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Institute for Energy and  
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Heidelberg GmbH



## **Final Report**

# **An Assessment of Energy and Greenhouse Gases of NExBTL**

**By order of the  
Neste Oil Corporation,  
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## **NExBTL:**

Neste Oil of Finland has developed a proprietary technology capable for producing a high-quality diesel fuel from animal fats and vegetable oils. The process is called NExBTL (Next Generation Biomass to Liquid). Engine and emission testing results has shown that NExBTL has superior properties over current diesel products or alternative renewable fuels.

A 100 million euro, 170 000 tonne/year plant is currently under construction at the Neste Oil Porvoo refinery with start-up scheduled to begin in the 2nd quarter of 2007.

The NExBTL process is a catalytic hydrotreating process that is integrated into the Porvoo refinery. It utilises the refinery's existing infrastructure and utilities including hydrogen, steam, electricity, personnel, blending tanks, waste facilities, harbour etc. Feedstocks are received at the harbour or by surface transport and stored in holding tanks before being transferred to the pretreatment unit where, using conventional degumming technology, impurities are removed. From here the feed is heated and pumped into the hydrotreating reactors. In the reactors, oxygen is removed and the feed (triglyceride) is converted into three separate branched chain paraffins. Side products of the process are fuel gas which is used for energy and a small amount of biogasoline. Oxygen in the triglyceride is removed as water and carbon dioxide.

The resultant NExBTL product can either be used as a pure diesel fuel or mixed with diesel to be used as a fuel component. The NExBTL product is a pure hydrocarbon product which meets EN590 diesel specifications except for density which is  $\gg 780 \text{ kg/m}^3$ . It is free of aromatics, sulphur and oxygen. It has good stability (no unsaturated material). It has a low cloud point which can be adjusted from - 5 to - 28°C by severity of process conditions in order to produce either summer or winter diesel. The renewability of NExBTL can be verified by radioactive C14 analysis.

*A contribution by the Neste Oil Corporation (/NESTE 2006/)*

## Executive summary

The Neste Oil Corporation has developed a technology to produce a diesel-like fuel (NExBTL) from animal fats and plant oils. The IFEU-Institute for Energy and Environmental Research Heidelberg, Germany, has been commissioned by Neste to undertake an evaluation of the energy and greenhouse gas balance of NExBTL.

A comparative analysis has been undertaken which uses the methodology of the life-cycle assessment standard ISO 14040-43 and allows to identify the parameters most relevant for the results. The production of NExBTL from rapeseed and palm oil has been analysed including all materials and processes for the provisions of plant oils and their processing in the NExBTL process. Furthermore, all by-products have been considered as credits for substituting equivalent products. This life-cycle has finally been compared to the life-cycle of conventional diesel fuel. Besides a scenario for the site in Porvoo, Finland, also a scenario for a typical European site has been analysed.

- **Result 1**

**The results show a clear, but quantitatively different advantage in the energy and greenhouse gas balance if NExBTL substitutes conventional diesel fuel.**

That means that the use of NExBTL saves primary energy and greenhouse gas emissions over the entire life-cycle in comparison with diesel fuel from fossil energy carriers for all comparisons, scenarios and sensitivity analyses considered in this study.

- **Result 2**

**The quantitative results mainly depend on the provision of crude plant oil for the process and not very much on the NExBTL-process itself.**

That means that all variations in the NExBTL-process, e.g. different provision of required hydrogen or the use of by-products such as fuel gas, bio-gasoline and sludge have a much lower influence on the overall result than the provision of plant oils. Thus it has to be distinguished between the production of NExBTL from rapeseed oil and palm oil.

### *NExBTL-production from rapeseed oil*

As has been described under Result 1, NExBTL shows a clear advantage over conventional diesel fuel. Differences in the results mainly depend on where the rapeseed is grown (Europe or overseas) and on the alternative land use if rapeseed would not be grown (natural or set-aside land). The results for rapeseed from overseas are on the upper limit of the bandwidth due to the longer transportation distance. The results over all considered scenarios show the following bandwidths of savings:

<i>Energy savings:</i>	<i>30 - 33 GJ primary energy per t of NExBTL</i>
<i>Greenhouse gas savings:</i>	<i>1.2 - 2.5 t CO<sub>2</sub>-equivalents per t of NExBTL</i>

### *NExBTL-production from palm oil*

The results for NExBTL from palm oil mainly depend on the alternative land use on the plantation if no palm oil would be produced:

- Case A: If the area would not be used and thus stayed untouched (natural forest), NExBTL, as for rapeseed oil, has a clear advantage over conventional diesel fuel. The production in the Porvoo plant, for which Malaysian palm oil will be used, leads to the following savings:

*Energy savings: 44 GJ primary energy per t of NExBTL*

*Greenhouse gas savings: 1.4 t CO<sub>2</sub>-Equivalents per t of NExBTL*

- Case B: If another plantation would occupy the area of the palm oil plantation, the results show a considerable difference between the two alternative plantation land uses investigated in this study: food oil and coconut plantations. For average Malaysian palm oil, energy savings are about 33 GJ for food oil and 16 GJ for coconut plantations. Greenhouse gas savings are about 2.2 t and 1 t of CO<sub>2</sub>-Equivalents, respectively.

