Alternative fuels

Emissions and energy use during production

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FOREWORD

The work on this report has been performed by Magnus Blinge, Ulrika Franzén and Elisabeth Sörheim on behalf of NTM (Network for Transport and the Environment). The work has been conducted in parallel with the work carried out by Mats-Ola Larsson concerning emissions from vehicles run on alternative fuels.

In connection with the decision to produce emissions data for alternative fuels, NTM started a temporary working group for the purpose. The following members have participated in the group meetings and have provided valuable comments.

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NTM would like to thank all participants for their involvement.

Gothenburg, March 2006

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CONTENTS

SUMMARY

The use of alternative fuels is increasing rapidly. Municipalities and public authorities are trying in various ways to stimulate the market and are providing support both for fuel production and for the purchase of so-called environmental vehicles. In order to be able to evaluate how public funds have been used and to evaluate what environmental benefits the efforts have entailed requires credible basic data for environmental calculations.

Over the years, a large number of life cycle analyses (LCAs) have been performed on fuels. Mention can be made, for example, of the German institution IFEU, which has made an inventory of the life cycle analyses that have been performed, and found more than 800 life cycle studies of fuel production! The authors note among other things that the large quantity of data is due to the large number of options for system boundaries and other product-specific characteristics, and that these options affect the results in a crucial way

A fuel's life cycle values can thus vary sharply depending on the method of production. It is therefore very important that all parties use the same data with the same boundaries when they estimate emissions for transports. The ambition to reach consensus on how to perform environmental calculations on transport has been NTM's aim during the time the network has been in existence, and it is now time to take a further step and produce usable energy and emissions values for alternative fuels.

The aim of this project is, on the basis of existing data for environmental impact from the manufacture and use of alternative fuels, to suggest which data are to be used and to identify the gaps in knowledge that exist. It can be noted that despite the extensive amount of data that exists within the area, relatively few LCAs have been performed on fuels in Sweden since the Official Inquiry on Alternative Fuels in 1997. Since it is important to analyse the fuels in accordance with the specific production methods used, data for Swedish production conditions have been chosen as far as possible. It is therefore important in this context to point out that these data will soon be more than 10 years old and are in need of updating.

1 THE ASSIGNMENT

Note that the data presented in this compilation are not intended to be used for assessing the future potentials or possibilities of the different fuels. Nor can it be used to compare the different fuel alternatives environmental performance. They should only be used only to calculate the environmental impact in the form of regulated emissions and fossil CO_2 for the fuels that are at present commercially available for Swedish consumers to a large extent, and not for the individual test vehicles.

The use of alternative fuels is increasing rapidly. Municipalities and public authorities are trying in various ways to stimulate the market and are providing support both for fuel production and for the purchase of so-called environmental vehicles. In order to be able to evaluate how public funds have been used and to evaluate what environmental benefits the efforts have entailed requires credible basic data for environmental calculations.

In environmental calculations for vehicles using alternative fuels, the production method of the fuel itself is very important. Different production methods can give big differences in emissions, particularly of CO_2.

Over the years, a large number of life cycle analyses (LCAs) have been performed on fuels. The German institution IFEU has made an inventory of the life cycle analyses that have been performed, and found more than 800 life cycle studies of fuel production! Admittedly only a few have been performed in accordance with the ISO 14 040 standard, and the majority deal only with energy use and CO_2.

Why then is there a need among so many stakeholders to pay for so many studies that aim to show the advantages and disadvantages of various fuels? In many cases it is public authorities that order analyses and decision data for strategies for future fuel supply. Thus many stakeholders probably do not recognise the environmental performance presented in the analyses and want therefore to publish another picture of the situation. This does not mean that any of them are wrong, but rather that there are many ways in which to produce fuels and also that it is possible to define the production system boundaries in a number of different ways. Different raw materials, different production methods, different degrees of large-scaleness and different assumptions on how possible by-products will be used are examples of reasons why the results of the life cycle studies point towards different results.

The choice of system boundaries and allocation method, time perspectives, and geographical conditions are some of the factors that are of crucial importance for the result of an LCA for fuels. This has been established in a number of reports (Blinge M, 1998), (Jonasson & Sandén, 2004), (Quirin et al., 2004).

LCA as a method is good for producing certain data and certain knowledge, and poor for producing other data and knowledge. The method is being developed continuously, and these advantages and disadvantages are becoming clearer with time. The fact that so many different results can be produced using the LCA method has resulted in the method being questioned from many quarters because "*with LCA you can obtain any result you want*". The criticism is understandable, but it is important to point out that it is not the method's fault that the reality is complex. Nor is there an alternative better method of studying a system's total environmental impact. It is instead a matter of accepting that LCA is a "compass" and that the results must be interpreted in a broader perspective and seen as a jigsaw piece in a complex body of decision data. Not performing an LCA of the entire system and only selecting a small part where it is possible to obtain exact and measurable data on a smaller subsystem is definitely wrong. It is therefore better to be roughly right than to be definitely wrong.

The only way to handle the above-mentioned problems and the need to obtain credible and accepted LCA data is to follow the rules that there are for LCA and to agree on what data are to be used.

A brief inventory of LCA data for the production of alternative fuels has been made, and shows that most LCA data are old and need updating. It also shows that there are different data with different boundaries and different types of production method. This indicates a need for a major review.

It is therefore important to produce a basis for decisions on what data are to be used for energy use and emissions values for alternative fuels. It is very important that all parties use the same data with the same boundaries when they estimate emissions for transports. This has been NTM's aim during the time the network has been in existence, and it is now time to take a further step and produce usable energy and emissions value for alternative fuels.

1.1 Aim and objective

The aim of this project is on the basis of existing data for environmental impact from the manufacture and use of alternative fuels to suggest what data are to be used to identify the existing gaps in knowledge.

The objective has been to present a proposal for emissions data for the fuel alternatives that are relevant for use in Sweden at present. By using the figures, it shall be possible to calculate how the current environmental impact can be reduced.

1.2 Boundaries

Note that the data presented do not say anything on what future potential a fuel has. Nor can it be guaranteed that it is the best available technology that is being presented. The recommended values are based on best available data with comparable system boundaries. It represents the normal production of the fuels that are commercially available on the Swedish market today.

2 LCA

In order to get to grips with the confusion, the recommendation from those researchers who have worked with LCA is that the users of the results must first define what the issues are and the preconditions under which the analysis is to apply. During what period of time is the analysis to apply? What are the volumes in question? What is the geographical scope? Where were the raw materials sourced and what production method has been used? Once these issues have been clarified, one can search for data and perform those analyses that are credible and that meet the user's conditions.

