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GREENHOUSE GAS AND ENERGY INTENSITY OF PRODUCT CHAIN: CASE TRANSPORT BIOFUEL

Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Engineering

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ABSTRACT OF THE MASTER'S THESIS

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Climate change and the growing need for energy force us to find solutions to produce sufficient energy, and to do so in a sustainable manner. There are different ways to tackle these challenges, both legislative and technological. Biofuels will play a part in expanding the range of energy sources available in the future. The OECD estimates that 13% of liquid fuel needs in 2050 will be supplied by transport biofuels. Transport biofuels cannot replace fossil fuels in the near future, but they can serve as partial solution to fulfilling the growing need for energy.

This study is a case study, which characterizes product chain of the transport biofuel greenhouse gas and energy intensity by using the life cycle assessment method. The transport biofuel product, NExBTL is a new product. Production in Neste Oil refinery at Kilpilahti started in summer 2007. Global discussion related to transport biofuels is focused on climate change. Therefore this study focuses on greenhouse gas emissions and energy consumption of biofuel product chain.

The product chain of NExBTL using three different raw materials - animal fats, palm oil and rapeseed oil - was constructed by using a system approach and life cycle assessment. The greenhouse gas and energy assessments were based on guidance given in United Kingdoms Carbon Reporting within the Renewable Transport Fuel Obligation (RTFO). Greenhouse gas savings were calculated by using methodology described in the proposal for a directive of the European Parliament, and of the European Council on the promotion of the use of renewable energy sources.

The results of greenhouse gas and energy intensity assessment show that total direct greenhouse gas emissions during the product chain depends on the type of feedstock and types of energy used in processes during the product chain. There are no indirect greenhouse gas emissions due to land use change in present cultivated feedstock. Direct greenhouse gas savings vary from 30% and to over 80% depending on the raw material. Energy intensity of the product chain is almost at the same level as the fossil fuel reference system.

Keywords: Animal waste, Climate change, Energy intensity, Environmental sustainability, Hydrotreatment, Land use, NExBTL, Life cycle assessment, Palm oil, Rapeseed oil, Transport biofuel

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Ilmaston muutos ja energian kulutuksen kasvu pakottavat etsimään keinoja tuottaa riittävästi energiaa ympäristöllisesti, taloudellisesti ja sosiaalisesti kestävällä tavalla. Haasteeseen voidaan vastata lainsäädännön ja teknologian keinoin. Liikenteen biopolttoaineet ovat osa laajentuvaa energialähteiden valikoimaa. OECD arvion mukaan vuonna 2050 olisi mahdollista tuottaa biopohjaisesti 13 % liikenteen tarvitsemasta polttoaineesta. Liikenteen biopolttoaineet eivät tule korvaamaan fossiilisia polttoaineita, ainakaan lähitulevaisuudessa, mutta ne voivat tuoda osaratkaisun kasvavan energiatarpeen tyydyttämiseen.

Tämä tutkimus on tapaustutkimus, jossa arvioitiin liikenteen biopolttoaineen kasvihuonekaasu- ja energiaintensiteetti elinkaariarviointia käyttäen. Liikenteen biopolttoaine NExBTL on uusi tuote, jonka valmistus aloitettiin Neste Oil Oyj:n jalostamolla Kilpilahdessa kesällä 2007. Kansainvälinen keskustelu on keskittynyt ilmaston muutokseen. Tästä johtuen tämä tutkimus keskittyy liikenteen biopolttoaineen tuoteketjun kasvihuonekaasupäästöihin sekä energiatehokkuuteen.

Tutkimusta tehtäessä liikenteen biopolttoaineen valmistuksessa oli käytössä kolme eri raaka-ainelähdettä, eläinrasva, palmuöljy ja rypsiöljy. Tuoteketju määriteltiin näiden raaka-aineiden pohjalta käyttäen systeemitarkastelua ja elinkaariarviointia. Kasvihuonekaasu- ja energiaintensiteetin arviointi tehtiin Iso-Britannian Carbon Reporting within the Renewable Transport Fuel Obligation (RTFO) metodologian mukaisesti. Kasvihuonekaasupäästöjen säästöt laskettiin käyttäen EU:n parlamentin ja neuvoston direktiiviehdotuksessa Promotion of the Use of Renewable Energy Sources kuvattua metodia.

Tulokset osoittavat, että tuoteketjun aikaiset kasvihuonekaasupäästöt sekä fossiilinen energiankulutus riippuvat käytetystä raaka-aineesta ja energiamuodosta. Tarkasteltavaan tuoteketjuun ei sisälly maankäytön muutoksesta johtuvia epäsuoria kasvihuonekaasupäästöjä. Suorat kasvihuonekaasupäästöjen vähentymät verrattuna fossiiliseen polttoaineen valmistusketjuun vaihtelevat 30 % ja yli 80 % välillä, riippuen raaka-aineesta. Tuoteketjun energiaintensiteetti on lähes samalla tasolla kuin fossiilisen polttoaineen valmistusketjun energiatehokkuutta.

Avainsanat: Elinkaariarviointi, Eläinrasva, Energiaintensiteetti, Ilmaston muutos, Liikenteen biopolttoaine, Maankäyttö, NExBTL, Palmuöljy, Rypsiöljy, Vetykäsittely, Ympäristökestävyys	Julkaisukieli: Englanti

Index

Terms and definitions

Anticipated life cycle greenhouse gas emissions means initial estimate of greenhouse gas emissions for a product that is calculated using secondary data, or a combination of primary and secondary data, for the processes used to produce the product (PAS 2050)

Arable land means land under temporary crops (double-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens, and land temporarily fallow (less than five years). The abandoned land resulting from shifting cultivation is not included in this category. (GEO-4 glossary)

Biodiversity (a contraction of biological diversity) means the variety of life on Earth, including diversity at the genetic level, among species and among ecosystems and habitats. It includes diversity in abundance, distribution and in behaviour. Biodiversity also incorporates human cultural diversity, which can both be affected by the same drivers as biodiversity, and itself has impacts on the diversity of genes, other species and ecosystems. (GEO-4 glossary)

Biofuels means liquid or gaseous fuel produced from biomass.

Biogenic carbon means carbon derived from biomass, excluding fossil carbon (PAS 2050)

Bioliquids means liquid fuel for energy purposes produced from biomass (EC 2008a, page 21)

Biomass means the biodegradable fraction of products, waste and residues from agriculture (including vegetal and animal substances), forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste (EC2008a , page 21)

Carbon dioxide equivalent (CO_2e) unit for comparing the radiative forcing of a GHG to carbon dioxide. The carbon dioxide equivalent is calculated using the mass of a given GHG multiplied by its global warming potential (SFS-EN ISO 14064-1)

Climate Change means any change in climate over time, whether due to natural variability or as a result of human activity. (The UN Framework Convention on Climate Change defines climate change as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods."). (GEO-4 glossary)

Deforestation means conversion of forested land to non-forest areas. (GEO-4 glossary)

Forest means land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 per cent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use. (GEO-4 glossary)

Fossil carbon means carbon derived from fossil fuel or another fossil source, including peat (PAS 2050)

Fossil fuel means coal, natural gas and petroleum products (such as oil) formed from the decayed bodies of animals and plants that died millions of years ago. (GEO-4 glossary)

Global warming means changes in the surface air temperature, referred to as the global temperature, brought about by the enhanced greenhouse effect, which is induced by emission of greenhouse gases into the air. (GEO-4 glossary)

Global warming potential (GWP) factor describing the radiative forcing impact of one mass-based unit of a given GHG relative to an equivalent unit of carbon dioxide over a given period of time (SFS-EN ISO 14064-1)

Greenhouse gas (GHG) gaseous constituent of the atmosphere, both natural and anthropogenic, that absorbs and emit radiation at the specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere, and clouds. GHGs include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6) (SFS-EN ISO 14064-1)

Land cover means the physical coverage of land, usually expressed in terms of vegetation cover or lack of it. It is influenced by, but not synonymous with land use. (GEO-4 glossary)

Land use means the human use of land for a certain purpose. It is influenced by, but not synonymous with, land cover. (GEO-4 glossary)

Life cycle means consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal (SFS-EN ISO 14040)

Life cycle assessment (LCA) means compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle (SFS-EN ISO 14040)

Life cycle inventory analysis (LCI) means phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle (SFS-EN ISO 14040)

Renewable energy obligation means a national support scheme requiring energy producers to include a given proportion of energy from renewable sources in their production, requiring energy suppliers to include a given proportion of energy from renewable sources in their supply or requiring energy consumers to include a given proportion of energy from renewable source in their consumption (EC 2008a, page 22)

Renewable energy source means an energy source that does not rely on finite stocks of fuels. The most widely known renewable source is e.g. hydropower; other renewable sources are biomass, solar, tidal, wave and wind energy. (GEO-4 glossary)

Sustainability the feasibility of activities continuing without long-term adverse social, economic or environmental impacts which outweigh beneficial impacts (ISO 26000 (under development))

Sustainable Development (SD) development that meets the needs of the present without compromising the ability of future generation to meet their own needs. (UN Commission on Sustainable Development (CSD), s. 2 and ISO 26000 (under development))

Wetland means area of marsh, fen, peat land, bog or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water to a depth at low tide that does not exceed 6 meters. (GEO-4 glossary)

Woodland means wooded land, which is not classified as forest, spanning more than 0.5 hectares, with trees higher than 5 meters and a canopy cover of 5-10 per cent, or trees able to reach these thresholds in situ, or with a combined cover of shrubs, bushes and trees above 10 per cent. It does not include areas used predominantly for agricultural or urban purposes. (GEO-4 glossary)

Abbreviations

Abbreviation	Explanation
AF	Animal Fat
BAT	Best Available Technique
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
CO2e	Carbon dioxide equivalent
CPO	Crude Palm Oil
EFB	Empty Fruit Bunch
EC	European Commission
EN	European Standard
EU	European Union
FFB	Fresh Fruit Bunch
GHG	Greenhouse Gas
HC	Hydro Carbons
IPPC	Intergovernmental Panel on Climate Change
ISO	International Standard
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
NExBTL	Trade name of Neste Oil’s synthetic biofuel
NO_x	Nitrous oxides
N_2O	Dinitrogen oxide
OECD	Organization for Economic Co-operation and Development

Abbreviation	Explanation
PK	Palm Kernel
PM	Fine particles
POME	Palm Oil Mill Effluent
RSO	Rapeseed Oil
RTFO	Renewable Transport Fuel Obligation
SFS	Finnish Standards Association and abbreviation of Finnish standard
SO_x	Sulphur oxides
UN	United Nations
WSSD	World Summit on Sustainable Development
SI-units	
g	Gram
kg	Kilogram
km	Kilometer
MJ	Mega joule
t	Tonnes

Preface

This study was done in Neste Oil Research Centre as a part of transport biofuel studies done by Neste Oil. This company is one of the leading industrial transport biofuel producers in the world and is committed to producing transport biofuels in sustainable manner.

I am grateful that my study has been a part of procedure to find ways to assess sustainability of transport biofuels.

During this study I was privileged to work with experts in the field transport biofuel environmental sustainability. I would like to thank them for all the support and advice they gave me during this study. My special thanks go to Riitta Lempiäinen whose experience and patient guidance during this study helped me to reach my goal. I would like also thank Annikki Perkiö, Juha Pentikäinen and Steven Gust their help with this project.

I would like to thank Environmental Director Pekka Tuovinen from Neste Oil and General Manager Hannu Vornamo and Director Aimo Kastinen from Chemical Industry Federation of Finland for their understanding the importance of this study. They gave needed time and financial resources to conduct this study.

My thanks also go to Professor Juha Kaila and Licentiate in Technology Helena Mälkki from Helsinki University of Technology their guidance during this study.

Finally, but not least I'd like to thank my wife Satu and our daughter Saimi their endless support during my studies and this study. They are lights of my life.

Helsinki, May 2008

1 Introduction

1.1 Background of the study

Reports from International Energy Agency IEA, UN-energy (Sustainable Bioenergy report, April 2007) and United Nations Environment programme UNEP (GEO4 report October 2007) suggest that we are facing global challenges like growing need for energy, climate change and loss of biodiversity. Mankind has to find solutions for producing enough energy and do so in a sustainable manner.

There are different ways to tackle these challenges. At the moment there are several legislative initiatives ongoing. European Union is preparing a directive which sets environmental sustainability criteria for biofuels, including transport biofuels. Corresponding development is also ongoing at a national level e.g. in United Kingdom, in Netherlands and in Germany.

In addition to legislation, tackling the challenge also requires developing present technology and developing totally new technologies. It should not be forgotten that changes in personal behavior are also needed.

Biofuels will play a part in expanding the range of energy sources available in the future. OECD estimates in its report published in September 2007 that 13% of liquid fuel needs in 2050 will be supplied by transport biofuels. So it is evident that transport biofuels will not replace fossil fuels, at least in near future. But they can serve as partial solution to fulfill growing need for energy.

1.2 Research problem

A holistic approach to evaluate sustainability of products is needed. A life cycle assessment of product chain seems to be suitable method for characterization of product’s sustainability. It is justifiable to use life cycle assessment as a method because the method has been developed and it has been widely used in scientific studies.

1.3 Goal and scope of the study

The goal of this study is to characterize transport biofuels greenhouse gas and energy intensity by using life cycle assessment method. At the moment global discussion related to transport biofuels is focused on climate change issues. Because of this focus on global discussion, the study is concentrated on greenhouse gas emissions and energy intensity.

This research is a case study. The product chain of transport biofuel with different raw materials is assessed. In this case study several modules of product chain have been characterized. Modules related to agriculture and transports are based on secondary data sources. Biofuel processing is based on primary data sources. Primary data is mainly actual production data from Kilpilahti site. The product is new. Production at the Neste Oil refinery at Kilpilahti started in summer 2007.

1.4 Research methodology

The product chain was built by using systems approach and life cycle assessment as described in international standards (SFS-EN ISO 14040, 2006 and 14044, 2006). Guidance given in international greenhouse gas verification standard (SFS-ISO 14064-1, 2006) was also taken into account in greenhouse gas calculations. The assessment part of this study was based on guidance given in United Kingdoms Carbon Reporting within the Renewable Transport Fuel Obligation (RTFO, 2008). This methodology, subsequently called the RTFO methodology, is intended to be transparent assessment methodology for characterized product chain of biofuel. It was developed and piloted in cooperation between industry, environmental experts and authorities. Greenhouse gas savings were calculated by using methodology described in the proposal for a directive of the European Parliament and of the Council on the promotion of the use of renewable energy sources (EC, 2008a).

2 Sustainability of transport biofuels

Reports from International Energy Agency (IEA 2006), UN-energy (UN-Energy 2007), United Nations Environment programme UNEP (GEO4 2007) and Sir Nicholas Stern (Stern 2006) declare that we are facing global challenges like growing need for energy, climate change and loss of biodiversity. Mankind has to find solutions for producing enough energy and do so in a sustainable manner.

Biofuels will play a part in expanding the range of energy sources available in the future. OECD estimates in its report (Doornbosch and Steenblik, 2007) that 13% of liquid fuel needs in 2050 will be supplied by transport biofuels. This estimation is based on technological and economical potential of transport biofuels. So it is evident that transport biofuels will not replace fossil fuels, at least in near future. But they can serve as partial solution to fulfill growing need for energy. (Doornbosch and Steenblik 2007, pages 5-6; 10-23; 30)

Technical and economical aspects are only a part of overall sustainability of transport biofuels. One critical challenge in order for transport biofuels to be sustainable is related to environmental benefits of transport biofuels. At the moment there are different assumptions on what the overall environmental impacts of transport biofuel production might be.

Discussion related to transport biofuels is global, because product chains of transport biofuels are usually global. In addition to this, discussion related to biofuel sustainability is ongoing at regional level and country by county. A company producing biofuel faces the global challenges of sustainability as well as local challenges. See Figure 1.

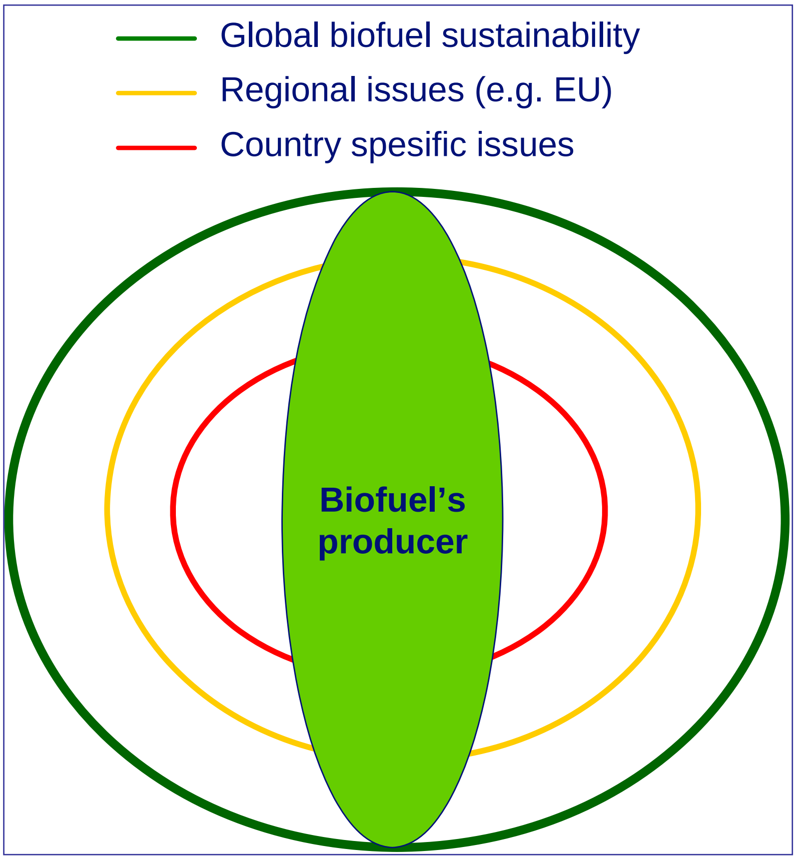


Figure 1. *Different context of transport biofuel sustainability. A company producing biofuel faces the global challenges of sustainability as well as regional and country specific challenges.*

2.1. Global biofuel sustainability

One of the results of global discussion is the latest report of UN-Energy "Sustainable Bioenergy: A Framework on Decision Makers" published on April 2007 (UN-Energy 2007). UN-Energy is collaborative framework for all UN (United Nations) bodies that contribute on energy solutions. It was born out of the World Summit on Sustainable Development in Johannesburg (WSSD 2002).

In its report UN-Energy concludes that growing commitments to bioenergy are based on studies showing that diversification of energy supplies can contribute both economic and environmental goals, including UN Millennium Development Goals (MDG 2000). Issues raised by bioenergy development are complex and highly depend on local circumstances (climatic, agronomic, economic and social). The report points out nine key sustainability issues raised by the rapid development of bioenergy. (UN-Energy 2007, pages 2-3).

These sustainability issues are presented, focusing only on transport biofuels, in Appendix 1. The purpose of this non-inclusive appendix is to show the complexity of different issues related to transport biofuel sustainability. In this case study, focus was only on last two issues: natural resources and climate change. These issues are part of overall environmental sustainability issues related to transport biofuels.

2.2 Regional sustainability in Europe

European Union has recognized the need to promote renewable energy given that its exploitation contributes to climate change mitigation through reduction of greenhouse gas emissions, sustainable development, security of supply and the development of a knowledge based industry creating jobs, economic growth competitiveness and regional and rural development. Directive 2003/30/EC of the European Parliament and of the Council demands that minimum share of transport biofuels sold on the market shall be 5.75-% by December 2010 (EC 2003). In follow-up report published in January 2007, this target was raised to 10 % (EC 2007). This 10-% share was also included in the proposal for a directive of the European Parliament and of the Council on the promotion of the use of renewable energy sources (EC 2008a). According to EU, this latest proposal is related to EU policies of combating climate change, reducing greenhouse gas emissions, achieving sustainable development (EC 2006), ensuring energy security (EC 2008c) and realizing Lisbon strategy (EC 2008b). The proposal is a part of a legislative package that will establish greenhouse gas and renewable energy commitments for all Member States, including Finland.

The proposal (EC 2008a) also includes environmental sustainability criteria for transport biofuels. According to these criteria, greenhouse gas savings from the use of biofuels shall be at least 35-% compared to greenhouse gas emissions from the use of fossil fuel. After January 2008, biofuels shall not be made from raw material obtained from:

- land with recognized high biodiversity value (meaning forest undisturbed by significant human activity)
- areas designated for nature protection purposes
- highly biodiverse grassland
- land with high carbon stock, such as
    - wetlands

- continuously forested areas (meaning land spanning more than 1 hectare with trees higher than 5 meters and a canopy cover more than 30%)

These land use criteria are not applied to land producing biofuel feedstock, if land was already under productive use in January 2008. This means that these criteria will apply to land use after this time. (EC 2008a, pages 32-33)

Economic operators have to show that abovementioned environmental sustainability criteria have been fulfilled. The directive proposal presents different tools that can be used to fulfil requirements. These tools include: auditing, multilateral agreements between community and third countries and voluntary national or international agreement setting standards for production of biomass production. (EC 2008a, pages 34-35)

The directive proposal also includes the methodology for calculation of the greenhouse gas impact of biofuels. This methodology was used in this case study in calculation of greenhouse gas savings.

2.4 Country specific sustainability in Finland

Finland is one of the EU's leading countries in terms of bioenergy use. The share of bioenergy in Finland's energy consumption is almost 25%. The main method of producing bioenergy in Finland is by the co-production of heat and power using the forest industries' wood based by products, such as wood chips, bark, sawdust and black liquor. (Antikainen et al. 2007, page 11).

So far the production and use of transport biofuels has been marginal. This situation will change rapidly. Directive 2003/30/EC of the European Parliament and of the Council demands that minimum share of biofuels sold on the market shall be 5.75 % by December 2010 (EC 2003). In follow-up report published in January 2007, this target was raised to 10-% (EC 2007). European development has reflected directly on Finnish legislation. Demand for use of transport biofuels will increase biofuels and their raw material production capacity. It will also lead to increased raw material imports.

When assessing the sustainability of transport biofuels in Finland, the same principles need to be applied for both domestic and foreign raw-materials, taking into account both direct and indirect energy and raw-material inputs and emissions. In case of transport biofuels, climate change (greenhouse gases) effect plays an important role.

But, addition to this acidification, eutrophication, tropospheric ozone formulation, particle and toxic emissions, biodiversity impacts and soil production capacity are other important environmental factors (Antikainen et al. 2007, pages 11-12, page 35)

According to the study "Bioenergy Production in Finland – New Challenges and Their Environmental Aspects" made by Finnish Environment Institute, life cycle assessment and life cycle thinking provide a systematic tool for comparing of combinations of different product chains. It is essential to know as well as possible environmental, economical and social impacts of transport biofuel life cycle. Upon determining this, it is possible to estimate right balance between national production and import of transport biofuel raw materials (Antikainen et al. 2007, pages 40 and 42).

2.5 Environmental sustainability of transport biofuel

The ongoing discussion related to transport biofuel sustainability is focused on greenhouse gas emissions during biofuel product chain. These emissions are only one part of overall environmental impact of product chain. In addition, all environmental impacts are only part of overall environmental sustainability. When evaluating environmental sustainability of product chain, technical properties and emissions during use of product shall be included in the evaluation. The diagram of environmental sustainability is shown in Figure 2.

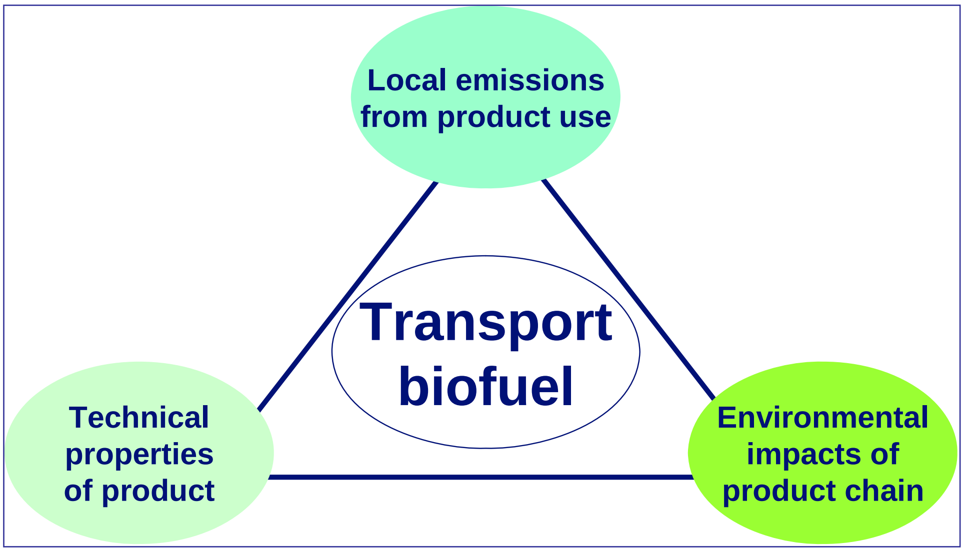


Figure 2. *The environmental sustainability diagram of transport biofuel. Environmental sustainability evaluation of product chain should include technical properties and emissions during use of product shall be included in the evaluation*

Some actual topics, especially at global level, are loss of biodiversity and climate change implications due the land use change caused by transport biofuel feedstock cultivation. These issues have an effect on environmental sustainability of transport biofuel product chain. The energy efficiency of the transport biofuel product chain is also under discussion but it has not reached the same intensity as climate change issue.

