IEA Bioenergy

Task 38

Greenhouse
Gas Balances
of Biomass and
Bioenergy Systems

Environmental Assessment of Liquid Biofuel from Woody Biomass in Germany

Summary

The use of biofuels has been promoted with the aim of reducing greenhouse gas (GHG) emissions. To be eligible to count towards the target of the European Commission, the GHG emissions of biofuels have to be at least 35 % lower than those from fossil fuel use. Second-generation biofuels are made from ligno-cellulosic materials; one of these biofuels is Fisher-Tropsch (FT) diesel. GHG emissions from biofuel use tend to be lower than those of fossil fuel use, because carbon dioxide (CO_2) emissions from biogenic sources are assumed to be offset by regrowth of plants. Nevertheless, avoidance of CO_2 emissions is to some extent counteracted by GHG emissions from biomass cultivation, processing and biofuel production. Therefore, it is important to account for all emissions occurring throughout the life cycle.

This study examines life cycle GHG emissions and other selected environmental impacts (eutrophication, acidification, creation of photochemical ozone) of FT diesel production and use. Five types of woody biomass materials and two different processing routes are assessed. It is shown that FT diesel use from all tested processing routes causes fewer GHG emissions than fossil diesel use. Largest reductions can be achieved by producing FT diesel from post-consumer waste wood via a closed processing route. The least emission reductions are reached by employing wood chips from fertilized short rotation coppice (SRC). The results of the study suggest considering further environmental impacts, like eutrophication, when liquid biofuels are evaluated.

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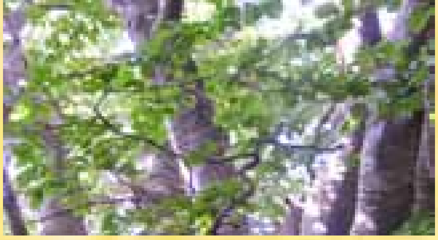

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Scope and objectives

European Directive 2009/28/EC sets up a 10 % minimum target for the share of biofuels in overall road transport fuel consumption in the European Union by the year 2020. To be eligible to contribute towards this target, GHG emissions from biofuel production and use have to be at least 35 % lower than its fossil alternative. To avoid additional environmental burdens and competition with food and feed production, there is significant interest in second-generation biofuels produced from wastes, residues or non-food cellulosic materials. FT diesel, a second-generation biofuel made from cellulosic biomass, may gain in importance so it is timely to assess its environmental impacts.

The aim of this study is to assess environmental impacts of FT diesel production via Choren's process, based on selected woody base materials. Various cellulosic resources are suitable for FT diesel production. As displayed in Figure 1, two alternative processing routes, which differ in terms of base material and chemicals and energy inputs, are studied. The following woody base materials are considered:

- wood from fertilized (fert.) short rotation coppice (SRC);
- wood from unfertilized (w/o fert.) short rotation coppice (SRC);
- wood from forests previously used for pulpwood[1] (pulpwood);
- forest residues; and
- untreated post-consumer waste wood.

The overall target of the study is to compare the wood-based biofuel chains with fossil diesel in terms of total GHG emissions and other key environmental impacts.

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[1] Small diameter roundwood, as defined in the FAO classification as "pulpwood round and split": Roundwood that is used for the production of pulp, particleboard or fibreboard: FAO (2012): Yearbook of Forest Products 2006–2010