Besides the different land use alternatives, the results also depend on the technology and infrastructure used for production and processing of palm oil. This especially applies to the results for greenhouse gas emissions. Compared to typical palm oil (world market), average Malaysian palm oil results in about 15% higher greenhouse gas savings for NExBTL. Good practice palm oil even results in about 65% higher savings compared to typical practice palm oil.

- **Result 3**

**Differences in the life-cycle results between the Porvoo site and a typical European site are marginal.**

Since the results mainly depend on the provision of feedstock, the site-specific differences only marginally affect the overall results. These differences may only become relevant under entirely different boundary conditions for the provision of electricity and natural gas or with a very different transportation distance.

### **Limitations**

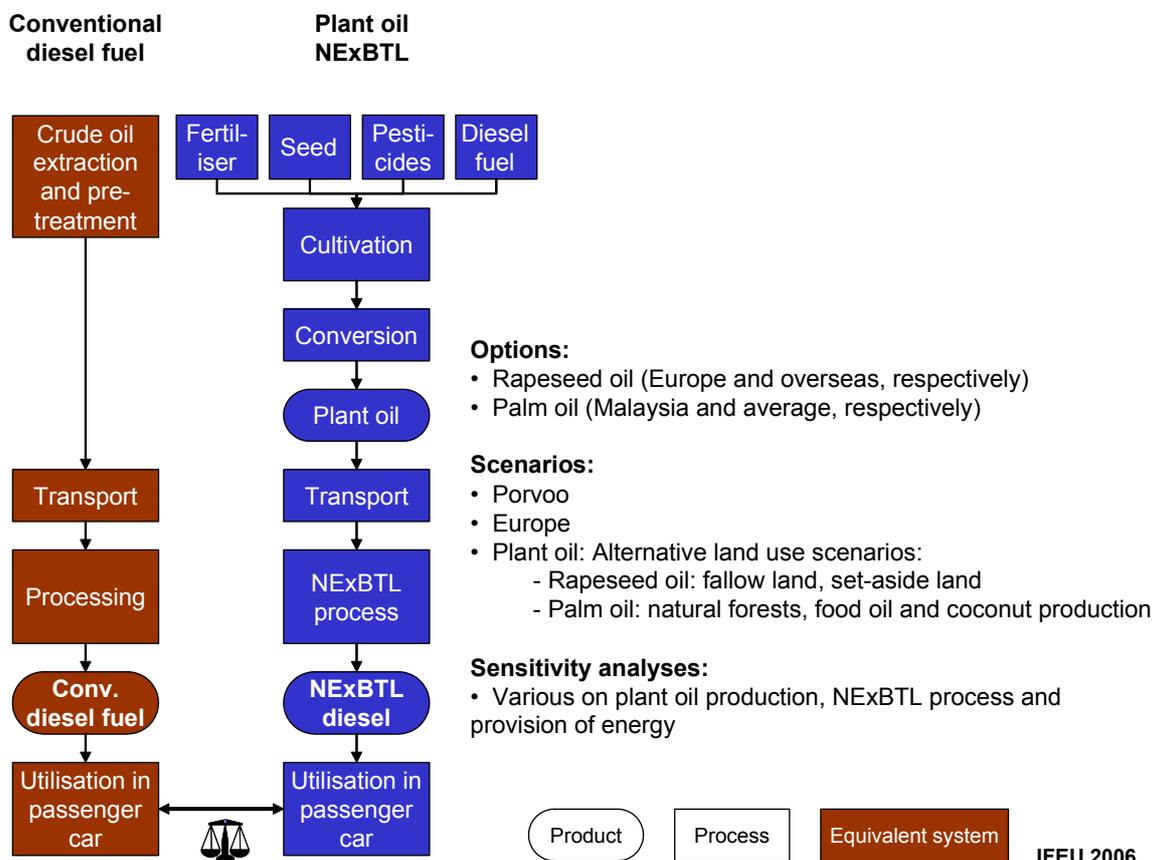
The results of this study can be regarded as very robust for the considered boundary conditions. However, the results show that they can not be directly transferred to other feedstocks such as other plant oils, animal fats or used food oils. The same applies if other than the investigated plantations for food oil and coconut production would occupy the area of the palm oil plantation. Furthermore, from other LCAs for bio-fuels it can be concluded by analogy, that the results can not be transferred to other environmental impacts acidification and eutrophication. Additionally, the question of biodiversity arises if tropical rain forest has to be cut for the production of palm oil. This might be important since this scenario shows the best results for savings of energy and greenhouse gases.

# 1 Background and objective

In recent years, the search for alternatives to the use of oil-based fossil fuels in the transport sector has become more important. Especially the use of fuels which are based on bio-mass, such as bio-ethanol, bio-diesel and BTL (Biomass-to-Liquid) has become a focus of political, public and scientific attention. The “Neste Oil Corporation” has developed a new process for the production of a BTL fuel called “NExBTL” which is the focus of this study.

For a first evaluation of the environmental impacts associated with the production of NExBTL compared to conventional diesel fuel, the Institute for Energy and Environmental Research (IFEU) Heidelberg has undertaken this study. This assessment covers energy consumption and greenhouse gas emissions. With this, it allows an identification and analysis of the most important parameters and, based on sensitivity analyses, a conclusive interpretation. For a comprehensive evaluation of all major environmental impacts, the study can subsequently be expanded into a full LCA.