2.1 ISO 14 040

During the 1990s, an ISO standard was developed for how LCA is to be performed. The standard provides recommendations for how system boundaries and allocation methods are to be used. At the same time, it states that it is not possible to use one and the same method for all issues and all product groups, and that the issue must govern the choice of method.

In order to gain credibility for those analyses that have been performed, the guidelines given in the ISO standard should therefore be used. One of the most critical factors that affects the result of an LCA of fuel is how the allocation shall be conducted when more than one product is produced. Here ISO 14040 gives the following ranking of recommendations:

1. System expansion. (Avoid allocation) This method means that one finds out exactly what happens with the by-product and what environmental effect this has in another technical system. An example is if animal feed is produced as a by-product during the production of rape. The system expansion means that one follows up that the animal feed is actually used, i.e. that it is financially advantageous for farmers to use the product in preference to other products. Thereafter, one finds out what type of animal feed is no longer bought because of this, and analyses how this product would have been produced. This "avoided" environmental impact is credited to the main product. For complex systems, this procedure is often lengthy and time-consuming, and sometimes utterly impossible to perform without a number of subjective

assumptions being made, which in turn can be criticised. Here too the question of large-scaleness (volumes) and time factors are important if one wants to use LCA in order to conduct strategic future studies. How much of the by-product is there a market for and how does it affect the economic preconditions for the production of the main product (the fuel)?

2. Underlying physical connections. In this instance it is recommended that one studies systems so thoroughly that each step can be traced to the various products that are produced. One shall be able to trace how a quantitative change in the inflows in the process affects the quantitative outflow. For example, can it be the case that the supply of steam to a process means that, to a proportional degree, the production of a product decreases or increases at the expense of another? This clear connection is thus very difficult to define, partly because so many processes are viewed as trade secrets by the producers.

3. Economic value. In this instance it is recommended that the environmental impact that is to be divided between different products is divided in accordance with how much income the respective products generate for the owners. This method is attractive because it reflects the benefit of producing the relevant product and how much the consumer wants it. When it comes to fuels, I am doubtful with regard to this method, since the market for fuels is so strongly linked with tax rates and subsidies. It is difficult to calculate the environmental impact of a product which, because of a change in the tax rate, acquires a changed profit margin and thereby in the long run a changed environmental impact, despite the fact that no change has occurred in the production process. Another problem with this method is that it often deals with corporate economic factors that companies prefer not to present officially. It can also be a problem to follow up and examine data.

4. Division according to physical size (weight, volume, energy content). In the final instance, it is recommended that the allocation is made in accordance with a measurable physical magnitude. This allocation method is admittedly the poorest and least correct viewed theoretically, but is nevertheless the absolutely most common method among the analyses performed. Naturally

this is because it is a pragmatic approach and for the most part there are data available. Comparability with other studies aimed at checking and following up the appropriateness of the analysis is also much greater.

2.2 Choice of system boundaries and allocation rules

The studies presented here have, so far as can be judged from the material available, used the last-named allocation method. In those cases where it has been necessary, conversions have therefore been made in order to increase the comparability.

In terms of time, the focus is on the present situation. No assessments of future potentials have been included. Geographically, data have been restricted to apply only to the fuels used in Sweden.

2.3 Updating required

It is striking that there has been great activity in Europe to produce new life cycle analyses. In principle, no large new life cycle analyses have been performed in Sweden since the Official Inquiry on Alternative Fuels in 1997. This is a shortcoming, and we urge industry players to update the values for those fuels that are produced and/or used in Sweden.

2.4 Earlier works

The main works that have served as a basis for the gathering of basic data for this report are shown below.

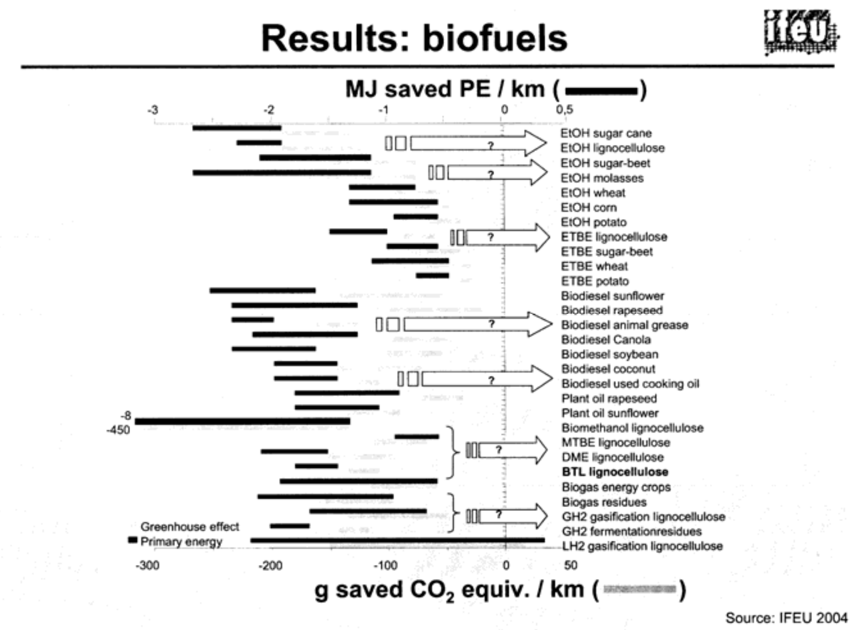
IFEU

The German institution IFEU

In 2004, the German institution IFEU published a report entitled “CO_2 mitigation through biofuels in the transport sector”(Quirin et al., 2004). As mentioned above, the work entailed going through more than 800 reports.

The main results show that there is a lack of credible reports particularly for different forms of biodiesel and F-T fuels from biomass. There is also a very wide spread of results, and it is important to ask what one wants to use the data for before looking at the values. Is it an “accounting analysis” or does one want to measure what effect a transfer or increased production would entail for the environment?

The report contains a compilation of the values for the most credible of the 800 analyses and presents the values in an interval.



Source: IFEU 2004

Figure 1 Results of the IFEU study (Quirin et al., 2004)

IVL Environmental Factbook for Fuels

IVL's Environmental Factbook for Fuels (IVL, 2001) is a compilation of data on the environmental impact from the use of different types of energy; fuels and directly generated electricity. This study takes into consideration the entire life cycle from raw materials extraction to use, and the data presented apply to Swedish conditions.

Conclusions concerning vehicle fuel presented in the study state that "the burning of the fuel accounts for roughly 90% of the emissions during the life cycle. In addition to choice of fuel, the choice of vehicle can have considerable importance for emissions data." Other conclusions are that life-cycle analyses contain substantial uncertainties, that comparisons between LCA performed by different practitioners can be difficult, and that other emissions such as emissions to water, land use etc should be taken into consideration.