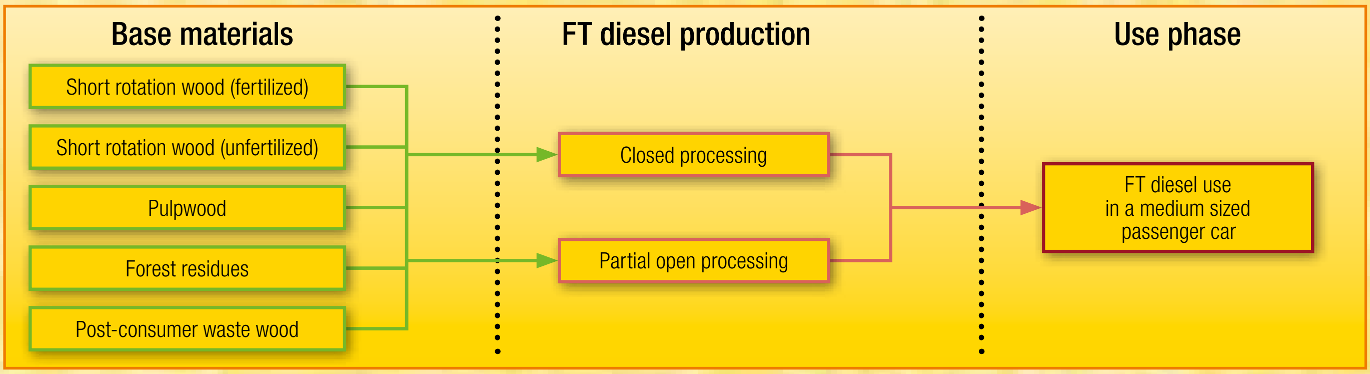

Figure 1: Woody biomass materials and processing routes assessed for FT diesel production