The comprehensive way to investigate environmental impacts during the product chain is life cycle assessment. There are some general biofuel life cycle assessments available but usually they are not suitable for a specific product chain. They can be used as benchmark information and they can form secondary data source. It is important to make product-chain-specific life cycle assessment. This sort of information is necessary, when improving the environmental performance of product chain.

2.6. Development of sustainability criteria for transport biofuels

Biofuels are not an easy solution for weaning the world from its dependency on petroleum. Transport biofuels will not replace fossil transport fuels, but they can serve as partial solution to fulfilling the need for energy. Transport biofuels environmental benefits rely on critical assumptions (e.g. reduction in greenhouse gas emissions, eutrophication and land use change) that must be met in order for biofuels to be sustainable. One possible solution could be set up the agreements or initiatives which would ensure the conformity of biofuels with minimum environmental and social standards on life-cycle basis. (UN-Energy, pages 46-47; 39, page 39; 56, page 34)

At the moment there are several initiatives ongoing to develop sustainability criteria for biofuels or their feedstock. Oilseed and sugarcane industries have formed the Roundtable on Sustainable Palm Oil (RSPO 2003), the Roundtable on Sustainable Soy (RTRS 2006) and the Better Sugarcane Initiative (BSI 2006). These initiatives aim to improve environmental and social standards of producers within the industry through voluntary codes and good practice. In addition to these separate initiatives, the Roundtable on Sustainable Biofuels (RSB 2007) was launched in April 2007. This global initiative has assembled non-governmental organizations, companies, governments, inter-governmental organizations, experts and other concerned parties “to draft principles and criteria to ensure that biofuels deliver on their promise of sustainability." Four sets of criteria are being developed: greenhouse gas lifecycle efficiency; environmental impacts, such as impacts on biodiversity, soil and water resources; social impacts, ranging from labor rights to impacts on food security; and implementation. The Roundtable has set a target of early 2008 for its first draft standards. (Doornbosch and Steenblik 2007, page 39)

Regulation linked to policy goals is also under development. In its directive proposal in January 2008, EU set the limits for biofuel sustainability (EC 2008a). UK has developed the Renewable Transport Fuel Obligation (RTFO, 2008), which includes sustainability reporting framework. The Netherlands (Bergsma et al. 2006 and Hamenlinck et al. 2006) and Germany (Vis and van den Berg 2008) have also been active in formulating and promotion sustainability criteria for biofuels

3 Methodology of the study

The purpose of this case study is to provide the basis for a comparative life cycle assessment of transport biofuel with three raw material options and traditional diesel fuel, focusing especially on carbon and energy intensity. Life cycle assessment (LCA) is proper research methodology, because it is standardized and has been used for various purposes by industry, academics, public interest groups, and government policymakers.

3.1 Life cycle assessment methodology

Life cycle assessment (LCA) considers the entire life cycle of a product, from raw material extraction and acquisition, through energy and material production and manufacturing, to use and end of life treatment and final disposal (SFS-EN ISO 14040, 2006). Through such a systematic overview and perspective, the shifting of a potential environmental burden between life cycle stages or individual processes can be identified and possibly avoided. LCA addresses the environmental aspects and impacts of a product system. Economic and social aspects and impacts are, typically, outside the scope of the LCA. Other tools may be combined with LCA for more extensive assessments. LCA is a relative approach, which is structured around a functional unit. This functional unit defines what is being studied. All subsequent analyses are then relative to that functional unit, as all inputs and outputs in the LCI and consequently the LCIA profile are related to the functional unit. LCA is an iterative technique. The individual phases of an LCA use results of the other phases. The iterative approach within and between the phases contributes to the comprehensiveness and consistency of the study and the reported results. Due to the inherent complexity in LCA, transparency is an important guiding principle in executing LCAs, in order to ensure a proper interpretation of the results (SFS-EN ISO 14040:2006, page 23).

LCA comprises four phases: the goal and scope definition, inventory analysis, impact assessment and interpretation.

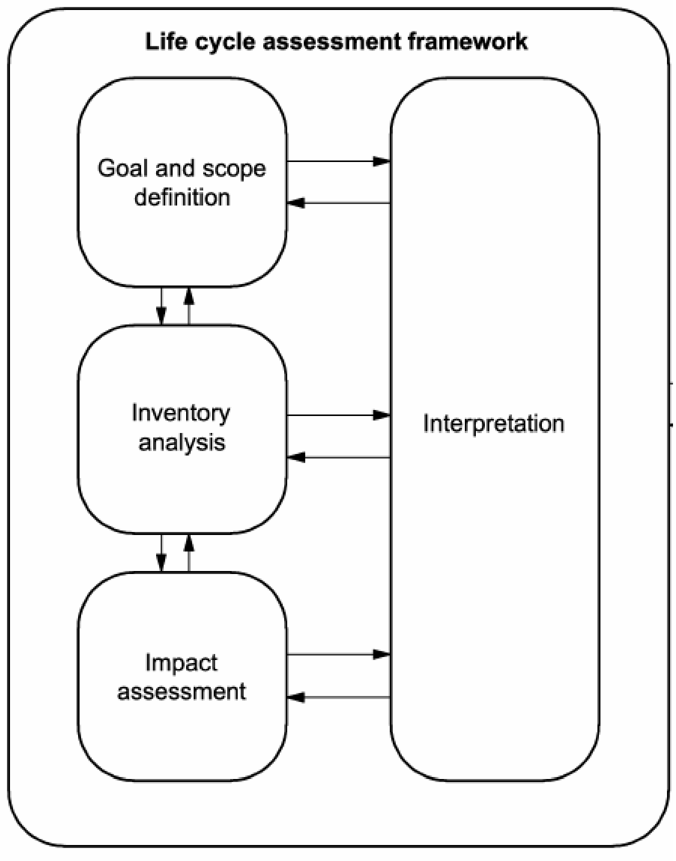


***Figure 3**. Stages of life cycle assessment (SFS-EN ISO 14040:2006, page 25)*

In this case study, inventory analysis has been carried out following requirements given in LCA standards. Impact assessment of this case study was focused on carbon and energy intensity and all relevant inputs and outputs of unit processes were included.

3.2 Carbon and energy intensity assessment methodology

Carbon and energy intensity assessment has been carried out following the RTFO methodology used in United Kingdoms Carbon Reporting within the Renewable Transport Fuel Obligation (RTFO 2008). This methodology used in RTFO was originally prepared by E4Tech (Bauen, Watson and Howes 2007). The RTFO methodology gives guidance on calculating the carbon intensity of biofuel. Specific guidance is given on a number of methodological issues such as specification of the boundaries of carbon intensity calculations, the use of reference systems, the way co-products are treated and the principles for setting default values for the data needed to calculate the carbon intensity of biofuels.

Greenhouse gas saving were calculated by using methodology described in the proposal for a directive of the European Parliament and of the Council on the promotion of the use of renewable energy sources (EC 2008a). This EU methodology does not give much detailed guidance on calculation. It basically gives simple equation for calculations. Results of impact assessment were compared to the fossil fuel reference system. This comparison formed a basis for interpretation of the assessment results in this study.

3.2.1 Calculation boundaries of assessment methodology

According to assessment methodology, the calculation on carbon intensity of a biofuel should include all direct and indirect emissions or avoided emissions that are a result of the production of biofuel (Bauen et al. 2007, page 7). This is basically the same idea as was followed in life cycle inventory phase of this study. Calculation boundaries of this study are presented in figure 4.

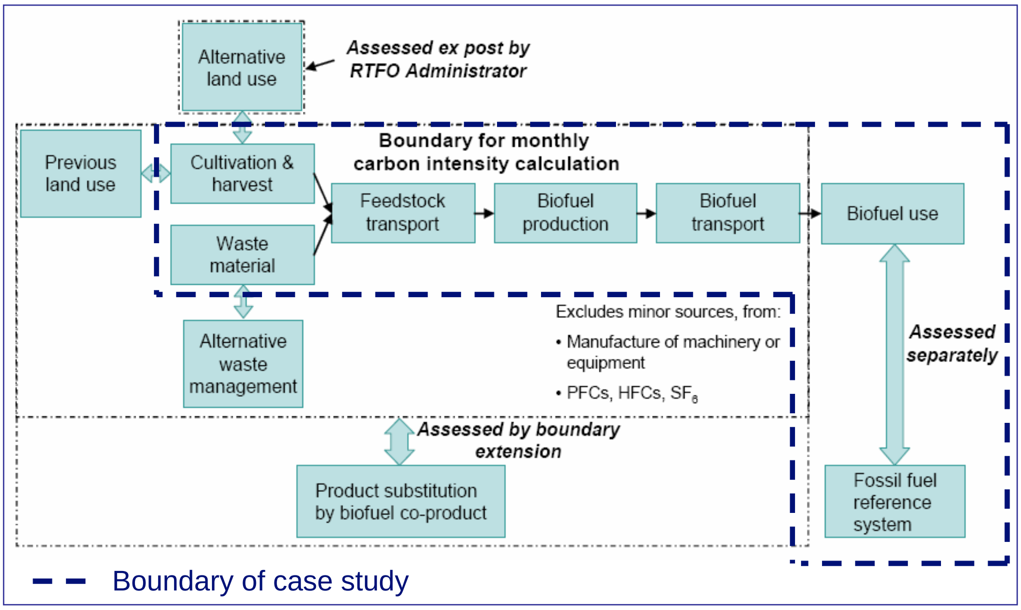


Figure 4*. Boundaries of carbon intensity calculation according to the RTFO methodology (Bauen et al. 2007, page 14) and boundary of this case study (stronger dotted line).*

Same boundaries and calculation methodology was also applied in transport biofuel energy intensity calculations in the case study.

3.2.2 Data sources of assessment calculation

Data for calculations were taken from the data gathered during life cycle inventory phase of this study by using system boundaries of inventory phase. The RTFO methodology allows minor GHG emission to be left out from calculations but this was not done. All emissions of fossil carbon dioxide (CO_2), dinitrogen oxide (N_2O) and methane (CH_4) that were identified are included in the calculations.

Emissions and energy consumption from production of process chemicals and fertilizers were not included in calculations. Production of these was outside of the system boundaries of life cycle inventory. The RTFO methodology itself estimates that emissions associated with production of process chemicals would contribute less than one percent of total fuel chain emissions (Bauen et al. 2007, page 8). Emissions from the use of fertilizers were included to the calculations. These emissions were estimated by using conversion factors given in United Kingdom Renewable Transport Fuel Obligation documentation (RTFO 2008).

3.2.3 Alternative land use

The RTFO methodology recommends exclusion of alternative land use of the land on which biofuel crop is grown. It is virtually impossible to verify that a specified alternative activity would have taken place. For example, it would not be possible for a farmer to provide evidence proving that they would have grown wheat for food instead of oilseed rape for biofuels. An exemption to this is land use change which could result in significant direct GHG emissions e.g. conversion of forests and managed or wild grasslands. In cases like this, there are usually also other negative environmental impacts, on biodiversity particular (Bauen et al. 2007, pages 8-10). Alternative land use was outside of the scope of this study.

3.2.4 Land use change

Land use change should be included in carbon intensity calculation. According to the RTFO methodology, it is required to report how the land used to produce a biofuel was being used in November 2005 based on land use type categories: cropland, forest land, grassland with agricultural use and grassland not in agricultural use. Intergovernmental Panel on Climate Change has developed an approach to calculating the GHG emissions from land use change (IPCC 2006) and given the default values which will enable to determine the GHG impact of land use change by selecting the appropriate default value based on: country where land change occurred, land use in 2005 and type of biofuel crop (annual or perennial). Where no information on land use change is provided - IPPC calculation method will penalize the carbon intensity of biofuel with a default impact of land use change. These default values are developed on basis of relatively limited set of qualitative information and it is unlikely that sufficiently detailed default values could be developed. At best it might be possible to develop default values for land use change at the state level. This level of detail would discriminate against biofuels produced within these areas which do not cause detrimental land use change and for which land use change information is unavailable or not reported. Because of this, the RTFO methodology recommends that carbon intensity be calculated with and without land use change. The RTFO methodology further recommends that impacts of renewable transport fuel chain on land use should be monitored separately. (Bauen et al. 2007, pages 11-12)

3.2.5 Waste material

Using wastes as a feedstock for biofuels displaces other waste management practices (e.g. land filling, composting). This change of practice could result in a net decrease in the greenhouse gas emissions. The RTFO methodology recommends that the biofuel producers using waste material as a feedstock should be allowed to claim a credit for “alternative waste treatment”. Of course, supporting evidence need to be provided. The word “waste” currently refers to used cooking oil, tallow, organic municipal solid waste, wet manure and dry manure. Because it is defined accurate reference system, the RTFO methodology recommends that the default assumption of credit from using of waste material should be zero. If the biofuel producer can show the evidence of decrease of net GHG emissions, it can claim credits from “alternative waste treatment”. (Bauen et al. 2007, pages 12-13)

3.2.6 Feedstock residues

Growing and processing the biofuel feedstock usually produces some residues – for example straw from growing rape plants. The use of these residues can have significant impact on the net GHG savings of a biofuel. The RTFO methodology recommends that residues are treated as co-products within calculations - if there is evidence that residues are actually processed. The default assumption is that residues are left on the field and there is no net impact on GHG emissions. The only exception is for the palm oil chain, where assumption is made that part of the residues (the fiber and shell) are burnt at the palm oil mill to produce heat and power.

3.2.7 Co-products

Producing biofuels usually produce certain amount of co-products. The number of co-products depends on fuel chain being studied. Many of these co-products can be used to substitute other products with different carbon intensities. For example rapeseed meal can substitute soy meal in animal feed, excess electricity or heat produced in some part of biofuel product chain can be substituted for energy produced from fossil fuel sources (Bauen et al. 2007, page 15).

There are a number of ways in which the effect of co-products on GHG emissions or energy consumption can be taken into account within the biofuel product chain. One approach is to allocate a portion of emissions and energy use of co-products based on physical properties (e.g. mass or energy content), economic properties or market value of the products. This kind of allocation does not always accurately represent the GHG and energy impact of co-products. Extending the boundaries of calculation and treating the substituted products as part of the biofuel system can be more representative of the impact. While this approach could be more accurate than an allocation approach, it can lead to double counting. To achieve sensible results and avoid double counting it is more appropriate to use an allocation approach. It should be kept in mind that only one allocation approach can be used at a time. For example, allocation by market value and allocation by energy content cannot be used simultaneously. If allocation of market value is required, it must be used for all co-products, including energy co-products. Market value should be calculated using three years' rolling averages, updated annually (Bauen et al. 2007 pages 15-16).

The RTFO methodology recommends that the approach to addressing co-products should be flexible and that the most appropriate approach should be determined for each individual co-product. In practice this means that substitution is the first choice and allocation is preferred when co-products are used for heat or electricity generation or are converted to some other biofuel. Allocation by market value is allowed when it is not possible to define a sensible substitution approach (Bauen et al. 2007, page 17).

4 Case study: Transport biofuel product chain

This case study form a life cycle inventory for a greenhouse gas and energy intensity assessment of Neste Oil's new transport biofuel product chain. This inventory has been carried out following requirements given in LCA standards (SFS-EN ISO 14040, 2006 and SFS-EN ISO 14044, 2006). The inventory part of study was divided into modules (See Figure 5 on page 28). This case study will form a basis to update life cycle assessment of transport biofuel NExBTL product chain.

4.1 Goal and scope definition of inventory analysis

The reason for carry out the life cycle inventory was to produce data for a greenhouse gas and energy assessment specific to Neste Oil new biofuel product. Discussion related to sustainability of transport biofuel is ongoing and there is a need for information which is specific to certain product chain.

The inventory included collection of secondary data from literature and producing primary data. Secondary data was collected from literature to estimate the environmental impacts of biofuels current raw material (crude palm oil, rapeseed oil and animal fats) cultivation and processing. Primary data was generated together with Neste Oil experts. Data related to biofuel production process was collected directly from company own process documentation and actual process data.

The biofuel product system is described in Figure 5. Modules are formed from different functions of product chain. These functions can be seen as unit processes.

Land use issue was not included in inventory. This issue was dealt with separately and taken into account during greenhouse gas intensity assessment.

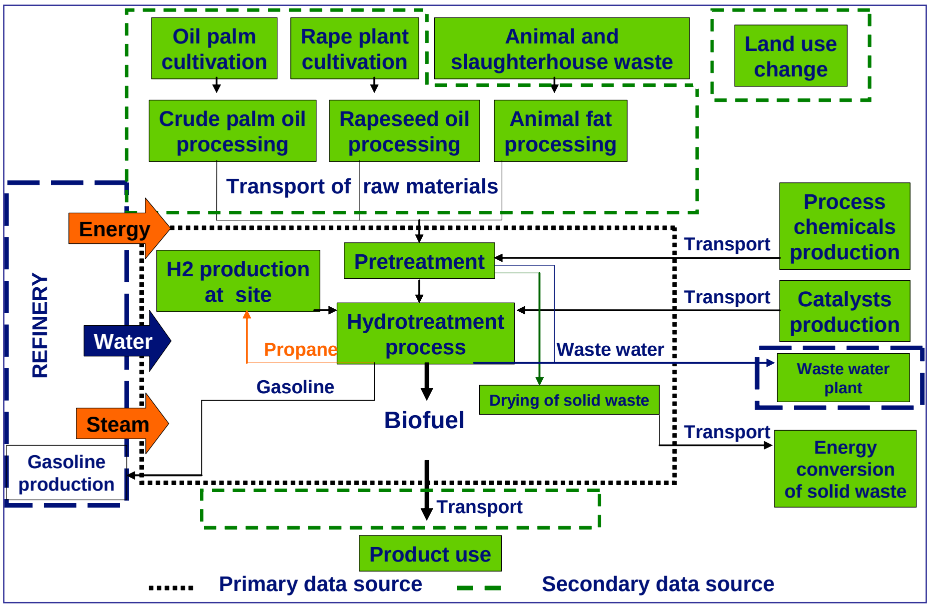


Figure 5. Modules of biofuel product system. Data related to modules of raw material cultivation and processing and raw material and product transport were based on secondary data from literature. Data related to biofuel production process was collected directly from company own process documentation and actual process data. This data is called primary data.

4.2 Functional units

The functional unit chosen to use in this study was MJ biofuel used (MJ). This functional unit was used in final calculations. Before it was possible to do final calculations, several other functional units were needed. First all inputs and outputs needed in biofuel production were calculated per 1000 kg biofuel. This helped to estimate need of vegetable oil or animal fat per 1000 kg biofuel.

Vegetable oils, meaning palm and rapeseed oil are agricultural products. In agriculture, it is common to calculate inputs and out puts per hectare. So, it was reasonable to use hectare as a functional unit in raw material cultivation modules. In next module the yield of one hectare was used as a functional unit. For example, yield from hectare of oil palm plantation is 19 t FFB. This means that inputs and outputs of palm oil processing were calculated per 19 t FFB. Yield of palm oil processing (4 t CPO) made possible to estimate how many hectares were needed to produce enough palm oil to produce 1000 kg biofuel. Similar logic was followed in rapeseed plant cultivation and rapeseed oil processing.

Final results are expressed in form of g CO_2e/MJ_{NExBTL} or $MJ_{consumed}/MJ_{NExBTL}$.

4.3 System boundary of case study

System boundary can be seen in Figure 6. System boundary follows the boundaries given in the RTFO methodology (Bauen et al. 2007). Only differences to the boundaries given in the RTFO methodology are previous land use and alternative waste management. These issues are not dealt with in this inventory

Production of crude palm oil CPO includes material and energy use, discharges and emissions related cultivation of fresh fruit bunches (FFB), transport of FFB to conversion mill and production of CPO from FFB at the mill. Production of rapeseed oil (RSO) includes material energy use, discharges and emissions related cultivation of rapeseed, transport of rapeseed to conversion mill and production RSO at the mill. Production of fertilizers used in cultivation at the palm plantations and rape fields are excluded from this study but emissions related to use of fertilizers are included. The production of animal fats in Finland includes conversion of oil from slaughterhouse wastes.

Energy use and emissions related to the transport of raw materials from conversion sites to refinery located in Kilpilahti, Porvoo, Finland, are included into this study. Crude palm oil is transported by ship to Kilpilahti from Malaysia. Rapeseeds needed in rapeseed oil production are transported from different parts of European Union to Raisio for processing. Processed rapeseed oil comes by road from Raisio to Pansio. Both are located in Finland. In Pansio rapeseed oil is loaded onto a ship and transported to Kilpilahti. Animal fats are transported by truck from western Finland. Material and energy use and emissions related to building and maintenance of ships and trucks are excluded from this study.

Material and energy use and emissions related to the pretreatment of oils and hydrotreatment process of biofuel product are fall within the primary scope of this study. Data included in this part of study are produced with the aid of experts from Neste Oil transport biofuel production. The drying of solid waste from pretreatment is included in this study. Dry-waste is transported by truck for energy conversion which is excluded from this study.

The production of hydrogen plays an important role in biofuel production. Hydrogen production process forms the main source of fossil CO_2 emission during biofuel production at Kilpilahti. Therefore material and energy use and emissions from production of hydrogen were included in this study. The production of process chemicals is excluded from this study.

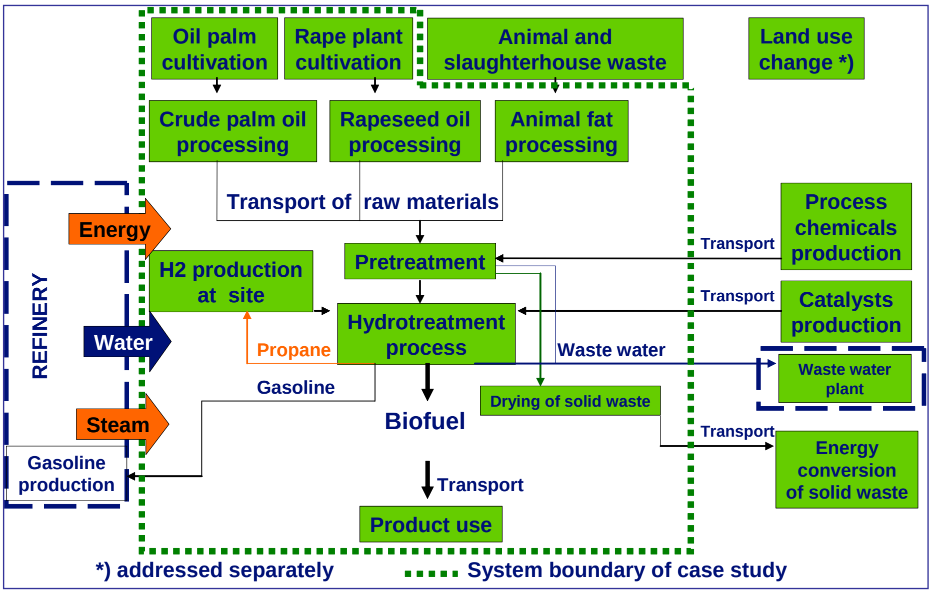


***Figure 6**. System boundary of NExBTL life cycle inventory (green dotted-line). System boundary follow the boundaries given in the RTFO methodology (Bauen et al. 2007). Only differences to the boundary given in the RTFO methodology are previous land use and alternative waste management. These issues are not dealt with in this inventory.*

4.4 Allocation procedures

In this case study allocations were done by mass bases. System expansion was not used.

4.4.1 Allocations in raw material cultivation and processing

In raw material cultivation and processing allocation procedure followed material and energy flows along the chain related to materials needed in biofuel production. If subsystem-created waste was left out of the product chain, environmental share of impacts were not allocated waste flows. If processes of subsystem created co-products or waste which were used in same subsystem or in previous subsystem of product chain, share of environmental impacts were not allocated to these co-product or waste fractions.