The report presents a review of life-cycle analyses performed on those fuels that are relevant for Swedish conditions. A qualitative analysis of the reports is made, and the factbook recommends a set of values for the respective fuels.

JRC

The report called "Well-to-Wheels analyses of future automotive fuels and powertrains in the European context" has been conducted by JRC (the Joint Research Centre of the EU Commission) in cooperation with EUCAR, and CONCAWE. It is a so called Well-to-Wheel study whith energy use and greenhouse gas emissions for a number of potential future energy carriers with different energy sources. This report is not an LCA and therefore does not give emissions of substances other than the various greenhouse gases CO_2, CH_4 and N_2O.

The report is very extensive and contains data for a large number of fuels in various time perspectives. It is evident that those who have performed this analysis have had major resources behind them. Since the EU Commission and representatives of the European vehicle and oil industries are behind the results, the report has had a relatively big impact. The report adopts a European perspective and presents mainly average values for very large-scale production. Like all other performers of life-cycle analyses, the parties have drawn system boundaries and made allocations. Naturally these can be discussed.

VIEWLS

The EU project Viewls (Achieving clear views on information concerning, and prospects of, biofuels for transportation) aims at compiling existing data concerning the production and use of biofuels. It therefore deals not only with LCA of fuels but also with what biomass potential we have in Europe and what possibilities and barriers a large-scale production of biobased fuels would encounter. The Viewls consortium found approximately 600 LCA or Well-to-wheel studies and arrives at roughly the same result as IFEU. (www.viewls.org)

3 PRODUCTION OF FUELS

3.1 Ethanol

The ethanol used in Sweden today comes from sugar contained in the sulphite pulp from the Domsjö mill in Örnsköldsvik (approx 13 000 m^3), from wheat in the Norrköping plant (50 000 m^3) and imported ethanol from Brazil (approx 180 000 m^3). E85 and the bus fuel E95 are manufactured from the sulphite ethanol and imported ethanol from Brazil. Presently comes half of the E85 and the E95 from sulphite ethanol and half from Brazil according to SEKAB.

The ethanol from the Norrköping plant is mainly used as a low blend in petrol. Ethanol is also available from European agricultural products or from the EU's wine surplus. This ethanol is presently only used as low blends in petrol.

Since the environmental impact varies sharply depending on the production method, it is important to know which ethanol is used in the system.

The energy content and density of the ethanol is 26.8 MJ/kg and 790 kg/m^3 respectively (IVL, 2001).

From wheat in Sweden

Information on wheat-based ethanol has been obtained from IVL (Almemark et al., 1996), which conducted a theoretical study on the Norrköping mill before it was built. A dissertation by Gartmeister (2000) has been conducted after the plant was built. IVL chooses, however, to recommend its own figures, explaining that Gartmaister's information differs sharply from its own and from similar studies that it has examined. No later studies have been found. NTM does not question IVL's assessment and chooses to recommend these figures.

The energy use during production is not divided between different energy production alternatives, and therefore this cannot be stated here. Only an overall value of 11 MJ/litre of fuel can be obtained.

Table 1 Emissions to air during production (g/litre and MJ/litre respectively)

Environmental factor	**Value**
CO_2	163
NO_X	1.9
HC	0.08
CH_4	0.12
CO	0.36
PM	1.3
SO_X	0.14
N_2O	0.70
Energy (renewable)	NIA
Energy (fossil)	NIA
Energy (nuclear)	NIA

NIA = no information available. Only an overall value for total energy use is presented.

When comparing Gartmaister's figures with IVL's, it can be noted that emissions apart from CO_2 are somewhat higher for Gartmeister, whilst CO_2 emissions are roughly three times lower.

From Sulphite

Data for sulphite-based ethanol has been obtained from Blinge et al. (1997). This source is also recommended by IVL (2001), and no later references have been found. Nor has energy used per energy type been specified.

Total energy use is 3.7 MJ/litre of fuel.

Table 2 Emissions to air during production (g/litre and MJ/litre respectively)

Environmental factor	**Value**
CO_2	58
NO_X	0.5
HC	0.02
CH_4	NIA
CO	0.01
PM	0.005
SO_X	0.02
Energy (renewable)	NIA
Energy (fossil)	NIA
Energy (nuclear)	NIA

NIA = no information available. Only an overall value for total energy use is presented.

From sugar cane (tropical)

We have not been able to find credible LCA data for Brazilian ethanol from sugar cane. A number of studies on energy balances and life cycle data for greenhouse gases have been published, however. The most credible reports are IEA’s (2004) “Biofuels for transport” and Macedo et al. (2004) “Assessment of greenhouse gas emissions in the production and use of fuel ethanol in Brazil”. Conducting new life cycle analyses is not included in this assignment. Since the import of Brazilian ethanol nevertheless constitutes a large part of the ethanol consumption in Sweden, the following very overall estimate of emissions to air is made. We strongly recommend that a more thorough analysis of the life cycle values for tropical ethanol is performed, in which environmental effects other than those caused by emissions to air are also analysed.

Macedo et al. (2004) have in their reports used so-called extended system boundary in their analyses. For reasons described in the section concerning LCA, this method of allocation is not used to produce LCA data for the other fuels used today. If a calculation is made from Macedo et al. (2004) where all greenhouse gases have been calculated during the production, a “best scenario” is obtained of 0.38 kg CO_2/litre ethanol based on 11.7 tonnes of sugar cane used per m^3 ethanol. The report also presents an “average scenario” where the corresponding figure is 0.40 kg/litre ethanol. At the same time, approximately 10-15% (energy content) bagasse is produced, a residual product that can be used as a replacement for other energy. An allocation of the greenhouse gases according to the same method used in the analyses of the other fuels, i.e. according to energy content, would with 15% of the emissions allocated to bagasse mean that the proportion of ethanol is roughly 0.33 kg CO_2/litre ethanol. Macedo et al. have not calculated transport and distribution of the fuel. SEKAB states that the ethanol comes direct in 10 000-tonne tankers from Brazil to Örnsköldsvik, or in 30 000-tonne tankers via Rotterdam (approx 6500 nautical miles). An overall calculation with the help of data from the EU project “MEET” (Methodology for calculating transport emissions and energy consumption) (MEET, 1999) gives approx 0.10 – 0.15 kg CO_2equ/litre ethanol for sea transport and distribution of the fuel. In total this gives approx 0.45 kg CO_2equ/litre ethanol.

With regard to calculation of other emissions, the following estimates are made:

Emissions during production of sugar cane and ethanol in Brazil are excluded entirely owing to lack of data.