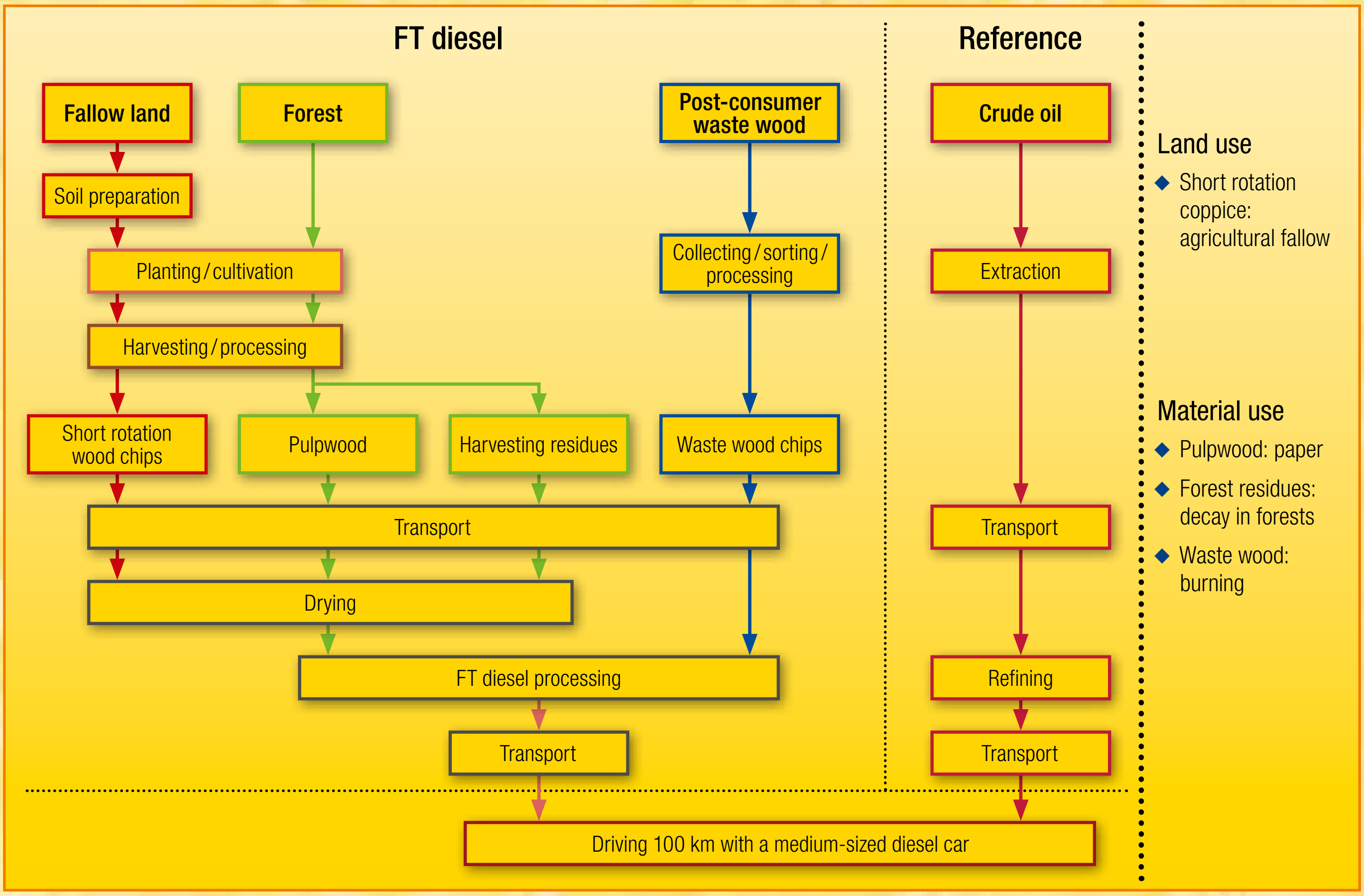

Figure 2: System boundaries of FT diesel production from different woody resources and its reference, including reference land use and reference material use


Courtesy of Anne Rödl

Methods

Methodology, data and allocation

For this study, life cycle assessment (LCA) according to ISO 14040 and 14044 was used. For impact assessment, the CML 2001 method has been adopted. Because IEA Bioenergy Task 38 focuses on the assessment of greenhouse gas emissions from biofuels and their impact, the major part of this LCA study is greenhouse gas impact assessment. In addition, eutrophication potential (EP), acidification potential (AP) and photochemical ozone creation potential (POCP) have been analysed.

The assessment of SRC cultivation is based on both literature data and data generated during the joint research project Agrowood. Existing LCA data on forestry production have been modified and updated with recent data. Data on post-consumer waste wood were taken from literature. Information about the inputs and outputs of the FT synthesis process is taken from Baitz et al. (2004).

For the LCA modelling, the software GaBi 4.0 was used. This tool includes a database which contains inputs and outputs of various raw and manufactured materials that was used to supply data for auxiliary inputs to the FT process.

For this study, an attributional approach to LCA modelling was chosen. Many biomass production chains generate multiple outputs; therefore, the emissions and consumables have to be allocated between co-products. Allocation is needed in the case of producing and processing forest-based materials and in the case of post-consumer waste wood processing.

System boundaries

FT diesel processing is currently in its testing phase, and there are uncertainties regarding the process parameters, the production facilities and their likely proximity to the required resources. Nevertheless, system boundaries have to be set which comprise production or collection of the woody resources, their transport, treatment and conversion into FT diesel. These supply chains are outlined in Figure 2.

Within the chain of FT diesel production from SRC, relevant biomass production steps starting with soil preparation of a fallow agricultural site are considered. In one scenario, the application of fertilizer is assumed (fert.) and in the other not (w/o fert.). Pulpwood assortments are received from thinnings as well as from final fellings in forests. After harvesting, they are chipped. The system boundary for forest residues is similar to that of pulpwood but additionally comprises their collection from the forest floor. A further base material considered is untreated post-consumer waste wood. Since waste wood arises from another product system, consumables and emissions of gathering, transportation and shredding of post-consumer wood are only partly contained within the system boundaries. The two alternative FT diesel processing routes considered in this study differ in terms of wood input and required inputs of chemicals and energy. The “closed processing” option generates most of the required consumables from the woody biomass itself, within the process. These are oxygen, hydrogen and heat. Only some consumables like natural gas, sodium hydrate, several additives and power for the drying process have to be added. Six kg (od) wood are consumed per kg FT diesel produced. The “partial open processing” option requires electricity, nitrogen, hydrogen, oxygen, natural gas, sodium hydrate and externally-produced additives. Thus 4.9 kg wood (od) are consumed per kg FT diesel produced. Both processing routes require the input of wood chips containing 25 % moisture. Chips from SRC, pulpwood or forest residues have to be pre-dried before gasification. Distribution of the finished product and its use in a medium sized passenger car to travel 100 km are included in the system boundaries. The construction of buildings and machinery is excluded from the assessment.

Reference systems

It is assumed that FT diesel substitutes fossil diesel. The assessment of the reference chain comprises all steps of diesel production, from the extraction and refining of crude oil to diesel distribution and use in a comparable medium sized passenger car over a distance of 100 km. The complete data on the fossil diesel reference chain were taken from GaBi databases.