Allocations in palm oil

The processing of crude palm oil produces palm kernels as co-product. Kernels are further used in extraction of palm kernel oil (PKO). The extraction of PKO is outside of system boundaries of this study. This means that a part of emissions and discharges of oil palm cultivation and crude palm oil production should be allocated to palm kernels leaving the system boundaries. There are different ways to allocate emissions, allocation by economic value or allocation by mass or by energy. The allocation by mass or by energy is recommended by ISO 14040 series of standard and allocation by mass was used in this study.

Schmidt (Schmidt 2007b) has calculated that processing 1 t FFB produces 0.1998 t CPO and 0.0532 t PK. This gives a ratio 0.27. The RTFO methodology documentation has used the economic value based ratio 0.3 in their calculations, but using mass based calculations for values given in the RTFO methodology the ratio is 0.25. This ratio was used in this study. This means that 25% of discharges and emissions were calculated to PK and 75% of discharges and emissions were calculated to CPO.

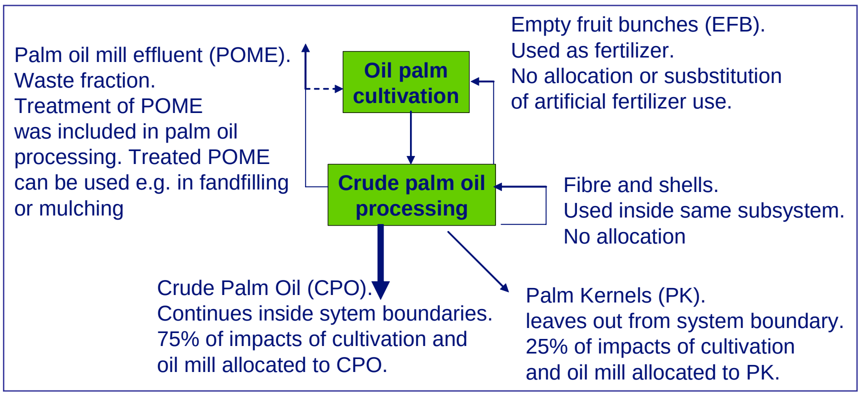


Figure 7. *Allocation procedure of crude palm oil cultivation and processing. Totally 75-% of environmental impacts of oil palm cultivation and crude palm oil processing were allocated to crude palm oil.*

Allocations in rapeseed oil

Processing of rapeseed oil also produces rapeseed meal. The meal is further used as feed. Use of meal is outside the system boundaries of this study which means that a part of emissions and discharges of rapeseed oil production should be allocated to rapeseed meal leaving system boundaries. Allocation was based on mass.

Total input in milling process is approximately 3 t rapeseed per hectare. Processing of rapeseeds generates 1.7 t rapeseed meal and 1.3 t rapeseed oil. This gives the ratio 0.567/0.433 meaning that 56.7% of emissions and discharges should be allocated to rapeseed meal. In case of greenhouse gas emissions, there was difference in results between allocation guidance given in the RTFO methodology and mass allocation. The RTFO methodology uses 273 kg CO_2e reduction per 1000 kg rapeseed meal. Reduction will be higher if mass allocation ratio is used (56.7% of emissions during rapeseed plant cultivation and processing of rapeseed oil). This allocation gives 984 kg CO_2e reduction per 1000 kg rapeseed meal. In this study, both allocation procedures were used.

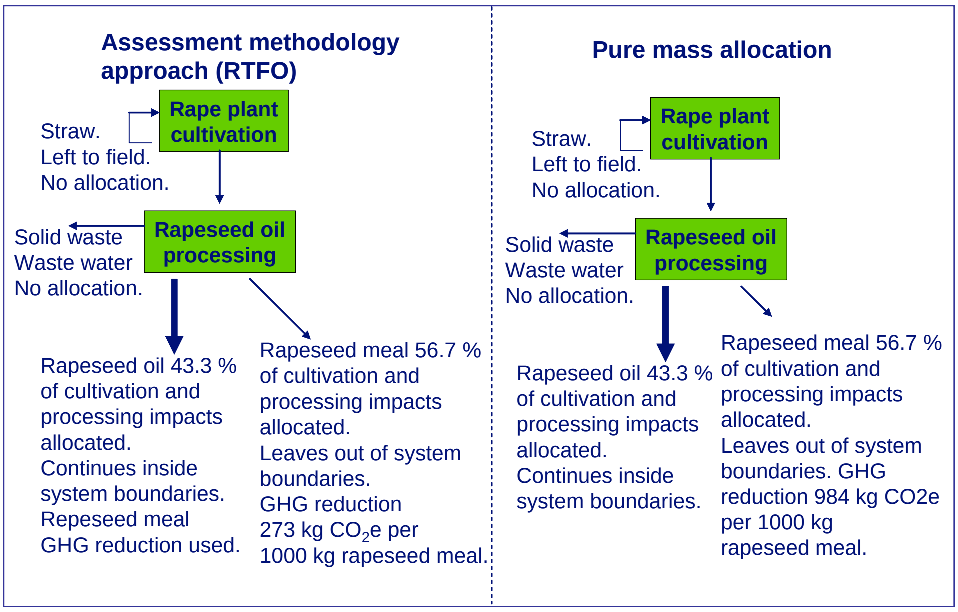


Figure 8*. Allocation procedures of rapeseed oil cultivation and processing. Totally 43.3-% of environmental impacts of rapeseed plant cultivation and rapeseed oil processing were allocated to rapeseed oil. In calculation of greenhouse gas emissions two different allocation procedures were used. The RTFO methodology uses 273 kg CO_2e reduction per 1000 kg rapeseed meal. Reduction will be higher if mass allocation is used, totally 984 kg per 1000 kg rapeseed meal.*

Allocations in animal fat processing

Using wastes as a feedstock for biofuels displaces other waste management practices. The RTFO methodology recommends that the default assumption of credit from the use of waste material should be zero (Bauen et al. 2007, pages 12-13). In this study, the zero-recommendation of the RTFO methodology was followed. The environmental impact of animal waste includes only environmental impacts of rendering process. During the rendering process used as a reference process for this study (EC 2005 and Lounais-Suomen ympäristökeskus 2006) several products are formed. Cat.1 animal fat (8.9 w-%) is used inside the system boundaries for energy use. The rest of production portfolio is as follows: 28.9 w-% cat.1 chips, 16.8 w-% cat. 2 and 3 animal fats and 54.3 w-percent feed meal. Sludge generated during process is not included in the calculations even if it is used to energy production. Cat. 2 and 3 animal fats are used in biofuel production. The share of these fats is 16.8 % of total volume of rendering process. This value was used in this study.

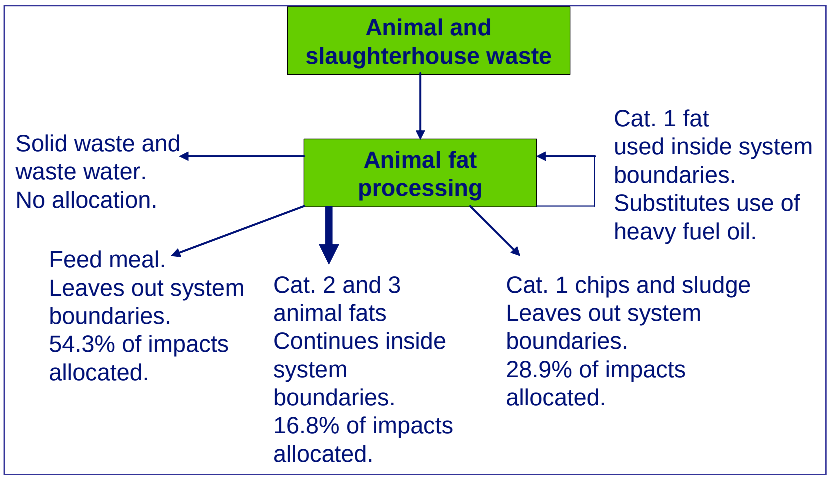


***Figure 9**. Allocation procedures of animal fat processing. Totally 16.8-% of environmental impacts of animal waste processing was allocated to animal fat.*

4.4.2 Allocations in biofuel production

There are three different product outputs from biofuel production process. In addition to transport biofuel NExBTL, propane and gasoline are also formed.

Total 24.8 kg biological gasoline per 1000 kg biofuel is formed. Produced gasoline is returned to the gasoline production of refinery. This gasoline reduces the fossil energy need in gasoline production. This reduction, total 6 kg CO_2e per 1000 kg biofuel produced was credited to NExBTL. This reduction was calculated from fossil CO_2 emissions formed during hydrogen production. Energy content of gasoline was not credited to NExBTL.

During biofuel production process a total of 71.5 kg propane per 1000 kg biofuel is formed. The energy content of propane is used in hydrogen production, which reduces the need for the use of natural gas as an energy source. This means also reduction in greenhouse gas emissions. In this study propane is credited to NExBTL. Reduction in greenhouse gas emissions is 184.5 kg CO_2e per 1000 kg biofuel. Reduction in energy demand outside of system boundaries is 3287 MJ per 1000 kg biofuel.

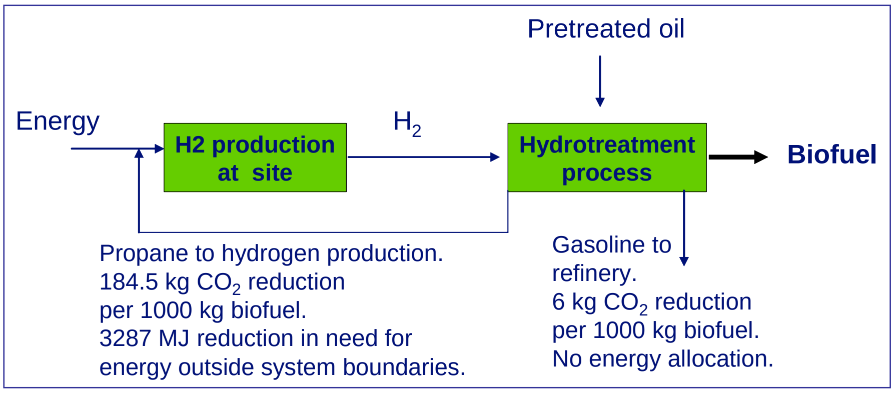
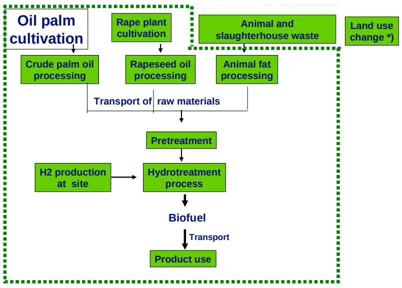


***Figure 10**. Allocation procedures of biofuel production. Production of biofuel produces also propane and gasoline. Propane is used as an energy source in hydrogen production. This reduces the fossil energy need from outside of system boundaries. Gasoline is returned to the gasoline production of refinery. This gasoline reduces the fossil energy need in gasoline production. Using less fossil energy means reductions in greenhouse gas emissions. This reduction, totally 190.5 kg CO_2 per 1000 kg biofuel was credited to biofuel.*

4.5 Raw materials

During this case study three different raw materials were used in biofuel production. The raw materials were palm oil, rapeseed oil and animal fats. Processes related to cultivation and processing of these raw materials are dealt with in following sections.

4.5.1 Palm Oil



4.5.1.1 Oil palm cultivation

Oil palm is a perennial crop which grows in equatorial area. During its 25 year lifespan oil palms grow to a height of ca. 10 m.
The sources of oil are the fruits of the oil palm. Fruits are attached in a bunch weighing approximately 25 kg and each carrying 1500-2000 single fruits. Harvested fresh fruit bunches (FFB) contain about 20% oil, 25% nuts (5% kernels, 13% fiber and 7% shells) and 23% empty fruit bunches (EFB) (Schmidt 2007b, page 83). It was estimated that rest 32% is water.

The cultivation of oil palms includes three different stages: nursery, immature plantation and mature plantation. Nursery is pre-planting phase and lasts around 12-13 months. Before the palms are planted the soil is prayed with pesticides, ploughed, compacted and legume cover (typically pueraria) is sown. The cover crop prevents erosion and fixes nitrogen from atmosphere. After this palms are planted with a density average 142 palms per hectare (on mineral soils or peat soils average is 160 palms). Around each palm is so called palm circle. This is a circle where no vegetation is established. The purpose of having circle for young palms is to prevent any competition to the palm. For mature palms purpose is to allow harvesting. The palm circle is kept free from weeds by application of herbicides. (Schmidt 2007b, pages 83-85)

The palm trees are mature from two years after planting to approximately 25 years. Harvesting is done manually with a knife attached to a shaft. Pruned fronds are left between the oil palm row for mulching and FFB are transported to oil mill. (Schmidt 2007b, pages 84-85)

During the plantation phase, the palm's requirements for nutrients are met by artificial fertilizers as well as mulching of pruned fronds, empty fruit bunches (EFB) and land application of an aerobically-treated palm oil mill effluent (POME) and solid sludge.

Weeds are treated with application of herbicides. Insecticides, fungicides and rodenticides are applied to control insect, fungus and rats. There are also some pest management programmes in place which reduce the need for insecticides and rodenticides. The amount of application of different substances depends the phase of plantation life.

The typical yield of plantation in Malaysia is between 19 t and 21 t per hectare. In this study, value 19 t per ha was used. The yield is not stable. It depends on such factors as agricultural practices, soil type and stage of plantation lifetime. By the end of their lifetime, plantation palms are getting too unproductive. They are then poisoned and felled and land is cleared. Biomass formed during breaking down of the plantation is used as mulch for next plantation generation. (Schmidt 2007b, pages 86-87).

Inputs and output of oil palm cultivation

Major inputs and outputs of cultivation are presented in Figure 11.

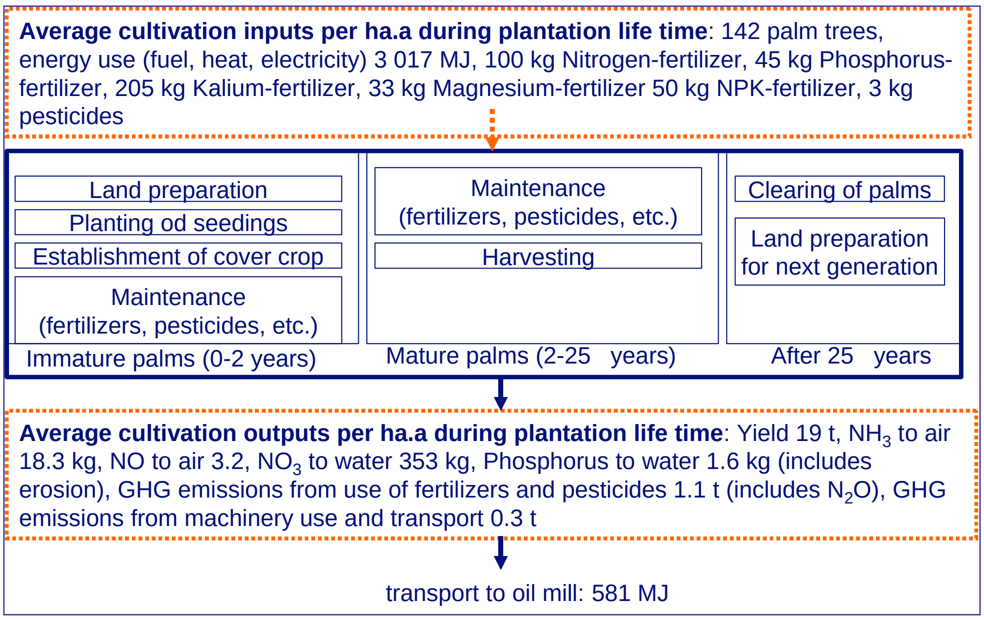


***Figure 11**. Major inputs and outputs of oil palm cultivation subsystem Inputs and outputs are average values used per hectare annually (ha.a).*

The major inputs in the cultivation process are use of energy and artificial fertilizers. See Table 1. Demand for energy and fertilizers vary during the lifetime of plantation. In calculations of this study average values are used. Production of fertilizers, pesticides and seeds has been omitted from inventory

Energy use was derived mainly from diesel consumption in agricultural machinery used in nursery, maintenance, harvesting and collection procedures. Diesel consumption was given in liters and it was converted to mega joules by using calorific value 36.4 MJ/liter diesel.

During lifetime of plantation several nutrient are needed. Values given in literature are total needs of nutrients. This need could be fulfilled either by using artificial fertilizers, biomass residuals (pruned fronds, EFB, and POME), decomposition from atmosphere or decrease from soil nitrogen pool. In this study it was assumed that nutrient need was fulfilled by using artificial fertilizers.

Several different pesticides are used during cultivation. In this study total amount of pesticides was used in calculations.

Energy needed for transport has been estimated by using 17 km as an average transport distance between plantation and oil mill. Using the average yield 19 t per hectare per year it was possible to calculate tonnage kilometers which were 323 tkm. This was converted to mega joules by using value 1.8 MJ/tkm (Energy consumption of transport according to WBSCD/IEA (2004) Transport spreadsheet model - Mobility 2030 Project. IEA/OECD and WBSCD)

Table 1*. Comparison of oil palm cultivation inputs per hectare per year given in literature. Bolded values are used in calculations in this study. Default values given in the RTFO methodology documentation (RTFO, 2008) were compared to the values given in Schmidt Study (Schmidt, 2007b).*

Input	**RTFO, 2008**	**Schmidt, 2007**
Energy use in plantation	**3 017 MJ (or 70 liters)**	2 118 MJ (or 58.2 liters)
N fertilizer (urea or ammonium sulphate)	**100 kg**	96 kg
P fertilizer (P_2O_5)	**45 kg**	28 kg
K fertilizer (K_2O)	**205 kg**	172 kg
Mg fertilizer (MgO)	**33 kg**	48 kg
NPK fertilizer	**50 kg**	Not used
Pesticides	**3 kg**	6.6 kg
Transport to oil mill	**581 MJ**	Included in energy use in plantation

Cultivation process does not generate co-products which exit from system boundaries.

Outputs of cultivation process are typical for agricultural processes. Annual yield of plantation in Malaysia is approximately 19 t per hectare. In this study, value 19 t per ha was used. The yield is not stable. It depends on e.g. agricultural practices, soil type and stage of plantation lifetime.

Emissions and discharges are also dependant on such factors as agricultural practices and soil type. As can be seen Table 2, there are differences in estimating discharges and emissions from cultivation. Within the scope of this study, energy use and GHG emissions had quite significant differences in values given in literature. Co-efficient factors used in calculations of oil palm cultivation are presented in Appendix 2.

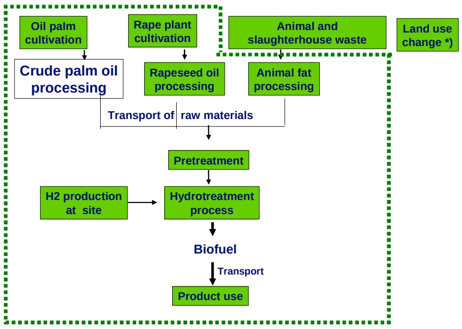
Table 2. *Comparison of oil palm cultivation outputs per hectare per year given in literature. Bolded values are used in calculations of this study. Default values given in the RTFO methodology documentation (RTFO, 2008) were compared to the values given in Schmidt study (Schmidt, 2007b).*

Output	**RTFO, 2008**	**Schmidt, 2007**
Yield (Fresh Fruit Bunches)	**19 000 kg**	19 800 kg
NH_3 to air (kg NH_3)	not calculated separately, included in CO_2-emissions	**18.3 kg**
NO to air (kg NO)		**3.2 kg**
Direct N_2O emissions to air (kg N_2O)		**10.1 kg**
Greenhouse gas emissions from fertilizer and pesticide use (kg CO_2e)	**1 086 kg**	1 500 kg
CO_2 emissions from machinery use	**217 kg**	Included in 1 500 kg
CO_2 emissions from transport from plantation to oil mill	**50.2 kg**	
Nitrate to water (kg $NO_{3)}$	not calculated	**353 kg**
Phosphorus to water (kg P)		**1.6 kg (includes erosion)**

Calculation example. Greenhouse gas emissions from fertilizer and pesticide use:

100 [kg nitrogen per ha] x 1.62 [kgCO_2e per kg nitrogen] +
100 [kg nitrogen per ha] x 0.01325 [kgN_2O per kg nitrogen] x 44/28 [molecular mass ratio CO_2/N_2] x 296 [IPCC GHG factor for N_2O] +
45 [kg phosphorus per ha] x 0.44 [kgCO_2e per kg phosphorus] +
5 [kg kalium per ha] x 0.8 [kgCO_2e per kg kalium] +
33 [kg magnesium per ha] x 1.73 [kgCO_2e per kg magnesium] +
50 [kg NPK fertilizer per ha] x 0.3 [kgCO_2e per kg NPK] +
3 [kg pesticides per ha] x 17.3 [kgCO_2e per kg pesticide] = **1086.1 kg CO_2e per ha**.

4.5.1.2 Crude palm oil processing



Processing of crude palm oil involves a set of unit processes. After reception of FFB, they are sterilized and stripped. Digestion then occurs. This is the process of releasing the palm oil in the fruit through the rupture or breaking down of the oil-bearing cells to allow oil to flow during extraction while separating fiber from nuts (Schmidt 2007b, pages 155-165).

Digestion is followed by pressing using applied pressure on the ruptured cellular contents to release fluid palm oil. Liquid coming out of the press is a mixture of palm oil, water, cell debris, fibrous material and "non-oil solids" (Schmidt 2007b, pages 155-165).

The last processing step is purification. This includes decanting and drying the crude palm oil. The idea of purification is to boil mixture of oil and water to remove water-soluble gums and resins in the oil. Decanted oil is heated to reduce the moisture content. The usual extraction rate of palm oil mill is between 0.2 and 0.24. An extraction rate 0.21 was used in this study. This means that processing 19 t FFB produces 4 t crude palm oil (Schmidt 2007b, pages 155-165).

During process significant amount of palm kernels (PK) are formed. Processing of 19 t FFB produces approximately 1 t palm kernels. Kernels are used for extraction of palm kernel oil (PKO). This process is generally separate from palm oil extraction (Schmidt 2007b, pages 155-165). Extraction of PKO is not included in this study.

Inputs and output of crude palm oil processing

Major inputs and outputs of crude palm oil processing are presented in Figure 12.

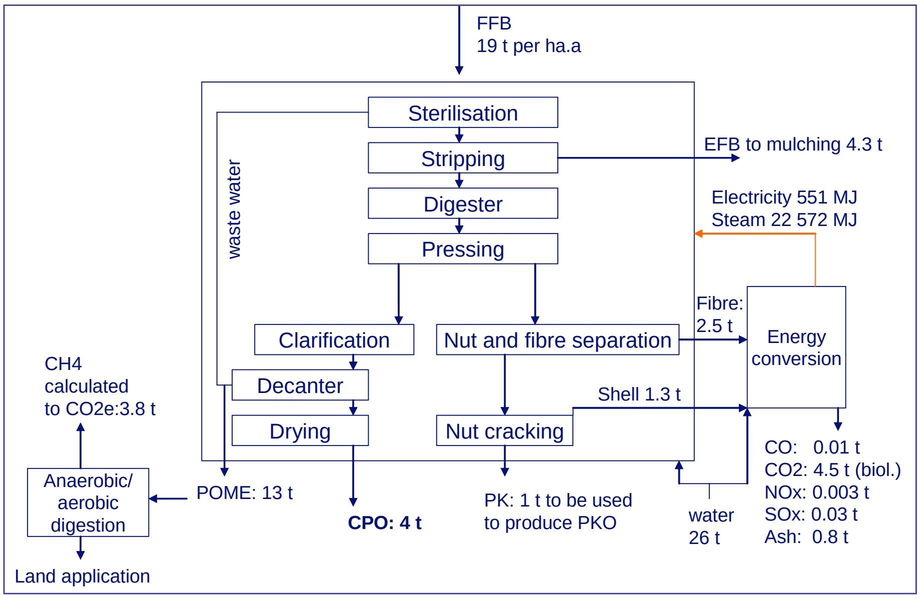


***Figure 12**. Major inputs and outputs of crude palm oil processing subsystem. Inputs and output are calculated against the yield of one hectare oil palm plantation (19 t FFB per ha.a).*

The major inputs of crude palm oil processing are use of energy and water. See Table 3. Demand for energy and water varies from process to process. Estimated plant efficiency is also a factor which influences the energy and water consumption values. There is a significant deviation in values given by greenhouse gas assessment methodology documentation (RTFO, 2008) and Schmidt (Schmidt 2007b). In calculations of this study default values given in the RTFO methodology documentation are used for steam and electricity. Water consumption values are based on values given by Schmidt.

