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ÖKOBILANZ VON ENERGIEPRODUKTEN:

LIFE CYCLE ASSESSMENT OF BIOMASS-TO-LIQUID FUELS

Final Report

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Abstract

This study elaborates a life cycle assessment of using of BTL-fuels (biomass-to-liquid). This type of fuel is produced in synthesis process from e.g. wood, straw or other biomass. The life cycle inventory data of the fuel provision with different types of conversion concepts are based on the detailed life cycle assessment compiled and published within a European research project. The inventory of the fuel use emissions is based on information published by automobile manufacturers on reductions due to the use of BTL-fuels. Passenger cars fulfilling the EURO3 emission standards are the basis for the comparison.

The life cycle inventories of the use of BTL-fuels for driving in passenger cars are investigated from cradle to grave. The full life cycle is investigated with the transportation of one person over one kilometre (pkm) as a functional unit. This includes all stages of the life cycle of a fuel (biomass and fuel production, distribution, combustion) and the necessary infrastructure (e.g. tractors, conversion plant, cars and streets).

The use of biofuels is mainly promoted for the reason of reducing the climate change impact and the use of scarce non-renewable resources e.g. crude oil. The possible implementation of BTL-fuel production processes would potentially help to achieve this goal. The emissions of greenhouse gases due to transport services could be reduced by 28% to 69% with the BTL-processes using straw, forest wood or short-rotation wood as a biomass input. The reduction potential concerning non-renewable energy resources varies between 37% und 61%.

A previous study showed that many biofuels cause higher environmental impacts than fossil fuels if several types of ecological problems are considered. The study uses two single score impact assessment methods for the evaluation of the overall environmental impacts, namely the Eco-indicator 99 (H,A) and the Swiss ecological scarcity 2006 method. The transportation with the best BTL-fuel from short-rotation wood has only slightly higher environmental impacts than the reference under an evaluation with the ecological scarcity 2006 method. BTL-fuel made from agricultural by-products like straw can achieve environmental impacts similar to petrol if the Eco-indicator 99 (H,A) is evaluated. BTL-fuel from forest wood is an interesting option to reduce the greenhouse gas emissions and environmental impacts.

This LCA study shows that it is possible to produce BTL-fuels, which are competitive to fossil fuels from an environmental point of view. But, it also shows that for the use of agricultural biomass further improvements in the life cycle would be necessary in order to avoid higher environmental impacts than for fossil fuels. There is no general conclusion concerning the comparison of BTL-fuels with other renewable or fossil fuels due to the variety of different conversion concepts and possible biomass resources.

Keywords

life cycle assessment, synthetic fuels, second generation fuels, biomass-to-liquid, wood, miscanthus, straw, greenhouse gas emissions, Eco-indicator 99 (H,A), ecological scarcity 2006

Schlagwörter

Ökobilanz, Synthetische Treibstoffe, Biotreibstoffe, Zweite Generation, Holz, Chinaschilf, Stroh, Eco-indicator 99 (H,A), Umweltbelastungspunkte 2006, Methode der ökologischen Knappheit (2006), Treibhausgasemissionen

Zusammenfassung

Ziel dieser Ökobilanzstudie ist die Beurteilung der Umweltbelastungen durch die Nutzung von synthetischen Biokraftstoffen. Diese Art von Treibstoffen kann theoretisch aus einer Vielzahl unterschiedlicher Ausgangsmaterialien wie Holz, Stroh oder Bioabfällen produziert werden. In einem ersten Schritt wird dabei mittels Vergasung des Rohstoffes ein Synthesegas erzeugt. In einem zweiten Schritt kann aus diesem Gas ein Treibstoff synthetisiert werden, der bezüglich seiner Eigenschaften dem heutigen Dieselmotortreibstoff relativ ähnlich ist. Dieser Typ von Biokraftstoffen wird auch als Treibstoff der zweiten Generation¹ oder BTL (biomass-to-liquid) bezeichnet.

Zur Zeit werden eine Reihe von möglichen Verfahrensabläufen erforscht. Bis Anfang 2008 wurden diese Kraftstoffe aber noch nicht grosstechnisch produziert oder vermarktet. Auf dem Markt erhältlich sind bereits sogenannte GTL (gas-to-liquid) Treibstoffe, die in einem ähnlichen Verfahren Erdgas als Ausgangsmaterial zur Synthese benutzen. Erforscht wird auch die Verwendung von Kohle (CTL). Ausserdem ist es in einem ähnlichen Verfahrensablauf auch möglich gasförmige Brenn- und Treibstoffe zu synthetisieren, z.B. SNG (synthetic natural gas).

In einer bereits veröffentlichten Studie wurde eine Reihe von Biokraftstoffen hinsichtlich ihrer Umweltbelastungen in einer Ökobilanz untersucht. Diese Studie wird nun in der gleichen Systematik um eine Beurteilung einiger synthetischer BTL-Kraftstoffe ergänzt. Hierzu standen Ökobilanzdaten für verschiedene Biomasse-Rohstoffe und Verfahrensvarianten für die Treibstoffherstellung aus einem Europäischen Forschungsprojekt zur Verfügung. Diese Daten wurden hinsichtlich der Treibstoffverbrennung ergänzt und entsprechend der Systematik der früheren Schweizer Studie ausgewertet.

Als Biomasse-Rohstoffe wurden Chinaschilf (*Miscanthus*), Kurzumtriebsholz (Weide), Weizen-Stroh und Waldholz untersucht. Für die landwirtschaftlich angebauten Produkte wurden dabei die zukünftigen durchschnittlichen Verhältnisse in Europa abgeschätzt. Im Weiteren wurde für diese Auswertung eine Variante mit Schweizer Waldholz und Stroh gerechnet.

Die verschiedenen Verfahrensvarianten unterscheiden sich hinsichtlich technischer Details, wie z.B. der Vergasung, hinsichtlich Anlagengrösse, zentraler bzw. dezentraler Vergasung und Menge des als Nebenprodukt verkauften Stromes und der verkauften Wärme. Aufgrund des bei der Datenerhebung gewählten Allokationsansatzes schneidet dabei Treibstoff aus einer Anlage mit hohem Anteil der extern genutzten Energieprodukte (Strom und Wärme) bei den Umweltbelastungen schlechter ab als jener aus Anlagen, die fast ausschliesslich Treibstoff produzieren. Bei der Allokationsentscheidung wird angenommen, dass der gesamte Biomasseverbrauch zu Lasten der Treibstoffproduktion geht da die Grundidee der Modellierung eine möglichst hohe Treibstoffausbeute ist.

Aufgrund der möglichen Variationen bei der Anlagenplanung sollten die Daten noch nicht zu einer endgültigen Beurteilung der verschiedenen Verfahrenswege genutzt werden. Die Auswertungen zeigen aber auf, in welcher Bandbreite die zu erwartenden Umweltbelastungen bei dieser Art von erneuerbaren Treibstoffen etwa liegen.

Grundsätzlich bestätigt diese Arbeit die Erkenntnis der vorangegangenen Ökobilanz, dass die Nutzung von Abfällen, Reststoffen und Waldholz meist tiefere Umweltbelastungen verursacht als die Nutzung von landwirtschaftlichen Biomasse Rohstoffen. Dies ist ein wesentlicher möglicher Vorteil von synthetischen Treibstoffen, die auf Basis Ligno-Zellulose-haltiger Rohstoffe gewonnen werden können. Aus der Verwendung einer Ganzpflanze ergibt sich allerdings nicht zwingend auch ein höherer Treibstoff-ertrag pro Hektar, da die energetischen Umwandlungsverluste bei diesen Verfahren 30% und mehr betragen.

¹ Der Begriff "zweite Generation" wird in recht unterschiedlichen Zusammenhängen gebraucht. Neben synthetischen Kraftstoffen wird dieser Begriff auch für Treibstoff verwendet, die aus nicht-essbaren Pflanzen z.B. Holz oder generell aus zellulosehaltigen Rohstoffen gewonnen werden. Als "erste Generation" werden oftmals bereits auf dem Markt erhältliche Treibstoffe bezeichnet, die mittels physikalischer (pressen) oder biogener (Vergärung, Fermentation) Verfahren gewonnen werden. Aufgrund der unklaren und wenig nützlichen Abgrenzung verwenden wir diese Begriffe hier nicht weiter.

Der Umwandlungsgrad der Syntheseanlage spielt eine wichtige Rolle für die Beurteilung der BTL-Treibstoffe. Ein geringer Umwandlungsgrad bedeutet nicht nur einen höheren Verbrauch an Biomasse, sondern meist auch höhere Emissionen mit Abgasen, Abfällen oder Abwässern. Die Verfahren mit dem höchsten Umwandlungsgrad von Biomasse zu Treibstoff schneiden deshalb am besten ab.

Dabei ist anzumerken, dass es hinsichtlich der Anlagenplanung noch viele weitere unterschiedliche Konzepte gibt, die hier nicht alle im Detail untersucht wurden. Ein möglicher Entwicklungspfad ist die Koppelproduktion von Treibstoff zusammen mit chemischen Grundstoffen, Strom und Wärme. Eine weitere Option ist die Verwendung zusätzlicher Energieinputs in der Synthese z.B. in Form von Wasserstoff oder Erdgas zur Erhöhung der Treibstoffausbeute.

Im Vergleich zur fossilen Referenz kann mit den BTL-Treibstoffen eine deutliche Reduktion der Treibhausgasemissionen und des nicht-erneuerbaren Energiebedarfs erreicht werden. Bei einer Beurteilung der gesamten Umweltbelastungen mit den Bewertungsmethoden Eco-indicator 99 (H,A) und Umweltbelastungspunkte 2006 (Schweizer Methode der ökologischen Knappheit) schneiden viele der Herstellungsverfahren allerdings im Moment noch schlechter ab als die fossile Referenz. Bei der Nutzung von Waldholz ist es möglich geringere Umweltbelastungen zu erreichen. Auch bei der Nutzung von Kurzumtriebsholz scheint es mit einigen weiteren Verfahrensverbesserungen möglich, BTL-Treibstoffe zu produzieren, die über den gesamten Lebensweg etwa gleich hohe Umweltbelastungen wie das heutige fossile Benzin verursachen, wenn mit der Methode Umweltbelastungspunkte 2006 bewertet wird. Bei einer Bewertung mit dem Eco-indicator 99 (H,A) können BTL-Treibstoffe aus landwirtschaftlichen Nebenprodukten, wie Stroh, ähnliche geringe Gesamtbelastungen wie beim Benzin erreichen.

Auch bei BTL-Treibstoffen besteht ein Zielkonflikt zwischen möglichst hohen Flächenerträgen auf der einen Seite und niedrigen Umweltbelastungen auf der Anderen. Höhere Erträge können oft nur durch höhere Düngemittel- und Pestizideinsätze erreicht werden. Weitere Forschungen sind notwendig um hier auch für Energiepflanzen ökonomisch und ökologisch optimale Anbaubedingungen zu bestimmen.

Insgesamt wird damit das in einigen bisherigen Publikationen gezeichnete Bild einer eindeutigen ökologischen Verbesserung durch die Nutzung von BTL-Treibstoffen bzw. Biotreibstoffen „zweiter Generation“ relativiert. Es wird deutlich, dass die Biomasseproduktion auch bei BTL-Treibstoffen einen wichtigen Einfluss auf die verursachten Umweltbelastungen ausübt. Somit können synthetische Treibstoffe nicht als generell besser (oder schlechter) beurteilt werden als andere erneuerbare Treibstoffe. Ausserdem bestehen beim derzeitigen Entwicklungsstand noch grosse Unsicherheiten hinsichtlich der tatsächlich zu erreichenden Umwandlungsgrade und der tatsächlichen Verfahrensabläufe.

