.D. Ellerman
Ex-post evaluation of tradable permits : the US SO_2 cap-and-trade program.
Massachusetts Institute of Technology
MIT/CEEPR 03-003 : working paper
Massachusetts : MIT, 2003

Feng, 2004
A. Feng, A. Sauer,
Comparison of passenger vehicle fuel economy and greenhouse gas emission standards around the world
S.I. : Pew Center on Global Climate Change, 2004

Goldemberg, 2004
Goldemberg, J., Coelho, S.T., Nastari, P.M., Lucon, O.
Ethanol learning curve – the Brazilian experience
In: Biomass and Bioenergy 26 (2004) 301 - 304

Goodwin, 2004
P. Goodwin, J. Dargay, M. Hanly
Elasticities of road traffic and fuel consumption with respect to price and income : a review
In: Transport Reviews, Vol. 24, No. 3, p. 275-292, May 2004

Greene and Schafer, 2003
David L. Greene, Andreas Schafer
Pew center on Global Climate Change: Reducing Greenhouse gas emissions from U.S. Transportation
May 2003

Greene, 2005
D.L. Greene
Improving the nation’s energy security: can cars and trucks be made more fuel efficient?
Testimony to the U.S. House of Representatives Science Committee
Washington : S.n., 2005

Harrington, 2000
W. Harrington, R.D. Morgenstern, P. Nelson
On the accuracy of regulatory cost estimates
In : Journal of Policy Analysis and Management : Volume 19, Issue 2, p. 297-322, 2000

Hueng, 2003
L.K. Hueng
Using Metal Hydride to Store Hydrogen
Fuel Cells 2003 -Third Annual BCC Conference, Stamford, CT, March 31 -April 1 2003
Stamford : Savannah River Technology Center, 2003

IEEP, 2005
Institute for European Environmental Policy, TNO, Centre for Automotive Industry Research
Service contract to carry out economic analysis and business impact assessment of CO_2 emissions reduction measures in the automotive sector
Brussels: Institute for European Environmental Policy, 2005

IPPC, 2001
The Third Assessment Report of the Intergovernmental Panel on Climate Change
Cambridge (UK) : Cambridge University Press, 2001

JAMA, 2003
JAMA position on the potential for achieving the CO_2 reduction target of 120 g/k in 2012
Japan Automobile Manufactures Association (JAMA)
S.l. : S.n., 2003

Kluwer, 1997
J.C. van den Bergh, K.J. Button, P. Nijkamp, G.C. Pepping
Meta-Analysis in Environmental Economics
Dordrecht : Kluwer Academic Publishers, 1997

Koljonen, 2004
T. Koljonen, E. Pursiheimo (VTT Processes), K. Jørgensen (Risø), K. Gether (NTNU)
System analysis and assessment of technological alternatives for Nordic H2 Energy Foresight, DRAFT REPORT OF THE WP 4
January 2005
www.h2foresight.info

Marintek, 2000
MARINTEK, CMU, DNV, ECON
Study of greenhouse gas emissions from ships
S.l. : IMO, 2000

Ministry of the Environment, 2005
New Zealand, Ministry of the Environment
Review of Climate Change Policies
http://www.climatechange.govt.nz/resources/reports/policy-review-05/
S.I. : S.n., 2005

Mishan, 1991
E.J. Mishan
Introduction to normative economics.
New York : Oxford University Press, 1991

National Technical University of Athens, 1998
P. Capros
Note on the Costs for the EU of Meeting the Kyoto Target (-8%), Preliminary Analysis
Athens : National Technical University of Athens, 1998

NRC, 2002
National Resource Council, Committee on the Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards
2002

OECD, 1997
OECD (Organisation for Economic Cooperation and Development)
Evaluating Economic Instruments for Environmental Policy
Paris : OECD, 1997

RAO, 2002
A.B. Rao, E.S. Rubin
A technical, economic, and environmental assessment of aminebased CO_2 capture technology for power plant greenhouse gas control
In: Environmental Science and Technology, nr. 36, p. 4467-4475

RIVM, 2001
J.A. Annema, E. Bakker, R. Haaijer, J. Perdok, J. Rouwendal
Stimuleren van verkoop van zuinige auto's : de effecten van drie prijsmaatregelen op de CO_2-uitstoot van personenauto's (summary in English)
Bilthoven : RIVM, 2001

Sandén, 2005
B.A. Sandén, C. Azar
Near-term technology policies for long-term climate targets – economy wide versus technology specific approaches
In : Energy Policy, vol. 33 (2005); p. 1557-1576

SEI, 1999
Costs and strategies presented by industry during the negotiation of environmental regulations
Stockholm : Stockholm Environment Institute Sweden, 1999

T&E, 2005
P. Kageson
Reducing CO_2 emissions from new cars
Brussels : T&E, 2005

TNO/ IEEP/CAIR, 2004
D. Elst, et al.
Measuring and preparing reduction measures for. CO_2 emissions from N1 vehicles. - final report
2004

University of Technology, 2002
E. den Boer
Oil ages? : an assessment of conventional and on NG and biomass based alternative transportation fuel chains
Eindhoven : University of Technology, 2002

University of Westminster, 2004
P. Agnolucci
Ex-post evaluations of CO_2–based taxes: a survey
Tyndall Centre for Climate Change,
Research Working Paper 52, 2004
London : University of Westminster, 2004

USDOE, 2003
Fuel cell report to congress, US Department of Enengy, February 2003.
http://www.eere.energy.gov/hydrogenandfuelcells/pdfs/fc_report_congress_feb2003.pdf

Utrecht University, 2005
Junginger
Learning in Renewable Energy Technology Development
Utrecht : Utrecht University, 2005

VROM, 1998
Ministerie van VROM
Kosten en baten van het milieubeleid, definities en berekeningsmethoden
Den Haag : VROM, 1998