Energy (steam and electricity) used in crude oil processing is generated in boilers which are fuelled by fiber and shell. This means that process does not need energy from grid. In other words, energy is produced inside the system boundaries and does not cause greenhouse gas emissions from energy production.

***Table 3**. Comparison of processing inputs needed to process the yield of one hectare in palm oil mill. Bolded values are used in calculations of this study. Default values given in the RTFO methodology documentation (RTFO, 2008) were compared to the values given in Schmidt study (Schmidt, 2007b).*

Input	**RTFO, 2008**	**Schmidt, 2007**
Fresh Fruit Bunches (FFB)	**19 000 kg**	19 800 kg
Electricity	**551 MJ**	1 368 MJ
Steam	**22 572 MJ**	32 129 MJ
Water	not calculated	**26 000 kg (12 350 kg for steam and 13 850 kg for process)**
Plant efficiency	**80 %**	65.6 %

A palm oil mill has several product outputs. Process outputs are listed in Table 4. Co-efficient factors used in calculations of crude palm oil processing are presented in Appendix 2. Palm kernels (PK) are further used in palm kernel oil (PKO) production. Fiber and shell generated during process are used in energy boilers. The generation of energy causes some CO, NO_x and SO_x emissions. It also generates some amounts of ash. Ash is used as road material in the plantations. Because CO_2 emissions from energy production originate from renewable energy sources, they are calculated as zero.

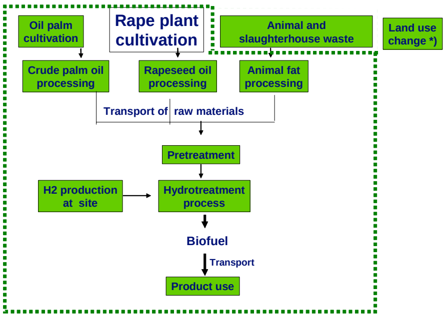
Environmental impacts of process are mainly related to the treatment of palm oil mill effluent (POME), required steam consumption in the mill and the utilization or waste treatment of empty fruit bunches (EFB). Typical technology for treating of POME is open anaerobic/aerobic ponds and has been used in this study. Treatment of POME causes methane emissions. Methane emissions are the source of greenhouse gas emissions from crude palm oil production.

There are three main treatment options to EFB: application as mulch in the plantation, land filling and utilization as a biofuel. Application as a mulch is most common practice so it was used in this study.

***Table 4**. Comparison of processing outputs when the yield of one hectare is processed in palm oil mill. Bolded values are used in calculations of this study. Default values given in the RTFO methodology documentation (RTFO, 2008) were compared to the values given in Schmidt study (Schmidt, 2007b).*

Output	**RTFO, 2008**	**Schmidt, 2007**
Crude Palm Oil (CPO)	**4 000 kg**	3 960 kg
Empty Fruit Bunches (EFB)	not calculated	**4 300 kg**
Fibre to energy production		**2 500 kg**
Shell to energy production		**1 300 kg**
Palm Kernels (PK)		**1 000 kg**
Palm Oil Mill Effluent (POME)	10 000 kg	**13 300 kg**
Carbon monoxide (CO) from energy production.	not calculated	**10 kg**
Biological carbon dioxide (CO_2 biol.)		**4 500 kg**
Methane from POME treatment as a CO_2e	2 500 kg	**3 800 kg**
Nitrous oxides (NO_x) from energy production	not calculated	**3 kg**
Sulphur oxides (SO_x) from energy production		**30 kg**
Ash from energy production		**800 kg**

4.5.2 Rapeseed oil



4.5.2.1 Rapeseed plant cultivation

The rapeseed plant is an annual crop which contains approximately 44% oil and 23% protein. Even though it is an annual crop, there should be at least four years between two rapeseed crops in order to avoid fungus attack. (Schmidt 2007b, page 47).

There are typically approximately 50-100 plants per m^2. The cultivation stage includes normal agricultural activities such as pesticide spraying, sowing, fertilizer application and harvesting. Before sowing the soil should be sprayed with herbicides to control weeds, ploughed and compacted. The need for nitrogen (N) fertilizers depends on crop, soil type, previous crop and application of manure. Other fertilizers include among others phosphorus (P), potassium (K) and lime ($CaCO_3$). Harvesting can be done either by lying in swaths or by a conventional harvester (Schmidt 2007b, page 47).

There are two types of rapeseed: spring and winter rapeseed. This study does not separate different types. It is based on average production figures from European countries given in literature. Typical yield in Europe is between 2.38 and 3.45 tones per hectare. In this study yield 3 tones per hectare was applied. There are several reasons for varying yield in the different countries such as climate, soil type and agricultural practices (e.g. fertilizer application and weed control).

Inputs and outputs of rapeseed plant cultivation

Major inputs and outputs of rapeseed plant cultivation are presented in Figure 13.

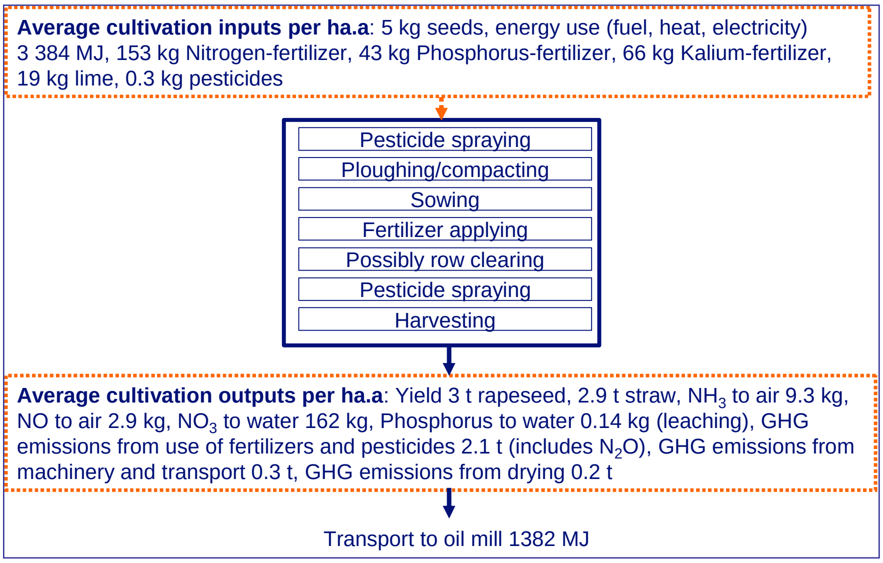


***Figure 13**. Major inputs and outputs of oil seed rape cultivation subsystem. Inputs and outputs are average values used per hectare annually (ha.a).*

Major inputs of cultivation process are use of energy and artificial fertilizers. See Table 5. Demand for energy and fertilizers depend on agricultural practices and area of cultivation. In calculations of this study default values of the RTFO methodology documentation were used. Production of fertilizers, pesticides and seeds has been omitted from inventory

Energy use was derived mainly from diesel consumption in agricultural machinery used in ploughing/compacting, sowing, maintenance and harvesting procedures. Diesel consumption was given in liters and was converted to mega joules by using lower heating value (LHV) 36.4 MJ/liter diesel.

Several nutrients are needed. Values given in literature are total needs of nutrients per year per hectare. The need for nutrients is usually fulfilled by using artificial fertilizers, decomposition from atmosphere or decrease from soil nitrogen pool. In this study it was estimated that nutrient need is fulfilled by using artificial fertilizers.

Several different pesticides are used during cultivation. In this study total amount of pesticides is used in calculations.

Energy needed to transport has been estimated by using 300 km as an average transport distance between field and oil mill. Using the average yield 3 t per hectare per year it is possible to calculate tonnage kilometers to be 900 tkm. This is converted to mega joules by using value 1.53 MJ/tkm (Energy consumption of transport according to WBSCD/IEA (2004) Transport spreadsheet model - Mobility 2030 Project. IEA/OECD and WBSCD)

There are some differences in input values, shown in Table 5. The major difference is in the energy use.

***Table 5**. Comparison of rapeseed plant cultivation inputs per hectare per year given in literature. Bolded values are used in calculations in this study. Default values given in the RTFO methodology documentation were compared to the values given in Schmidt study (Schmidt, 2007b).*

Input	**RTFO, 2008**	**Schmidt, 2007**
Energy use in cultivation	**2 888 MJ (or 67 liters)**	3 612 MJ (or 83,8 liters)
Energy use in drying and storage	**466 MJ fuel oil and 31 MJ electricity**	600 MJ fuel oil and 360 MJ electricity
N fertilizer (urea or ammonium sulphate)	**153 kg**	140 kg
P fertilizer (P_2O_5)	**42.5 kg**	57 kg
K fertilizer (K_2O)	**65.5 kg**	99 kg
Lime ($CaCO_3$)	**18.9 kg**	not calculated
Pesticides	**0.28 kg**	0.27 kg
Transport to oil mill	**1 382 MJ**	1 382 MJ

The outputs of cultivation process are typical to agricultural processes. Outputs are listed in Table 6. Co-efficient factors used in calculations of rapeseed plant cultivation are presented in Appendix 2. Annual yield of rapeseed in Europe is between 2.38 t and 3.45 t per hectare. In this study yield 3 t per hectare was applied. There are several reasons for varying yield in different countries such as climate, soil type and agricultural practices (e.g. fertilizer application and weed control.

Emissions and discharges are also dependant on such factors as agricultural practices and soil type. As can be seen from Table 6, there are differences in estimating discharges and emissions from cultivation.

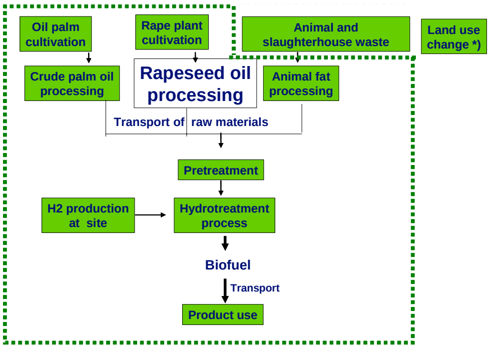
The cultivation process generates straw as a co-product. Schmidt has estimated in his study that a total 2 931 kg of straw per hectare is formed in cultivation of rapeseed plant. Of this, 13% is used for energy purposes in combined heat and electricity power plants (overall efficiency 88-90%). Straw has a calorific value 13.5 MJ/kg. This would mean that 5143.6MJ energy per hectare is generated from using straw as energy source. In his study Schmidt has estimated that using straw as energy source will displace 3.92MJ electricity and 8.10MJ heat (Schmidt 2007b, pages 65-66). Because the Schmidt study is focused on the situation in Denmark and it is uncertain that straw is generally used as an energy source across Europe, it has been left outside of the scope of this study. Energy or greenhouse gas credits from the use of straw are not included in the calculations.

***Table 6**. Comparison of rapeseed plant cultivation outputs per hectare per year given in literature. Bolded values are used in calculations of this study. Default values given in the RTFO methodology documentation (RTFO, 2008) were compared to the values given in Schmidt study (Schmidt, 2007b).*

Output	**RTFO, 2008**	**Schmidt, 2007**
Yield (rapeseeds)	**3 000 kg (average)**	3 240 kg (average in Denmark)
Straw	not calculated	**2 930 kg**
NH_3 to air (kg NH_3)		**9.3 kg**
NO to air (kg NO)		**2.9 kg**
Direct N_2O emissions to air (kg N_2O)		**4.9 kg**
SO_2 emissions from fertilizer use (kg SO_2)		**0.033 kg**
Greenhouse gas emissions from fertilizer and pesticide use (kg CO_2e)	**2 120 kg**	2 645 kg
CO_2 emissions from machinery use	**207.7 kg**	265.9 kg
CO_2 emissions from drying	**157 kg**	not calculated
CO_2 emissions from transport from field to oil mill	**111.9 kg**	
Nitrate to water (kg NO_3)	not calculated	**162 kg**
Phosphorus to water (kg P)		**0.14 kg**
Water from drying (kg)		**100 kg**

4.5.2.2 Rapeseed oil processing

The processing of rapeseed oil (RSO) involves a set of unit processes. Generally, there are two different technologies used in RSO production: solvent extraction and full press. Solvent extraction is most common technology and is described here (Schmidt 2007b, pages 143-145).



Rapeseed oil processing can be divided to two different process steps: pressing and extraction. The first process step includes reception, screening, pre-heating, rolling and heating of rapeseed. Heated rapeseeds are pressed and approximately 40-% of oil is separated in this process phase. Separated oil is clarified and dried (Schmidt 2007b, pages 143-145).

Before solvent extraction, pressed material is cooled and rolled. Hexane is the most dominant solvent used in extraction phase. During solvent extraction two different products are formed: rapeseed oil and rapeseed meal. Rapeseed meal, derived from extraction cake is produced by removing the solvent and drying. Before rapeseed oil goes through this process phase, it is heated; solvent is removed, clarified, centrifuged and dried. Approximately 60% of oil comes from this process step (Schmidt 2007b, pages 143-147).

Processing 3 t rapeseeds produces approximately 1.3 t rapeseed oil and 1.7 t rapeseed meal (Schmidt 2007b, pages 143-145).

Inputs and outputs of rapeseed oil processing

Major inputs and outputs of rapeseed oil processing are presented in Figure 14.

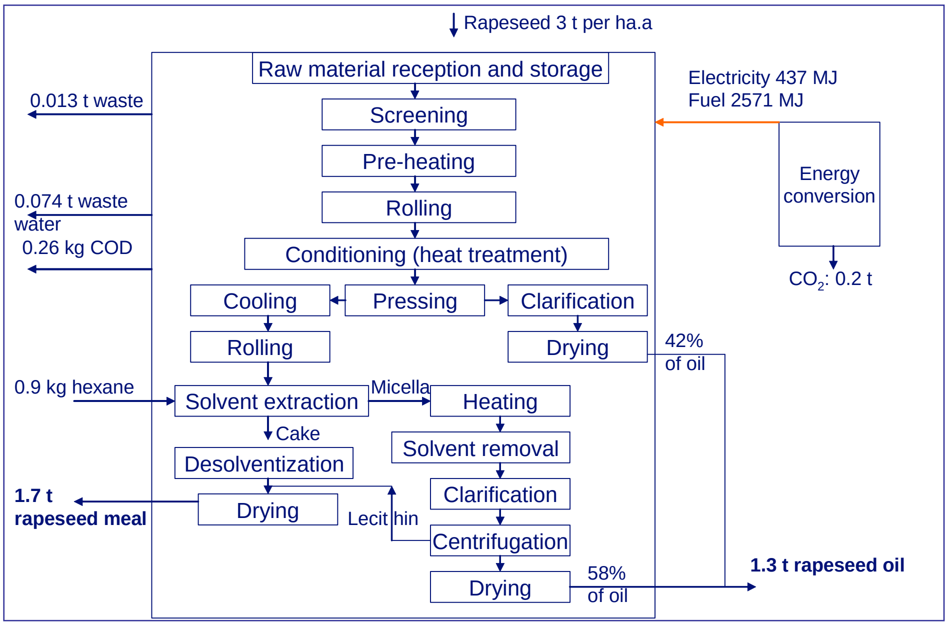


***Figure 14**. Major inputs and outputs of rapeseed oil processing subsystem. Inputs and output are calculated against the yield of one hectare of oil palm plantation (3 t oilseed rape per ha.a).*

Major inputs of rapeseed oil processing are rapeseeds, energy and hexane. See Table 7. Demand for energy varies from process to process. Heating energy is produced by using natural gas as an energy source. Electricity is taken from grid. There is some deviation in values given by the RTFO methodology documentation and Schmidt (Schmidt 2007b). In calculations of this study default values given in the RTFO methodology documentation are used for heat and electricity. Hexane consumption values are based on values given by Schmidt. The production of hexane is omitted from this study.

***Table 7**. Comparison of processing inputs needed to process the yield of one hectare in rapeseed oil mill. Bolded values are used in calculations of this study. Default values given in the RTFO methodology documentation (RTFO, 2008) were compared to the values given in Schmidt Study (Schmidt, 2007b).*

Input	**RTFO, 2008**	**Schmidt, 2007**
Rapeseeds	**3 000 kg**	3240 kg
Electricity	**436.5 MJ**	1 368 MJ
Natural gas for heating	**2 571.3 MJ**	2 261 MJ
Hexane as a solvent	not calculated	**0.9 kg**

Rapeseed oil mill has two major product outputs, oil and rapeseed meal. Process outputs are listed in Table 8. Co-efficient factors used in calculations of rapeseed oil processing are presented in Appendix 2. Approximately 1.7 t rapeseed meal is generated during processing of 3 t rapeseeds. Meal is further used as a feed. Possible lecithin generated during solvent extraction is added to meal, so it is not counted as co-product. The second product output is rapeseed oil. Approximately 1.3 t oil is generated during processing 3 t rapeseeds. Oil is used as biofuel raw material.

Emissions of milling process are related to CO_2 emissions from energy production electricity use. The process itself generates only dust and some minor hexane emissions (approximately 0.0052 kg hexane per 1000 kg rapeseed oil).

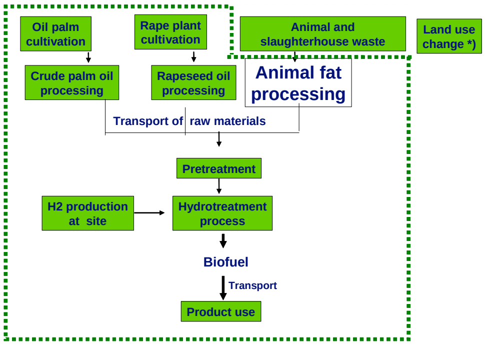
According to Schmidt (Schmidt 2007b), solid waste from the process could be sent to biogas production. Unfortunately, there were no exact data indicating that it is common approach in Europe at the moment. Because of this, biogas production was not included in this inventory.

The process generates approximately 57 liters of waste water per 1000 kg rapeseed oil produced. In this study assumption was that waste water is sent to waste water plant for treatment.

***Table 8**. Comparison of processing outputs needed to process the yield of one hectare in rapeseed oil mill. Bolded values are used in calculations of this study. Default values given in the RTFO methodology documentation (RTFO, 2008) were compared to the values given in Schmidt Study (Schmidt, 2007b).*

Output	**RTFO**	**Schmidt**
Rapeseed Oil	**1 300 kg**	1 430 kg
Rapeseed meal	**1 700 kg**	1 750 kg
Waste water	not calculated	**73.8 liters**
COD		**0.26 kg**
Solid waste		**13 kg**
Carbon dioxide (CO_2) from natural gas use as a CO_2e	**160 kg**	140 kg
Carbon dioxide (CO_2) from electricity use as a CO_2e	**53 kg**	73 kg

4.5.3 Animal fat processing



According to European Commission reference document on Best Available Techniques (EC 2005) in the slaughterhouses and animal by-products industries the rendering process uses animal by-products from meat production. These originate from, e.g. slaughterhouses, meat processing plants, butcher shops, supermarkets and livestock rearing facilities. The by-products include carcasses, parts of carcasses, heads, feet, offal, excess fat, excess meat, hides, skins, feathers and bones. (EC 2005, page 50)

The rendering process comprised a number of processing stages as follows: (although the order may vary between installations). The raw material is received at the installation and stored. Preparing the raw material for rendering generally involves size reduction. The material is then heated under pressure to kill micro-organisms and to remove moisture. The liquefied fat and the solid protein are separated by centrifugation and/or pressing. The solid product may then be ground into a powder to make animal protein meal. The final products are transferred to storage and distribution. The waste solids, liquids and gases are then treated and disposed of, possibly with some intermediate storage. For certain materials, the conditions under which sterilization must be carried out. (EC 2005, page 50)

In this study the reference process was a Finnish rendering plant (Lounais-Suomen ympäristökeskus, 2006), which produces animal fats for biofuel process.

Inputs and outputs of animal waste processing

Major inputs and outputs of animal waste processing are presented in Figure 15.

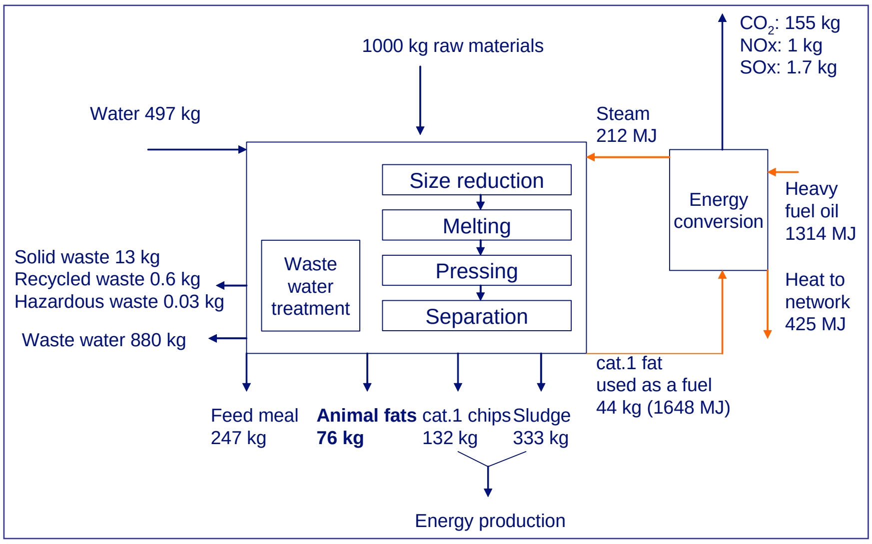


Figure 15*. Major inputs and outputs of animal fat processing subsystem. Inputs and output are calculated against the 1000 kg raw material used.*

Major inputs of animal waste processing are use of Category 1, 2 and 3 animal waste as a raw material, energy and water. See Table 9. Demand for energy varies from process to process. In the reference process used in this study heating energy is produced by using heavy fuel oil and Category 1 animal fat an energy source. Electricity is taken from grid.

Table 9. *Processing inputs needed to process 1000 kg animal waste (Cat. 1, 2 or 3 animal waste).*

Inputs of animal waste processing	
Raw materials	1000 kg
Steam	212 MJ
Heavy fuel oil for heating	1 314 MJ
Cat.1 fat for heating	1 648 MJ
Water	497 kg

The rendering process has several product outputs. See Table 10. Additionally energy conversion unit produces district heat to be sold to the network. Feed meal has several applications such as fertilizer and animal feed. Process sludge and Category 1 chips are used in energy production. Category 2 and 3 animal fat is used as raw material in biofuel process.

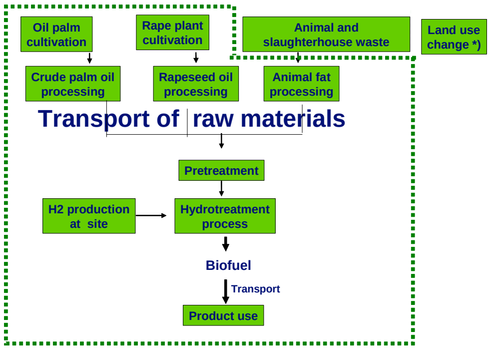
Emissions of process are related to CO_2 NO_x, SO_x, small particles and (PM) emissions mainly from energy production. The process itself generates varying amounts of odour emissions.

Discharges from process are wastewater and solid waste. Waste water is treated in waste water plant located on site. Solid waste treated according to waste treatment legislation. Process sludge is used as a fuel in energy production.

Table 10. *Processing outputs when 1000 kg animal waste is processed (Cat. 1, 2 or 3 animal waste).*

Outputs of animal waste processing	
Cat.1 animal fat	44 kg
Cat.1 chips	132 kg
Cat.2 and 3 animal fat	76 kg
District heat	425 MJ
Feed meal	247 kg
Sludge	333 kg
CO_2 from energy production	155 kg
NO_x from energy production	1 kg
SO_x from energy production	1.7 kg
Hazardous waste	0.03 kg (waste oils)
Recycled waste	0.6 kg
Solid waste	13 kg
Waste water	880 kg

4.6 Transport of raw materials



During this study, there were three different raw materials in use: palm oil, rapeseed oil and Category 2 and 3 animal fats. Palm oil originated in Malaysia, rapeseeds for processing or rapeseed oil originated in area of European Union. Rapeseed oil is processed in Finnish rapeseed oil plant. Animal fats used in process are processed from animal waste in Finnish rendering plant. It was estimated that processing capacity of Finnish rapeseed oil plant and rendering plant is enough to fulfill raw material need of biofuel process. In case of palm oil, this is a reality. But annual capacity of rapeseed oil and rendering plant is not adequate to fulfill total raw material need of biofuel process.