Im Hinblick auf die Steuerbefreiung bei einer zukünftigen Markteinführung ist deshalb für eine Beurteilung der Umweltbelastungen eine Neubewertung notwendig. Hierzu sind insbesondere detaillierte Informationen zur verwendeten Biomasse und Betriebsdaten zu Umwandlungsgraden, Emissionen und Abfällen für die Berechnung zu verwenden.

In dieser Studie wird auch eine andersartige Nutzung der Biomasse Ressourcen nicht weiter untersucht oder mit der Treibstoffproduktion verglichen. Auch andere Optionen zur Erreichung des Zieles geringerer Treibhausgasemissionen werden nicht diskutiert. Solche Möglichkeiten, z.B. geringer Treibstoffverbrauch bringen unter Umständen nicht nur Vorteile bei den Treibhausgasemissionen sondern bei allen Umweltbelastungen.

Bei den Umweltauswirkungen werden zur Zeit auch noch weitere Aspekte diskutiert, die hier nicht berücksichtigt wurde. Ein mögliches Problem ist die Veränderung der Kohlenstoffbindung im Boden durch die Umnutzung von Landflächen für die Biomasseproduktion. Diese Veränderungen können auch negative Auswirkungen auf die Treibhausgasbilanz haben.

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1. Introduction and overview

The study at hand has been elaborated as a follow-up study of a recent investigation on several types of biofuels [1, 2]. In that study the environmental impacts of several biofuel options like biogas, plant oil methyl ethers, ethanol and methanol have been investigated from a Swiss market perspective. The study investigated mainly renewable fuels, which are directly produced from a biomass resource by a physical, chemical or biological process like oil pressing, chemical reaction, fermentation or anaerobic digestion.² The study concludes that with many biofuels it would be possible to reduce the emissions of greenhouse gases. But, on the other side there are severe disadvantages regarding several other environmental problems if biofuels are compared with fossil fuels.

That study forms the basis to develop criteria for the tax exemption on biofuels in Switzerland [3]. At present it is planned to cut the tax on those fuels which are made from residues or which achieve a substantial reduction of greenhouse gas emissions (-40%) without harming the environment more than fossil gasoline.

In the meantime this study with the critical evaluation of the rapidly increasing use of biofuels has been cited in several media, journals and reports of international organizations [4-6]. Some of these publications considered so called "second-generation"² biofuels as a promising option in order to overcome the concerns about the presently marketed biofuels [5, 7].

For the production of synthetic fuels first a synthesis gas is produced from the biomass by means of gasification. In a second stage a synthetic fuel is produced out of this gas. A typical process therefore is the Fischer-Tropsch synthesis. In principle several types of biomass including wood and cellulose or lignin containing plants can be used as a raw material. Also the use of many non-edible plants would be possible, which should avoid negative implications due to competition with the food production.

Different types of synthetic fuels can be produced in this type of processes. The most common ones made from biomass are:

- BTL: biomass-to-liquid. A synthetic fuel with similar fuel properties as conventional diesel
- SNG: synthetic natural gas. A possible replacement of natural gas
- DME: dimethylether. A fuel with similar properties as LPG (liquid petroleum gas)
- ethanol
- methanol

The same type of process can also be used with fossil resources, e.g. for the production of GTL (gas-to-liquid) using natural gas or coal-to-liquid (CTL).

So far such fuels are not marketed. The first commercial plant worldwide with an annual production capacity of 15'000 tonnes BTL (biomass-to-liquid) per year should be commissioned in 2008. The conversion plant is erected in Freiberg, Germany by the company Choren. A second, larger plant is planned to be erected in Schwedt, Germany with an annual production of 250 Mio. litre of fuel.³ The fuel from the first plant should be used for the first tankful of cars sold by Volkswagen and Daimler Chrysler.⁴

This report aims to compare the environmental impacts over the full life cycle of using BTL-fuels with fossil diesel or petrol. The following questions are addressed and answered in this report:

- What are the environmental impacts of using BTL-fuels compared to fossil diesel?

² In some publications the term "first generation fuels" is used for this type of renewable fuels. In contrast synthetic fuels are sometimes termed as "second-generation fuels". But, this term is also used for fuels made from biomass resources, which are not edible and are thus not competitive to food production. A third definition of "second generation" fuels refers to the use of ligno-cellulosic plants as a raw material. Due to the unclear definition of these terms we will not use them in this report.

³ <http://www.choren.com>, retrieved 24.1.2008.

⁴ <http://de.wikipedia.org/wiki/BTL-Kraftstoff>, retrieved 24.1.2008.

- What is the importance of fuel combustion in relation to the total environmental impacts caused by using the fuels?
- How high is the reduction in the global warming impacts compared to fossil fuels?
- What are the results of a comparison with biofuels already available on the market and investigated in a former study?
- What are the yields per hectare compared to other types of biofuels?

The life cycle inventory from well-to-tank of several types of so called biomass-to-liquid (BTL) fuels has been elaborated in a report [8]. Results of the comparison based on the energy content delivered to the tank are discussed in a public LCA report [9]. That LCA has been critically reviewed according to the ISO 14040 standards.

The life cycle inventory of the use of BTL-fuels in passenger cars (tank to wheel) and for the transportation services provided by cars can be found in Chapter 2. The functional unit is the transportation of one person over one kilometre in a passenger car. The life cycle impact assessment is elaborated in Chapter 3. The results of this LCA are compared with results from similar LCA studies on BTL-fuels in Chapter 4. Final conclusions are drawn in Chapter 5. Some methodological issues concerning the differences of so called well-to-wheel studies and full life cycle assessments or cradle-to-grave studies are clarified in Chapter 9. The life cycle inventory data on fuel combustion can be found in an annex, which is available for ecoinvent v2.0 members only.

This life cycle assessment of using BTL-fuels follows in general the normal procedure of an LCA. Comments of the project steering committee have been considered for the final version. The LCA has not been critically reviewed according to the ISO 14040 standards.

2. Life cycle inventories of transport services with BTL-fuels

2.1. INTRODUCTION

A detailed description of the electronic EcoSpold data format has been made for the LCA on BTL-fuel production [8]. Readers not familiar with this format can refer to this publication. All calculations in this report have been made with the SimaPro software [10] and ecoinvent background data v2.01 [11].

2.2. BIOMASS PRODUCTION

Three types of biomass inputs were investigated for the conversion to BTL-fuels [8]. These are short rotation wood (willow-salix or poplar), miscanthus and wheat straw. The life cycle inventory data of biomass production are based on regional information investigated for Northern, Eastern, Southern and Western Europe.

Tab. 2.1 shows some key figures from the life cycle inventory analysis of biomass products and intermediate storage. A critical issue in the inventory of wheat straw is the allocation between wheat straw and wheat grains. This allocation is made with today's market prices. This gives an allocation factor of about 10% to the produced straw (on a per kg basis). This is comparable to the approach used in ecoinvent data v2.0 for Swiss crops [12] (e.g. 7.5% allocation factor on wheat straw).

Biogenic emissions of NMVOC during growing of biomass are excluded from the inventory (in contrast to the original data in [8]) in order to be consistent with ecoinvent data on other types of biofuels, which also do not include these emissions [12, 13].

Two further scenarios are investigated regarding the type of biomass input. One calculates the environmental impacts of using forest wood instead of short-rotation wood. The dataset "logs, mixed, at forest wood" has been used for that purpose [14]. A second scenario investigates the use of wheat straw with Swiss data for integrated production instead of European straw [12].

Tab. 2.1 Key figures of the life cycle inventory of biomass production; allocation between wheat straw and grains based on today's market price [15]

		bundles, short-rotation wood	miscanthus-bales	wheat straw, bales
		RER	RER	RER
N-fertilizer	g/kg DS	5.2	4.0	2.2
P2O5-fertilizer	g/kg DS	4.0	3.1	1.1
K2O-fertilizer	g/kg DS	6.4	5.1	0.9
Lime	g/kg DS	6.5	3.6	4.4
diesel use	g/kg DS	5.1	4.3	2.3
yield, bioenergy resource	kg DS/ha/a	10'537	14'970	3'718
yield, wheat grains	kg DS/ha/a	-	-	4'900
energy content of biomass	MJ/kg DS	18.4	18.8	17.2
losses during storage	%	7%	6%	6%

DS : dry substance

2.3. PRODUCTION OF BTL-FUELS

The life cycle inventory of BTL-fuel production has been investigated in a European research project (RENEW⁵) [8] and documented electronically [16]. Different conversion plant developers provided data of the conversion processes. The data are mainly based on technical modelling of such plants, which is based on experiences and knowledge gained from the research work done in the RENEW project.

⁵ Renewable Fuels for advanced powertrains, www.renew-fuel.com.

Where so far no reliable first-hand information is available (e.g. emission profiles of power plants, concentration of pollutants in effluents or the use of catalysts) assumptions are based on literature data. Thus, sometimes it is difficult to distinguish between different process routes because differences could not be investigated. Tab. 2.2 provides an overview on the data provided by different developers and the generic assumptions used for modelling the conversion processes.

Tab. 2.2 Overview on data provided by different conversion plant developers [8]

Concept	Centralized Entrained Flow Gasification	Centralized Autothermal Circulating Fluidized Bed Gasification	Decentralized Entrained Flow Gasification	Allothermal Circulating Fluidized Bed Gasification
Abbreviation	cEF-D	CFB-D	dEF-D	ICFB-D
Developer	UET	CUTEC	FZK	TUV
Biomass input	Amount and type	Amount and type	Amount and type	Amount and type
Biomass type	Wood, straw	Wood, straw	Straw	Wood, miscanthus
Heat and electricity use	Data provided	Data provided	Data provided and own assumptions	Data provided
Auxiliary materials	Hydrogen, Fe(OH) ₂	Filter ceramic, rape methyl ether, silica sand, quicklime, iron chelate	Nitrogen, silica sand	Nitrogen, rape methyl ether, quicklime, silica sand
Catalysts	Literature	Literature	Literature	Amount of zinc catalyst
Emission profile	Literature for gas firing and plant data for CO	Literature for gas firing	Literature for gas firing, plant data for H ₂ S and own calculations	Literature for gas firing and plant data for CO, CH ₄ , NMVOC
Amount of air emissions	Calculated with emission profile and CO ₂ emissions	Calculated with emission profile and CO ₂ emissions	Calculated with emission profile and own assumptions on CO ₂ .	Calculated with emission profile and CO ₂ emissions
Effluents	Amount of effluents and concentration of pollutants	Only amount. Rough assumption on pollutants	Only amount. Rough assumption on pollutants	Only amount. Rough assumption on pollutants
Wastes	Amount and composition	Only amount	Only amount	Only amount
Fuel upgrading	Included in process data	Standard model for upgrading	Standard model for upgrading	Standard model for upgrading
Products	BTL-FT, electricity	FT-raw product, electricity	FT-raw product, electricity	FT-raw product, electricity

We like to emphasise that the different conversion processes investigated in this study have different development degrees. Thus, data presented in the report represent the current development status of the respective technology. According to the authors a lot of effort was used in order to investigate LCI data as accurate as possible [8].