As different feedstock options, rapeseed oil and palm oil are considered. The more detailed scope of this study as requested by Neste is summarised under options and scenarios (see chart below). For the comparison of NExBTL with conventional diesel fuel, the investigation first examines the provision of rapeseed (chapter 3.1) and palm oil (chapter 3.2), the NExBTL process itself (chapter 3.3) and the whole NExBTL production chain (chapter 3.4). Based on these basic processes, the results for a life-cycle comparison of NExBTL and conventional diesel fuel – as shown in the chart below – are finally presented in chapter 4.



## 2 Approach and definitions

### Methodical approach

The system boundaries of the life cycle comparisons considered in the current study have been chosen using the methodology of the life cycle assessment standard /ISO 14040-43/. The system boundaries, boundary conditions, and procedures are documented in /BORKEN ET AL. 1999/ as well as in /REINHARDT ET AL. 1999/. The latest available reference years have been used. All extensions necessary for the calculations to be conducted have been adjusted to the respective procedures and system boundaries.

For both options, NExBTL production with rapeseed oil and with palm oil, a number of scenarios on land use issues according to the LCA methodology have been assessed (for methodological background see /JUNGK AND REINHARDT 2000/). Furthermore, two scenarios are distinguished: The plant currently being built in **Porvoo**, Finland, and a plant under average **European** conditions. The most important parameters and system boundaries of these two scenarios are:

- **Porvoo:** For this scenario, the actual electricity split in Finland and natural gas from Russia are used for the NExBTL process. Rapeseed provision from the EU and overseas is considered. For the provision of palm oil, exclusive supply contracts with Malaysia are assumed and respective data used. All feedstock is transported to Porvoo, Finland.
- **Europe:** For this scenario, the average European electricity split (UCTE) and an average European split of natural gas is used for the NExBTL process. Palm oil is assumed to be purchased on the international market from various countries. In addition to typical practice also a good practice option is considered. For rapeseed oil, the same scenarios as for Porvoo are looked at. All feedstock is transported to central Europe.

Further scenarios and sensitivity analysis have been taken into account. They are listed in the respective sections (chapter 3.1 to 3.4). The main differences of the two main scenarios are listed in the following table:

<b>Porvoo scenario</b>	<b>European scenario</b>
Natural gas from Russia	Average European split of natural gas
Electricity split for Finland	Electricity split for Europe (UCTE)
Transport of feedstock to Porvoo	Transport of feedstock to Central Europe
Palm oil from Malaysia	Palm oil from world market (typical and good practice)

### Database used

All data on the NExBTL process in Porvoo have been supplied by the Neste Oil Corporation, Finland (/NESTE 2006/) and checked for plausibility by IFEU-Institute. For sensitivity analyses of the NExBTL process, IFEU assumptions and calculations have been used. For the European scenario, all necessary input data have been adapted to the average European situation by IFEU. The majority of basic data, including data for all processes before and after the NExBTL process and the European scenarios, are taken from the IFEU database (/IFEU 2006/) which considers recent research activities and is continuously updated. Concerning the provision of rapeseed oil, data from /GÄRTNER AND REINHARDT 2003/ are used

and have been updated for this project. For the provision of palm oil further updates have been made including those for coconut production. Important references for basic data are /FRANKE 1994/, /REHM AND ESPIG 1996/, /PCA 2006/, /OHLER 1999/, /PATEL ET AL. 1999/, /HIRSINGER 1999/, /HANSEN AND YUSOFF 2005/, /MUTERT AND FAIRHURST 1999/, /UNIFEI 2006/ and /MPOB 2006/.

### The environmental impacts analysed

Energy consumption and greenhouse gas emissions are analysed in this study as environmental impacts. Both categories are further described in the table below.

Environmental category	Description
Energy	The consumption of non-renewable energy carriers is considered, i.e. the non-renewable fossil fuels mineral oil, natural gas, and coal as well as uranium ore. In the following, this impact category is neutrally termed 'energy' and thus covers energy consumption as well as energy savings or credits. Energy is mostly expressed in Giga-Joule (GJ). The procedures and data for the calculation are documented in detail in /BORKEN ET AL. 1999/.
Greenhouse gases	Global warming as a consequence of the anthropogenic release of greenhouse gases is considered. The most important greenhouse gas is carbon dioxide (CO <sub>2</sub> ) due to the combustion of fossil energy carriers. Additionally, also emissions of methane (CH <sub>4</sub> ) and nitrous oxide (N <sub>2</sub> O) are considered. In order to allow for the presentation of greenhouse gases in one single value, carbon dioxide equivalents (CO <sub>2</sub> equiv.) are used with a weighting of 23 for CH <sub>4</sub> and 296 for N <sub>2</sub> O applied for 100 years (/IPCC 2002/). The procedures for the calculation are documented in detail in /BORKEN ET AL. 1999/.

### Results presentation

This report highlights the most important results of the assessment. The presented results have been selected in order to identify the parameters of significant influence on the overall results.