Palm oil is transported to the process by ship. Palm oil is first transported from Malaysia to Rotterdam. Average ship load of this transport is approximately 40 000 t and transport distance is 8579 nautical miles (15 871.2 km, one nautical mile equals 1.85 km). From Rotterdam palm oil is transported to Porvoo with average load 12 500 t and distance 841 nautical miles (1555.9 km).

Rapeseeds needed for processing rapeseed oil are first transported to Raisio. Because there was not enough information about transport routes and types, same transport distance, type and loads as palm oil transport from Rotterdam to Porvoo was used. Processed rapeseed oil is first transported by truck from Raisio to Pansio. The transport distance is 10 km and one truck load is approximately 39 t. From Pansio rapeseed oil is transported to Porvoo by ship. The transport distance is 150 nautical miles (277.5 km) and average load is 5 000 t.

Animal fats are transported by road from Finnish rendering plant. The average weight of one truck load is 34.6 t and transport distance is 322 km.

Inputs and outputs of raw material transport

The transport of raw materials requires energy and causes emissions from the use of ship and truck fuel. The need for energy to transport raw materials is included in this inventory. Energy requirements and emissions caused from raw material transport are calculated for all different raw materials separately by using co-efficient factors given in calculation model of Technical Research Centre of Finland (VTT Lipasto 2006) and International Maritime Organization (IMO 2000). VTT Lipasto factors were used in road and waterway transport calculations, IMO factors were used in open sea transport. Calculated values are presented in Table 11.

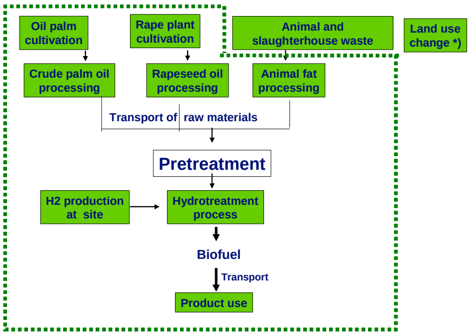
***Table 11**. Energy use and emissions from raw material transport per 1000 kg biofuel. In transport calculations it was estimated that only one raw material is used in biofuel production process.*

Raw material type	**Pam oil**	**Rapeseed oil**	**Animal fats**
Transport distance	total sea 17 300 km	sea 1450 km road 10 km sea 277 km	road 322 km
Energy use	4 288 MJ	77 MJ	383 MJ
Emissions from raw material transport per 1000 kg biofuel produced			
CH_4 as kg CO_2e	0.2 kg	0.02 kg	0.01 kg
CO	0.24 kg	0.03 kg	0.01 kg
CO_2	104 kg	15 kg	28 kg
NO_x	2.4 kg	0.4 kg	0.3 kg
N_2O as a kg CO_2e	0.8 kg	0.1 kg	0.2 kg
SO_x	1.1 kg	0.1 kg	0.0003 kg

4.7 Biofuel production

The production of biofuel consist two process steps: pretreatment of raw materials and processing of biofuel by using hydrotreatment process.

4.7.1 Pretreatment of raw materials



Raw materials are transferred from storage tanks to the pretreatment unit. They are purified in pretreatment process. Waste water formed in pretreatment is treated in refinery's waste water treatment plant. Solid waste formed in pretreatment is dried and transported outside Kilpilahti site. Dried solid waste is used as energy resource.

Inputs and outputs of pretreatment
Major inputs and outputs of pretreatment process are presented in Figure 16.

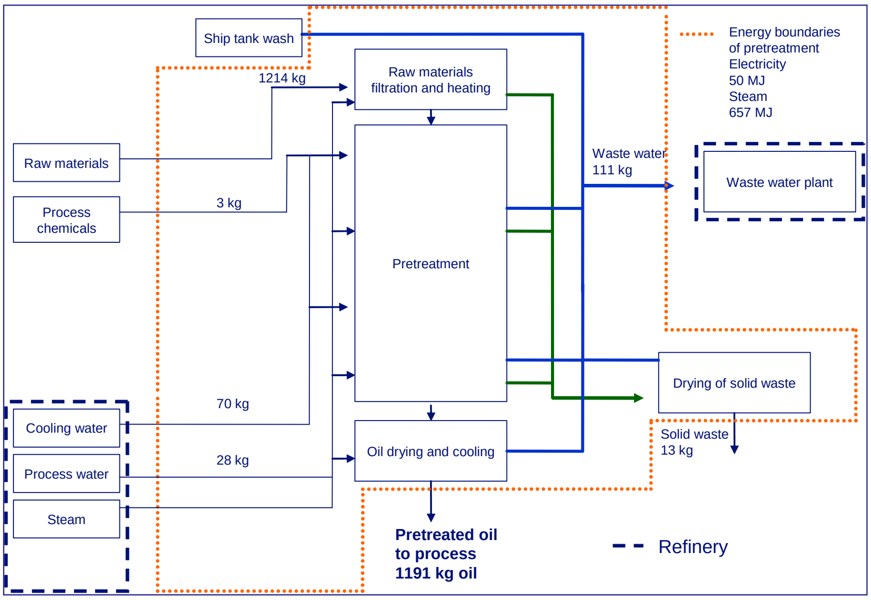


***Figure 16**. Major inputs and outputs of pretreatment subsystem. Inputs and outputs are calculated against the 1000 kg biofuel.*

Inputs of pretreatment process are vegetable oils and/or animal fats as raw material, electricity, steam, washing chemicals and water. Steam is produced at Kilpilahti site. Electricity is partially taken from grid. Seventy percent of electricity is produced at Kilpilahti and 30% is taken from the grid. The amount of washing chemicals is approximately 0.2 % of used raw material. Table 12 presents inputs per 1000 kg biofuel.

Table 12. *Processing inputs of pretreatment process needed to process 1000 kg biofuel.*

Inputs of pretreatment process	
Raw material need	1 214 kg
Cooling water	70 kg
Electricity	50 MJ
Process chemicals	3 kg
Process water	28 kg
Steam	657 MJ

The pretreatment process has only one product as output. Table 13 presents outputs per 1000 kg biofuel. The efficiency of pretreatment is high. Only small amounts of solid waste are formed during pre-filtration and separation. Solid waste is dried and sent for further treatment, where it ii converted into energy.

Wastewater comes from washing and drying of raw material. Washing of ship tanks also generates some amounts of waste water. All waste water is pumped to wastewater plant located at Kilpilahti site. Wastewater contains phosphorus which acts as a nutrient in wastewater system.

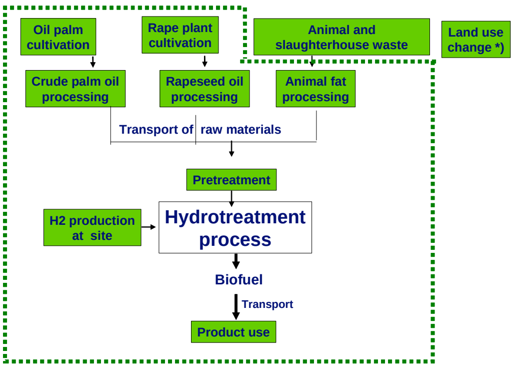
Greenhouse gas emissions for the process are related to CO_2 emissions from energy production. The process itself does not generate emissions.

Table 13. *Processing outputs of pretreatment process needed to process 1000 kg biofuel.*

Outputs of pretreatment process	
Pretreated oil	1 191 kg
Dried solid waste	13 kg
Waste water	111 kg
CO_2e from production of electricity (indirect)	3 kg
CO_2e from production of steam (indirect)	40 kg

4.7.2 Hydrotreatment process

The hydrotreatment process is integrated in Kilpilahti refinery process commodity systems. Hydrogen needed for the process is taken from refinery hydrogen production line. Production of hydrogen is described in Section 4.8.



Pretreated raw material is pumped to hydrotreatment. At this process stage triglycerides of vegetable oils and animal fats are converted to saturated straight-chain hydrocarbons. The oxygen of triglycerides is converted to water, carbon monoxide and carbon dioxide. Hydrotreatment is exothermal reaction which means that heat is generated during the process.

Inputs and outputs of hydrotreatment process

Major inputs and outputs of hydrotreatment process are presented in Figure 17.

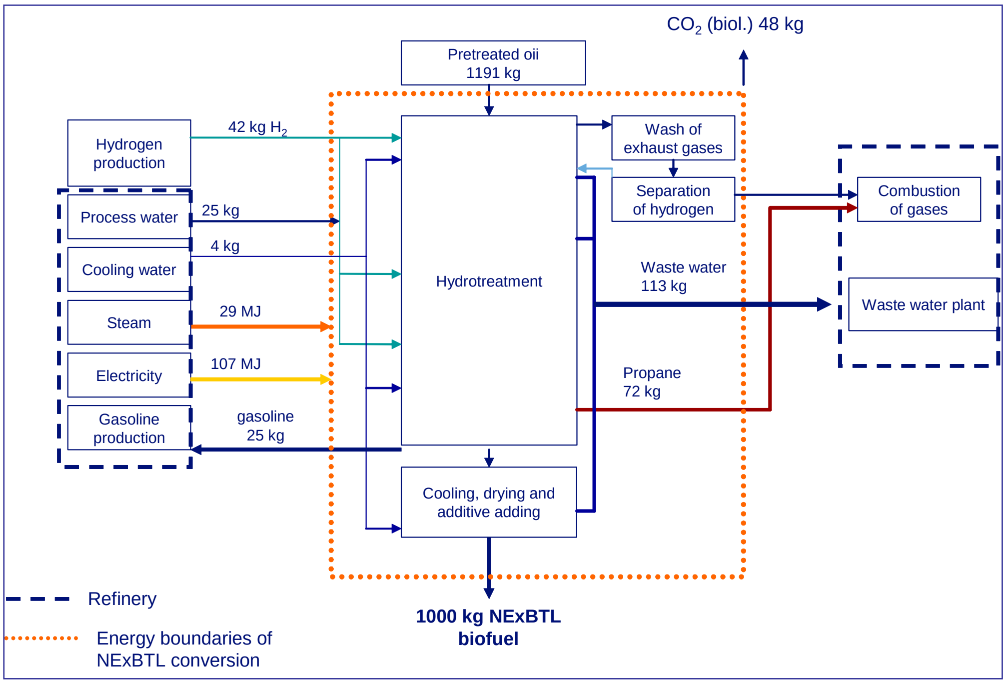


***Figure 16**. Major inputs and outputs of hydrotreatment subsystem. Inputs and outputs are calculated against the 1000 kg biofuel.*

Inputs of hydrotreatment process are pretreated vegetable oils and/or animal fats as a raw material, electricity, hydrogen, steam and cooling water. Steam is produced at Kilpilahti site. Electricity is partially taken from grid. Seventy percent of electricity is produced at Kilpilahti site and 30% is taken from the grid. Table 14 presents inputs per 1000 kg biofuel.

Table 14. *Processing inputs of hydrotreatment process needed to process 1000 kg biofuel.*

Inputs of hydrotreatment process	
Raw material need	1 191 kg
Hydrogen need	42 kg
Cooling water	4 kg
Electricity	107 MJ
Process water	25 kg
Steam	29 MJ

The main product of hydrotreatment process is NExBTL biofuel. The process also has small amounts of other outputs: propane, biogasoline and water. Annually 171 678 t

NExBTL, 12 268 t propane and 1 405 t biogasoline are formed during hydrotreatment process. Table 15 presents outputs per 1000 kg biofuel.

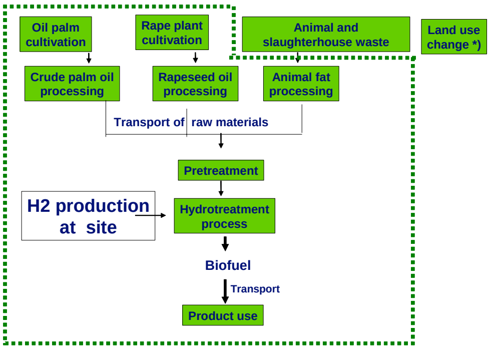
The hydrotreatment process does not generate solid waste. Wastewater produced in the process is pumped to refinery wastewater plant.

The process generates some biological CO_2 emissions. Other greenhouse gas emissions of process are related to emissions from energy production.

Table 15. *Processing outputs of hydrotreatment process needed to process 1000 kg biofuel.*

Outputs of hydrotreatment process	
NExBTL	1000 kg
Biogasoline	25 kg
Propane	72 kg
Waste water	113 kg
Biological CO_2 from process	48 kg
CO_2e from production of electricity (indirect)	7 kg
CO_2e from production of steam (indirect)	2 kg

4.8 Hydrogen production process



The hydrogen production process is integrated into refinery site. The hydrogen processing unit which serves the hydrogen needs of biofuel production is a set of unit processes containing steam reformer, water gas shift (WGS) Swift reaction and Pressure Swing Adsorption (PSA) where the CO_2 formed in the process is removed.

The production of hydrogen is based on steam reforming the mixture of fuel gas and natural gas. In the reforming reaction, methane and steam react forming hydrogen and carbon monoxide. In this step, excess steam is recovered and pumped to the steam network of refinery.

After steam reforming is shift reaction where residual carbon monoxide and steam react forming more hydrogen. Produced hydrogen is cooled and transferred to PSA unit for purification. After purification hydrogen is transferred to the refinery's hydrogen network. The purification unit creates 100% hydrogen.

Inputs and outputs of hydrogen production process

Major inputs and outputs of hydrogen production process are presented in Figure 17.

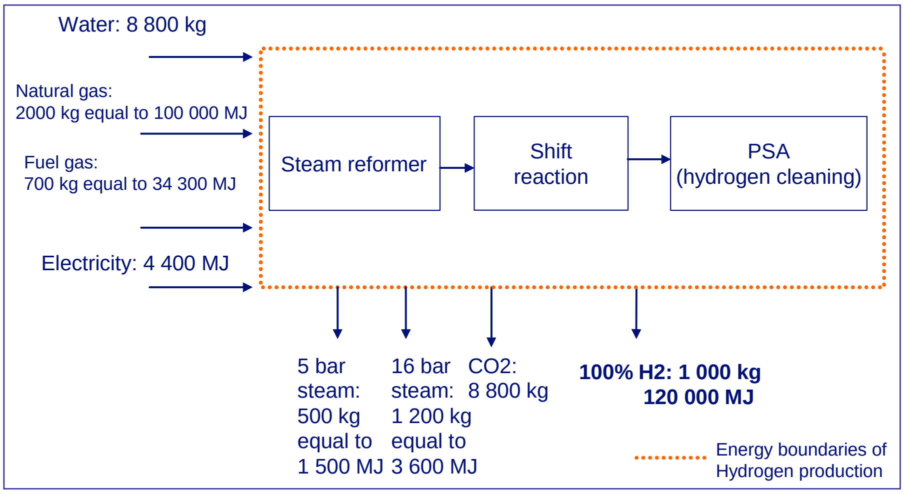


***Figure 17**. Major inputs and outputs of hydrogen production subsystem. Inputs and outputs are calculated against the 1000 kg hydrogen.*

Major inputs of hydrogen conversion process are use of energy. Electricity is partially taken from grid. Seventy percent of electricity is produced in Kilpilahti and 30% is taken from the grid. Natural gas and fuel gas are used in hydrogen production in steam reformer. Fuel gas includes about 30% hydrogen, which is originated from processes of refinery e.g. from NExBTL production. Table 15 presents inputs per 1000 kg hydrogen produced.

Table 16. *Processing inputs of hydrogen production needed to process 1000 kg hydrogen.*

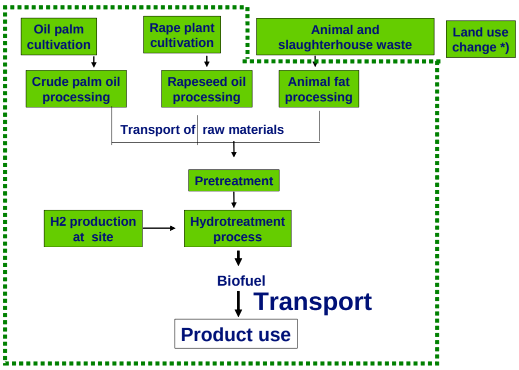
Inputs of hydrogen conversion process	
Electricity	4400 MJ
Fuel gas	700 kg equal to 34 300 MJ
Natural gas	2 000 kg equal to 100 000 MJ
Process water	8 800 kg

Major outputs of hydrogen conversion process are 100 % hydrogen, 5 bar and 16 bar steam, which are transferred to hydrogen and steam networks of refinery. There are no direct discharges from hydrogen production, but process generates some direct CO_2 emissions. Table 17 presents outputs per 1000 kg hydrogen produced

Table 17. *Processing outputs of hydrogen production needed to process 1000 kg hydrogen.*

Outputs of hydrogen conversion process	
100 % Hydrogen	1 000 kg equal to 120 000 MJ
5 bar steam	500 kg equal to 1 500 MJ
16 bar steam	1 200 kg equal to 3 600 MJ
CO_2e from production of electricity	270 kg
CO_2e from production of hydrogen	8 530 kg
Energy losses	13 600 MJ

4.9 Transport and use of biofuel



In this study it was estimated that produced NExBTL is transported by truck to pumping stations. It was further estimated that average transport distance is 200 km between refinery and pumping station. This means that total product transport distance is 400 km. The average weight of one truck load is 39 t.

Inputs and outputs of product transport

Transport of biofuel product requires energy and causes emissions from the use truck fuel. Energy need to transport final product to pumping stations and return journey of empty truck back to refinery are included in this inventory. It is estimated that fuel consumption of empty truck is same as truck with a full product load. Values are presented in Table 18.

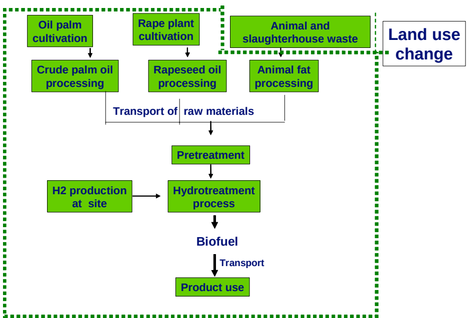
***Table 18**. Energy use and emissions from biofuel product transport per 1000 kg biofuel.*

Product transport	
Energy use	392 MJ
Emissions from product transport	
CO	0.01 kg
CO_2	28.8 kg
CH_4 as a t CO_2e	0.01 kg
N_2O as a t CO_2e	0.24 kg
NO_x	0.31 kg
SO_x	0.0003 kg

Use of biofuel

The use of biofuel has no impact on the results. Because biological origin of fuel there are no fossil greenhouse gas emissions during use of product. Technical properties of fuel and local emissions during the use are part of overall environmental sustainability of transport biofuel. The technical properties of fuel need to be at least same as fossil fuels. Local emissions during the use of fuel need to be cleaner than corresponding fossil fuel. This is estimated by comparing regulated emissions between biofuel and fossil fuel according to fuel quality standard (SFS-EN 590). The results are described more detailed in White Paper on Neste Oil Biofuel (Rantanen et al. 2005). In general, it can be said that biofuel under study, NExBTL has same or in some case even better technical properties and has cleaner local emissions than fossil fuel.

4.10 Land use change



Transforming non-cultivated (e.g. forestland, grassland, fallow land) into cultivated land usually creates emissions. Basically there are two types of emissions: from transformation itself and from cultivation. These two sources of emissions are treated separately. Emissions from cultivation itself are treated in sections concerning oil palm cultivation and rapeseed plant cultivation. The focus of this section is emissions from transformation of land use.

Schmidt (Schmidt 2007b, pages 211-215) has evaluated the emissions from transformation. According to Schmidt emissions are hard to relate to the functional unit. The relevant emissions are related to carbon and nitrogen cycles. Carbon emissions from transformation processes are emissions of CO_2, CO, and CH_4. Emissions of CO and CH_4 are considered in burning of residues and considered as insignificant when clearing forest without burning (it is prohibited in Indonesia and Malaysia). Because of lack of data, emissions of CO and CH_4 have been omitted from Schmidt study. Nitrogen emissions of transformation processes are emissions of N_2O, NO, N_2 and nitrate. Schmidt has calculated emissions of N_2O based on change in the stock of nitrogen. Because of lack of data related to emissions of NO, this emission was omitted from Schmidt study. According to Schmidt the emission of N_2 is based on generalized figures on the ratio between N_2O and N_2 and the emission of nitrate is calculated as the residual from the N-balance. Table 19 shows the emissions related to transformation processes.

***Table 19**. Summary of the changes in carbon and nitrogen stocks related to land use change according to Schmidt (Schmidt 2007b, page 216)*

Oil Palm	**From secondary/degraded tropical rainforest to oil palm plantation in Indonesia and Malaysia**
CO_2	415 t CO_2/ha
N_2O	0.075 t N_2O/ha
Nitrate	16 t NO_3/ha
Oil Palm	**From alang-alang grass land oil palm plantation in Indonesia and Malaysia**
CO_2	-33 t CO_2/ha
N_2O	0 t N_2O/ha
Nitrate	0 t NO_3/ha
Rapeseed	**From set-aside to rapeseed, Denmark**
CO_2	88 t CO_2/ha
N_2O	0.022 t N_2O/ha
Nitrate	4.6 t NO_3/ha

WWF has also estimated changes in carbon storage capacity in tropical forests. In WWF study Rain Forest for Biodiesel it has been estimated that total of 365 t CO_2 per hectare will be lost when natural forest is changed to plantation. If natural forest is cleared for oil palm plantation this additional CO_2 burden need to be taken into account. (WWF, pages 32-35)

In the same study has also been estimated that when tropical fallow land (alan-alang grassland) is changed to plantation, between 7 - 19 t CO_2 per hectare will be saved during one production cycle of oil palm plantation (25 years). In other words, plantation in fallow land actually creates a carbon sink. (WWF, pages 35-37)

Land use change is not only issue of tropical land. It needs to be taken into account if feedstock is cultivated in Europe or in some other part of the world. Land use change effects have been evaluated by RTFO (RTFO, 2008). These values can be used to impact calculations, if there is some actual data (e.g. crop production and conversion plant) on the fuel chain. If biofuel producer has more detailed information about the fuel chain (e.g. soil types, climate zones etc) then more accurate calculations can be carried out using approach set out in the IPPC 2006 Guidelines for National Greenhouse Gas Inventories Volume 4 Agriculture, Forestry and Other Land Use.

The land use change is complicated issue which is under ongoing debate. When evaluating the effects of land use change there are many issues that need to be taken into account. For example former use of plantation (existing plantation, forest or fallow land etc.), was the forest cleared to create the plantation or for from some other reason (e.g. for agriculture). Land use change is also macro-level issue which is led by political debate. In the end, biofuel producers can influence land use through own principles and partnerships within the chain of custody but political leaders can have real influence through legislation and political agreements.

At the time of writing, there was no consensus-based general approach for calculating this indirect impact on carbon intensity of transport biofuels. For the purpose of this study it was chosen to use calculation described in the RTFO methodology (RTFO 2008, pages 98-105).

In case of present NExBTL feedstock portfolio there is no need for land use change. All vegetable feedstock is cultivated in existing plantations or fields. This means that there is no indirect greenhouse gas impact due the land use change.

4.11 Summary of product chain life cycle inventory

This study was focused on greenhouse gas emissions and energy use during transport biofuel product chain. Table 20 shows the summary results of greenhouse inventory. Table 21 shows the result of energy consumption inventory. The tables showing more the detailed summary results of biofuel life cycle inventory can be found in Appendix 3. Results are calculated against 1000 kg of biofuel and functional unit ($MJ_{biofuel}$). Both non-allocated and allocated values are presented in Appendix 3. Allocations were based on allocation procedures described in section 4.3. When looking the results related on raw materials, it should keep in mind that calculation of inputs and outputs of raw materials cultivation, processing and transport was based on assumption that only one raw material is used in processing of biofuel.