All conversion concepts are based on their optimal technology. Four concepts are investigated on a scale of 500 MW biomass input and one was investigated based on 50 MW biomass input. Some conversion concepts might be improved by increasing the plant size to up to 5 GW. This has not been considered in the LCI study [8]. The RENEW partners UET and Choren work closely together for the planning of the first commercial plant.⁶

⁶ <http://www.choren.com>, retrieved 24.1.2008.

The products produced by the different process chains are not 100% identical with regard to their physical and chemical specifications. All interpretations based on the data investigated in this study must consider the herewith-linked technology background [8].

Key figures of the modelling are summarized in Tab. 2.3 [8]. Here we show the conversion rate from biomass to fuel in terms of energy, the plant capacity and the production volume per hour. The BLEF-DME⁷ process has the highest conversion rate followed by the cEF-D process. The ICFB-D process has a rather low conversion rate (biomass to fuel) because it produces large amounts of electricity as a by-product. The electricity is only burdened with the direct air emissions from the power plant, but not with the production of biomass. This is a worst-case assumption for the BTL-fuel and reflects the project idea of mainly producing fuel.

A further fuel investigated in the LCI study [8] is dimethylether produced from black liquor in paper plants. The use of dimethylether is mainly foreseen for the use with trucks. So far it is mainly discussed in Scandinavian countries. It is excluded here for the discussion on passenger cars in the Swiss context, because reliable information on exhaust emissions was not available.

Tab. 2.3 Key figures of conversion processes: conversion rate between biomass input and BTL-fuel output in terms of energy [8]

	Biomass	Wood	Straw	Wood	Straw	Straw	Wood	Miscanthus	Wood
		Centralized Entrained Flow Gasification	Centralized Entrained Flow Gasification	Centralized Autothermal Circulating Fluidized Bed Gasification	Centralized Autothermal Circulating Fluidized Bed Gasification	Decentralized Entrained Flow Gasification	Allothermal Circulating Fluidized Bed Gasification	Allothermal Circulating Fluidized Bed Gasification	Entrained Flow Gasification of Black Liquor for DME-production
Product Code		BTL-FT	BTL-FT	BTL-FT	BTL-FT	BTL-FT	BTL-FT	BTL-FT	BTL-DME
Developer		cEF-D	cEF-D	CFB-D	CFB-D	dEF-D	ICFB-D	ICFB-D	BLEF-DME
		UET	UET	CUTEK	CUTEK	FZK	TUV	TUV	CHEMREC
conversion rate (biomass to all liquids)	energy	53%	57%	40%	38%	45%	26%	26%	69%
capacity biomass input (MW)	power	499	462	485	463	455	52	50	500
all liquid products (diesel, naphtha, DME)	toe/h	22.5	22.3	16.6	15.0	17.5	1.1	1.1	29.0

toe: tonnes oil equivalent with 42.6 MJ/kg

Some changes have been applied to the LCI data compared to a previous evaluation of the environmental impacts [9]. Now theecoinvent data v2.0 instead of v1.3 are used as a background database [11]. The use of rape methyl ether in some conversion processes is now investigated with real data instead of a rough approximation with soy oil.

2.4. USE OF BTL-FUELS IN PASSENGER CARS

A basic inventory of passenger cars with EURO 3, 4 and 5 standard using diesel or petrol has been elaborated in [1]. The inventory of the most important air emissions during the combustion of BTL-fuels is based on published information from measurements made within the RENEW project by DaimlerChrysler, Renault and VW ([17-19], see Tab. 2.4). The following air emissions, also regulated by the EURO standards, have been reported: NO_x, CO, hydrocarbons, particulate matter and CO₂.

Only some direct comparisons between using diesel and BTL in the same powertrain and under the same conditions are published. Most information on emissions with BTL-fuels are only published on a relative scale compared to EURO 4 standards. These figures cannot be directly interpreted as an emission reduction compared to the use of diesel because also powertrains using diesel will have emissions lower than the maximum limit. In general the figures show a high variation depending on the powertrain and the test conditions. So far no information investigated independently from possible fuel producers and car manufacturers is available.

Real emissions of driving cars are not necessarily equal to the emissions measured under standardized conditions. Due to this reason, average emission figures used by [1] are partly higher than the EURO limits.

⁷ BLEF-DME stands for Entrained Flow Gasification of Black Liquor for DME (dimethylether)-production, see Tab. 2.3 for further abbreviations of production processes.

In order to achieve comparable results to the previous study [2] it is necessary to determine the emissions of an average EURO3 car using BTL. In a first step reduction factors are estimated based on the available information. These factors shown in the last row of Tab. 2.4 are used to calculate the emission with the data available for EURO3 diesel cars. The rough estimation is mainly based on the information available for the reduction factors between diesel and BTL use. The large variation and the relative scale in the publications make it difficult to estimate these emissions. But, the later evaluation shows that the direct emissions are only of minor importance for the evaluation of the total environmental impacts.

The measurements on BTL-fuel have been made with the type of fuel produced by the centralized entrained flow gasification (partner UET in the RENEW project) [18]. No differences are accounted for the other types of BTL-fuels investigated in this project [8], because measurements were not available.

According to [19] the energetic fuel consumption can be assumed to be equal for BTL and diesel, but differences in lower heating value per kilogram have to be considered. Other parts of the life cycle inventory as e.g. other air emissions and the used infrastructure for roads are considered the same as investigated for EURO 3 cars [1, 20].

Tab. 2.4 Air emission reductions of different passenger cars using BTL-fuel and low-sulphur diesel [17-19] and estimation of reduction factors compared to EURO3 diesel cars for this study. Negative figures stand for higher emissions than the reference

	NOx	PM	CO	HC	HC+Nox	Source	Manufacturer	Test specification
EURO4 (g/km)	0.25	0.025	0.5	0.05	0.3			
EURO4 to BTL	0%	22%	75%	80%		Degen 2007	DaimlerChrysler	no adaption
EURO4 to BTL	30%	-20%	50%	80%		Degen 2007	DaimlerChrysler	Nox optimization+particle filter
EURO4 to BTL	30%	-30%	90%	85%		Degen 2007	DaimlerChrysler	Nox optimization
EURO4 to BTL	20%	30%				Heinl 2007	VW	adjusted injection rate
EURO4 to BTL			90%	80%		Heinl 2007	VW	independent of data set
EURO3 to BTL	2%	28%	59%	55%		Degen 2007	DaimlerChrysler	no adaption
CEC diesel to BTL	0%	45%	70%	60%		Heinl 2007	VW	to CEC diesel fuel
Diesel to GTL	0%	26%	50%	75%		Rouveirolles 2007	Renault	GTL with conv Diesel, EURO 4
Diesel to BTL	15%	-20%	20%	10%	15%	Degen 2007	DaimlerChrysler	Nox optimization+particle filter
Diesel to BTL	18%	25%	40%	18%	18%	Degen 2007	DaimlerChrysler	Nox optimization
<i>mean EURO to BTL</i>	<i>16%</i>	<i>6%</i>	<i>73%</i>	<i>76%</i>				
<i>mean diesel to BTL</i>	<i>8%</i>	<i>19%</i>	<i>45%</i>	<i>41%</i>				
<i>mean all to BTL</i>	<i>13%</i>	<i>12%</i>	<i>60%</i>	<i>60%</i>				
estimation diesel to BtL	10%	10%	45%	40%		This study		

Tab. 2.5 describes the modelling of the life cycle inventory data.

Tab. 2.5 Documentation of the inventory data of the operation of passenger transport devices and the transport service

ReferenceFunction	Name	combustion, diesel, EURO3, in powertrain	combustion, BTL-fuel, EURO3, in powertrain	operation emissions, passenger car, evaporation and tyre abrasion	transport, passenger car, BTL-fuel, straw, EURO3
Geography	Location	RER	RER	RER	FZK
ReferenceFunction	InfrastructureProcess	0	0	0	0
ReferenceFunction	Unit	km	km	km	pkm
TimePeriod	IncludedProcesses	Direct airborne emissions of gaseous substances, particulate matters and heavy metals are accounted for. Particulate emissions comprise exhaust emissions.	Direct airborne emissions of gaseous substances, particulate matters and heavy metals are accounted for. Particulate emissions comprise exhaust emissions.	Particulate emissions comprise abrasions emissions. Heavy metal emissions to soil and water caused by tyre abrasion are included.	operation of vehicle; production, maintenance and disposal of vehicles; construction and maintenance and disposal of road.
	Synonyms	Centralized Entrained Flow Gasification//cEF-D	Allothermal Circulating Fluidized Bed Gasification//lCFB-D		Decentralized Entrained Flow Gasification//dEF-D
	GeneralComment	Average data for the operation of a newly registered Euro3 car in Switzerland in the year 2005.	Average data for the operation of a newly registered Euro3 car in Switzerland in the year 2005.	Average data for the operation of a newly registered Euro3 car in Switzerland in the year 2005.	Inventory refers to the entire transport life cycle. For road infrastructure, expenditures and environmental interventions due to construction, renewal and disposal of roads have been allocated based on the Gross tonne kilometre performance. Expenditures due to operation of the road infrastructure, as well as land use have been allocated based on the yearly vehicle kilometre performance. For the attribution of vehicle share to the transport performance a vehicle life time performance of 2.39E05 pkm/vehicle has been assumed.
	InfrastructureIncluded	1	1	1	1
	Category	transport systems	transport systems	transport systems	transport systems
	SubCategory	road	road	road	road
	Formula				
	StatisticalClassification				
	CASNumber				
	StartDate	2000	2000	2000	2000
EndDate	2005	2005	2005	2005	
Geography	OtherPeriodText	Year in which Euro-standard is coming into effect.	Year in which Euro-standard is coming into effect.	Year in which Euro-standard is coming into effect.	Year in which Euro-standard is coming into effect.
	Text	Data refer to Swiss Conditions	Data refer to Swiss Conditions	Data refer to Swiss Conditions	The data for vehicle operation and road infrastructure reflect Swiss conditions. Data for vehicle manufacturing and maintenance represents generic European data. Data for the vehicle disposal reflect the Swiss situation.
Technology	Text	Diesel, Euro3	Diesel, Euro3	Diesel, Euro3	Diesel, Euro3
	ProductionVolume	Literature data.	Literature data.	Literature data.	Literature data.
	SamplingProcedure				
	Extrapolations	none	none	Some data are investigated under Swiss conditions.	none
UncertaintyAdjustments	none	none	none	none	
PageNumbers	operation	operation	operation	transportation	

The data of the operation of passenger cars is shown in Tab. 10.1. The inventory describes the fuel use and emissions due to the operation of the car over one kilometre. On the right side of the table, the basic data can be found. One column shows the emission reduction figure estimated in Tab. 2.4. One column shows the legal limits in the EU. The last column shows the literature data used for the estimation of standard diesel emission factors [1].

The sulphur content of BTL-fuel is estimated roughly with 1ppm [17] and the one of diesel with 50ppm [21]. Sulphur dioxide emissions are calculated from these contents.

Emissions due to evaporation and tyre abrasion are included in a separate dataset as shown in Tab. 10.1.