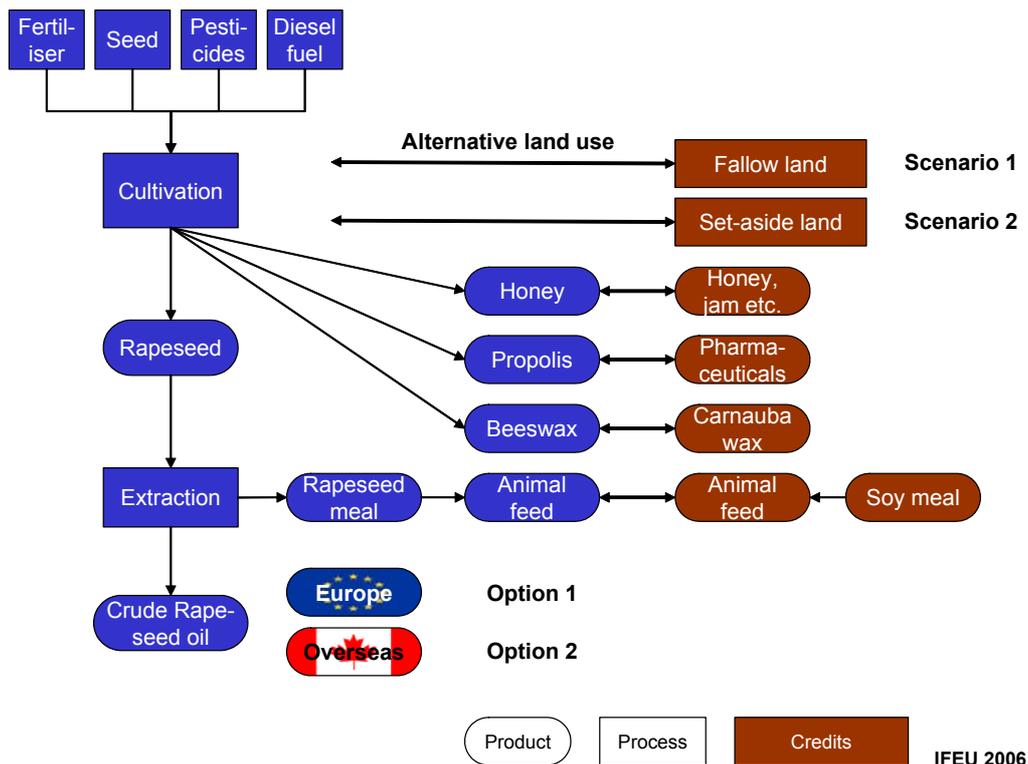
First, results will be presented for the individual basic systems. These results allow for a differentiated evaluation of feedstock provision and the NExBTL process with different sensitivities. Afterwards, the balance results for the entire NExBTL production chain are presented. The most important results are finally brought together for a life-cycle comparison of NExBTL with conventional diesel fuel.

All results will be presented in a concise diagram which is briefly discussed, presenting the most important findings. For the presentation and analysis, articulate terms were preferred to the abstract scientific terms.

### 3 Basic systems

#### 3.1 Provision of rapeseed oil

This analysis is based on scientific investigations comparing the ecological impact of rapeseed production which have been conducted by IFEU over the last few years (IFEU 2006/, for most basic data and the methodological approach see /GÄRTNER AND REINHARDT 2003/). These data have been adapted to the reference area selected and in relation to the alternative land use scenarios.



The life cycle of rapeseed production covers all processes from the provision of all agricultural inputs to the provision of crude rapeseed oil. It also includes all by-products as credits in relation to the provision of the equivalent function of each by-product.

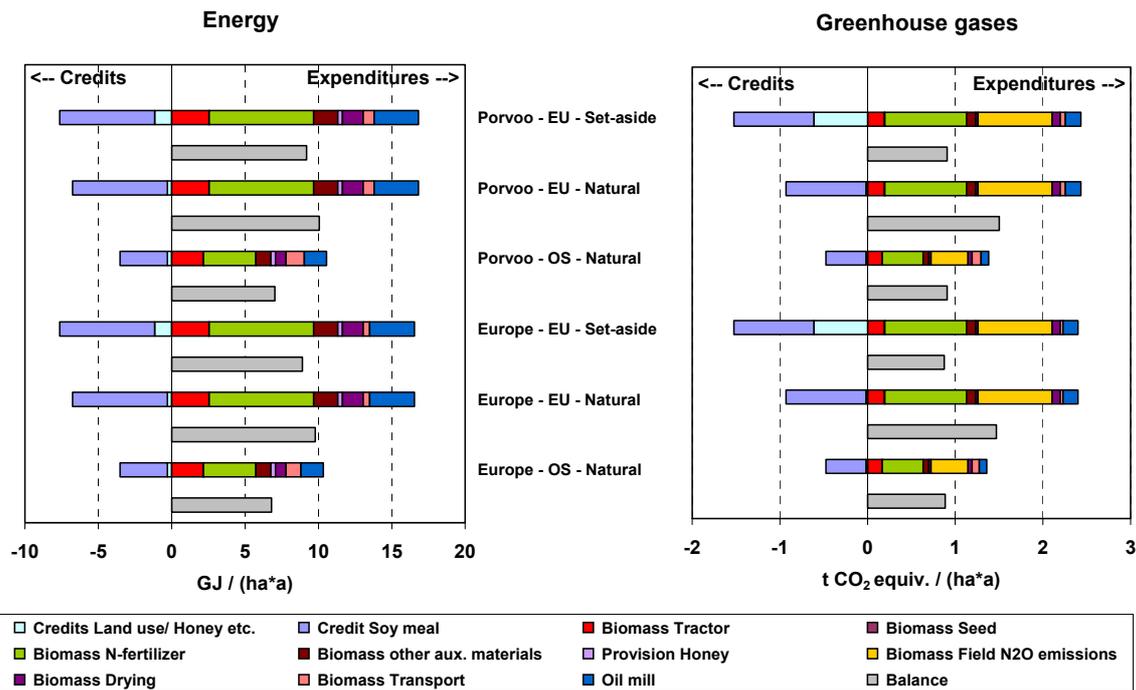
#### Agriculture:

In addition to rapeseed cultivation in Europe, feedstock provision from overseas has been chosen to discuss the impact of using plant oil from different production regions. Main differences for the supply of rapeseed from overseas are longer transportation distances and lower yields.