***Table 20**. Summary of biogenic and fossil greenhouse gas emissions during product chain of biofuel. Emissions of CO_2, CH_4 and N_2O are included in inventory.*

Product chain phase		**Palm oil not allo-cated**	**Palm oil allo-cated**	**Rape-seed oil not allo-cated**	**Rape-seed oil allocated according to RTFO**	**Rape-seed oil allo-cated by mass**	**Animal fats not allo-cated**	**Animal fats allo-cated**
Raw material cultivation	Fossil CO_2e ($gCO_2e/MJ_{Biofuel}$)	8.72	6.54	58.69	58.69	25.41	Not included in inventory	
Raw material processing	Biogenic CO_2 ($gCO_2e/MJ_{Biofuel}$)	26.27	19.70	No biogenic CO_2 emissions				
	Fossil CO_2 ($gCO_2e/MJ_{Biofuel}$)	26.36	19.77	4.52	-5.44	1.96	56.08	9.42
Raw material transport	Fossil CO_2 ($gCO_2e/MJ_{Biofuel}$)	2.37	2.37	0.33	0.33	0.33	0.64	0.64
Biofuel production	Biogenic CO_2 ($gCO_2e/MJ_{Biofuel}$)	0.001	0.000	0.001	0.000	0.000	0.001	0.000
	Fossil CO_2e ($gCO_2e/MJ_{Biofuel}$)	10.47	5.04	10.47	5.04	5.04	10.47	5.04
Product transport	Fossil CO_2e ($gCO_2e/MJ_{Biofuel}$)	0.66	0.66	0.66	0.66	0.66	0.66	0.66
Product use	Fossil CO_2 ($gCO_2e/MJ_{Biofuel}$)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Land use change	Fossil CO_2 ($gCO_2e/MJ_{Biofuel}$)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total								
	Biogenic CO_2 ($gCO_2e/MJ_{Biofuel}$)	26.27	0.00	0.00	0.00	0.00	0.00	0.00
	Fossil CO_2 ($gCO_2e/MJ_{Biofuel}$)	48.58	34.40	74.67	59.28	33.43	67.84	15.75

***Table 21**. Summary of energy consumption during product chain of biofuel.*

Product chain phase		**Palm oil not allo-cated**	**Palm oil allo-cated**	**Rape-seed oil not allo-cated**	**Rape-seed oil allo-cated by mass**	**Animal fats not allo-cated**	**Animal fats allo-cated**
Raw material cultivation	Fossil energy ($MJ/MJ_{Biofuel}$)	0.203	0.016	0.116	0.074	Not included in inventory	
Raw material processing	Fossil energy ($MJ/MJ_{Biofuel}$)	Only renewable energy used		0.044	0.028	0.002	0.001
	Renewable energy ($MJ/MJ_{Biofuel}$)	0.151	0.120	Renewable energy not used			
Raw material transport	Fossil energy ($MJ/MJ_{Biofuel}$)	0.100	0.100	0.011	0.011	0.010	0.010
Biofuel production	Fossil energy ($MJ/MJ_{Biofuel}$)	0.15	0.07	0.15	0.07	0.15	0.07
Product transport	Fossil energy ($MJ/MJ_{Biofuel}$)	0.01	0.01	0.01	0.01	0.01	0.01
Product use	Fossil energy ($MJ/MJ_{Biofuel}$)	0.00	0.00	0.00	0.00	0.00	0.00
Land use change	Fossil energy ($MJ/MJ_{Biofuel}$)	0.00	0.00	0.00	0.00	0.00	0.00
	Fossil energy ($MJ/MJ_{Biofuel}$)	0.431	0.196	0.331	0.191	0.172	0.091
	Renewable ($MJ/MJ_{Biofuel}$)	0.151	0.120	Renewable energy not used			

4.12 Critical review

Two different types of data were used in this study. The first part of the product chain data (from cultivation to raw material and raw material transport) is based on secondary data sources. Selection of these data sources was based on their openness and explanation of data origin. It was also possible to compare two different data sources which made secondary data more credible. The second part of product chain data was based on actual operating data collected from site. Data and process-related calculations were checked by experts in the pretreatment, hydrotreatment and hydrogen production process. Because there are no long-term monitored and measured data, there is possibility that data used in this study might need revision later. Future result of this revision should not lead to any major changes in processing data and should not have any significant effects on the final results.

Data related to raw material cultivation and processing is collected from different sources. There were two different data sources for oil palm cultivation and processing. Similarly, those two different data sources were used also for rapeseed plant cultivation and rapeseed oil processing. The first source is draft Recommendation to Renewable Transport Fuel Obligation developed by United Kingdom Government Department for Transport (RTFO 2008). The second data source is PhD, thesis of Jannick H Schmidt, Aalborg University (Schmidt 2007b). Both sources were published in 2007 so they present latest data related to raw material cultivation and processing. Data presented in the sources has been used in calculations.

Secondary data used in this study presents the good quality of literature data. Two different sources were compared with each other to ensure that data used in inventory presents the best available data. Very detailed sensitivity analyses related to data used in study made by Schmidt (Schmidt 2007b, pages 221-253). The sensitivity analyses, completeness and consistency checks done by Schmidt were the main reason; this study was chosen as a benchmark for secondary data sources. All secondary data used in calculations of this case study were compared to data calculated by Schmidt. After this comparison it was decided which data value should used.

Two different data sources were used for animal fat processing. The first was European Commission Integrated Pollution Prevention and Control (IPPC) reference document on best available techniques (BAT) in the Slaughterhouses and Animal By-products Industries, published in May 2005 (EC 2005). The second data source was an environmental permit of Finnish rendering plant which is direct link in NExBTL product chain (Lounais-Suomen ympäristökeskus 2006).

Data related to raw material transport were collected from two different sources. The first source was International Maritime Organization (IMO) Study of Greenhouse Gas Emissions from Ships, 2000 (IMO 2000). Emission factors of this study are used in calculations of emissions from ocean transport of raw materials. VTT factors (VTT Lipasto 2006) were used in road and waterway transport calculations.

Primary data used in this study was collected directly from Kilpilahti refinery site and it presents high quality of data. Collected data was checked by experts in pretreatment process, hydrotreatment process and hydrogen production. This was done to make sure that data used in calculations were accurate, consistent and complete.

Co-efficient factors used in calculation of this study are same as presented in data sources. All factors used can be found from Appendix 2. According to understanding of writer these co-efficient factors are commonly used and approved.

According to International life cycle assessment standard (SFS-EN ISO 14044, 2006), if results of study are intended to be used in public communication, critical review may be carried out by external expert. This study is intended for public use, so it was decided to use external experts to conduct the critical review of this study. Because most critical issues of the biofuel product chain were related to the cultivation and processing of feedstock, critical review was done by the experts of Agrifood Research Finland. Their critical review report is in Appendix 4.

5 Carbon and energy intensity assessment

Carbon and energy intensity of biofuel was calculated by using the RTFO methodology described in Section 3.1. According to assessment methodology, the calculation of carbon intensity of a biofuel should include all direct and indirect emissions or avoided emissions that are a result of the production of biofuel. This idea was followed in the life cycle inventory phase of this study. The same system boundaries and calculation methodology were also applied in energy intensity calculations. Data for calculations were taken from the life cycle inventory data. All emissions of fossil carbon dioxide (CO_2), dinitrogen oxide (N_2O) and methane (CH_4) that were identified are included in the calculations.

It is necessary to have fossil fuel reference system to convert the carbon intensity of a biofuel to a GHG and energy savings. The direct GHG savings resulting from the use of a biofuel depend on:

- The carbon and energy intensity of the biofuel
- The carbon and energy intensity of the displaced fossil fuel
- The energy efficiency of the vehicles using fossil fuel and the energy efficiency of the vehicles using biofuel (Bauen et al. 2007, page 17)

The indirect GHG savings resulting from a biofuel take into account additional factors e.g. alternative land use and previous land use. These factors are reported as part of the overall impact. (Bauen et al. 2007, page 17)

According to JEC (Joint Research Centre of the European Commission, EURCAR and CONCAWE) carbon intensity of diesel made from crude oil is 87.4gCO_2e/MJ_{fuel} (JEC 2007). In the RTFO methodology documentation carbon intensity value 86.4gCO_2e/MJ_{fuel} was used. Emissions beyond the refinery are excluded from this value. The proposal for a directive from the European Parliament and of the Council on the promotion of the use of renewable energy sources corresponding carbon efficiency value is 83.8gCO_2e/MJ_{fuel} (EC 2008a). Because of ongoing discussion in Europe related to transport biofuels environmental sustainability, the EU value was used.

The carbon and energy intensity of fossil fuel chain is estimated in the study report published in June 2007 (Stans et al. 2007). This report, “Inclusion of Sustainability Criteria in the Fuel Quality Directive”, was requested by European Parliament’s Committee on the Environment, Public Health and Food Safety. Values given in this report were used in this study to estimate differences during the product chain, which is so called well-to-tank product chain. In assessing greenhouse gases, the fossil GHG emission from the use of fuel (so called tank-to-wheel) are added to the total carbon intensity. When evaluating biofuels, fossil GHG emissions from the use of fuel are zero. (Stans et al. 2007, pages 4-10)

Neste Oil uses in its processes two raw materials for which land use issues need to be addressed: palm oil and rapeseed oil. At this time all cultivated feedstock used to produce NExBTL is cultivated on croplands which were in same use in November 2005. This means that there are no land use related impacts to carbon and energy intensity from NExBTL.

Neste Oil uses waste material originated from animal and slaughterhouse waste, which is rendered before becoming a raw material of NExBTL. Because of this rendering process GHG emissions of this raw material are not credited as a zero. GHG emissions from production of energy needed in rendering process and energy used in this process are included in calculations.

Growing and processing the biofuel feedstock usually produces some residues – for example straw from growing rape plants. The use of these residues can have significant impact on the net GHG savings of a biofuel. The RTFO methodology recommends that residues are treated as co-products within calculations if there is evidence that residues are actually processed. The default assumption is that residues are left on the field and there is no net impact on GHG emissions. The only exception is for the palm oil chain, where assumption is made that part of the residues (the fiber and shell) are burned at the palm oil mill to produce heat and power. In energy and greenhouse gas calculations of NExBTL product chain, straw was not credited, because there was no solid evidence that straw originated from growing feedstock for NExBTL is really converted to energy.

During product chain of transport biofuel NExBTL, several co-products are produced. The detailed approach used for different co-products can be found in life cycle inventory section of this study. In general, allocation of co-products was done by mass or by energy content. Allocation by market value was not done.

Calculated carbon and fossil energy intensity of NExBTL product chain can be found from Tables 22 and 23. Final values are referred to fossil fuel reference system.

***Table 22**. Carbon intensity of NExBTL product chain compared to fossil fuel reference chain*

Biofuel product chain	**gCO_2e/MJ_{NExBTL} palm oil**	**gCO_2e/MJ_{NExBTL} rape-seed oil** (allocation by RTFO method-ology)	**gCO_2e/MJ_{NExBTL} rape-seed oil** (allocation by mass)	**gCO_2e/MJ_{NExBTL} oil from animal waste**	**Fossil fuel chain**	**$gCO_2e/MJ_{Fossil\ fuel}$ fossil fuel reference chain according to EU**	**$gCO_2e/MJ_{Fossil\ fuel}$ fossil fuel reference chain according to RTFO**
Cultivation and processing of raw materials	26.3	53.3	27.4	9.4	Crude oil production and conditioning at source	3.3	3.3
Transport of raw materials	2.4	0.3	0.3	0.6	Crude oil transport to markets	0.8	0.8
Production of NExBTL	5.0	5.0	5.0	5.0	Crude oil refining to diesel	8.6	8.6
Transport of final product	0.7	0.7	0.7	0.7	Diesel fuel distribution	0.7	0.7
Product use	0	0	0	0	Product use	83.8-13.4 = 70.4	86.4-13.4 = 73.0
Total	**34.4**	**59.3**	**33.4**	**15.8**		**83.8**	**86.4**

In case of present NExBTL feedstock portfolio there is no need for land use change. All vegetable feedstock is cultivated in existing plantations or fields. According to the RTFO methodology used, this means that there are no indirect impacts on carbon intensity from land use change. In other words, indirect impact of land use change is 0 gCO_2e/MJ_{NExBTL}.

Table 23. Fossil energy intensity of NExBTL product chain compared to fossil fuel reference chain

Biofuel chain	**MJ/MJ$_{NExBTL}$ palm oil**	**MJ/MJ$_{NExBTL}$ rapeseed oil**	**MJ/MJ$_{NExBTL}$ oil from animal waste**	**Fossil fuel chain**	**MJ/ MJ$_{fossil\ fuel}$ fossil fuel reference chain**
Cultivation and processing of raw materials	0.02	0.1	0.001	Crude oil production and conditioning at source	0.03
Transport of raw materials	0.1	0.01	0.01	Crude oil transport to markets	0.01
Production of NExBTL	0.07	0.07	0.07	Crude oil refining to diesel	0.10
Transport of final product	0.01	0.01	0.01	Diesel fuel distribution	0.01
Total	**0.2**	**0.19**	**0.09**		**0.15**

A summary of total product chain direct fossil greenhouse gas emission and fossil energy consumption is shown in Figures 18 and 19. In this summary only fossil greenhouse gas emissions were included in because greenhouse gas and energy intensity of biofuel product chain was referred to corresponding fossil fuel reference chain

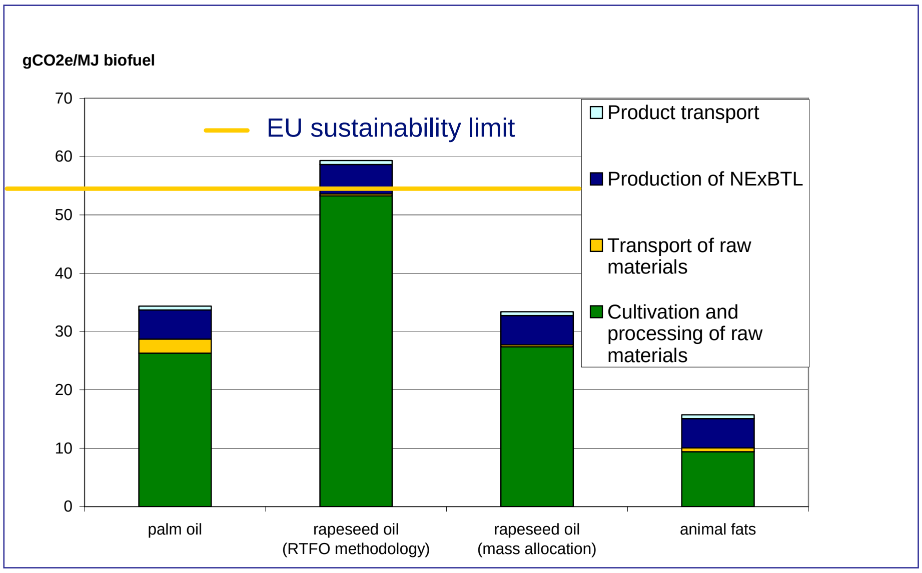


***Figure 18**. Total greenhouse gas emissions per functional unit. Greenhouse gas emissions of product chain were compared to proposed EU sustainability limit in proposal for a directive of the European Parliament and of the Council on the promotion of use of renewable energy sources. This proposal demands 35% greenhouse gas savings to fossil fuel reference system (yellow line).*

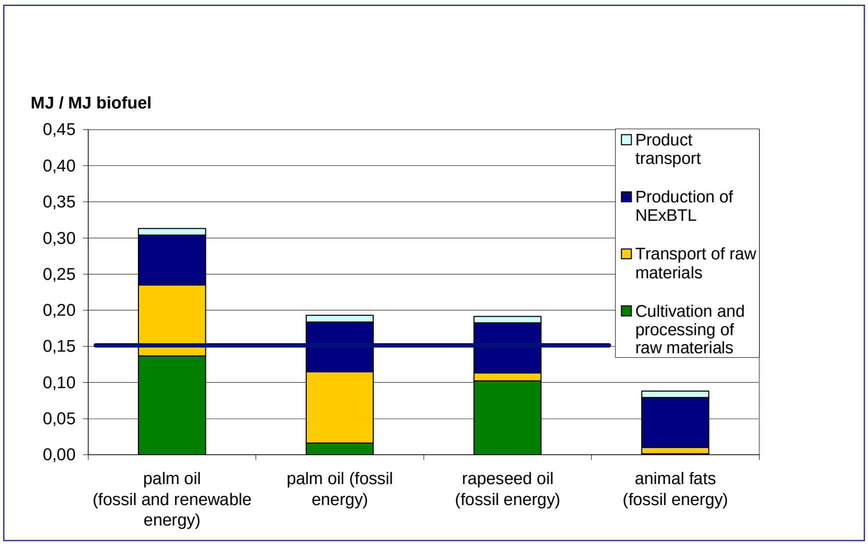


Figure 19. *Total fossil energy consumption per functional unit. According to study report "Inclusion of Sustainability Criteria in the Fuel Quality Directive", energy efficiency of fossil fuel reference system is 0.15 MJ/MJ (blue line)*

Calculation of greenhouse gas savings

Greenhouse gas savings were calculated by using the equation:

GHG saving = (carbon intensity of biofuel – carbon intensity of fossil fuel)/ carbon intensity of fossil fuel

This simple equation is given in EU directive proposal and the RTFO methodology is used in this study. The results of the calculations are presented in Figure 20. As can be seen, the amount of savings depends on raw material used. If NExBTL is made 100% from animal fats (tallow oil), savings would be over 80%. Similarly, NExBTL made 100% from palm oil gives savings over 60%. If product is made 100% from rapeseed oil the savings will be between 30 and 60%, depending on allocation procedure. Finding the reasons for this difference between two allocation methods needs further study.

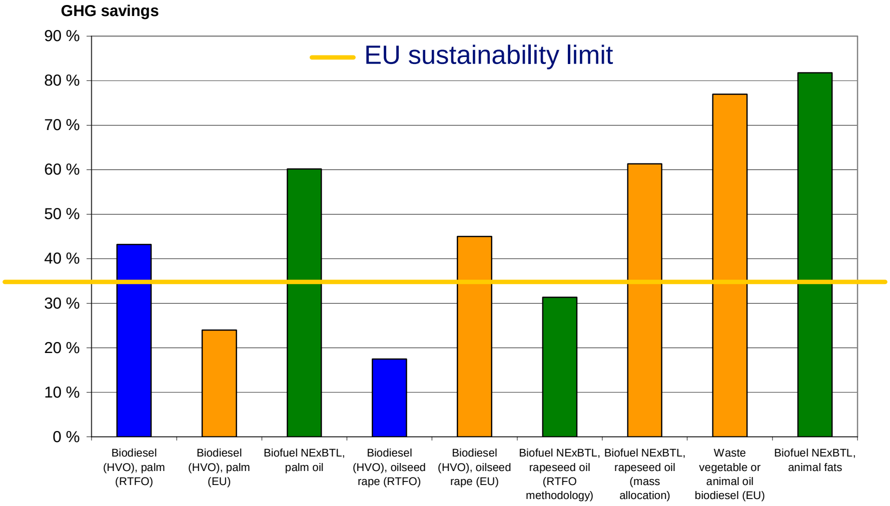


Figure 20*. Greenhouse gas saving of biofuel NExBTL made from palm oil, rapeseed oil and animal fats (tallow oil) compared to default product chains given in EU directive proposal (EC 2008a) and the RTFO methodology used (RTFO 2008). Yellow line marks proposed EU sustainability limit in proposal for a directive of the European Parliament and of the Council on the promotion of use of renewable energy sources. This proposal demands 35% greenhouse gas savings to fossil fuel reference system.*

6 Interpretation of results

When reading results of this study, it is important to remember that it is case study, specific to a certain product chain and production site. Results of this study are not necessarily comparable to production in another location or to a site which does not have similar integrated commodity systems.

The reason, this study was done as a case study is that technology is new and production started less than year ago. Basically, this means that there was insufficient monitored and measured process data for statistical analyses but there was enough calculated and actual operating data to make a case study. On other hand, one purpose of case study is to deepen the product chain understanding and raise the points where better performance or more information is needed. This served well for the purposes of this study. A case study was needed because study made at a general level using only commercial databases and programs might lead to situation where some important issues related to greenhouse gas end energy intensity of product chain could be missed.

The results of greenhouse gas and energy assessment show that total direct greenhouse gas emissions during the product chain depends on type of feedstock and types of energy (renewable or fossil) used in processes during product chain. In this study three different raw material were compared: crude palm oil, crude rapeseed oil and animal fats produced from animal waste.

Cultivation of oil palms and rapeseed plants creates greenhouse gas emissions due to fertilizer and machinery use. Energy consumption of field machinery is main energy requirement for cultivation. Input of cultivation to total greenhouse gas emissions differ greatly depending on feedstock. Cultivation of oil palms creates less fossil greenhouse gas emissions than rapeseed plant cultivation. There are several reasons for this difference. One major reason is the difference in yields. To produce enough rapeseed to fulfil the raw material need of refinery process requires over three times more rapeseed plant hectares than oil palm plantation hectares. This also means huge difference in fertilizer use. Additionally, rapeseed has to dry before further processing. Oil palms' fresh fruit bunches does not have this demand. The drying of rapeseed also requires fossil energy.

Based on information from data sources used, energy need for production of crude palm oil is high but it is mostly renewable origin. The production of rapeseed oil is done by using fossil fuels. This has direct influence on greenhouse gas emission calculations. Treatment of crude oil mill effluents and co-products also has direct impact on greenhouse gas emissions. Crude palm oil production creates palm oil mill effluent (POME) which is most commonly treated in anaerobic ponds. This causes methane emissions which have a strong impact on product chain greenhouse gas emissions. Crude rapeseed oil production creates rapeseed meal, which indeed, has the effect of decreasing greenhouse gas emissions. The processing of animal waste is quite energy intensive. The energy needed for processing is a mixture of animal fat and fossil fuels. Fossil energy needed for this process is the main source of greenhouse gases in this part of product chain.

Feedstock and product transport distances also have some effect on greenhouse gas emissions, but they are not as significant as emissions from cultivation or oil or animal fat processing. In case of energy demand, there are differences depending on raw material type. Because of long distances, transport of crude palm oil to refinery requires a lot of energy. In transport of other raw materials, this demand is much smaller but as described in inventory section, the transport of rapeseeds from field to

Raisio is underestimated in this study. The actual transport distance of rapeseeds or preprocessed rapeseed might be longer but there was insufficient data to calculate these distances. If produced biofuel is transported to domestic markets, the share of product transport does not play a significant role when evaluating total energy consumption of product chain.

Production processes do not create direct fossil greenhouse gas emissions. All fossil greenhouse gas emissions originate from production of energy needed for the production process, including pretreatment, hydrotreatment and hydrogen production. The hydrotreatment process results in two co-products, propane and gasoline. Both are used in refinery into which biofuel production process is integrated. Energy needed for production is produced by using fossil fuels. The integration of biofuel process into the refinery's commodity system makes process energy efficient.

Land use change always has some impacts on biodiversity and greenhouse gas emissions. Discussion of this issue is ongoing and there was no global consensus reached how this issue should be taken into account in sustainability evaluations. If this issue is included in life cycle analysis, it might lead to misinterpretation of results. It is better to deal with this issue separately and report land use change as indirect emissions. In this study, these indirect emissions were calculated by using the RTFO methodology. Neste Oil uses two raw materials in its process for which land use issues need to be concerned, palm oil and rapeseed oil. At the time of this study, cultivation of oil palms and rapeseed plants was done in existing plantations and fields. According to the RTFO methodology used, this means that there is no indirect impact on carbon intensity from land use change. In other words, indirect impact of land use change is 0 gCO_2e/MJ_{NExBTL}.

As a result of this case study, it can be said that final greenhouse gas and energy intensity of biofuel product chain depends on raw material used. If only fossil fuel is taken in account, the distance between feedstock source and production site has quite strong influence on the energy intensity of product chain. In addition to this, allocation procedures have a strong influence in greenhouse gas intensity. In this study this was noticed especially in calculation of greenhouse gas intensity on rapeseed oil production. If allocation procedure described in the RTFO methodology documentation greenhouse gas savings of product chain based on rapeseed were approximately 30%. When pure mass-based allocation was used savings were approximately 60%. These results do fit in overall range of greenhouse gas saving results which were between

30% and 80%. Best savings were achieved by using animal fats. Using palm oil as a raw material resulted approximately 60% savings in greenhouse gas emissions.

More study is needed, even in this biofuel product chain. This study will serve as a basis for further studies

7 Conclusions

This was a case study in which life cycle assessment was conducted on product chain of biofuel NExBTL. The product chain consisted of modules. The modules were built by using system approach and life cycle assessment as described in International standards (SFS-EN ISO 14040, 2006 and 14044, 2006). The life cycle inventory (LCI) of product chain was conducted. In this study, assessment was focused only on greenhouse gas emissions and energy consumption. The assessment methodology used was based on guidance given in United Kingdoms Carbon Reporting within Renewable Transport Fuel Obligation (RTFO 2008). This methodology, subsequently called the RTFO methodology, intends to transparent assessment methodology for biofuels. Greenhouse gas savings were calculated by using methodology described in the proposal for a directive of the European Parliament and of the Council on the promotion of the use of renewable energy sources (EC 2008b). In addition, a critical review of case study was also done by the experts of Agrifood Research Finland. Their review statement is in Appendix 4.