Emissions of SO_X, NO_X and PM are calculated on half of the sea distance. According to information from Christer Ågren of The Swedish NGO Secretariat on Acid Rain, most of the emissions of SO_X, particles and NO_X are transported in over land at least from a point from the economic maritime boundary (200 nautical miles). We assume overall that the emissions from sea transport from approximately half of the distance between Brazil and Örnsköldsvik are included. (The distance from Lisbon to Örnsköldsvik is about 2300 nautical miles). Other emissions from distribution and fuelling have been excluded.

Emissions data from NTM “product chem. tanker” have been used.

Table 3 Emissions to air during production (g/litre and MJ/litre respectively)

Environmental factor	**Value**
CO_2	450
NO_X	1.29
HC	NIA
CH_4	NIA
CO	NIA
PM	0.074
SO_X	1.06
Energy (renewable)	NIA
Energy (fossil)	NIA
Energy (nuclear)	NIA

NIA = no information available

Note that in Macedo’s data above, emissions of N_2O and CH_4 are included as CO_2 equivalents.

From wine in the EU

Data for ethanol from wine has been obtained from Ericson & Odéhn (1999). This source is also recommended by IVL (2001) and no later references have been found. The reference presents two scenarios. In the first case, the wine manufacture is included in the analysis, and in the second case the wine is regarded as “waste” without any other use. Here we consider that the wine is to be regarded as waste and is excluded from the calculation. Ethanol from wine has a special situation, as it can never be a matter of large-scale use as motor fuel. The only reason it is produced is because of the EU’s agricultural subsidies. If the preconditions change, the ethanol production will cease. If the production of wine was included in the analysis, the emissions values for CO_2 would go up from 360 g/litre to 1480 g/litre. Other emissions would go up by between 200 and 400%, depending on which emissions are concerned.

The energy need during production was, for nuclear power, specified at 0.0015 gram of uranium ore per MJ fuel. The conversion factor 127.389 MJ electricity per gram of uranium ore (Setterwall, 2006) has been used for the conversion.

Table 4 Emissions to air during production (g/litre and MJ/litre respectively)

Environmental factor	**Value**
CO_2	360
NO_X	6.6
HC	0.6
CH_4	NIA
CO	0.6
PM	0.35
SO_X	3.1
Energy (renewable)	4.9
Energy (fossil)	10.4
Energy (nuclear)	0.2

NIA = no information available

From wheat in the EU

There are large amounts of LCA data for ethanol from agricultural products. Since this type of ethanol is not sold in Sweden, no detailed search has been performed for quantitative data, for reason of resources. IFEU (Quirin et al., 2004) and the Viewels project have both studied the analyses that exist, and arrive at a similar result. Firstly they note that the result of the analyses varies sharply and that it depends on the production conditions. They also indicate that the potential for improving the systems is substantial, which is something that can be confirmed by the figures for the Norrköping plant in the section “From whete in Sweden”.

IFEU reports that wheat-based ethanol reduces CO_2 emissions by roughly 75 g (+/- 25g) per 100 km compared with a petrol-powered passenger car. Viewels reports that sugar-based agricultural products entail a reduction by about 50 g (+/-50g), whilst starch-based agricultural products entail a small increase by approximately 10 g (+/- ca

60 g). JRC arrives at roughly the same conclusion, i.e. that ethanol based on traditionally grown agricultural products with traditional production technology does not reduce CO_2 emissions compared with petrol.

In order to assess an estimation based on the above presented assumtions for emissions of fossil CO_2 from wheat based ethanol production in the EU:

Assumtions:

One litre of petrol environmental class 1-2 = 31.4 Mj/liter (IVL, 2001); One litre of ethanol = 20.5 MJ/lit (IVL, 2001)

Energy content in E85 becomes = 22.3 MJ/km

Energy content in one ltre of ethanol = 0.65 of the content in petrol

Energy content in one litre of E85 = 0.71 of the content in petrol.

Hence 1.41 times of E 85 is needed (31.4/22.3) in order to deliver the same amount of energy content as for one litre of petrol or conversely 0.71 litre of petrol corresponds to 1.0 litre of E85.

According to IFEU all wheat based production of ethanol reduces CO2-emissions by approcimately 75 g (+/-25g) per 100 km in comparision with a petrol fuelled passenger car. According to Viewels, sugar based agriculture products leads to a reduction of approximately 50 g (+/-50g)

Assuming an average car consuming 8.0 litre of petrol per 100 km. 8.0 lit x 2300 g = 18400 g CO_2, i.e, the size of the emissions from the petrolled fueld car per 100 km. We assume constant engine efficiency.

15% of the fuel is still petrol . (2760g): 18.400 - 2760 = 15640g

Assume that emissions from wheat besed ethanol decreases by 75 g. 15640 - 75 = 15565g. That is the CO2-emissions from the ethanol part. But how big is the volume?

85% of the volume of petrol shall be replaced by ethanol with an energy content of 0g65. 8.0 litre x 85% / 0,65 = 10.5 litre. 15565 gram / 10.5 litre = 1482 gram CO2 / litre ethanol. That is 1450g.

According to Viewels, the energy use in vehicle operation from starch-based ethanol requires roughly 2-3 times more energy than diesel and petrol. Note, however, that it is not a matter of the same type of energy. Here fossil and renewable energy of different qualities are mixed together.

With regard to other emissions, IFEU can present overall results of its review. With regard to acidification, ozone depletion and eutrophication, ethanol from agricultural products entails a worsening compared with diesel, whilst the content of harmful and smog-forming substances decreases. For comparison, it can be mentioned that for cellulose-based ethanol, all emissions classes apart from ozone depletion are better than petrol power. No detailed emission values are given in the report.

3.2 RME

Data for RME have been obtained from Blinge et al. (1997). This source is also recommended by IVL (2001) and no later references for Swedish-grown RME have been found. A comparison with studies conducted in Europe indicates that the results are as many as the analyses. We consider, therefore, that it is closer to the truth to use roughly 10-year old data for Swedish conditions than to use more modern data that reflect Central and Southern European production. Note that with regard to RME production, N_2O and also CH_4 account for a large part of the total greenhouse gases.

The energy need for the production is not specified, and a total energy need of 10 MJ/litre fuel is stated.

Table 5 Emission to air during production (g/litre and MJ/litre respectively)

Environmental factor	**Value**
CO_2	298
NO_X	2.6
HC	1.03
CH_4	1.03
CO	0.66
PM	0.06
SO_X	0.6
N_2O	2.22
Energy (renewable)	NIA
Energy (fossil)	NIA
Energy (nuclear)	NIA

NIA = no information available. Only an overall value for total energy use is presented.

3.3 Fossil natural gas

Data for natural gas have been obtained from IVL (2001). Data are based on Danish natural gas, which currently accounts for the entire Swedish consumption. In the absence of production data from Denmark, supplementation has been conducted using data from Norwegian extraction of gas. It can be noted that if new gas supply routes are opened to Sweden, emissions data will change. This is partly because gas from Russia or Norwegian fields in the Artic Ocean, for example, is transported longer distances, which requires compression energy, and the fact that methane leakage in the pipelines can arise.