The production was calculated under average conditions in the reference area, based on the guidelines of good professional practice compared to an annual actively re-vegetated “set-aside” (Scenario 1) or “natural land” (Scenario 2). The harvest is done by direct thrashing; rapeseed straw is incorporated into the soil. Rapeseed is dried, cleaned and stored.

#### Processing:

Rapeseed is transported to the oil mill, pressed, and crude rapeseed oil is extracted. Rapeseed meal is a by-product of this process and is used as animal feed, substituting soy meal imported from North America.



**Example how to read the first result of the left diagram:**

The differentiated expenditures to produce rapeseed oil on set aside land are displayed to the right and sum up to about 17 GJ per ha whereas credits are displayed to the left and result in about 8 GJ per ha. The balance of about 9 GJ is displayed below the differentiated results.

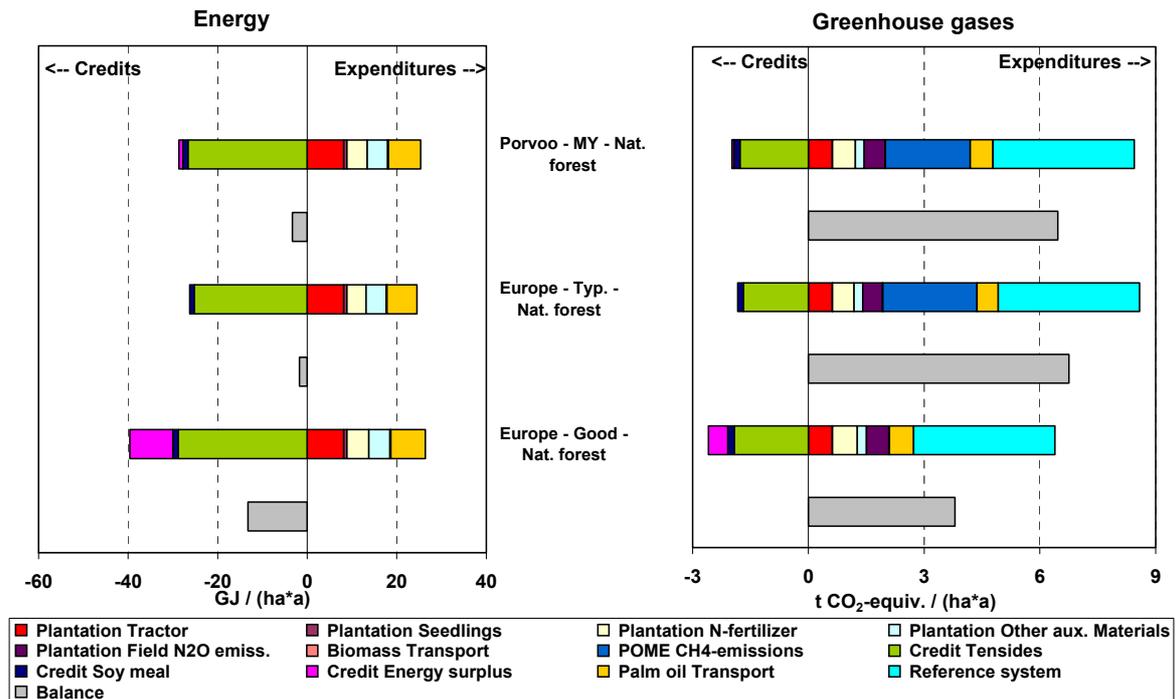
From the differentiated figures, the following can be concluded:

- Concerning energy consumption, only marginal differences occur between the Porvoo and European scenario and are due to different transportation distances.
- Supply of rapeseed from overseas (OS) leads to a lower energy consumption and greenhouse gas emissions per hectare despite a longer transportation distance (about 7 GJ instead of 10 GJ / ha). The reason is a significantly lower per hectare yield and thus less agricultural inputs, especially fertilisers.
- In one case, the results for greenhouse gases are not parallel to the results for energy: The greenhouse gas result for the set-aside scenario is about 30% lower than the result for the natural land scenario. This is due to a credit from N<sub>2</sub>O emissions on the set-aside land (for details see /GÄRTNER AND REINHARDT 2003/).
- The bandwidth of the results is comparatively small. Nevertheless, the following analyses distinguish the scenarios set-aside and natural land as well as EU and overseas.



- **Typical practice** is understood as palm oil production under average conditions without any biogas recovery and energy sell out.
- **Good practice** in contrast recovers the entire amount of biogas and sells out the surplus power which is produced from shells and fibres in the boiler.