Tab. 10.1 Unit process raw data of passenger transport devices for the fuel combustion and other emissions due to operation. The last four columns show the basic literature data and the EU limit

(The table contains data of the ecoinvent database. It is available on request for ecoinvent v2.0 members only)

The life cycle inventory of the transport service includes the fuel consumption and combustion, operation of the car, the production of roads and cars and their disposal. In addition, the maintenance of all necessary items is included. The inventory is calculated with an average occupation of 1.59 persons per car. The inventory shown in Tab. 10.2 is based on literature [1, 20].

Tab. 10.2 Unit process raw data of passenger transport services

(The table contains data of the ecoinvent database. It is available on request for ecoinvent v2.0 members only)

3. Life cycle impact assessment

The Swiss study by Zah *et al.* [2] compared the environmental impacts of several biofuels with using fossil fuels in conventional cars. The authors used two single score impact assessment methods for their evaluation, namely the Eco-indicator 99 (H,A) and the ecological scarcity 2006 method [22, 23] as well as the cumulative energy use and the global warming potential [24]. For all figures which have a direct link to a comparable figure in the study of Zah *et al.* we provide a reference with the number and page such as e.g. {Abbildung 67, Seite 78}.

3.1. COMPARISON OF BTL-FUELS WITH FOSSIL FUELS

We investigate the transport service provided by passenger cars and compare this with the fossil reference. This includes the necessary infrastructure for roads and its maintenance and the production, maintenance and disposal of cars. Thus, this is the evaluation of the full life cycle of transport services, which is also commonly referred to as “cradle to grave” (see Annexe: Reduction Potential Methodology for further explanations).

Fig. 3.1 shows a comparison of transports with passenger cars operated with BTL-fuel and fossil fuel. The comparison is presented for the use of non-renewable energy resources. The ranking of the different types of fuels is the same as already discussed on the basis of one MJ of fuel delivered to the tank [8].

Of interest is the difference between the transport with cars operated on BTL-fuel and the reference cars operated with petrol. The inventory of a EURO 3 passenger car is taken as the baseline. The use of non-renewable energy resources can be reduced by 37% to 61% due to the use of the investigated BTL-fuels.

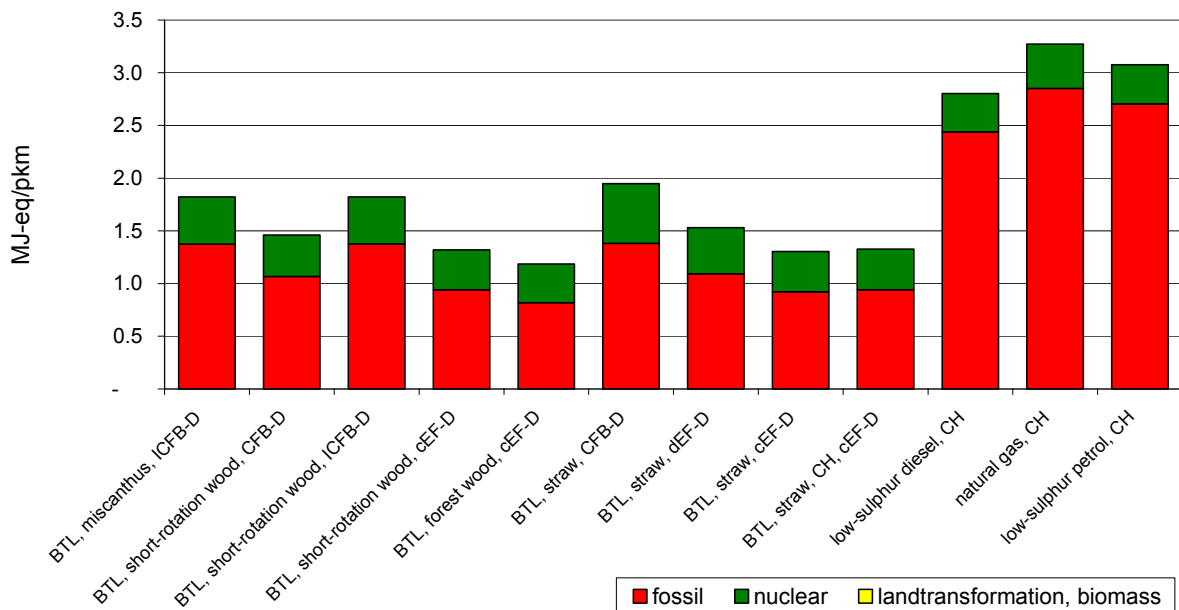


Fig. 3.1 Non-renewable cumulative energy demand of the transport service (MJ-eq/pkm) {Abbildung 66, Seite 77}⁸

Fig. 3.2 compares the emission of greenhouse gases in the life cycle of BTL-fuels and fossil fuels. The emission of greenhouse gases is reduced between 28% and 60% compared to the petrol car if BTL-

⁸ For all figures which have a direct link to a comparable figure in the study of Zah *et al.* we provide here a reference with the number and page in brackets.

fuels are used. Thus, most BTL-fuels investigated here would meet the present criteria of 40% GWP reduction as foreseen in [3].

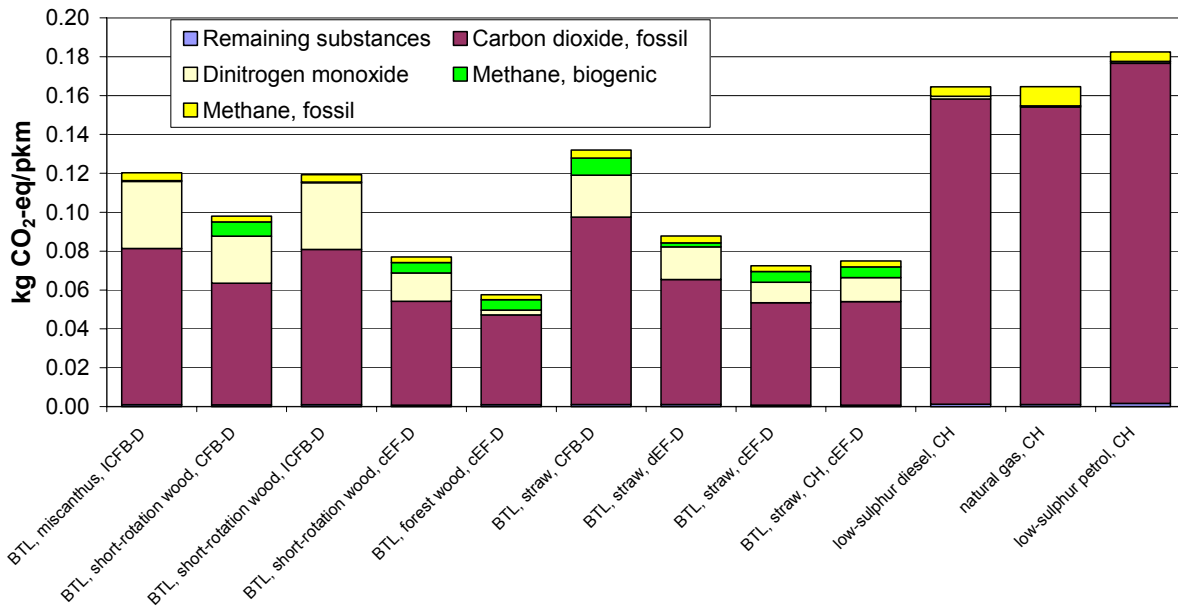


Fig. 3.2 Global warming potential of transport services (kg CO₂-eq per pkm) over a time horizon of 100 years {Abbildung 67, Seite 78}

Fig. 3.3 shows the Eco-indicator 99 (H,A) scores of the different alternatives. Most BTL-fuels have higher impacts than the fossil reference if the full method is used. The most important impact is the land use. For energy crops like short-rotation wood not only the land occupation has a negative effect. Also the transformation of set-aside land to highly intensive agricultural area makes an important contribution of about 20% to the total impacts.

BTL-fuels based on straw show environmental impacts not much higher than the reference. In this case the land occupation is considerably lower because the major part is allocated to the produced wheat grains.

If land use would be excluded from the assessment (as proposed in a sensitivity analysis by Zah *et al.*) most BTL fuels would achieve results comparable to the fossil reference. The BTL-fuel made in the most efficient process from forest wood, has lower impacts than the fossil reference. This can be explained by the lower negative impacts of forests on biodiversity compared to agricultural land. This fuel would achieve the criterion for tax reduction, which is not to have higher environmental impacts than fossil petrol [3]. The use of forest residues, which is not investigated here, would be even more favourable.

The impacts caused by for carcinogenic emissions are negative in Fig. 3.3 for the BTL from short-rotation wood because the uptake of certain heavy metals from soil during biomass growing is assessed higher than the emissions in the life cycle.

Life cycle impact assessment

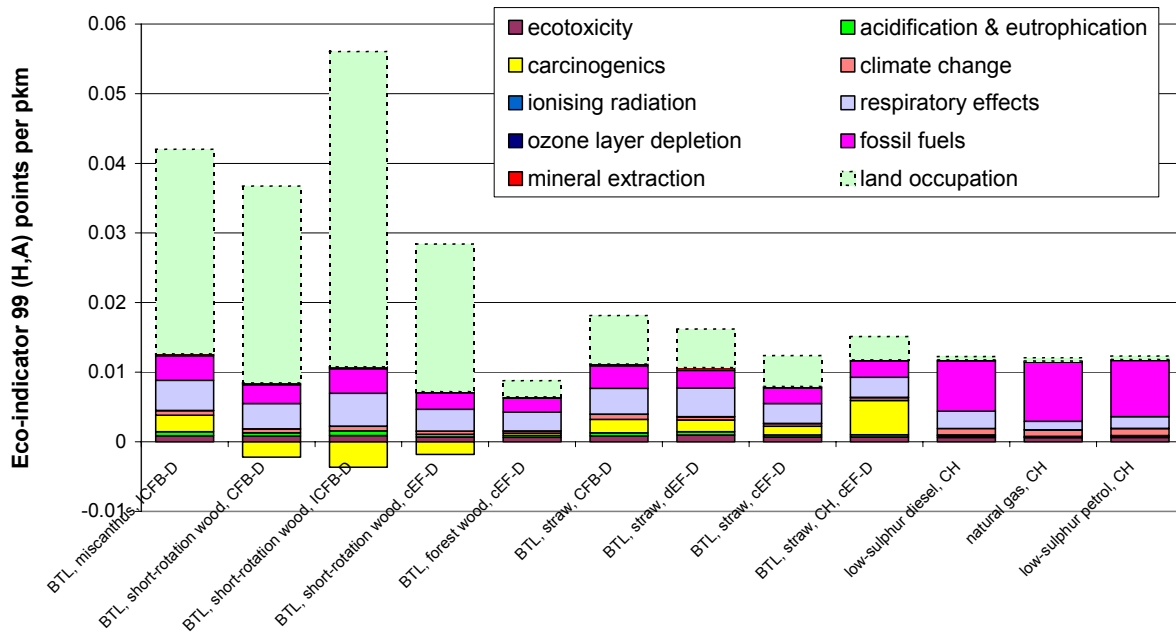


Fig. 3.3 Eco-indicator 99 (H,A) score of the transport service (points/pkm) {Abbildung 68, Seite 79}

Fig. 3.4 shows the results with the method ecological scarcity 2006 [23, 25]. Also here some heavy metals are removed from the agricultural soil during plant growing and thus results in the category emissions into topsoil are negative. All BTL-fuels made from agricultural biomass have higher environmental impacts than the fossil reference. The emissions of nitrate are comparably higher for miscanthus. This is the reason for the relatively higher contribution from emissions into groundwater.