Table 6 Emission to air during production (g/m^3 and MJ/m^3 respectively)

Environmental factor	**Value**
CO_2	168
NO_X	0.78
HC	0.10
CH_4	0.50
CO	NIA
PM	0.01
SO_X	0.13
Energy (renewable)	0.0066
Energy (fossil)	2.6
Energy (nuclear)	NIA

NIA = no information available

Naturally the burning of fossil natural gas means that fossil CO_2 is emitted in the consumption phase. Each cubic metre used therefore emits a further 2030 grams.

3.4 Biogas

Emissions of methane from biogas have long been discussed. The question has been whether biogas production means that the emissions of methane decrease viewed overall, even if a little still leaks out in the handling, or if the methane leakage is caused by biogas production, since otherwise the waste would have been incinerated in controlled ways. The problem resembles that of ethanol production, i.e. that system extension would have been preferable, but that it is complex to define the alternative use and where the system extension is placed. For information regarding this type of comparative analysis, Börjesson & Berglund (2003) is recommended.

The emissions values for biogas are obtained, as for other fuels, from an “accounting LCA” that describes today’s system with the same choice of system boundaries as other fuel alternatives. The most current that we have found of an existing system is by Nilsson (2000). The plant is not the most modern, but is the one that is available for Swedish conditions.
Data are based on production from sewage sludge and other organic waste. IVL (2001) contends that biogas produced from domestic waste can be considered to give emissions of the same magnitude, with the difference that the emissions of fossil CO_2 are somewhat higher owing to longer transports during the collecting.

The energy need for the production is not specified, and a total energy need of 18 MJ/litre fuel is stated.

Table 7 Emissions to air during production (g/m^3 and MJ/m^3 respectively)

Environmental factor	**Value**
CO_2	123
NO_X	0.64
HC	NIA
CH_4	22.60
CO	0.04
PM	0.05
SO_X	0.15
Energy (renewable)	NIA
Energy (fossil)	NIA
Energy (nuclear)	NIA

NIA = no information available. Only an overall value for total energy use is presented.

3.5 Fischer-Tropsch

Synthetic fuels are recommended by many analysts, mainly because of the flexibility both in the form of raw materials and fuels. Theoretically, all forms of carboniferous substances can be gasified. A number of fuels can then be manufactured from synthetic gas, such as methanol, diesel, petrol, methane, DME. In South Africa, 180 000 barrels of synthetic fuel are produced per day from coal. At present, only fuel based on fossil sources such as natural gas or coal are sold. The availability of LCA studies is limited, particularly with regard to bio-based F-T fuels. One of the three studies examined, (GM, 2002) shows the following relationships:

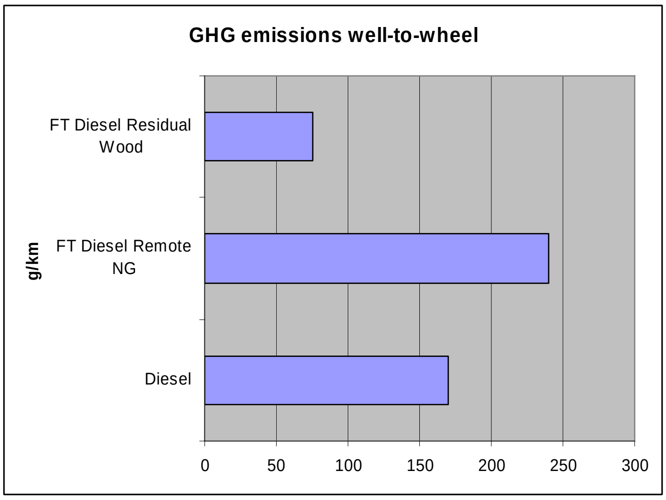


Figure 2 Comparison of greenhouse gases from F-T fuel from biomass and fossil natural gas respectively, and low sulphur diesel from crude oil (GM, 2002)

The following table has been obtained from Beer et al. (2000) and shows a comparison between FT diesel from natural gas and low sulphur diesel.

Table 8 Comparison between FT diesel from natural gas and low sulphur diesel

Exbodied emissions per km	**FTD**	**LS diesel**
Greenhouse (kg CO_2)	0.9926	0.9250
NMHC total (g HC)	0,94	1.509
NMHC urban (g HC)	0.524	1.192
NO_X total (g NO_X)	10.305	11.250
NO_X urban (g NO_X)	8.896	10.638
CO total (g CO)	2.333	2.723
CO urban (g CO)	2.010	2.612
PM10 total (mg PM10)	266.1	438.4
PM10 urban (mg PM10)	246.6	423.1
Energy embodied (MJ LHV)	17.10	12.7

Source: Beer et al., 2000.

JRC (2005) has in its updating of its Well-to-wheel analysis assessed the development f GTL technology up to 2010 and arrives at the following result:

Figure 5.3.2a/b WTW energy requirement and GHG emissions for synthetic diesel fuel and DME pathways (2010+ vehicles)

(GHG bars represent the total WTT+TTW)

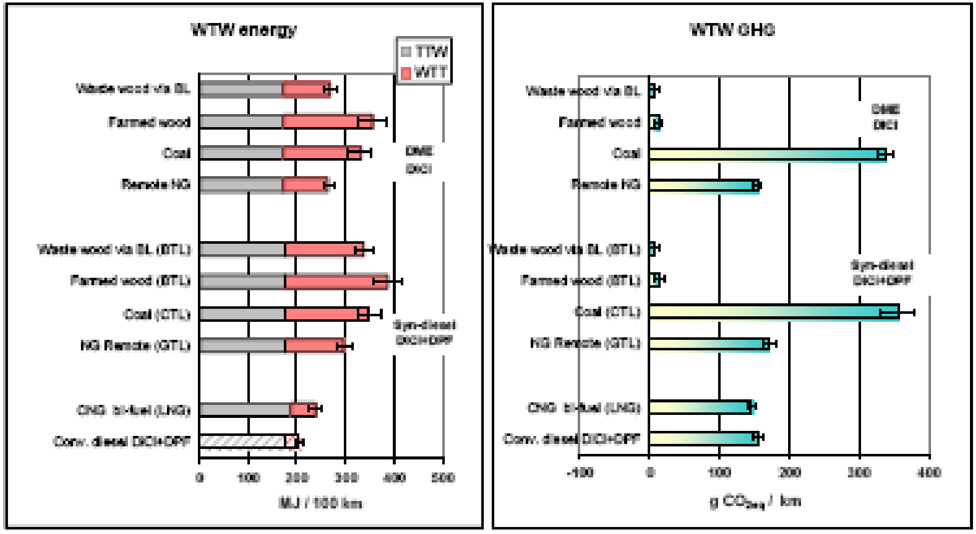


Figure 3 Energy use and emission of greenhouse gases for synthetic diesel and DME for the time period up to 2010 (JRC, 2005)

The diagram shows that bio-based F-T fuels or DME greatly reduce the greenhouse gases. If natural gas is used, it is roughly comparable to produce F-T fuels compared with running on fossil methane that has been liquefied for long-distance transports. It is slightly better to run on normal diesel or CNG. By far the worst alternative is to manufacture F-T or DME from coal.