The main assumptions for the different scenarios are summarised in the Annex. In order to demonstrate the influence of the different feedstock options, the results are exemplified below for the scenario that natural forest has been cut to set up an oil palm plantation (the other scenarios within the scope of this study are discussed on the next pages).



**Example how to read the first result of the left diagram:**

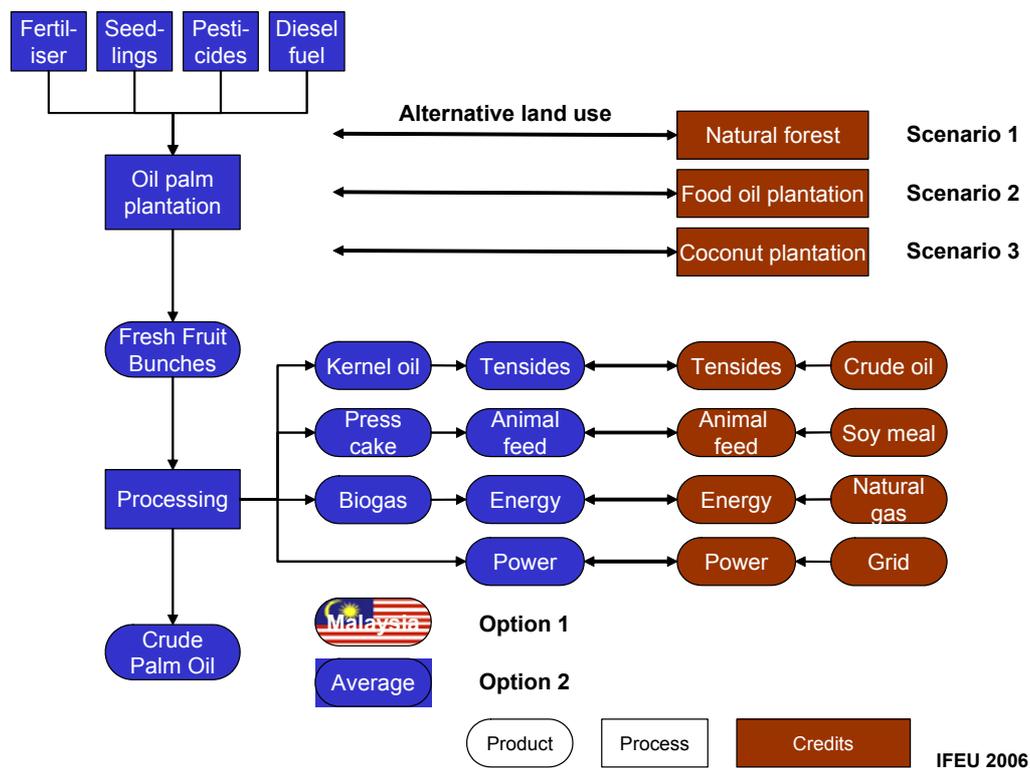
The differentiated expenditures to produce palm oil instead of leaving the area untouched (natural forest) are displayed to the right and sum up to about 25 GJ per ha in Malaysia whereas credits are displayed to the left and result in about 29 GJ per ha. The balance of about - 4 GJ is displayed below the differentiated results.

From the differentiated results, the following can be concluded:

- Balance results for energy and greenhouse gases are inverted which means that energy is saved while greenhouse gases are emitted. The net savings are due to the credits given for the by-products, especially kernel oil replacing fossil based tensides. The difference between the results for greenhouse gases and energy consumption is due to three expenditures which only occur for greenhouse gases: emission of laughing gas from the plantation due to bacterial activities (plantation field emissions), emissions of methane from palm oil mill effluent (POME) and the carbon storage capacity of natural forest as the reference system.
- While the results for Malaysian palm oil and typical practice palm oil are similar, the results improve significantly for good practice palm oil. The difference is mainly due to

the credits for biogas use (and thus lack of CH<sub>4</sub> emissions from the palm oil mill effluent (POME)) and credits for energy surplus.