Evaluating greenhouse gas and energy intensity should not be based on general studies or default product chains. It is better describe a product chain specific to actual product. This was done in this case study. It is important to investigate all relevant environmental impacts during product chain. When relevant environmental impacts are known, it is possible to make different assessments. In this study greenhouse gas and energy assessment were conducted. The assessment results were compared against environmental sustainability limits presented in draft European Directive (EC 2008a) and energy efficiency of fossil fuel reference chain (Stans et al. 2007). When referring to this comparison, it can be said that biofuel NExBTL made from crude palm oil or animal fat will meet greenhouse gas saving criteria (35% saving compared to fossil fuel). Using palm oil as a raw material, gives 60% direct greenhouse gas savings. If animal fats are used, the saving is 80%. If rapeseed oil is used as a raw material direct greenhouse gas savings are between 30% and 60%, depending on allocation procedure used. Using allocation procedure given in the RTFO methodology gives smaller savings as by using mass-based allocation. According to LCA standard (SFS-EN ISO 14044, 2006), the inputs and outputs of the system should partitioned between its different products or functions in a way that reflects the underlying physical relationships between them. For the purposes of this study, especially concerning agricultural practices, mass-based allocation seems to be more relevant than e.g. allocation based on energy content or market value.

Before answering the question as to whether biofuel made from various biomass sources meets the EU environmental sustainability criteria, a common applicable allocation procedure should be set.

In conclusion, it can be said that based on the RTFO methodology used in this case study, direct greenhouse gas savings will meet the draft environmental sustainability criteria of European Union. In addition to that, the fossil energy intensity of biofuel product chain is almost at the same level as energy intensity of fossil fuel reference chain.

Before overall environmental sustainability of biofuel can be evaluated, further studies are needed. Now, technical quality, local emissions and greenhouse gas savings are investigated. Results of these studies are encouraging. There are still many questions that need to be answered. The overall environmental impact such as impact on biodiversity, eutrophication, land use etc. should be evaluated.

8 The needs for further study

During the course of this study, it became evident that there is a need for further study in the area of biofuels' environmental sustainability. Life cycle assessment is a suitable method but assessment should not be concentrated only on greenhouse gases. In evaluating environmental sustainability it is essential to consider all relevant environmental aspects. Greenhouse gas assessment should be seen only as a starting point for more complete evaluation.

This study should be updated when more actual and monitored process data is available. At the time of this study, the production of NExBTL and new hydrogen process were new and insufficient amount of monitored data were available. This could also be the time for more extensive life cycle assessment.

There should also be strong consensus for allocations done during the product chain. This was also noted in this study. Currently there are different ways to allocate such factors as co-products which may make comparison of different product chains and technologies more difficult. In this case study allocation by mass was used. It is also possible to allocate by energy which seems to be basis of allocations used in default values of product chain used in EU Directive proposal (EC, 2008a). Another possibility for making an allocation during product chain is to use the market values of products. This should be done only when physical relationships cannot be used as the basis of allocation.

In addition to allocation issue, the formation of product chains differs between different studies. This has significant impact on the results. It is essential to build product-specific chains. The general chains used as a base of default values might lead decision makers to misguided conclusions. There is a strong need for further and transparent studies in this area.

Even if palm oil milling process was described quite well in literature, there is a need for study related to energy efficiency in the milling process. When conducting this study, it came evident that it is possible to make the milling process more environmental and energy efficient. Treatment of palm oil mill effluent could be improved and excess energy of the process could be sold to network.

The rendering process of animal fats should be studied more. The processing of animal waste is evolving all the time and this might lead even more efficient production of animal fats. The rendering business and technology is developing continuously, for example capacity of production, products of rendering and used energy sources. The product chain module related on animal fat processing should be updated in near future.

The land use change issue is extreme difficult and needs to be solved in some reasonable way. To separate this from life cycle analysis seems to be appropriate way to proceed but it should not focus only on biofuels. The real actual reasons for land use change should also be taken into account. The reasons behind forest harvesting and construction business should be studied more carefully. For example, construction of new buildings for people whose standards of living have risen might lead to harvesting of forests. Biofuel production may have started after harvesting for construction purposes was already conducted. In this case biofuels should not carry all the burdens of indirect emissions, as is done in present discussions. Before this issue is solved, there is a need for further studies and global discussion on this topic, both at local and global level.

9 Summary

Reports from International Energy Agency IEA (IEA 2006) and United Nations (UN-Energy 2007 and GEO-4 2008) declare that loss of biodiversity, climate change and growing need for energy force to find solutions for producing enough energy and doing so in a sustainable manner.

There are different ways to tackle these challenges, legislative and technological. Biofuels will play a part in expanding the range of energy sources available in the future. OECD (Doornbosch and Steenblik 2007) estimates that 13% of liquid fuel needs in 2050 will be supplied by transport biofuels. Transport biofuels will not replace fossil fuels, at least in near future, but they can serve as partial solution to fulfill growing need for energy.

Even as a partial solution, transport biofuels need to be produced in sustainable way. At the moment there are lot of questions related to biodiversity loss and land use change because of biofuel feedstock, energy intensity of biofuels production and greenhouse gas emissions of biofuels' product chain. Currently there are many different ways to determine these issues. To be able to make right choices decision makers, agriculture and industry need a common global and transparent approach to sustainable production transport biofuels. This approach need to be based on life cycle thinking and its results should be communicated openly between stakeholders.

This research was a case study where life cycle assessment was conducted on product chain of biofuel NExBTL. The product chain was built by using system approach and life cycle assessment as described in International standards (SFS-EN ISO 14040, 2006 and SFS-EN ISO 14044, 2006). Guidance given in International greenhouse gas verification standard (SFS-ISO 14064-1, 2006) was also taken into account in greenhouse gas calculations. The assessment part of this study was based on guidance given in United Kingdoms Carbon Reporting within the Renewable Transport Fuel Obligation (RTFO 2008). This intends to be first transparent assessment methodology prepared and piloted in cooperation between industry, environmental experts and authorities. Greenhouse gas savings were calculated by using methodology described in the proposal for a directive of the European Parliament and Council on the promotion of the use of renewable energy sources (EC 2008a).

Results of this study show that when evaluating the greenhouse gas and energy intensity of certain transport biofuel, it is essential to make a case study specific to this certain biofuel. If more general studies are used, it might lead to misinterpretations. In this study all relevant environmental impact were investigated, but the assessment part of study concentrated on greenhouse gases and energy consumption. This was done mainly because these issues are under lively discussion at this moment.

The assessment results were compared against environmental sustainability limits presented in draft European Directive (EC 2008a) and energy intensity of fossil fuel reference chain (Stans et al. 2007). Direct greenhouse gas savings will meet the draft environmental sustainability criteria of European Union. In addition to that, the energy intensity of biofuel product chain is almost at the same level as energy efficiency of fossil fuel reference chain. Biofuel NExBTL made from crude palm oil or animal fats, will meet greenhouse gas saving criteria (35% saving compared to fossil fuel). Using palm oil as a raw material, gives 60% direct greenhouse gas savings. If animal fats are used, these saving are 80%. If rapeseed oil is used as a raw material direct greenhouse gas savings are between 30% and 60%, depending on allocation procedure used. Using allocation procedure given in assessment methodology (RTFO, 2008) gives smaller savings than by using mass-based allocation. Before answering the question as to whether biofuel made from various biomass sources meet the EU environmental sustainability criteria, a common allocation procedure should be agreed upon.

The results of this study are encouraging. There are still many questions that need to be answered. Overall environmental impact such as impact on biodiversity, eutrophication, land use etc. should be evaluated before final answers about environmental sustainability of biofuel can be given.

This study should be updated when more actual and monitored process data is available. At the time of this study, the production of biofuel NExBTL and new hydrogen process were new and insufficient amount of monitored data were available. This could also be the time for more extensive life cycle assessment.

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Appendixes

Appendix 1. Nine key sustainability issues according to UN-Energy

Table A.1. *Nine key sustainability issues according to UN-Energy (pages 9-50)*

Sustainability issue	**Factors related on that**
1. The ability of modern bioenergy to provide energy services for the poor	Resource availability and competing use, e.g. use of biomass resources for food Economic access, reliability and accessibility, e.g. cost of small scale production are higher Implementation issues, e.g. government subsidies
2. Implications for agro-industrial development and job creation	Short- and long-term development, e.g. in short-term feedstock costs, reliability of supply, availability of competing energy sources, government policy decisions and in long-term agricultural productivity, technological advancement Type, quality and distribution of employment, e.g. labour conditions in poor countries Infrastructure considerations, e.g. feedstock sources, transport, location of processing plant Powering or fuelling other industries, e.g. using animal fats as a raw material will strengthen co-product industry and create jobs Small-scale production, all players must operate in synchrony Encouragement of job creation, ratio of investment cost per job created is good compared to non-agricultural counterparts Product need to fulfil fuel quality standards Encourage international investment, public sector should lay down policy and regulatory framework to ensure social and environmentally responsible investment environment. Partnership between public and private sector.
3. Health and gender implications	Health risks associated with the production of biomass feedstock are similar to those of modern agriculture. Of course during processing phase, there is a need for labour safety considerations. Biofuel used in blend, may cause public health risk e.g. using ethanol in blends may bring about higher emissions of acetaldehyde.
4. Implications for the structure of agriculture	Production facilities of liquid biofuels produced by using new technologies will create market for far greater amounts of agricultural biomass, and promises to create higher-value co-products. However, it will also require the development of more capital-intensive, complex production facilities, giving further edge to large companies. Large investments are signalling the emergence of new “bio-economy” in the coming decades. Key factors to be considered when selecting feedstock include: economic viability, suitability for different biofuel application, yield per hectare, input requirements, yield increase potential, crop versatility, drought and pest resistance potential, competing uses, price volatility and opportunity costs. International capacity building is particularly critical at this early stage of the bioenergy industry, where the expertise unique to bioenergy cropping practices, such as carbon-cycle

	cropping considerations, is concentrated in only a few countries. Fulfilling information needs, e.g. UN and UNESCO renewable energy review, FAO agricultural management models and energy manuals International Bioenergy Platform (IBEP) assistance to developing countries on information for decision-making methods, approaches to assess bioenergy potential and sustainability. Global Bioenergy Partnership (GBEP) on multi-stakeholder cooperation on biofuel sustainability. Global Village Energy Partnership (GVEP) on setting up energy action plans, financial and technical support in developing countries.
5. Implications for food security	The expansion of liquid biofuel production could affect food security through four major dimensions: availability (e.g. land and water), access (e.g. rise of prises), stability (time dimension) and utilization (e.g. health implications because of lack of pure water). These effects may be positive or negative. The effects of bioenergy on food security will be context-specific, depending on the particular technology and country characteristics involved. Liquid biofuels derived from food crops will have different food security implications than modern bioenergy systems based on lignocellulosic or waste materials. An analytical framework based on country typologies should be developed to facilitate the understanding of country-specific effects. Planting arid, semi-arid, degraded and marginal lands that are unsuitable for food production with inedible biofuels crops such as jatropha would not compete directly with current food production and could help rehabilitate such soils. At least four distinct policy domains are shaping development of the liquid biofuels sector: energy, environment, agriculture and trade. Similarly. Policies at the national , regional and global levels are highly relevant and may interact unexpected ways. Policy makers need to understand the interactions among these various policy domains and levels and to ensure that food security considerations are given priority.
6. Implications for government budget	Tax reductions for liquid biofuels are possible if fuel taxes are high to begin with. Fuel taxes are not very efficient in reducing externalities from emissions that contribute to urban air pollution because pollutant emissions and their externalities depend not only on fuel choice, but also vehicle technology, maintenance, driving patterns and the location and time of emissions. But fuel taxes are efficient for reducing externalities associated with carbon dioxide emissions because these emissions are linked directly to fuel consumption. A carbon tax based on each fuel's lifecycle CO_2 emissions characteristics would be appropriate
7. Implications for trade foreign exchange balances and energy security	Diversifying global fuel supplies could have beneficial effects on the global oil market. Greater biofuel use could help bring the oil market into balance and greatly reduce oil prices. Diversified fuel portfolios would also have benefits at national level, but biofuel prices will rise and fall in line with world oil market. Opening international market to biofuels would accelerate investments and ensure that production occurs there where market are. Linking agricultural commodity prices to oil market creates

	a risk, but it is needed to boost the development of new technologies. The development of biofuels industries requires substantial government intervention, giving policymakers ample opportunity to both advance and thwart a variety goals. Biofuels should not be considered in a vacuum, but rather in the context of wider energy and agriculture policies. Implementation issues are: subsidies, blending requirements and capacity building.
8. Impacts on biodiversity and natural recourse management	Potential to significantly reduce the greenhouse gas (GHG) emissions associated with fossil fuels. One of the greatest risks is the potential impact on land used for feedstock production and harvesting (particularly virgin land or land with high conservation values) and the associated effects on habitat, biodiversity and water, air and soil quality. Changes in the carbon content of soils, or in carbon stocks in forests and peat lands related to biomass production, might offset some or all of the GHG benefits. Biomass production offers the potential to reduce the environmental load relative to conventional industrialised agriculture, e.g. higher yield and reduced use of fertilizers through better farming practices. Issues that need to be addressed: Feedstock choice, land use and soil health Impact on grasslands, tropical forests and other biodiverse ecosystems Impact on water quality and availability Impact on air quality Implementation issues: Effectiveness of land-use controls Need for further research Potential voluntary or mandatory certification
9. Implications for climate change	One of major drivers in development of transport biofuels is climate change. Transportation, including emissions from the production of transport fuels, is responsible for about one quarter of global energy-related GHG emissions, and that share is rising. To assess the GHG balance, it is essential to consider emissions throughout the full life-cycle. Full life-cycle GHG emissions on biofuels vary videly based on: land use changes; choice of feedstock; agricultural practices; refining or conversion process; and end-use practices. Research on the net life-cycle GHG emissions associated with bioenergy production and use is still under development, and estimates vary widely duo variations in circumstances. Results are highly sensitive to assumptions about land use changes, the effects of fertiliser application and by-product use. The CO_2 avoided by using biofuels is only a part (albeit a significant part) of the societal benefit from transitioning to these fuels. Biofuels offer the only realistic near-term renewable option for displacing and supplementing liquid transport fuels. Yet even within the transport sectors there are more cost-effective options for reducing carbon emissions, including investments in and promotion public transportation, increased use of bicycles and other non-motorised vehicles, improvements in vehicle fuel-efficiency, and changes in urban planning and use. Implementation issues: Policy makers need to safeguard virgin grasslands, primary forests and other lands with high nature value and to encourage the use of sustainable production and management practices for biomass feedstock.

	An international certification scheme needs to be developed that includes GHG verification for the entire life cycle of biofuels. Improving energy-efficiency. In the case of liquid biofuels, the greatest potential for reducing GHG emissions and their associated costs lies in the development on new feedstocks, technologies and fuels.

Appendix 2. Greenhouse gas co-efficient factors used in calculations

***Table A.2-1**. Co-efficient factors used in calculations of oil palm cultivation*

Description	Co-efficient factor	origin
CO_2 from N fertilizer use	1.62 kg CO_2e per kg nutrient applied	Jenssen, T.K. and Kongshaug, G. (2003). Energy consumption and greenhouse gas emissions in fertiliser production. Proceedings of the International Fertiliser Society. Proc No 509
N_2O from N fertilizer use as a CO_2e	GHG emissions of N fertilizer caused by N_2O are calculated by multiplying amount of use of nitrogen fertilizers by N_2O co-efficient factor (0.01325) [kgCO_2e/kg nutrient]. This is multiplied by 44/28 (44 is molecular weight of N_2O and 28 is molecular weight of N_2). This is multiplied by 296, which is GHG factor of N_2O according to IPCC	
CO_2 from P fertilizer use	0.44 kg CO_2e per kg nutrient applied	
CO_2 from K fertilizer use	0.8 kg CO_2e per kg nutrient applied	
CO_2 from Mg fertilizer use	1.73 kg CO_2e per kg nutrient applied	
CO_2 from NPK fertilizer use	0.3 kg CO_2e per kg nutrient applied	
CO_2 from pesticide use	17.3 kg CO_2e per kg pesticide applied	JEC (2006). Well-to-wheels analysis of future automotive fuels and powertrains in the European context. Well to wheels report. CONCAWE, EUCAR and JRC.
CO_2 from machinery use	3.1 kg CO_2e per litre diesel fuel	RTFO
CO_2 from transport from plantation to oil mill	0.0864 kg CO_2e per MJ	RTFO

***Table A.2-2**. Greenhouse gas co-efficient factors used in calculations of palm oil processing*

Description	Co-efficient factor	origin
Methane from POME treatment as a CO_2e	8.743 kg CH_4 per 1 t FFB	Schmidt
GHG factor for CH_4	23	IPPC
Ash from burning of boiler fuel (65% fibre and 35% shell)	0.34 kg ash per kg boiler fuel	Schmidt
CO from burning of boiler	3.353 g CO per kg boiler	Schmidt

fuel (65% fibre and 35% shell)	fuel burned	
NO_x from burning of boiler fuel (65% fibre and 35% shell)	1.361 g NO_x per kg boiler fuel burned	Schmidt
NO_x from burning of boiler fuel (65% fibre and 35% shell)	0.012 g SO_x per kg fuel burned	Schmidt

Table A.2-3. *Greenhouse gas co-efficient factors used in calculations of rapeseed plant cultivation*

Description	**Co-efficient factor**	**origin**
CO_2 from N fertilizer use	6.8 kg CO_2e per kg ammonium nitrate nutrient applied	Jenssen, T.K. and Kongshaug, G. (2003). Energy consumption and greenhouse gas emissions in fertiliser production. Proceedings of the International Fertiliser Society. Proc No 509
N_2O from N fertilizer use as a CO_2e	GHG emissions of N fertilizer caused by N_2O are calculated by multiplying amount of use of nitrogen fertilizers by N_2O co-efficient factor (0.01325) [kgCO_2e/kg nutrient]. This is multiplied by 44/28 (44 is molecular weight of N_2O and 28 is molecular weight of N_2). This is multiplied by 296, which is GHG factor of N_2O according to IPCC	
CO_2 from P fertilizer use	1.62 kg CO_2e per kg TSP nutrient applied	
CO_2 from K fertilizer use	0.8 kg CO_2e per kg nutrient applied	
CO_2 from lime ($CaCO_3$) use	0.56 kg CO_2e per kg nutrient applied	
CO_2 from pesticide use	17.3 kg CO_2e per kg pesticide applied	JEC (2006). Well-to-wheels analysis of future automotive fuels and powertrains in the European context. Well to wheels report. CONCAWE, EUCAR and JRC.
CO_2 from machinery use	3.1 kg CO_2e per litre diesel fuel	RTFO
CO_2 from fuel oil use	0.081 kg CO_2e per MJ fuel	RTFO
CO_2 from electricity use	0.1214 kg CO_2e per MJ electricity	RTFO
CO_2 from transport from plantation to oil mill	0.0864 kg CO_2e per MJ	RTFO

Table A.2-4. *Greenhouse gas co-efficient factors used in calculations of rapeseed oil processing*

Description	**Co-efficient factor**	**origin**
CO_2 from natural gas use	0.062 kg CO_2e per MJ fuel	RTFO
CO_2 from electricity use	0.1214 kg CO_2e per MJ electricity	RTFO

Table A.2-5. *Co-efficient factors used in transport calculations*

Description	**Co-efficient factor**	**origin**
CH_4 (road)	0.00094 g/tkm	VTT LIPASTO 2006
CH_4 (sea)	0.3 kg/t fuel	IMO
CO (road)	0.018 g/tkm	VTT LIPASTO 2006
CO (sea)	7.4 kg/t fuel	IMO
CO (waterway)	0.021 g/tkm	VTT LIPASTO 2006
CO_2 (road)	72 g/tkm	VTT LIPASTO 2006
CO_2 (sea)	3170 kg/t fuel	IMO
CO_2 (waterway)	17 g/tkm	VTT LIPASTO 2006
Diesel consumption of oceanic tanker	1.55 g/tkm	Tanker oceanic ETH U (ETH-ESU) data from early 1990´s gives value 1.8 g/tkm and is not ship specific. Transoceanic tanker/OCE (ecoinvent 2004) gives value 1.3 g/tkm and is specific to tankers 150 000 t capacity. Two different types of tankers are used in raw material transport, it was decided to use average 1.55 g/tkm
Energy use (road)	0.98 MJ/tkm	VTT LIPASTO 2006
Energy use (sea)	0.2 MJ/tkm	RTFO
Energy use (waterway)	0.23 MJ/tkm	VTT LIPASTO 2006
HC (road)	0.011 g/tkm	VTT LIPASTO 2006
HC (waterway)	0.011 g/tkm	VTT LIPASTO 2006
NMVOC (sea)	2.4 kg/t fuel	IMO
NO_x (road)	0.77 g/tkm	VTT LIPASTO 2006
NO_x (sea)	72 kg/t fuel	IMO, Average emissions of NOx from sea transport of

		fuels according to CORINAIR factor is 87 kg/t fuel (slow speed) 57 (medium speed). Average of these values was used.
NO_x (waterway)	0.45 g/tkm	VTT LIPASTO 2006
N_2O (road)	0.002 g/tkm	VTT LIPASTO 2006
N_2O (sea)	0.08 kg/t fuel	IMO
PM (fine particles, road)	0.0069 g/tkm	VTT LIPASTO 2006
PM (fine particles, waterway)	0.011 g/tkm	VTT LIPASTO 2006
SO_x (road)	0.00068 g/tkm	VTT LIPASTO 2006
SO_x (sea)	20*1.6%	IMO, Average emissions of SOx from sea transport of fuels according to CORINAIR factor is for residual 20* 2,7% (S content of fuel) and for distillate 20*0,5%. Average of these values was used.
SO_x (waterway)	0.16 g/tkm	VTT LIPASTO 2006

Table A.2-6. *Co-efficient factors used in biofuel processing*

Description	**Co-efficient factor**	**origin**
CO_2 from electricity use	220 kgCO2/MWh	Motiva
CO_2propane	202 kgCO2/MWh	Motiva
CO_2 from steam use	226 kgCO2/MWh	Motiva
Energy content of 5 bar steam	2.95 GJ/t	Neste Oil
Energy content of 16 bar steam	3.05 GJ/t	Neste Oil
Energy content of hydrogen	120 000 MJ/kg	Neste Oil
Energy content of propane	46 MJ/kg	Neste Oil

Table A.2-7. *IPCC factors used in biofuel processing*

Description	**Co-efficient factor**	**origin**
CO_2	1	IPCC
CH_4	23	IPCC
N_2O	296	IPCC

Appendix 3. Summary of life cycle inventory results

***Table A.3-1**. Summary of oil palm cultivation per 1000 kg biofuel*

Oil palm cultivation inputs	**Unit per 1000 kg biofuel**	**Not allocated**	**Allocated to crude palm oil**	**Oil palm cultivation outputs**	**Unit per 1000 kg biofuel**	**Not allocated**	**Allocated to crude palm oil**
Nitrogen fertilizer	kg nutrient	30.4	22.8	FFB	kg	7072	5658
Phosphorus fertilizer (P_2O_5)	kg nutrient	13.7	10.2	CO_2 from Nitrogen fertilizer use	kg CO_2e	49.2	36.9
K fertiliser (K_2O)	kg nutrient	62.2	46.7	N_2O from Nitrogen fertilizer use	kg CO_2e	187.1	140.3
Mg fertiliser (MgO)	kg nutrient	10.0	7.5	CO_2 from Phosphorus fertilizer use	kg CO_2e	6.0	4.5
NPK fertiliser	kg nutrient	15.2	11.4	CO_2 from K fertilizer use	kg CO_2e	27.4	20.5
Pesticides	kg	0.9	0.7	CO_2 from Mg fertilizer use	kg CO_2e	17.3	13.0
Nursey & plantation establishment	litres	9.1	6.8	CO_2 from NPK fertilizer use	kg CO_2e	4.6	3.4
Harvest and collection	litres	12.1	9.1	CO_2 from pesticide use	kg CO_2e	15.8	11.8
Fuel consumption for transport from field to mill	MJ	176.5	132.4	CO_2 from Nursey & plantation establishment machinery	kg CO_2e	1.1	0.9
				CO_2 from Harvest and collection machinery	kg CO_2e	37.6	28.23
				CO_2 from Fuel consumption of transport from field to mill	kg CO_2e	15.3	11.4