The lack of LCA data concerning what production method is used in the manufacture of F-T fuels sold in Sweden today means that we have chosen not to recommend any data. The biggest benefit from the environmental point of view with using F-T fuels instead of diesel lies in reduced toxicity and other emissions from the vehicles. An estimate of the environmental impact from the production phase is that the difference in emissions of local health-affecting and regional emissions between traditional diesel and petrol production and F-T fuels is negligible from the life cycle point of view, as the emissions from the vehicles are included. With regard to fossil CO_2, F-T from natural gas is comparable with diesel provided that the system boundaries are comparable, i.e. that the waste energy can be used.

From biomass

The lack of commercial gasification plants for biomass means that this type of fuel has not yet become commercially available. The potential for reducing greenhouse gases is considerable. This applies not least to the use of paper mill waste products in the form of black liquor. The following estimate of the reduction potential from an LCA perspective is presented in the German report Vergleichende Ökobilanz von SunDiesel (Choen-Verfahren) und konventionellem Dieselkraftstoff (Baitz et al., 2005).

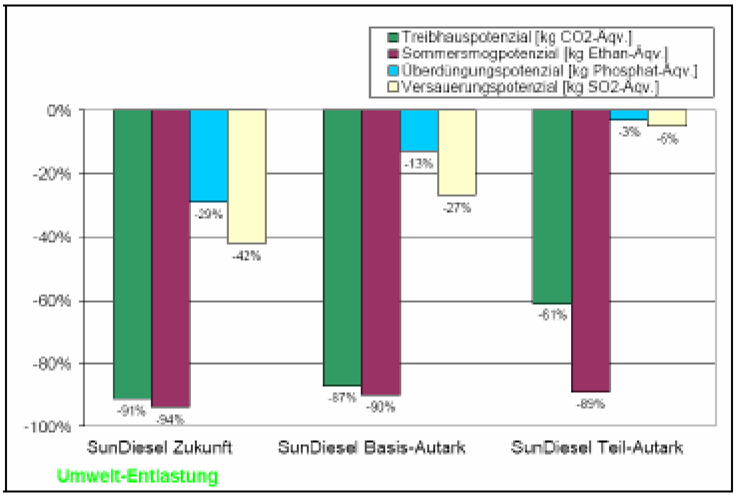


Figure 1: Reduction potentials of environmental impacts of different technology scenarios compared to conventional diesel

Figure 4 The reduction potential of greenhouse gases by using biomass based F-T diesel compared to conventional diesel in three different scenarios. (Baitz et al., 2005)

3.6 Petrol and Diesel

Data for petrol and diesel used in Sweden have been obtained from Blinge et al. (1997). The same data are also recommended in IVL's Environmental Factbook (Uppenberg et al., 2001). These data are based on best possible technology in 1996, which means data from Scanraff in Lysekil. Large investments in Scanraff have been made since then, and an analysis of the new plant probably looks different. No new figures are available for Swedish-produced petrol and diesel, however. If one compares with other studies on average values for European-produced petrol and diesel, much higher figures are presented for energy use and emissions of greenhouse gases. Other emissions data are lacking in the studies we have found. The big difference between best available technology in Sweden and average production in Europe does not mean that the studies are incorrect, but rather shows the uncertainty that is involved. This naturally gives problems with regard to what data are to be recommended. We have therefore chosen to publish both of the sets, in order to show a minimum value and an average value respectively. We have chosen to present GM's (2002) values, since they have selected average European production as the starting point. JRC (2004) has chosen marginal effect (the production that does not materialise in the event of introduction of alternative fuels in Europe) as the starting point.

Using this method of calculation, the emissions from diesel are actually higher than for petrol (500 and 440 g/litre respectively).

The energy need for the production of petrol and diesel is not specified. In Blinge et al. (1997), a total energy use is stated of 3.1 MJ/litre fuel for petrol and 2 MJ/litre for diesel.

Table 9 Emission to air during production (g/litre and MJ/litre respectively)

Environmental factor	**Petrol BAT**	**Petrol average**	**Diesel BAT**	**Diesel average**
CO_2	166	465	123	366
NO_X	1.0	NIA	1.1	NIA
HC	1.3	NIA	1.2	NIA
CH_4	0.06	NIA	0.07	NIA
CO	0.06	NIA	0.07	NIA
PM	0.03	NIA	0.04	NIA
SO_X	0.66	NIA	0.7	NIA
Energy (renewable)	0	NIA	0	NIA
Energy (fossil)	3.1	6.3	2.0	7.3
Energy (nuclear)	NIA	NIA	NIA	NIA

NIA = no information available
BAT = Best Available Technology

In the case of combustion of petrol, 2300 g/litre of fossil CO_2 are also emitted. In the case of combustion of diesel, 2600 g/litre are emitted (IVL, 2001)

4 FUEL BLENDS

4.1 ETAMAX D

ETAMAX D is the ethanol fuel used in bus operation in Sweden. It is manufactured by SEKAB in Örnsköldsvik. The content of the fuel is specified by SEKAB – see table below. The fuel is sometimes also called E95. The ethanol content is slightly lower than 95%, however. The ethanol raw material also contains a small percentage of water, and therefore it is only around 95%. The ethanol raw material for petrol blends does not contain water.

SEKAB does not specify the ignition improver in its fuel specification. In Ericson and Odéhn (1999), an LCA of ethanol as bus fuel has been conducted, where the ignition improver has been studied in detail. They state a somewhat lower ethanol content (90.2% by weight) and higher content of ignition improver (7% by weight) than what SEKAB currently states.

Table 10 Fuel specification for ETAMAX D

Substance	Unit	Value
95% ethanol	% by wt	85.3
Ignition improver	% by wt	5.0
MTBE	% by wt	2.3
Isobutanol	% by wt	0.5
Corrosion inhibitor	ppm	90
Water	% by wt	6.9
Colourant (red)		
Density (D 20/4)	g/ml	0.810-0.830

Source: SEKAB

The emissions from production of ethanol have been dealt with earlier in this report. The ignition improver added is fossil-based, however, and is decisive for the total emissions of CO_2 from the fuel. No consideration has been given to the corrosion inhibitor or the colourant.