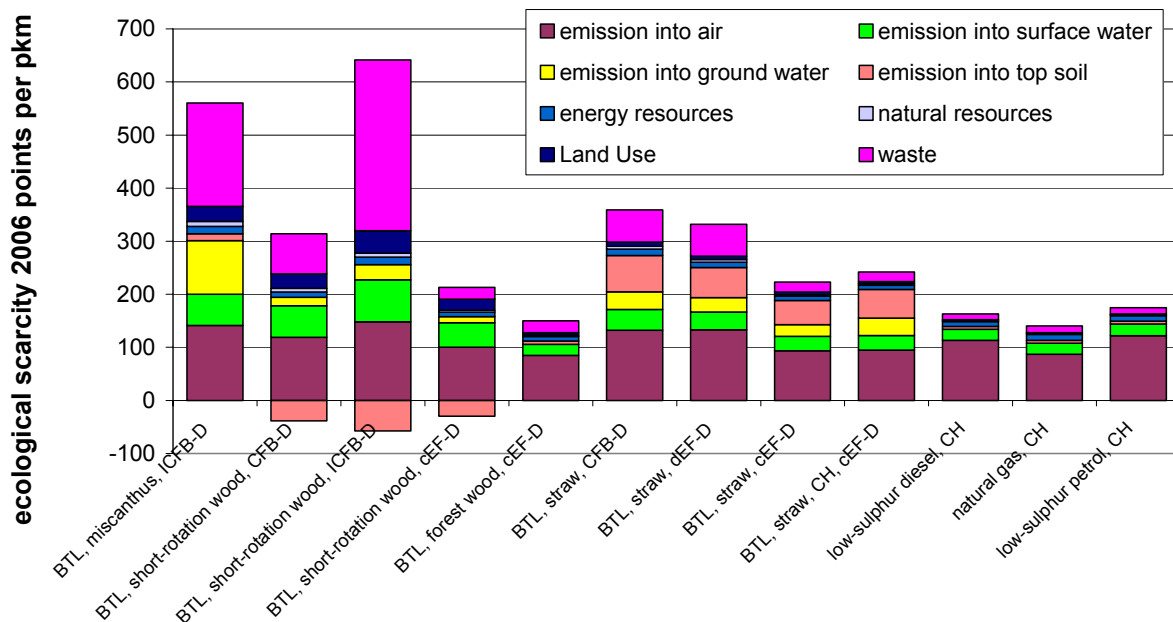


Fig. 3.4 Ecological scarcity (2006) score of the transport service (points/pkm) {Abbildung 68, Seite 79}

For some fuels environmental impacts due to waste management are quite important. This is due to the disposal of ashes and slag from the conversion process. It might be possible to further improve the disposal or even to reuse the remaining as fertilizers in biomass production. So far such options have not been considered in the modelling of the conversion plants.

The total environmental impacts of the best option using forest wood are about the same as for the fossil reference. Thus, it is possible to produce BTL-fuels competitive to fossil fuel.

3.2. COMPARISON WITH OTHER BIOFUELS

A comparison with other biofuels is possible based on the data investigated by Jungbluth *et al.* [1] and evaluated by Zah *et al.* [2]. Fig. 3.5 shows a comparison with the fuels evaluated in those studies. All BTL-fuels from agricultural biomass have higher environmental impacts than the fossil reference. Some BTL-fuels from agricultural biomass have only slightly higher environmental impacts than the reference. BTL-fuel from forest wood is a good possibility concerning reduction of greenhouse gas emissions and protection of the environment. This shows that it is possible to produce BTL-fuels, which are competitive to fossil fuels from an environmental point of view. But, it also shows that the use of agricultural biomass needs further improvements in order to achieve this goal with BTL.

In comparison to other already available biofuels like e.g. rape methyl ether the results are in the same order of magnitude. These results confirm the findings of Zah *et al.* [2]. Many biofuels derived from agricultural biomass are not preferable from an environmental point of view if the full life cycle is taken into account. But, BTL-processes may also use wood from forestry or biomass residues. In comparison to short-rotation wood or other energy crops, this would substantially reduce the environmental impacts.

It is not possible to draw general conclusions for the comparison of synthetic BTL-fuels with e.g. plant oils, ethanol or methyl ethers. For all types of renewable fuels the used biomass is an important factor for the environmental impacts. Thus, there are better and worse fuels in each category. A general advantage of BTL-fuels compared to other biofuels, as claimed in some publications, is not confirmed by our study.

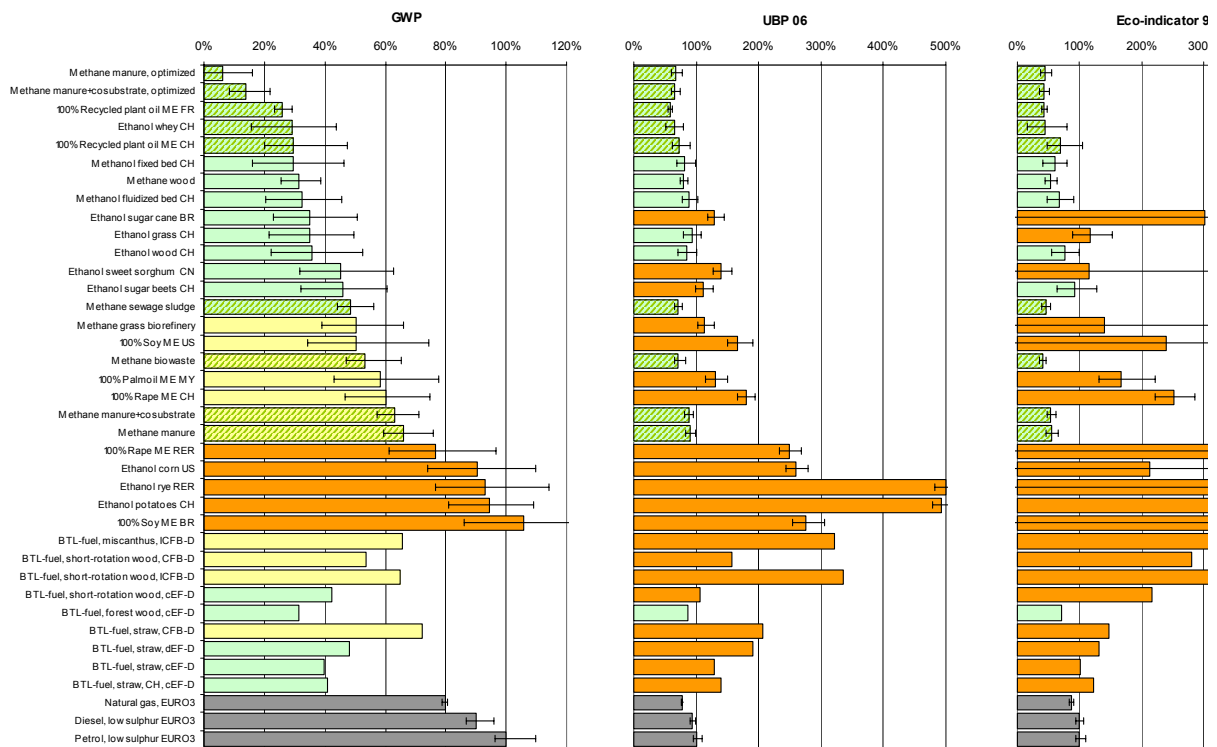


Fig. 3.5 Relative comparison of passenger transports using different category indicators (basis pkm of transport). Reference for all fuels is the use of an EURO 3 petrol car. Life cycle impact assessment with global warming potential, Eco-indicator 99 (H,A) and ecological scarcity 2006 (Pt – points) {Abbildung 4, Seite IX}

3.3. STAGES IN THE LIFE CYCLE

The share of different stages in the life cycle of diesel using cars is analysed in Fig. 3.6. The combustion of the fuel is mainly relevant for CO₂ emissions and thus for the global warming potential. The production of the diesel fuel is relevant for many other category indicators. The production of the passenger car is also relevant for some environmental impacts.

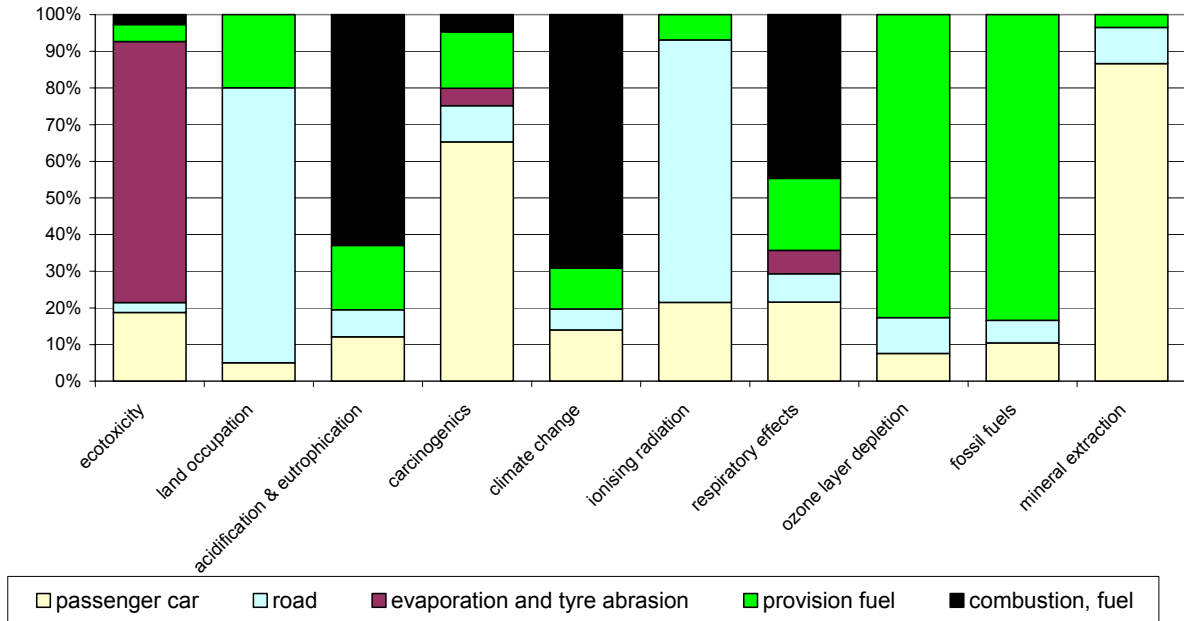


Fig. 3.6 Analysis of using diesel fuel in a passenger car with Eco-indicator 99 (H,A)

Fig. 3.7 analyses the use of BTL-fuel made from short-rotation wood in the cEF-D process. The combustion of the fuel is now not relevant anymore with the exception of acidification and eutrophication (NO_x) as well as respiratory effects (particles). The production of the BTL-fuel is the most relevant stage in most category indicators. The production of the passenger car is also relevant. For conversion processes with a lower performance the production of the fuel gets even more important than in this example that shows the most efficient cEF-D process.