Reference land use and reference material use are displayed on the right side of Figure 2. In the SRC reference case, agricultural land remains fallow. In the pulpwood case, the biomass is assumed to be used for paper production. In the reference case forest residues are assumed to decay in forests, and post-consumer waste wood is assumed to be burned.

The reference systems represent alternative uses of land and materials based on assumptions, rather than on application of market models. (Such modelling would require marginal analysis of resources substitutability, and is beyond the scope of this study.) In the reference case of pulpwood use, it is likely that German prices will rise and pulpwood will be imported from other countries. This could lead to depletion of forest resources or degradation of forested lands, but it is also possible that forest area will be expanded in other countries through the cultivation of plantations on agricultural land.

Land use change

A land-use change occurs only in the case of SRC cultivation on agricultural fields. It is assumed that no land-use change within the assessed system occurs in the case of pulpwood use from forests. There is just a different use of regularly harvested wood from commercial forests, but not an increase in the harvested amount of wood. Indirect land-use changes, through increased pressure on forests elsewhere to continue to supply pulpwood to the paper industry, may occur. While the risk that this will directly result in deforestation is considered to be low, there might be intensification of forest management but this will not be considered here. Removing harvesting residues from forest stands is not a land-use change but an increase in harvest intensity. The decline in total forest carbon stock is included in the calculation.

Functional unit and carbon accounting

In the first step, the functional unit “oven-dry tonne” is used to present the differences in greenhouse gas emissions between the biomass supply chains. To show environmental impacts of the whole FT diesel life cycle,


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the functional unit "100 km travelled" is used, so that emissions of the FT diesel use can be compared to its fossil diesel counterpart.

Traditionally in LCA, CO_2 emissions from biogenic sources released during vehicle operation are not taken into account, because it is assumed that in the long-term they do not load the atmosphere additionally as the biomass will regrow. This assumption is not always true. However, in this study, because of the assumed scenarios, it is approximately correct to ignore CO_2 emissions from biogenic sources. There may be direct carbon stock losses from the use of harvest residues, but these will be small. Planting SRC on fallow land may even cause a short term increase in carbon stocks during the time period considered by this study.

Greenhouse gas balance and further environmental impacts

Figure 3 shows GHG emissions of production and delivery per oven-dry tonne (odt) for each resource analysed. GHG emissions are more than doubled if one tonne of wood chips is produced from fertilized SRC instead from unfertilized SRC. The rest of the resources do not differ much, but production and supply of pulpwood chips releases the least GHG emissions. Transport emissions for pulpwood are lower than for waste wood because of shorter assumed transport distances.

Greenhouse gas emissions from the whole life cycle of FT diesel production and use are displayed in Figure 4. Most notable are differences in GHG emissions between the two FT diesel processing routes. The partial open processing route requires additional non-renewable inputs which increase GHG life cycle emissions. The hierarchy from low to high GHG emissions from FT diesel production and use is: waste wood < forest residues < pulpwood < unfertilized SRC < fertilized SRC. The life cycle emissions of the whole FT production chain show a different emission hierarchy compared to analyzing the biomass production step alone. This is due to different energy requirements for pre-drying to the necessary moisture content, because the base materials from forests and SRC coppice have higher moisture levels than waste wood. Forest residues, which are left in the forest during summer, have lower moisture content than pulpwood which is used shortly after harvest.

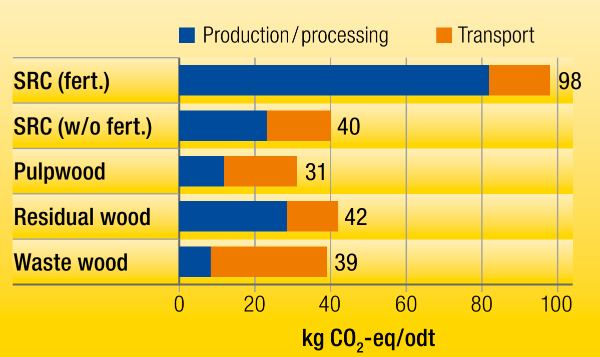

Figure 3: GHG emissions of production and delivery of one oven-dry tonne (odt) of wood