Table A.3-2. *Summary of oil palm cultivation per MJ biofuel*

Oil palm cultivation inputs	**Unit per MJ biofuel**	**Not allocated**	**Allocated to crude palm oil**	**Oil palm cultivation outputs**	**Unit per MJ biofuel**	**Not allocated**	**Allocated to crude palm oil**
Nitrogen fertilizer	g nutrient	0.69	0.52	FFB	kg	0.16	0.12
Phosphorus fertilizer (P_2O_5)	g nutrient	0.31	0.23	CO_2 from Nitrogen fertilizer use	g CO_2e	1.12	0.84
K fertiliser (K_2O)	g nutrient	1.41	1.06	N_2O from Nitrogen fertilizer use	g CO_2e	4.25	3.19
Mg fertiliser (MgO)	g nutrient	0.23	0.17	CO_2 from Phosphorus fertilizer use	g CO_2e	0.14	0.10
NPK fertiliser	g nutrient	0.34	0.26	CO_2 from K fertilizer use	g CO_2e	0.62	0.47
Pesticides	g	0.021	0.016	CO_2 from Mg fertilizer use	g CO_2e	0.39	0.30
Nursey & plantation establishment	litres	0.0002	0.00016	CO_2 from NPK fertilizer use	g CO_2e	0.10	0.08
Harvest and collection	litres	0.00028	0.00021	CO_2 from pesticide use	g CO_2e	0.36	0.27
Fuel consumption for transport from field to mill	MJ	0.004	0.003	CO_2 from Nursey & plantation establishment machinery	g CO_2e	0.03	0.02
				CO_2 from Harvest and collection machinery	g CO_2e	0.86	0.64
				CO_2 from Fuel consumption of transport from field to mill	g CO_2e	0.35	0.26

Table A.3-3. *Summary of crude palm oil processing per 1000 kg biofuel*

Crude palm oil processing inputs	**Unit per 1000 kg biofuel**	**Not allocated**	**Allocated to crude palm oil**	**Crude palm oil processing outputs**	**Unit per 1000 kg biofuel**	**Not allocated**	**Allocated to crude palm oil**
FFB	kg	7072	5658	Crude palm oil	kg	1191	1191
Steam	MJ	1713	1298	Empty Fruit Bunches	kg	1300	976
Electricity	MJ	42	32	Fibre	kg	752	653
Fibre & Shell, CHP plant	MJ	8773	6580	Shells	kg	404	303
Water	kg	150113	112585	Palm Kernels	kg	300	0
				Palm Oil Mill Effluent (POME)	kg	3028	2271
				CO_2 (biol.) from processing	kg CO_2e	1156	867
				CO	kg	3.9	2.9
				NO_x	kg	1.6	1.2
				SO_x	kg	0.01	0.01
				Ash	kg	393	295
				CH_4 from POME	kg CO_2e	1160	870

Table A.3-4. *Summary of crude palm oil processing per MJ biofuel*

Crude palm oil processing inputs	**Unit per MJ biofuel**	**Not allocated**	**Allocated to crude palm oil**	**Crude palm oil processing outputs**	**Unit per MJ biofuel**	**Not allocated**	**Allocated to crude palm oil**
FFB	kg	0.16	0.12	Crude palm oil	g	27.07	27.07
Steam (Renewable)	MJ	0.04	0.03	Empty Fruit Bunches	g	29.56	22.17
Electricity (Renewable)	MJ	0.00096	0.00072	Fibre	g	17.08	12.81
Fibre & Shell, CHP plant	MJ	0.20	0.15	Shells	g	9.17	6.88
Water	kg	3.4	2.6	Palm Kernels	g	6.97	0
				Palm Oil Mill Effluent (POME)	g	68.81	51.61
				CO_2 (biol.) from processing	g CO_2e	26.27	19.70
				CO	g	0.09	0.07
				NO_x	g	0.04	0.03
				SO_x	g	0.00032	0.00024
				Ash	g	8.93	6.70
				CH_4 from POME	g CO_2e	26.36	19.77

Table A.3-5. *Summary of rapeseed plant cultivation per 1000 kg biofuel*

Rapeseed plant cultivation inputs	**Unit per 1000 kg biofuel**	**Not allocated**	**Allocated to rapeseed oil**	**Rapeseed plant cultivation outputs**	**Unit per 1000 kg biofuel**	**Not allocated**	**Allocated to rapeseed oil**
Nitrogen fertilizer	kg nutrient	143.4	62.1	Rapeseeds	4980	4980	2823
Phosphorus fertilizer (P_2O_5)	kg nutrient	39.8	17.3	CO_2 from Nitrogen fertilizer use	kg CO_2e	975.1	422.2
K fertiliser (K_2O)	kg nutrient	61.4	26.6	N_2O from Nitrogen fertilizer use	kg CO_2e	883.8	382.7
Lime ($CaCO_3$)	kg nutrient	17.7	7.7	CO_2 from Phosphorus fertilizer use	kg CO_2e	64.5	27.9
Pesticides	kg	0.3	0.1	CO_2 from K fertilizer use	kg CO_2e	49.1	21.3
Harvest and collection	MJ	2706	1172	CO_2 from Lime use	kg CO_2e	9.9	4.3
Fuel for heating in drying	MJ	3961	1715	CO_2 from pesticide use	kg CO_2e	4.5	2.0
Use of electricity in drying	MJ	263	114	CO_2 from Harvest and collection machinery	kg CO_2e	194.7	84.3
Fuel consumption for transport from field to mill	MJ	557	241	CO_2 from Fuel for heating in drying	kg CO_2e	320.9	138.9
				CO_2 from Use of electricity in drying	kg CO_2e	31.9	13.8
				CO_2 from Fuel consumption of transport from field to mill	kg CO_2e	48.2	20.9
				Straw	kg	149.4	64.7
				Ammonia to air	kg NH_3	8.1	3.5
				N_2O to air	kg N_2O	4.2	1.8
				NO to air	kg NO	2.5	1.1
				SO_2 to air	kg SO_2	3.9	1.7
				Nitrate to water	kg NO_3	137.9	59.4
				Phosphorus to leaching	kg P	0.1	0.05

***Table A.3-6**. Summary of rapeseed plant cultivation per MJ biofuel*

Rapeseed plant cultivation inputs	Unit per MJ biofuel	Not allo-cated	Allocated to rape-seed oil	Rapeseed plant cultivation outputs	Unit per MJ biofuel	Not allocated	Allo-cated to rape-seed oil by metho-dology	Allo-cated to rape-seed oil by mass
Nitrogen fertilizer	g nutrient	3.26	1.41	Rapeseeds	kg	0.11	0.11	0.06
Phosphorus fertilizer (P_2O_5)	g nutrient	0.91	0.39	CO_2 from Nitrogen fertilizer use	g CO_2e	22.16	22.16	9.60
K fertiliser (K_2O)	g nutrient	1.40	0.60	N_2O from Nitrogen fertilizer use	g CO_2e	20.09	20.09	8.70
Lime ($CaCO_3$)	g nutrient	0.40	0.60	CO_2 from Phosphorus fertilizer use	g CO_2e	1.47	1.47	0.64
Pesticides	g	0.01	0.003	CO_2 from K fertilizer use	g CO_2e	1.12	1.12	0.48
Harvest and collection	MJ	0.06	0.03	CO_2 from Lime use	g CO_2e	0.23	0.23	0.10
Fuel for heating in drying	MJ	0.09	0.04	CO_2 from pesticide use	g CO_2e	0.10	0.10	0.04
Use of electricity in drying	MJ	0.006	0.003	CO_2 from Harvest and collection machinery	g CO_2e	4.42	4.42	1.92
Fuel consumption for transport from field to mill	MJ	0.013	0.005	CO_2 from Fuel for heating in drying	g CO_2e	7.29	7.29	3.16
				CO_2 from Use of electricity in drying	g CO_2e	0.72	0.72	0.31
				CO_2 from Fuel consump-tion of transport from field to mill	g CO_2e	1.09	1.09	0.47
				Straw	g	3.4	1.47	1.47
				Ammonia to air	g NH_3	0.18	0.08	0.08
				N_2O to air	g N_2O	0.09	0.04	0.04
				NO to air	g NO	0.06	0.02	0.02
				SO_2 to air	g SO_2	0.09	0.04	0.04
				Nitrate to water	g NO_3	3.14	1.36	1.36
				Phosphorus to leaching	g P	0.0027	0.0012	0.0012

***Table A.3-7**. Summary of rapeseed processing per 1000 kg biofuel*

Rape-seed oil proces-sing inputs	Unit per 1000 kg biofuel	Not allo-cated	Allo-cated to rape-seed oil	Rapeseed oil proces-sing outputs	Unit per 1000 kg biofuel	Not allo-cated	Allocated to rapeseed oil according to metho-dology	Allo-cated to rape-seed oil by mass
Elec-tricity	MJ	409	177	Rapeseed oil	kg	1214	1214	1214
Natural gas	MJ	2410	1044	Rapeseed meal - sold as animal feed	kg	1603	0	0
				Residual	kg	12	5.6	5.6
				Water	kg	85	37	37
				Waste water	kg	69	30	30
				COD	kg	0.3	0.1	0.1
				Solid waste	kg	12	5.6	5.6
				CO_2 from use of natural gas in processing of oil	kg CO_2e	149.4	149.4	64.7
				CO2 from use of electricity in processing of oil	kg CO_2e	49.7	49.7	21.5
				CO_2 reduction from Rapeseed meal - sold as animal feed	kg CO_2e	reduc-tion 273 kg CO_2e per 1000 kg rape-seed meal	-437.5	

***Table A.3-8**. Summary of rapeseed processing per MJ biofuel*

Rape-seed oil proces-sing inputs	Unit per MJ biofuel	Not allo-cated	Allo-cated to rape-seed oil	Rapeseed oil proces-sing outputs	Unit per MJ biofuel	Not allo-cated	Allocated to rapeseed oil according to metho-dology	Allo-cated to rape-seed oil by mass
Elec-tricity	MJ	0.009	0.004	Rapeseed oil	g	27.59	27.59	27.59
Natural gas	MJ	0.055	0.024	Rapeseed meal - sold as animal feed	g	36.42	0	0
				Residual	g	0.28	0.12	0.12
				Water	g	1.94	0.84	0.84
				Waste water	g	1.57	0.68	0.68
				COD	g	0.01	0.002	0.002
				Solid waste	g	0.28	0.12	0.12
				CO_2 from use of natural gas in processing of oil	g CO_2e	3.4	3.4	1.47
				CO2 from use of electricity in processing of oil	g CO_2e	1.13	1.13	0.49
				CO_2 reduction from Rapeseed meal - sold as animal feed	g CO_2e	reduction 273 kg CO_2e per 1000 kg rapeseed meal	-9.94	0

Table A.3-9. *Summary of animal fat processing per 1000 kg biofuel*

Animal waste processing inputs	**Unit per 1000 kg biofuel**	**Not allocated**	**Allocated to animal fat**	**Animal waste processing outputs**	**Unit per 1000 kg biofuel**	**Not allocated**	**Allocated to animal fat**
Animal parts (TSE cat 1)	kg	3973	668	Feed meal	kg	3929	0
Parts of slaughter animals (cat 2)	kg	9933	1669	TSE-chips	kg	2907	0
Dead production animals	kg	1987	334	TSE-fat	kg	706	0
Steam	MJ	3366	565	Animal fat	kg	1214	1214
Energy for waste water treatment	MJ	105	18	District heat	MJ	6754	1135
Water	kg	7902	1328	NH_3	kg	0.2	0.04
Heavy fuel oil	MJ	20890	3510	VOC	kg	0.8	0.1
TSE-fat as a fuel	MJ	29196	4401	H_2S	kg	0.02	0.003
				SO_2	kg	26.3	4.4
				NO_x	kg	15.4	2.6
				CO_2	kg	2647	415
				PM	kg	1.3	0.2
				Solid waste	kg	205	34
				Hazardous waste	kg	0.5	0.08
				Recycled waste	kg	9.3	1.6
				Waste water	m^3	14001	2352
				Ammonium	kg	1.4	0.2
				Sludge	m^3	0.05	0.01

***Table A.3-10**. Summary of animal fat processing per MJ biofuel*

Animal waste processing inputs	**Unit per MJ biofuel**	**Not allocated**	**Allocated to animal fat**	**Animal waste processing outputs**	**Unit per MJ biofuel**	**Not allocated**	**Allocated to animal fat**
Animal parts (TSE cat 1)	g	90.30	15.17	Feed meal	g	89.30	0
Parts of slaughter animals (cat 2)	g	225.76	37.93	TSE-chips	g	47.66	0
Dead production animals	g	45.15	7.59	TSE-fat	g	16.05	0
Steam	MJ	0.077	0.013	Animal fat	g	27.59	27.59
Energy for waste water treatment	MJ	0.0024	0.0004	District heat	MJ	0.15	0.03
Water	g	179.6	30.17	NH_3	g	0.01	0.001
Heavy fuel oil	MJ	474.78	79.76	VOC	g	0.02	0.003
TSE-fat as a fuel	MJ	0.595	0.100	H_2S	g	0.0005	0.0001
				SO_2	g	0.60	0.01
				NO_x	g	0.35	0.06
				CO_2	g	56.08	9.42
				PM	g	0.03	0.005
				Solid waste	g	4.65	0.78
				Hazardous waste	g	0.01	0.002
				Recycled waste	g	0.21	0.04
				Waste water	m^3	0.32	0.05
				Ammonium	g	0.03	0.005
				Sludge	m^3	0.001	0.0002

***Table A.3-11**. Energy use and emissions from raw material transport per 1000 kg biofuel.*

Raw material type	**Unit per MJ biofuel**	**Palm oil**	**Rapeseed oil**	**Animal fats**
Transport distance	km	total sea 17 300	sea 1450 road 10 sea 277	road 322
Energy use	MJ	4 288	77	383
Emissions from raw material transport per 1000 kg biofuel				
CH_4 as kg CO_2e	kg	0.23	0.02	0.01
CO	kg	0.24	0.03	0.01
CO_2	kg	104	15	28
NO_x	kg	2.36	0.35	0.3
N_2O as a kg CO_2e	kg	0.8	0.1	0.2
SO_x	kg	1.05	0.14	0.0003

***Table A.3-12**. Energy use and emissions from raw material transport per MJ biofuel.*

Raw material type	**Unit per MJ biofuel**	**Palm oil**	**Rapeseed oil**	**Animal fats**
Transport distance	km	total sea 17 300	sea 1450 road 10 sea 277	road 322
Energy use	MJ	0.097	0.002	0.009
Emissions from raw material transport per MJ biofuel				
CH_4 as kg CO_2e	g	0.005	0.0004	0.0002
CO	g	0.006	0.0006	0.0002
CO_2	g	2.364	0.333	0.639
NO_x	g	0.054	0.008	0.007
N_2O as a kg CO_2e	g	0.018	0.002	0.005
SO_x	g	0.024	0.003	0.00000001

Table A.3-13. Summary of pretreatment per 1000 kg biofuel

Inputs of pretreatment process	Unit per 1000 kg biofuel	Not allocated	Outputs of pretreatment process	Unit per 1000 kg biofuel	Not allocated
Raw material need	kg	1 214	Pretreated oil	kg	1 191
Cooling water	kg	70	Dried solid waste	kg	13
Electricity	MJ	50	Waste water	kg	111
Process chemicals	kg	3	CO_2e from production of electricity (indirect)	kg	3
Process water	kg	28	CO_2e from production of steam (indirect)	kg	40
Steam	MJ	657			

Table A.3-14. Summary of pretreatment per MJ biofuel

Inputs of pretreatment process	Unit per MJ biofuel	Not allocated	Outputs of pretreatment process	Unit per MJ biofuel	Not allocated
Raw material need	g	27.59	Pretreated oil	g	27.07
Cooling water	g	1.59	Dried solid waste	g	0.3
Electricity	MJ	0.0014	Waste water	g	2.52
Process chemicals	g	0.07	CO_2e from production of electricity (indirect)	g	0.05
Process water	g	0.64	CO_2e from production of steam (indirect)	g	0.69
Steam	MJ	0.015			

Table A.3-15. *Summary of hydrotreatment per 1000 kg biofuel*

Inputs of hydrotreatment process	**Unit per 1000 kg biofuel**	**Not allocated**	**Outputs of hydrotreatment process**	**Unit per 1000 kg biofuel**	**Not allocated**
Raw material need	kg	1 191	NExBTL	kg	1000
Hydrogen need	kg	42	Biogasoline	kg	25
Cooling water	kg	4	Propane	kg	72
Electricity	kg	107	Waste water	kg	113
Process water	kg	25	Biological CO_2 from process	kg	48
Steam	MJ	29	CO_2e from production of electricity (indirect)	kg	7
			CO_2e from production of steam (indirect)	kg	

Table A.3-16. Summary of hydrotreatment per MJ biofuel

Inputs of hydrotreatment process	**Unit per MJ biofuel**	**Not allocated**	**Outputs of hydrotreatmen t process**	**Unit per MJ biofuel**	**Not allocated**
Raw material need	g	27.07	NExBTL	g	22.73
Hydrogen need	g	0.95	Biogasoline	g	0.57
Cooling water	g	0.09	Propane	g	1.64
Electricity	MJ	0.0024	Waste water	g	2.57
Process water	g	0.57	Biological CO_2 from process	g	1.1
Steam	MJ	0.0007	CO_2e from production of electricity (indirect)	g	0.15
			CO_2e from production of steam (indirect)	g	0.04

Table A.3-17. Summary of hydrogen production per 1000 kg biofuel

Inputs of hydrogen production	Unit per 1000 kg biofuel	Not allo-cated	Allo-cated	Outputs of hydrogen production	Unit per 1000 kg biofuel	Not allo-cated	Allo-cated
Natural gas	MJ	2371	2371	Hydrogen	kg	42	42
Fuel gas	MJ	813	735	Steam 5 bar	MJ	35.5	35.5
Process water	kg	209	209	Steam 16 bar	MJ	86.8	86.8
Electricity	MJ	104	104	CO_2e from hydrogen production	kg CO_2e	371.2	180.7
				Energy lossess	MJ	322	325

***Table A.3-18**. Summary of hydrogen production per MJ biofuel*

Inputs of hydrogen production	Unit per MJ biofuel	Not allo-cated	Allo-cated	Outputs of hydrogen production	Unit per MJ biofuel	Not allo-cated	Allo-cated
Natural gas	MJ	0.054	0.054	Hydrogen	g	0.96	0.96
Fuel gas	MJ	0.018	-0.0018	Steam 5 bar	MJ	0.0008	0.0008
Process water	g	4.7	4.7	Steam 16 bar	MJ	0.002	0.002
Electricity	MJ	0.002	0.002	CO_2e from hydrogen production	g CO_2e	8.4	4.1
				Energy lossess	MJ	0.007	0.007

***Table A.3-19**. Energy use and emissions from biofuel product transport per 1000 kg biofuel.*

Product transport	**Unit per 1000 kg biofuel**	
Energy use	MJ	392
Emissions from product transport		
CO	kg	0.01
CO_2	kg	28.8
CH_4 as a t CO_2e	kg	0.01
N_2O as a t CO_2e	kg	0.24
NO_x	kg	0.31
SO_x	kg	0.0003

***Table A.3-20**. Energy use and emissions from biofuel product transport per MJ biofuel.*

Product transport	**Unit per MJ biofuel**	
Energy use	MJ	0.009
Emissions from product transport		
CO	g	0.0002
CO_2	g	0.65
CH_4 as a t CO_2e	g	0.0002
N_2O as a t CO_2e	g	0.005
NO_x	g	0.007
SO_x	g	0.00001

Appendix 4. A critical review of the study by external experts

GREENHOUSE GAS AND ENERGY INTENSITY OF PRODUCT CHAIN: CASE TRANSPORT BIOFUEL

Master Thesis by Sami Nikander
Version 2008-03-25 (DRAFT FOR LANGUAGE CONSULTATION)

1. NATURE AND OBJECTIVES OF THE REVIEW

We were invited to review this LCA study. The points we have raised in the following are based on our knowledge and experience on the life-cycle assessment methodology, and its application on many different product chains, including biological products and materials. This is our personal review as LCA experts, and it is not an official review of Agrifood Research Finland (MTT).

Our objective is to evaluate key aspects of LCA, as stated in LCA standards (ISO 14040 standard). These include that the methods used to carry out the LCA are consistent with the standard, and scientifically and technically valid, the data used are appropriate and reasonable with respect to the goal of the study, the interpretations reflect the goal of the study and the limitations identified, and that the study report is transparent and consistent. We will evaluate these aspects of this study following the phases of an LCA, based on the presentation given by the author, Sami Nikander in a meeting in Porvoo, the draft report version mentioned above, as well as inventory data and calculations supplied to us.

As an overall impression, we consider this study a fairly good LCA, even though limited, with important results for all the stakeholders.

2.1 Goal and scope definition

The goal of the study has been to characterize environmental sustainability of transport biofuels by using life cycle assessment method. The study is limited, however, on the climate change issue, and hence, fails to reach this goal in the broader perspective of the environmental sustainability. Development of the framework for conducting LCA studies in chemical industry, and improving reporting and communication of the results were defined as an additional goals. According to our understanding, this goal has also been reached in this study.

Functional unit of the study has been defined as 1 MJ of lower heating value, which is a relevant base for comparisons of the different system options, assuming that the inputs and the outputs of the use phase do not depend on the system. The scope of the study has been limited to specific NExBTL product chains all including the assumption that the production takes place in Porvoo, Finland, and that the raw materials are produced on existing fields at specific locations and circumstances. This limitation leaves out e.g. new production sites for the product and the raw materials for the global market in the future.

System boundaries of the studied systems are well defined in the report. Also, all system options are treated fairly equally from this perspective. Some minor sub-systems (e.g. process chemicals and catalysts) have been excluded from the systems based on the cut-off criteria, which is clearly reported and justified in the report. Energy consumption of fertilizer production is excluded from the palm oil and rape seed oil systems. This could have had a major effect on the specific energy figures reported (Figure 21 and Table 28), and should be checked.

All of the studied biofuel systems leave out the use-phase of the product. This decision seems justified, because, as reported, the quality of the product does not essentially vary between the studied systems, and does not essentially differ from the fossil-based alternatives either. Thus this limitation does not lead to any major uncertainties in the results. Naturally, information about the use would increase the understanding about the entire life cycle of the fuels.

2.2 Inventory analysis

The form of presenting the inventory results is very illustrative. The figures immediately give the reader a clear picture about the differences of the results between the studied and the reference systems.

2.2.1 Data collection, quality and calculations

According to our understanding the basic data for the systems seem to be fairly correct for the selected configurations of the systems. Yet, uncertainty related to the data of raw materials, i.e. palm oil and rape seed oil, could be more addressed in the report. Hectare yields of both vary considerably. The effects of land transformation on carbon balances may enter the equation, and should be addressed as an uncertainty factor. Uncertainty could be assessed e.g. by sensitivity analysis.

2.2.2 Allocation and crediting

Procedures for allocation of total environmental loads to simultaneous products, e.g. crude palm oil and palm kernels from oil palms, and crediting for substitutions by side products, e.g. rapeseed meal by rapeseed oil production are well described in the report.

In raw material sub-systems allocations are based on masses. They are well justified, and in accordance with the LCA standard. The palm oil sub-system, as well as the animal waste sub-system include no crediting. In the rapeseed oil sub-system a credit was calculated for the rapeseed meal using a specific credit factor issued by RFTO. Whether there were also additional allocations done in this sub-system, appears not quite clear from the report. Allocation and crediting are usually exclusive alternatives for treating simultaneous products, i.e. if allocation then no crediting and vice versa.

The allocation done for the propane gas amount formed in NExBTL conversion and used as a fuel gas in hydrogen conversion process, is justified as a closed-loop recovery solution (chpt. "Allocations done in hydrogen conversion process"). Because of a reference to credits (chpt. "Allocations done in conversion process"), however, it remains unclear, whether additional credits were taken into account.

2.3 Impact assessment

Impact assessment includes the climate change and energy consumption. According to our judgement, the impact categories included in the study are very relevant for these product systems. However, the choice and the setting of priorities to impact categories is a controversial issue, where no one right solution exist. Impact categories excluded include e.g. land use, biodiversity, human health, and eco-toxicology. When interpreting the results, the choice of the impact categories should also be kept in mind.

2.4 Interpretation

The interpretation of the results sticks well to the climate change and energy aspects, and the results of the assessment. Uncertainty aspect and limitations to the applicability of the results stemming from the specific scope of study could be more brought up. According to our understanding this study and its results can potentially offer important input for many interest groups. There are possible applications of the results for industry, trade, consumers, and governments. Industrial companies and trade have the power to control e.g. farming, and hence the key factor of climate change impacts of the entire life cycle of the biofuels. The consumers are able to better consider the effects of their choices and to vote with money when they are made aware of the potential climate change impacts of their consumption decisions. Legislative bodies are able to control various details of the biofuel systems, and financial authorities have the opportunity to guide the development of biofuel chains and decisions of consumers with targeted instruments.

14.4.2008

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