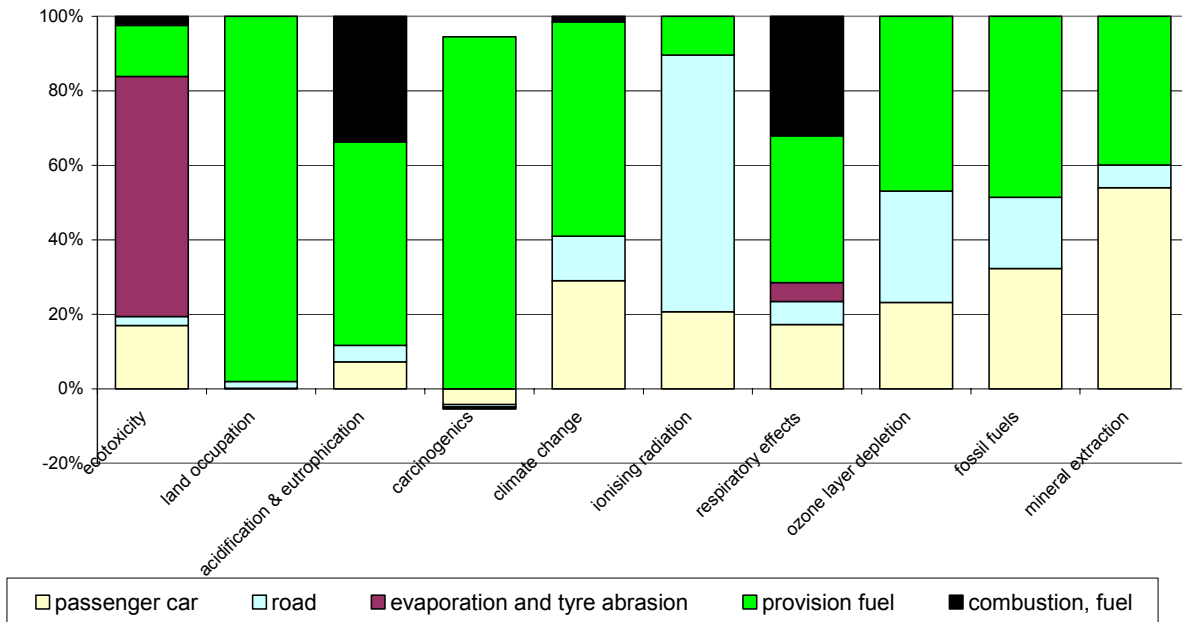


Fig. 3.7 Analysis of Eco-indicator 99 (H,A) results of using BTL-fuel made from short-rotation wood in the cEF-D process in a passenger car

Fig. 3.8 compares the Eco-indicator 99 (H,A) results of a BTL-fuel made from wood with fossil diesel. One sees that results for most stages are the same for both fuels. Only fuel combustion and fuel production are different. Diesel causes higher impacts during combustion especially due to the CO₂-emissions and higher emissions of regulated pollutants, but distinctly lower impacts during fuel production.

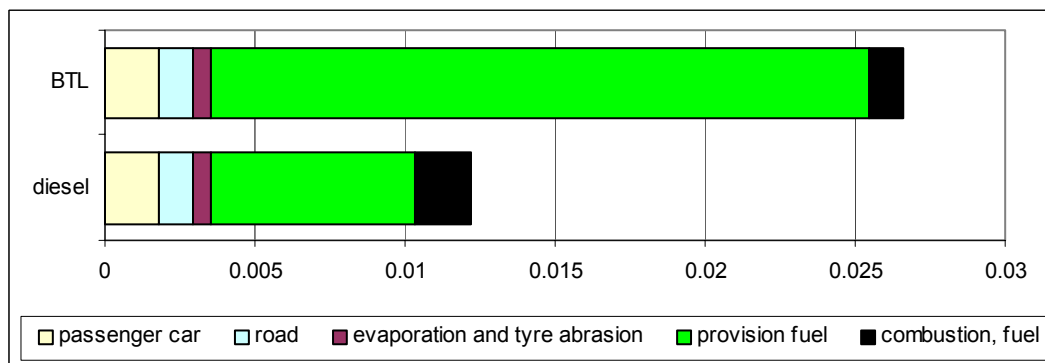


Fig. 3.8 Detailed comparison of Eco-indicator 99 (H,A) results of BTL from short-rotation wood and diesel in different stages of the life cycle

3.4. TRADE OFF BETWEEN ENVIRONMENTAL IMPACTS AND GLOBAL WARMING POTENTIAL

Fig. 3.9 evaluates the trade-off between the reduction of greenhouse gas emissions and environmental impacts. The environmentally best option is the cEF-D process, which reduces the GWP by about 60% with environmental impacts close to the fossil reference. With the use of forest wood it is possible to achieve a GWP reduction of 69% and 14% lower environmental impacts than the reference.

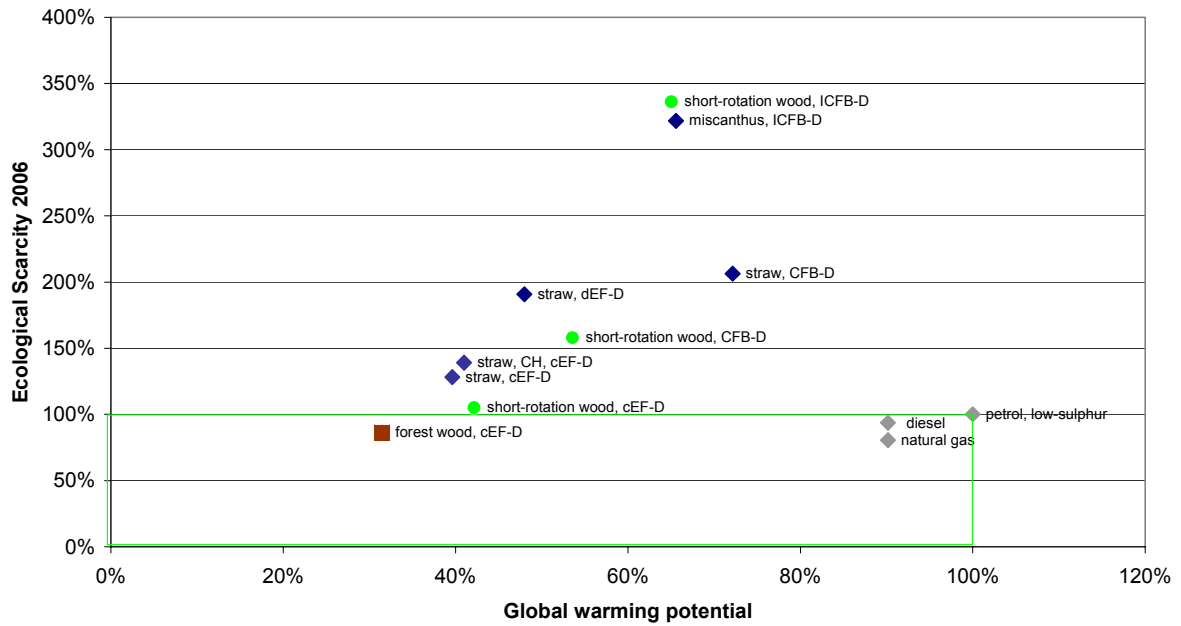


Fig. 3.9 Trade off between GHG emissions and overall environmental impact (UBP 06). Values are relative to fossil reference petrol. Green area means both lower GHG emissions and lower overall environmental impact than petrol {Abbildung 6, Seite X}

3.5. FUEL YIELDS PER HECTARE

The following Fig. 3.10 shows the GHG emissions per hectare and year in comparison to the mileage that can be attained with the biomass grown on that hectare. The figure reveals large differences in agricultural cultivation, both with regard to energy yield and GHG emissions.

The best BTL process achieves fuel yields, which allow driving about 50'000 km from the short-rotation wood grown on one hectare. This is about the same as for sweet sorghum and in the upper range of the biofuels investigated by Zah *et al.* [2]. On the other side also greenhouse gas emissions per hectare are relatively high compared to the renewable fuels investigated in a previous study. The best option is again forest wood, but this fuel achieves slightly lower mileage per hectare than short-rotation wood.

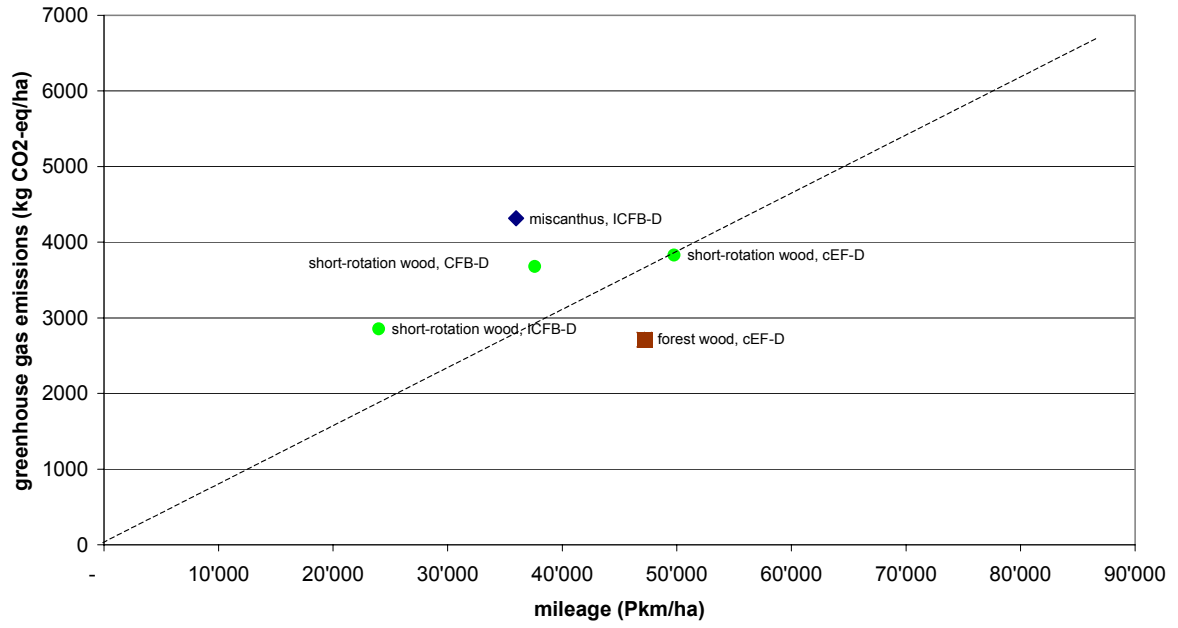


Fig. 3.10 Trade off between mileage and GHG impact per hectare for different biomass resources. Black dotted line represents mean value of all biofuels (linear regression as calculated by [2]) {Abbildung 8, Seite XI}

4. Comparison with other studies

A recent German study investigated some of the BTL-pathways also investigated here [26]. The approach used in that LCA is quite different from the modelling taken here because allocation problems are tackled with the approach of system expansion. This means a credit with an alternative product is given for those by-products not used in the system [26]. Also the basic concepts used for the modelling, such as background data or impact assessment, are not necessarily the same.

The study concludes that BTL-fuels from short-rotation wood are an environmental benefit with regard to the category indicators climate change and use of abiotic resources, but that there are disadvantages with regard to several other category indicators. For the comparison of different types of conversion concepts, it also concludes that the conversion efficiency is quite important. The authors do not see any clear preference for one of the conversion concepts, as there are still different lines of development within the conversion concepts. The approach how by-products, mainly electricity and heat, are tackled is also quite important for the conclusions from this study [26].