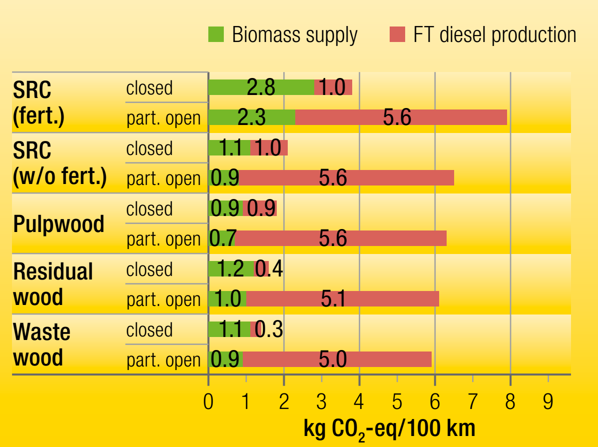

Figure 4: GHG emissions of FT diesel production and use on 100 vehicle kilometres

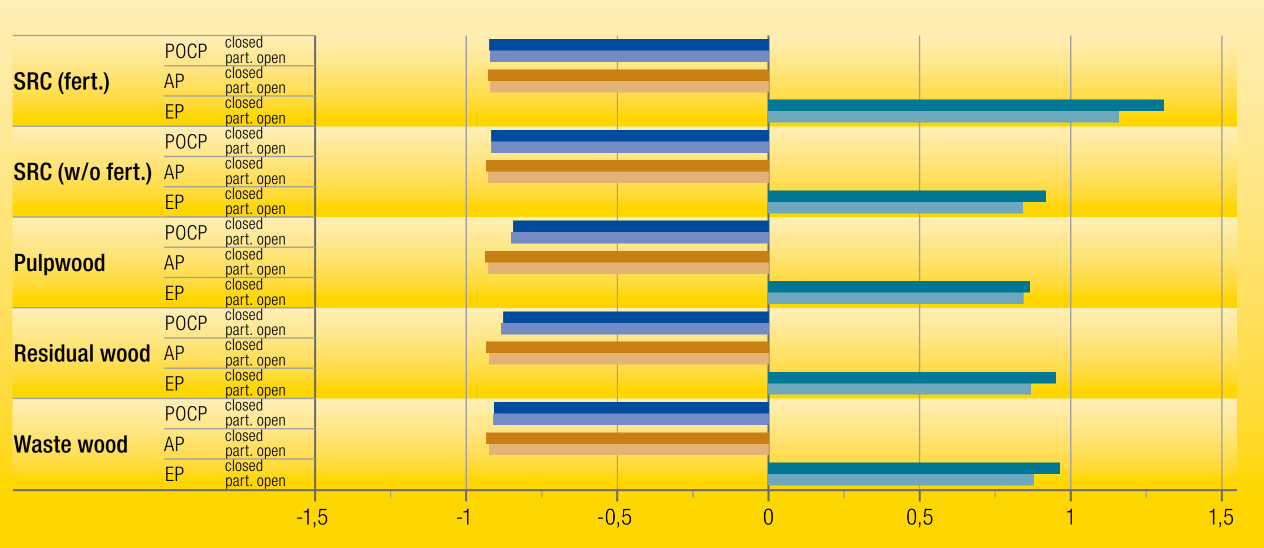

Figure 5: Relative reduction or increase of emissions other than greenhouse gases compared to fossil diesel use per 100 vehicle kilometres (POCP = Photochemical Ozone Creation Potential, AP = Acidification Potential, EP = Eutrophication Potential)

Table 1 displays GHG emission reductions, in absolute and relative numbers, when FT diesel is used instead of fossil diesel. Greatest reductions of non-biogenic GHG emissions per 100 vehicle kilometres compared to fossil diesel are achieved by FT diesel produced from post-consumer waste wood. By employing the closed FT processing, 24 – 26 % of greenhouse gas emissions can be saved in comparison to the partial open processing routes.