In Ericson and Odéhn, the ignition improver is specified as Beraid 3540 and is said to be manufactured by Akzo Nobel. They state that the emissions of CO_2 per bus kilometre from the ignition improver are roughly 49 grams. From the MTBE, the emissions are approx 18 grams. For isobutanol, the emissions are roughly 2.5 grams. The fuel consumption is stated as 0.68 kg per bus kilometre. They do not specify a density for the fuel, but SEKAB states a density of 810-830 grams per litre fuel. Here 820 g/l is used. The emissions from the additives have been calculated per litre of ETAMAX D. Since Ericson and Odéhn have stated a higher ignition improver content than what SEKAB currently states, the data for this are adjusted. Instead of 7% the content today is 5%. The other substances have the same content.

Table 11 Emissions during production and use of additives in ETAMAX D (g/l and MJ/l ethanol respectively)

	Beraid 3540	MTBE	Isobutanol	**Total additives**
CO_2 total[1]	42	22	3.0	**67**
NO_X	0.15	0.036	0.0052	**0.19**
HC	0.19	0.073	0.016	**0.28**
CH_4	0.0020	0.00018	0.00010	**0.0023**
CO	0.015	0.0013	0.00011	**0.016**
PM	0.024	0.0023	0.00026	**0.026**
SO_X	0.098	0.0061	0.0018	**0.11**
N_2O	NIA	NIA	NIA	**NIA**
Energy (fossil)	1.3	0.64	0.14	**2.1**
Energy (renewable)	0.059	0.012	0.0051	**0.076**
Energy (nuclear)	0.058	0.0087	0.0040	**0.071**

NIA = no information available

[1] – The division between CO_2 emissions from production and during operation is not known. Therefore the total emissions are stated.

In order to calculate the total emissions from ETAMAX D, the emissions from manufacture and use of the additives are added to the emissions from production of the ethanol. Since ETAMAX D contains only 92.2% ethanol, adjustment has been made for this.

The emissions for the additives are not divided into emissions from production and use respectively. The fossil CO_2 emissions from the use of ethanol are 0, but since it is not known how large the emissions are from the additives, all emissions have been applied to the manufacturing phase.

Table 12 Emissions during production and use of ETAMAX D, depending on the origin of the ethanol used (g/l and MJ/l fuel respectively)

ETAMAX D					
	Ethanol Wheat (Sweden)	Ethanol Sulphite (Sweden)	Ethanol Sugar cane (Brazil)	Ethanol Wine (EU)	Ethanol Wheat (EU)
CO_2 manufacture[1]	209	117	461	382	1 994
CO_2 use	NIA	NIA	NIA	NIA	NIA
NO_X	1.9	0.6	1.32	6.0	NIA
HC	0.4	0.3	NIA	0.8	NIA
CH_4	0.11	NIA	NIA	NIA	NIA
CO	0.33	0.02	NIA	0.5	NIA
PM	1.2	0.03	0.091	0.33	NIA
SO_X	0.23	0.1	1.03	2.8	NIA
N_2O	NIA	NIA	NIA	NIA	NIA
Energy (renewable)	NIA	NIA	2.07	11.2	NIA
Energy (fossil)	NIA	NIA	0.08	4.4	NIA
Energy (nuclear)	NIA	NIA	0.07	0.25	NIA

NIA = no information available

[1] – The division between CO_2 emissions from production and during operation is not known. The total emissions are stated in the manufacturing phase.

4.2 ETAMAX B / E85

SEKAB calls the ethanol used as fuel for passenger cars ETAMAX B. The ethanol raw material consists in principle of water-free ethanol, in contrast with the bus ethanol. The density is stated by SEKAB as 0.765-0.785 g/ml. Here 0.775 g/ml is used. ETAMAX B contains none of the ignition improver used in bus ethanol, since the fuel contains petrol, which improves the ignition characteristics. The pure ethanol content in the fuel is 99.5% of 86%, i.e. 85.6%.

Table 13 Fuel specification for ETAMAX B / E85

Substance	Unit	Value
99.5% ethanol	% by wt	86.0
Petrol, environ. cl. 1 green	% by wt	11.6
MTBE	% by wt	2.0
Isobutanol	% by wt	0.4
Colourant (red)		
Density (D 20/4)	g/ml	0.765-0.785

Source: SEKAB

With regard to petrol, data for Petrol BAT – Best Available Technology (Sweden) has been used.

The emissions of CO_2 during combustion are very significant for the petrol component in the fuel. The emissions for additives are not divided into emissions from production and use respectively. The emissions of CO_2 from additives for ETAMAX B have therefore been applied entirely to the production phase. This element in the total values is considered to be of minor importance.

Table 14 Emissions during production and use of ETAMAX B / E85, depending on the origin of the ethanol used (g/l and MJ/l fuel respectively)

ETAMAX B	Ethanol Wheat (Sweden)	Ethanol Sulphite (Sweden)	Ethanol Sugar cane (Brazil)	Ethanol Wine (EU)	Ethanol Wheat (EU)
CO_2 manufacture	183	93	428	351	1 926
CO_2 use	276	276	276	276	276
NO_X	1.8	0.6	1.3	5.8	NIA
HC	0.31	0.26	NIA	0.8	NIA
CH_4	0.11	NIA	NIA	NIA	NIA
CO	0.32	0.017	NIA	0.52	NIA
PM	1.1	0.010	0.069	0.31	NIA
SO_X	0.21	0.10	1.0	2.7	NIA
N_2O	NIA	NIA	NIA	NIA	NIA
Energy (renewable)	NIA	NIA	NIA	NIA	NIA
Energy (fossil)	NIA	NIA	NIA	NIA	NIA
Energy (nuclear)	NIA	NIA	NIA	NIA	NIA

NIA = no information available

5 TABLES

The above-mentioned emissions data can be summarised in the tables below. Note that the data is given in the units m^3 and litre fuel respectively. This means that the different fuels can not be compared directly with eachother in the tables since the energy content and fuel consumption per kilometre in the vehiles differs.