The results of the study for the BTL-fuel production [9] concerning the emissions of greenhouse gases are quite different compared to a recent study published by EUCAR, CONCAWE and JRC [27]. We compare here the WTT emissions calculated by [27] with the figures calculated in the RENEW LCA and they are considerable lower (Fig. 4.1). The RENEW LCI study, which forms the basis for the evaluation in the previous chapters, give CO₂-eq emissions between 20 - 60 g per MJ of fuel delivered to the tank [9] while the WTW-study [27] calculated about 5 g CO₂-eq/MJ. The green area in Fig. 4.1 shows the range of results of BTL-fuel production, which has been calculated in RENEW [9]. Below one sees the results of [27] of comparable synthetic fuels made from wood.

Figure 4.6.2-3 WTT GHG balance of syn-diesel pathways (including fossil CO₂ content of final fuels)

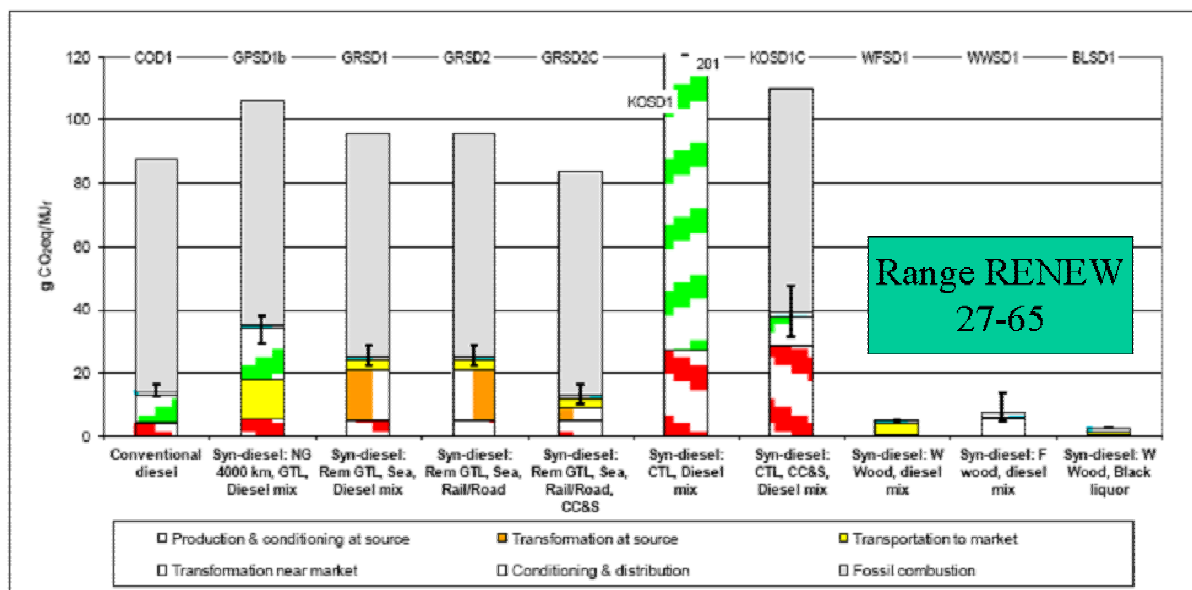


Fig. 4.1 Comparison of well-to-tank results in the RENEW LCA [9] with results from the CONCAWE study [27]

The differences were discussed with the responsible authors. The following main differences were identified:

- Higher nitrogen input in [9] for the short-rotation wood production (2.5 g vs. 5-6 g/kg DS). This results in about 50% higher N₂O emissions during biomass growing of the data used here compared to [27].
- Only low direct emissions of CH₄ and N₂O are assumed for conversion plant in the ConcaWE study, because of data gaps. This reduces the greenhouse gas emissions by about 10-20%

- Infrastructure was not considered in the Concawe study. Infrastructure in agriculture and fuel conversion contributes about 10-20% to the total greenhouse gas emissions in our study
- Credits for electricity production with biomass power plant are granted in the Concawe study while our study makes an allocation. This is mainly relevant for the ICFB-D and thus for the highest cumulative greenhouse gas emissions.

A former study of the Choren process (cEF-D) investigated the use of residual wood in several scenarios [28]. The study showed also a reduction potential for acidification, eutrophication and summer smog. The investigations made in our study show that such a reduction can only be achieved with the use of residuals or wastes as an input to the conversion process, but not with biomass from agriculture or intensive forestry. Thus, the results of the former study of the Choren process can not be generalized due to the specific type of biomass used investigated as an input.

The German "Fachagentur für nachwachsende Rohstoffe - FNR" published some information regarding the environmental performance of BTL-fuels.⁹ They claim a CO₂-reduction of more than 90% and calculated a fuel yield of more than 4000 litres (3400 kg/ha) for BTL-fuels. It is not explained how these figures were calculated. The fuel yield is much higher than the best yield according to the data used for this study. Here we calculated 1800 kg of oil equivalent per hectare for the best BTL-process using short-rotation wood [9]. The maximum CO₂-reduction according to the evaluations in our report is only 60%. For the calculation of such reduction potentials differences due to different scopes of the study also have to be considered (see Annexe: Reduction Potential Methodology). Especially the high fuel yield per hectare on the FNR homepage was cited in other publications and should be interpreted with considerable care.

⁹ <http://www.btl-plattform.de>, retrieved 23.1.2007.

5. Discussion and conclusions

The use of biofuels is mainly promoted for the reason of reducing greenhouse gas emissions and the use of scarce non-renewable resources e.g. crude oil. The possible implementation of BTL-fuel production processes would help to achieve this goal. The emissions of greenhouse gases due to transport services can be reduced by about 60% with the best BTL-processes using short-rotation wood or straw as a biomass input. This is comparable to other types of biofuels made from agricultural biomass resources. With forest wood, reductions up to 69% are possible.

On the other side, there are severe disadvantages from an environmental point of view if fuels are produced from agricultural biomass. The introduction of BTL-fuels made from energy crops would further increase environmental problems mainly caused due to today's agricultural practice. Emissions of substances contributing to eutrophication and acidification are much higher than these of transport services based on fossil fuels. Only one BTL-fuel shows about the same acidification potentials as the fossil fuel car, while all others have higher emissions. Further process improvements are necessary in order to overcome the disadvantage at least regarding acidification. But, the pressure on land and water resource is increased considerable due to the increased production of all BTL-fuels. This would be especially relevant if set-aside land is transformed to intensively used agricultural area. Until now many BTL-fuels produced from energy crops would have higher overall environmental impacts than fossil fuels.

The use of BTL-fuels is more preferable from an environmental point if wood residues can be used [28] or if wood stems from forestry instead of short-rotation plantations.

These findings are in line with several former life cycle assessment studies on biofuels [2, 26, 29]. Differences compared to so-called well-to-wheel studies (see Annexe: Reduction Potential Methodology for further explanations) can mainly be explained by data gaps and different assumptions on the biomass production.

The BTL concepts investigated in this study are modelled for self-sufficient energy supply of the conversion plant and the aim to achieve high fuel yields per hectare. There might be several other ways of development, which are not considered in detail. One possible line of development is the co-production of BTL-fuels together with electricity, heat and feedstock for the petrochemical industry. With such a concept the achievable fuel yields would be lower, but the overall energetic efficiency could be higher. It would also be possible to use other energy carriers than biomass in the conversion plant. One such concept is the use of hydrogen produced e.g. from renewable electricity. This would allow higher fuel yields but therefore considerable supplies of clean electricity would be necessary.

So far all data for the conversion processes are based on modelling and not on commercial plants. The environmental impacts of BTL-fuels must be reevaluated if BTL-fuels are introduced to the market. To quantify the real environmental impacts it is necessary to know the type of biomass used and key figures of the conversion plant, in particular the conversion efficiency, amount and revenues of by-products, emissions and wastes.

Due to the variety of conversion concepts and possible biomass resources it is not possible to make generally valid statements concerning the overall environmental impacts of BTL-fuels compared to other types of renewable or fossil fuels.

Some aspects are not covered in the modelling of this LCA. An important aspect is the impact of land transformation on the carbon stock in soils. First publications claim that such land use changes might be well relevant in the assessment of greenhouse gas emissions. Another aspect is the release of N₂O emissions due to the use of fertilizers in agriculture. New research work claims that these emissions might be higher than modelled until today.¹⁰

¹⁰ "Schlechtes Zeugnis für viele Biotreibstoffe". Neue Zürcher Zeitung, 13.2.2008.

6. Abbreviations

a	annum (year)
BTL	biomass-to-liquid fuel including FT-fuel, methanol and DME produced from synthesis gas
cEF-D	Centralized Entrained Flow Gasification
CFB	circulating fluidized bed
CFB-D	Centralized Autothermal Circulating Fluidized Bed Gasification
CFBR	Circulating-Fluidized-Bed-Reactor
CH	Switzerland
CTL	coal to liquid
dEF-D	Decentralized Entrained Flow Gasification
DME	dimethylether
E-1	Exponential description of figures. The information 1.2E-2 has to be read as $1.2 * 10^{-2} = 0.012$
EI'99	Eco-indicator 99 (H,A)
FT	Fischer-Tropsch (synthesis)
GWP	global warming potential
GHG	greenhouse gases
GTL	(natural) gas-to-liquid
HHV	higher (upper) heating value
ICFB-D	Allothermal Circulating Fluidized Bed Gasification
ISO	International Organization for Standardization
LCA	life cycle assessment
LCI	life cycle inventory analysis
LCIA	life cycle impact assessment
LHV	lower heating value
LPG	liquid petroleum gas
LTV	low temperature gasifier
PM	particulate matter
Pt	points, i.e. Eco-indicator 99 (H,A) or ecological scarcity 2006
RENEW	Renewable Fuels for Advanced Powertrains
RER	Country code for Europe
SNG	synthetic natural gas
UBP	Umweltbelastungspunkte (unit of ecological scarcity impact assessment method)

7. Glossary

first generation fuels	The term is used by some authors for biofuel options like biogas, plant oil methyl ethers and ethanol. They are directly produced from a biomass resource by a physical, chemical or biological process like oil pressing, chemical reaction, fermentation or anaerobic digestion. Another criteria is that these processes allow only a fraction of the processed biomass to be used for fuel production. Sometimes the term refers also to the biofuels being presently on the market. The term is not clearly defined and thus not used in this report.
second generation fuels	Synthetic biofuels are sometimes termed as “second generation” or “advanced” fuels (in contrast to the above mentioned “first generation”). This term is also used for fuels made from biomass resources, which are not edible and are thus not competitive to food production. A third definition of “second generation” fuels refers to the use of lignin, cellulose or hemi-cellulose parts of the plants as a raw material. Beside the synthetic fuels also ethanol production by advanced enzymes and yeasts can be referred to. Quite often the term is used in a context of claiming “second generation” to be better than “first generation”. Due to the unclear definition of this term we do not use it in this report.
synthetic fuels	<p>For the production of synthetic fuels first a synthesis gas is produced from biomass or another resource by means of gasification. In a second stage a synthetic fuel is produced out of this gas. A typical process therefore is the Fischer-Tropsch synthesis. In principle several types of biomass including wood and cellulose or lignin containing plants can be used as a raw material. Also the use of many non-edible plants would be possible. The same type of process can also be used with fossil resources, e.g. for the production of GTL (gas-to-liquid) using natural gas or coal-to-liquid (CTL).</p> <p>Different types of synthetic fuels can be produced in this type of processes. The most common ones made from biomass are:</p> <ul style="list-style-type: none"> • BTL: biomass-to-liquid. A synthetic fuel with similar fuel properties as conventional diesel • SNG: synthetic natural gas. A possible replacement of natural gas • DME: dimethylether. A fuel with similar properties as LPG (liquid petroleum gas) • ethanol • methanol
SunFuel, SunDiesel	Brand names for BTL-fuels produced by the company Choren and supported by Volkswagen and DaimlerChrysler ¹¹

¹¹ http://www.volkswagenag.com/vwag/vwcorp/content/de/innovation/fuel_and_propulsion/production/putting_the_sun_into_your_fuel_tank.html

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9. Annexe: Reduction Potential Methodology

9.1. INTRODUCTION

This chapter explains why the scope of the so-called "well-to-wheel" assessments matters. It provides reasons why the product system of an assessment of the reduction potential of biofuels as compared to fossil fuel needs to be complete regarding capital equipment and infrastructure. The chapter starts with an explanation of the difference in result presentation (relative versus absolute differences). It provides five different product system definitions starting with the one used in the LCA study for fuel production [30].