In addition to GHG emissions, further selected environmental impacts are analysed. As shown in Figure 5, FT diesel use does not lead to reduced impacts in all categories considered. EP increase when FT diesel is used instead of fossil diesel. Eutrophication is the ecosystem response to the addition of artificial or natural substances, such as nitrates and phosphates, through fertilizers or sewage, to an aquatic system. The highest EP of the resources analyzed are caused by the use of FT diesel from fertilized SRC, particularly when it is produced via the closed processing route. This is mainly due to the application of nitrogen fertilizer. The use of FT diesel from other woody resources also has a higher eutrophication potential compared to fossil diesel, because EP occur during FT diesel processing and its use. AP are reduced by about 90 % when FT diesel is used instead of fossil diesel in all cases. Also POCP are reduced by FT diesel use compared to fossil diesel use. Ozone-creating emissions do not differ very much between the two FT diesel processing routes but are affected by the feedstock. Harvesting and processing of pulpwood and forest residues by chainsaw cause emissions of NMVOCs (non-methane volatile organic compounds) and carbon monoxide which contribute to photochemical ozone creation potential.

Discussion and conclusions

Compared to fossil diesel use, the use of FT diesel made from woody biomass has lower GHG emissions and therefore has the potential to mitigate climatic change. All FT diesel processing alternatives reach GHG emission savings of at least 35 %, and thus meet the requirements of the Renewable Energy Directive. The exclusion of biogenic CO_2 from the calculation of GHG impacts, on the basis that it is taken up when the plants regrow, plays a major role in achieving this target. However, this accounting method, which follows the Directive and IPCC guidelines for UNFCCC reporting, is controversial, some argue that carbon emissions from biomass combustion should not always be considered climate neutral (Pingoud et al. 2010; Searchinger et al. 2010).

It was found that, in general, the use of FT diesel from all processing alternatives causes fewer GHG emissions than fossil diesel use. Only small differences arise between the woody biomass resources, except for the greater impact of fertilized SRC. Small variations are caused by differences in wood moisture, transport distances and the needs of biomass processing. Greater variations are caused by the choice of FT diesel processing route. Partial open processing, in which more energy and consumables from non-renewable sources are used, has higher GHG emissions. On the other hand, partial open processing saves wood resources that instead could be used for other purposes which might avoid more GHG emissions. The eutrophication potential, however, increases with the production of FT diesel. An assessment that focuses only on greenhouse gas emissions may overlook other environmental impacts.

For more detailed information on this study, see the full report at: www.ieabioenergy-task38.org/projects.

Table 1: Reductions of GHG emissions per 100 vehicle kilometres compared to fossil diesel

		SRC (fert.)	SRC (w/o fert.)	Pulp-wood	Residual wood	Waste wood
closed processing	[kg CO_2-eq/100 km]	13.3	15.0	15.3	15.6	15.8
	[%]	77.8	87.4	89.5	90.8	91.9
partial open processing	[kg CO_2-eq/100 km]	9.2	10.6	10.9	11.1	11.3
	[%]	53.9	61.7	63.5	64.5	65.8

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IEA Bioenergy
Task 38

IEA Bioenergy (www.ieabioenergy.com) is an international collaborative agreement, set up in 1978 by the International Energy Agency (IEA) to improve international cooperation and information exchange between national bioenergy research, development and demonstration (RD&D) programs. IEA Bioenergy aims to achieve a substantial bioenergy contribution to future global energy demands by accelerating the production and use of environmentally sound, socially accepted and cost-competitive bioenergy on a sustainable basis, thus providing increased security of supply whilst reducing greenhouse gas (GHG) emissions from energy use.

IEA Bioenergy Task 38 brings together research work of national programs in all participating countries on GHG Balances for a wide range of biomass systems, bioenergy technologies and terrestrial carbon sequestration. Emphasis is placed on the development of state-of-the-art methodologies for assessing GHG balances; demonstrating the application of established methods, supporting decision-makers in implementing effective GHG mitigation strategies. As one example of work, case studies have been conducted by applying the standard methodology developed by Task 38. The case studies have assessed and compared GHG balances of different bioenergy and carbon sequestration projects in the participating countries, and this German case study is one example.

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