Table 15 Summary Table of emissions from production of different fuels (g/m^3 and g/l respectively, and MJ/m^3 and MJ/l respectively)

	Ethanol (100%) Wheat (Sweden)	Ethanol (100%) Sulphite (Sweden)	Ethanol (100%) Sugar cane (Brazil)	Ethanol (100%) Wine (EU)	Ethanol (100%) Wheat (EU)	Biogas (Sweden	RME (Sweden)
CO_2 manufacture	163	58	450	360	1450	123	298
CO_2 use	0	0	0	0	0	0	0
NO_X	1.9	0.5	1.29	6.6	NIA	0.64	2.6
HC	0.08	0.02	NIA	0.6	NIA	NIA	1.03
CH_4	0.12	NIA	NIA	NIA	NIA	22.6	1.03
CO	0.36	0.01	NIA	0.6	NIA	0.04	0.66
PM	1.3	0.005	0.074	0.35	NIA	0.05	0.06
SO_X	0.14	0.02	1.06	3.1	NIA	0.15	0.6
N_2O	0.70	NIA	NIA	NIA	NIA	NIA	2.22
CO_2 equivalents*	390	(58)	(450)	(360)	(1450)	(688)	1033
Energy (renewable)	NIA	NIA	NIA	4.9	NIA	NIA	NIA
Energy (fossil)	NIA	NIA	NIA	10.4	NIA	NIA	NIA
Energy (nuclear)	NIA	NIA	NIA	0.2	NIA	NIA	NIA

NIA = no information available

* CO_2 equivalents entail a total value for the greenhouse effect. The value for CO_2 has thus been added with N_2O, multiplied by 320 and CH_4 multiplied by 25. (IVL, 2001) Note that above all, the values for N_2O are often lacking. Since N_2O is an aggressive greenhouse gas, this means that the values must be used with caution in any comparisons. Values in brackets mean that information is lacking, which can affect the result.

Table 16 Summary Table of emissions from production of different fuels (g/m^3 and g/l respectively, and MJ/m^3 and MJ/l respectively)

	CNG	Petrol BAT (Sweden)	Petrol average (EU)	Diesel BAT (Sweden)	Diesel average (EU)	Synthetic diesel
CO_2 manufacture	168	166	465	123	366	366
CO_2 use	2030	2300	2300	2600	2600	2600
NO_X	0.78	1.0	NIA	1.1	NIA	NIA
HC	0.10	1.3	NIA	1.2	NIA	NIA
CH_4	0.50	0.06	NIA	0.07	NIA	NIA
CO	NIA	0.06	NIA	0.07	NIA	NIA
PM	0.01	0.03	NIA	0.04	NIA	NIA
SO_X	0.13	0.66	NIA	0.7	NIA	NIA
N_2O	NIA	NIA	NIA	NIA	NIA	NIA
CO_2 equ.*	180	168	465	125	366	366
Energy (renewable)	0.0066	NIA	NIA	NIA	NIA	NIA
Energy (fossil)	2.6	NIA	NIA	NIA	NIA	NIA
Energy (nuclear)	NIA	NIA	NIA	NIA	NIA	NIA

NIA = no information available
BAT = Best Available Technology

With regard to the fuels ETAMAX D and ETAMAX B, the emissions depend on what type of ethanol is used. Summary tables for these fuels therefore refer to tables 12 and 14.

5.1 Energy use

“Measuring energy in kWh or MJ without measuring its quality is like measuring money in the number of coins and banknotes”

(Prof. Hannes Alvén)

Measuring energy without specifying what type of energy is involved is a blunt and often completely misleading measure. Fossil energy should not be counted together with energy from biomass or electricity from nuclear power or renewable sources. We have therefore decided not to present an aggregate figure for energy use in the tables. For those users who need to calculate the energy use, those figures that have emerged are presented below. However, we would strongly advise against all types of comparisons between the fuels based on these figures.

	Ethanol (100%) Wheat (Sweden)	Ethanol (100%) Sulphite (Sweden	Ethanol (100%) Sugar cane (Brazil)	Ethano (100%) Wine (EU)	Ethanol (100%) Wheat (EU)	Biogas (Sweden	RME (Sweden)
Energy use (MJ/l)	11	3.7	NIA	15.5	Ca 15	18	10

	CNG	Petrol BAT (Sweden)	Petrol average (EU)	Diesel BAT (Sweden)	Diesel average (EU)	Synthetic diesel
Energy use (MJ/l)	2.6	3.1	6.3	2.1	7.3	Ca 11

REFERENCES

Almemark et al., (1996)	*LCA-analys av spannmålsbaserad produktion av etanol för bussdrift i jämförelse med dieseldrift*, IVL, Stockholm, 1996
Baitz et al., (2005).	*Vergleichende Ökobilanz von SunDiesel (Choen-Verfahren) und konventionellem Dieselkraftstoff*, PE-Europe GmbH, Leinfelden-Echterdingen, Germany
Beer et al. (2000)	*Life-cycle Emissions Analysis of Alternative Fuels for Heavy Vehicles; CSIRO*, Aspendale, Australia, March 2000.
Blinge et al., (1997)	*Livscykelanalys av drivmedel*, KFB-meddelande 1997:5, KFB, Stockholm, 1997
Blinge M, (1998)	*ELM: Environmental Assessment of Fuel Supply Systems for Vehicle Fleets*, Report 35, Dept. Of Transportation & Logistics, Chalmers, 1998
Börjesson & Berglund (2003)	*Miljöanalys av biogassystem*, Rapport nr 45, Lunds Tekniska Högskola, 2003
Ericson & Odéhn (1999).	*A Life-Cycle Assessment on Ethanol Fuel from Wine*, Dept of Chemical Engineering, Chalmers, 1999
Gartmeister (2000)	*Livscykelinventering (LCI) för bensin och bensin med 5% etanolinblndning*, Examensarbete LiTH-IFM-884, Inst. För fysik och mätteknik, Linköping university, 2000
GM (2002)	*Well-to-wheel analysis of energy use and greenhouse gas emissions of advanced fuel/vehicle systems – a European study.* L-B-Systemtechnich GmbH for GM, ExxonMobil, Shell, BP and TotalFinaElf. September 2002.

IEA (2004) *Biofuels for transport*, International Energy Agency, Paris, France, 2004

IVL (2001) *Miljöfaktabok för bränslen,* IVL rapport B1334B-2, Stockholm, 2001

Jonasson & Sandén, (2004) *Time and scale aspects in life cycle assessment of emerging technologies,* CPM – Centre for Environmental Assessment and Material Systems, CPM report 2004:6, Chalmers, Göteborg, 2004

JRC (2004) *Well-to-Wheels analyses of future automotive fuels and powertrains in the European context*, European Commission, Joint Research Centre, Version 1b, January 2004

Macao et al. (2004) *Assessment of greenhouse gas emissions in the production and use of fuel ethanol in Brazil,* Government of the state of São Paulo, Brazil, 2004

MEET (1999) *Methodology for calculating transport emissions and energy consumption*, European Commission, Research for Sustainable Mobility, 1999

Nilsson M (2000) *LCI för biogas som fordonsbränsle – en systemstudie,* Examensarbete, Högskolan i Kalmar, 2000.

Quirin et al., (2004) CO_2 mitigation through biofuels in the transport sector, IFEU, Heidelberg, Germany

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