9.2. QUESTION TO BE ADDRESSED

The question asked for is "What is the reduction potential in % with respect to environmental impacts if we use BTL-fuel instead of fossil fuel".

There are two possible ways to answer this question:

1. Using BTL-diesel reduces the environmental impacts by X% compared to fossil fuel.
2. Using a specific amount (e.g. 1 MJ or 1 kg) of BTL-diesel reduces the environmental impacts by Y kg (or another appropriate unit) compared to fossil fuel.

Depending on the type of answer intended it is quite crucial how system boundaries of the analysis are defined. This is explained with an example. As most people might be more comfortable with money than with the environment, the fictive example is based on prices.

9.3. EXAMPLE: HOW DO SYSTEM BOUNDARIES DEFINE THE ANSWER?

Here we present a fictive example for the price of driving with a given amount of fuel. In this example production of the BTL-fuel is much more expensive than the use of diesel. All other price factors such as distribution, taxes and fixed costs of the car are assumed to be the same. But, the basic principles apply also for all environmental indicators investigated over the life cycle.

Tab. 9.1 Fictive example for price split up of BTL and diesel

	BTL	Diesel	cumulative cost increase	cumulative absolute increase
fuel production	€ 0.60	€ 0.30	100%	€ 0.30
fuel distribution	€ 0.50	€ 0.50	38%	€ 0.30
fuel taxes	€ 0.70	€ 0.70	20%	€ 0.30
costs of the car incl. maintenance	€ 0.50	€ 0.50	15%	€ 0.30
taxes, car	€ 0.50	€ 0.50	12%	€ 0.30
total	€ 2.80	€ 2.50	12%	€ 0.30

Fig. 9.1 shows the shares of costs of this example.

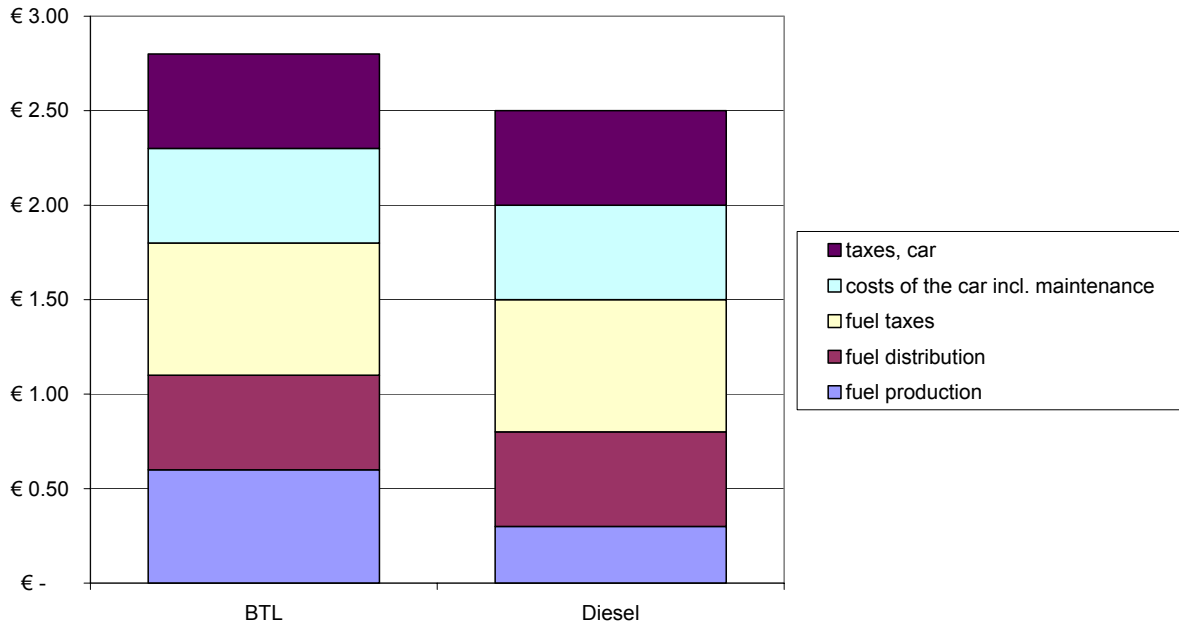


Fig. 9.1 Fictive example of price composition

Fig. 9.2 shows the answers to the two questions asked before. The difference is quite obvious. The absolute difference in price is always 30 cents per amount of fuel consumed regardless of the system boundaries taken (answer to question 2). But in relative terms the difference is quite dramatic (answer to question 1). If we only look at the production of the fuel, the price is twice as high as for fossil fuel. But, there is considerably less difference to conventional fuel if we take car driving as the functional unit. In the latter case, the price increase is only 12%.

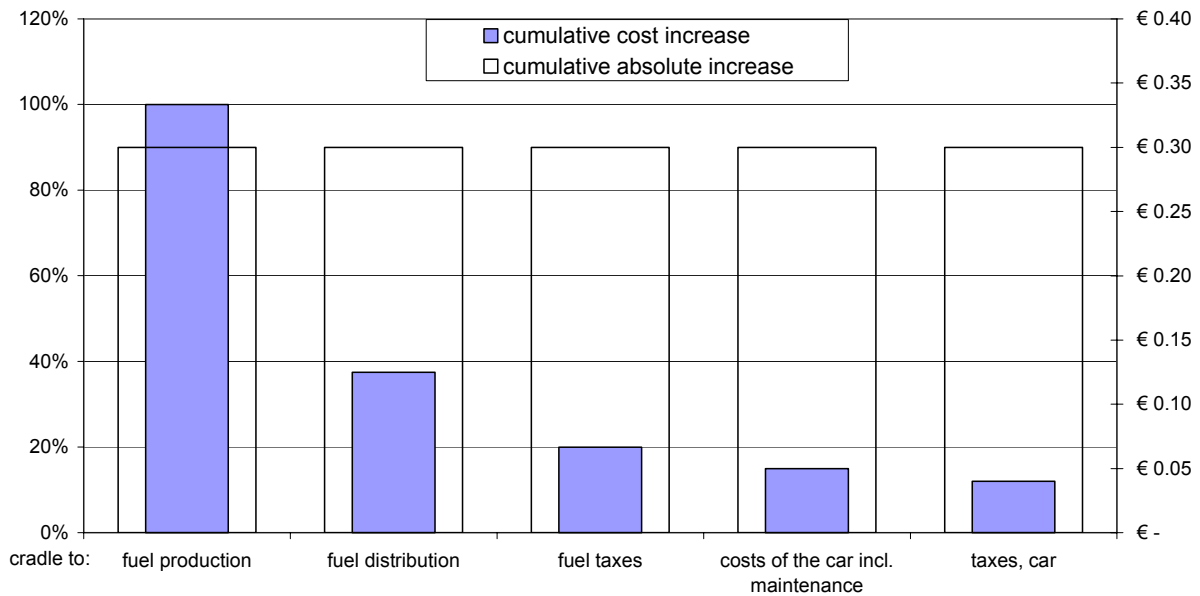


Fig. 9.2 Increase of costs depending on system boundaries and type of interpretation

The example shows that the exclusion of certain parts of the life cycle has severe implications on the overall answer if the answer is provided in the form of percent increase or decrease.

The same effect occurs, if we define the product system and use environmental impacts instead of costs. In this case both increase and decrease of certain types of environmental impacts may occur. The scope of the product system will define a large part of the answer and is thus quite important.

9.4. DEFINITIONS TO BE MADE

The message given with the answers to questions 1 and 2 might be quite different depending on the underlying assumptions. Considering only fuel production gives a totally different message than considering the whole life cycle, including car manufacturing, road construction and maintenance. These differences need to be known when discussing system boundaries of the environmental assessment.

System boundaries are important discussing “environmental reduction potentials” due to the use of biofuels. A clear and unified definition is required for the environmental assessment as well as for a price assessment.

The definition must describe what really has been done. If the definition is well-to-wheel for instance, it includes everything from well to wheel. It cannot exclude certain parts of this life cycle that is required to fulfil the function of this product system. This would be quite confusing and it would not be sound from a scientific point of view.

The definition of the system boundaries must define the following issues:

- Which parts of the system are included in and which parts are excluded from the analysis?
- What is a suitable name to describe the limitations in an appropriate way?
- Which indicators are used to describe the system?

The following list specifies names and the corresponding system delimitation that might be used. All systems start from the well (the cradle):

From well to:

tank	this is the product system of the LCA for BTL-fuel production [30], it includes the biomass and fuel production and distribution to the filling station. All necessary infrastructure of these processes is included in the inventory,
powertrain	well-to-tank plus combustion emissions before the catalyst plus construction and maintenance of fuel tank and powertrain,
end of tail pipe	well-to-tank plus emissions measured at the tail pipe (after the catalyst), plus construction and maintenance of fuel tank, powertrain, catalyst and full exhaust gas system,
wheel	well-to-tank plus emissions measured at the tail pipe (after the catalyst), tyre and breaks abrasive emissions, plus construction and maintenance of fuel tank, powertrain, catalyst and full exhaust gas system, plus manufacture of all other parts of the car incl. maintenance and disposal, Please note that many so called well-to-wheel study only include fuel production and combustion without taking into account the production of the car and wheels!
grave	well-to-wheel plus tyre and breaks abrasive emissions, plus construction and maintenance of streets, thus the full transport service per passenger or per km driven with a car/truck.

In this study we explicitly use only the cradle to grave approach that investigates the full life cycle of transporting passengers with cars.

10. Annexe: life cycle inventory data (confidential)

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Validation: Rolf Frischknecht, ESU-services Ltd., Uster
Last changes: 2008

This annexe contains data, which are partly directly derived from the ecoinvent data v2.0 [11]. The conditions of use do not allow a direct publication. Thus, the data are shown in this annexe. The annexe can be made available to ecoinvent members only. Please contact the authors in case you need these data. A proof of an ecoinvent data v2.0 membership is necessary.

Tab. 10.1 Unit process raw data of passenger transport devices for the fuel combustion and other emissions due to operation. The last four columns show the basic literature data and the EU limit

Tab. 10.2 Unit process raw data of passenger transport services with BTL-fuels