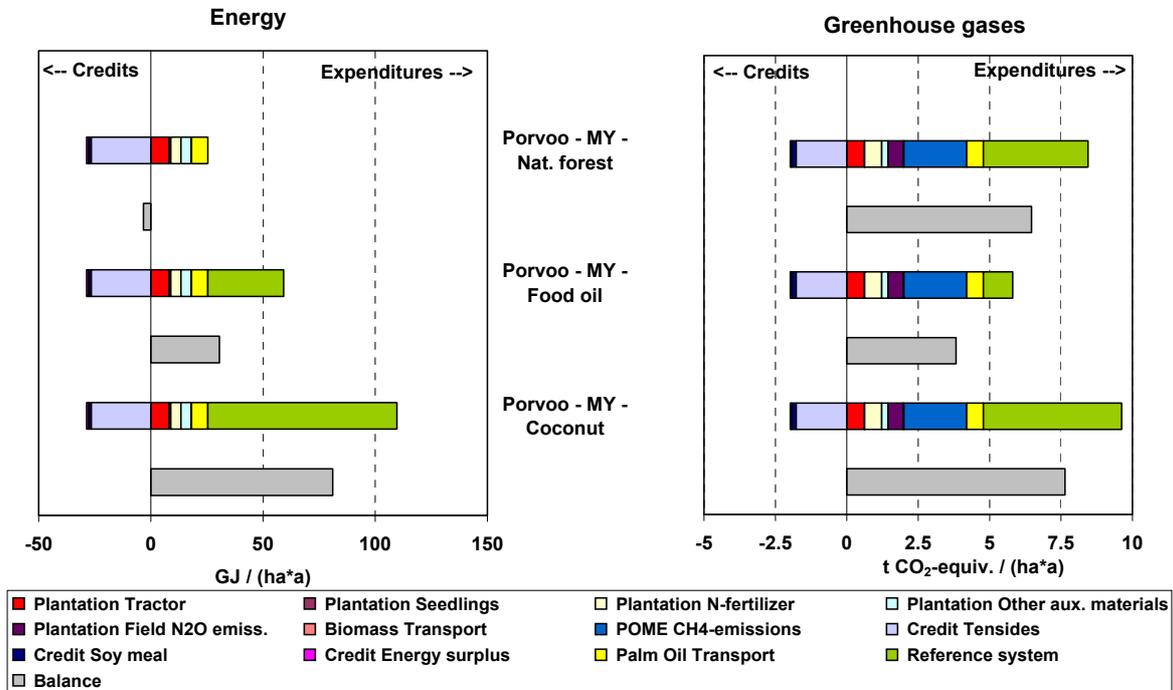
If energy crops are produced, a crucial question is: “What would the land be used for, if no energy crop is produced”. These alternative land uses are called “**agricultural reference systems**” and have to be included in the calculations (for more details on the methodological background see /Jungk & Reinhardt 2000/). Thus, the production of palm oil has to consider different alternative land uses such as the conversion to or conservation of untouched land as well as other plantations. In order to maintain the function of these land uses, it has to be taken into account, that the products from the alternative land use have to be substituted by equivalent products. This generally leads to additional expenditures which depend on the products of the alternative land use.



The following reference systems are considered within the scope of this study:

- **Natural forest:** “Growing palm oil instead of leaving the area as untouched natural forest”. Since natural forest has a higher carbon storage capacity than an oil palm plantation, this is considered as an additional expenditure.
- **Food oil:** “Growing palm oil for biofuel instead of food oil production”. In this case, the food oil must be produced somewhere else (if there is no need for the production of food oil, the other scenarios apply). It is assumed that food oil is produced from rapeseed, which is therefore an additional expenditure to palm oil. Also, additional land has to be occupied.
- **Coconut:** “Growing palm oil instead of a coconut plantation”. The coconut oil and cake is used for the production of tensides and animal feed, respectively. Again, their equivalents, synthetic tensides and soy meal, lead to additional expenditures to palm oil.

The following results cover all materials and processes for the provision of crude palm oil (CPO). All applicable by-products are considered as credits. Products of the references system are substituted in order to maintain the functional unit. The results are presented for the Porvoo case. Relative differences of the European scenarios have been discussed on the previous pages in this chapter.



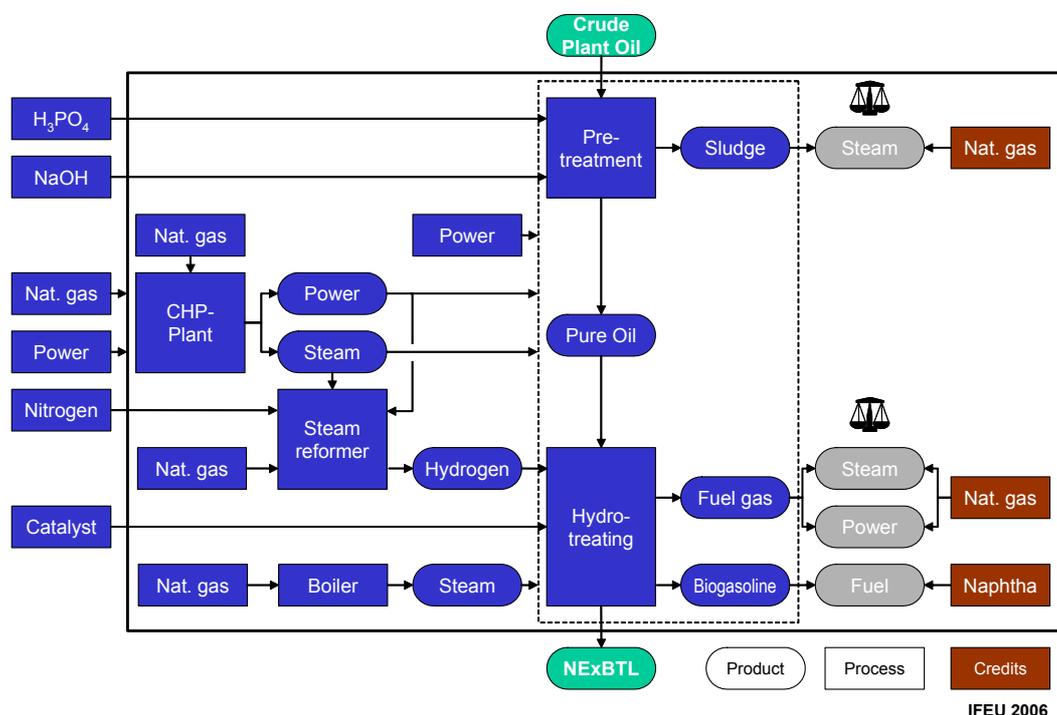
From the differentiated figures, the following can be concluded:

- Energy consumption and greenhouse gas emissions from the reference system significantly influence the balance results. The differences due to the reference system are much higher than the differences between the palm oil from Malaysia and from the world market.
- The comparison with natural forest leads to the best results and the comparison with a coconut plantation to the worst results for the provision of palm oil. This is due to differences in the useful function of the alternative land use. This function is considered as an expenditure to palm oil. One exemption is the result for greenhouse gas emissions in reference to natural forest and food oil production. They are about comparable as the carbon storage capacity of natural forest is by coincident roughly as high as the whole life cycle of the rape seed oil for food production.
- **To conclude: The reference system is the most important influence on the balance results for the provision of palm oil.**

### 3.3 NExBTL-Process

The processing of crude plant oil into NExBTL is analysed in this chapter. The main inputs are acid ( $H_3PO_4$ ), caustic (NaOH), natural gas, liquid nitrogen, power, and catalyst. The process comprises a pre-treatment and the main hydro-treating. There are three by-products: Sludge arises from pre-treatment (the amount of sludge is higher for rapeseed oil compared to palm oil). Fuel gas and biogasoline are important by-products of the hydro-treating process. All of them will be credited according to their useful function. As they can potentially be used in different parts of the process, different scenarios have been taken into account. In the **Porvoo** plant all fuel gas is used in the CHP-Plant, producing about the amount of energy required for the process.

**Chart:** Simplified schematic<sup>1</sup> flow chart for the **Porvoo** and **Europe (as Porvoo)** scenario

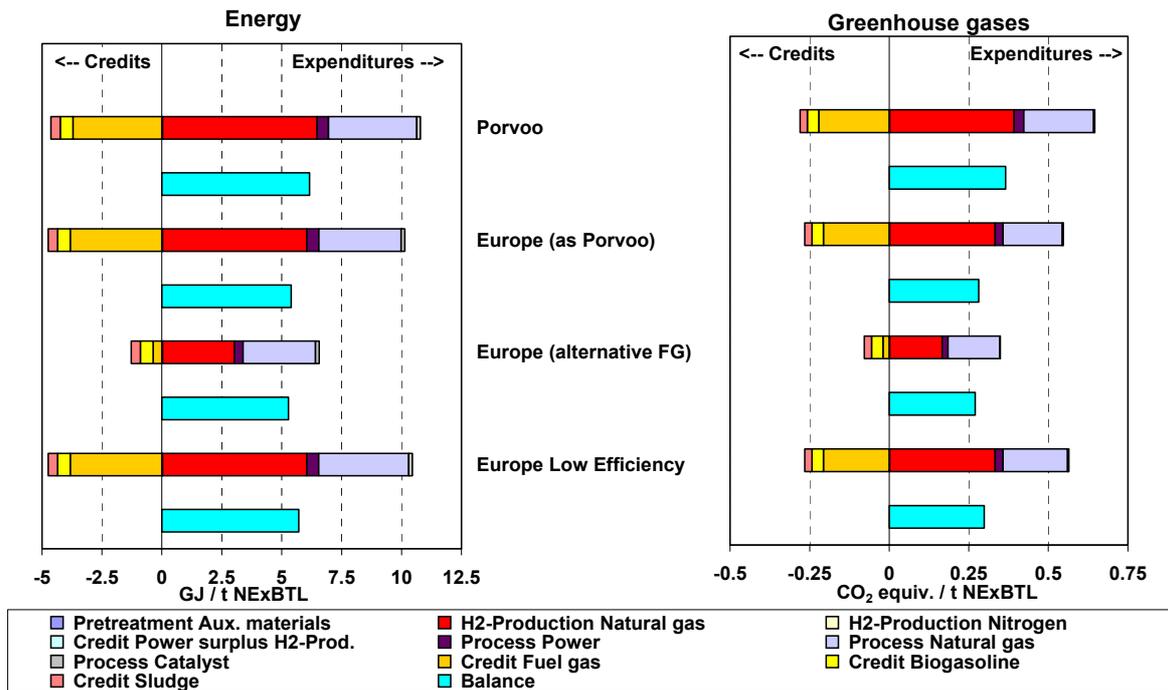


In order to assess the difference between the Porvoo scenario and a typical European scenario, the same conditions of using the fuel gas have been applied in the **Europe (as Porvoo)** scenario. Furthermore, two sensitivity analyses are presented in this chapter:

- In order to demonstrate the extreme limits of the results, a **Low Efficiency** scenario is considered for the Europe (as Porvoo) set up.
- To analyse an **alternative fuel gas (FG)** use within the process the entire fuel gas is assumed to be used in the steam reformer for hydrogen production.

Additional scenarios have been calculated taking into account different steam reformer types, different fossil fuels and feedstock inputs as well as different internal energy flows. The effect on the overall results is not significant. An additional example is documented in the Annex (Porvoo: equal power).

<sup>1</sup> For simplification, the chart shows a schematic flow diagram for the Porvoo process highlighting the credits for NExBTL. Detailed presentations of energy and mass flows for all sensitivities can be found in the Annex.



**Example how to read the diagram:**

Each bar shows the differentiated expenditures to the right, credits to the left, and the balance below. For Porvoo, about 6.2 GJ primary energy is consumed and about 350 kg of greenhouse gases are emitted to produce 1 t of NExBTL.

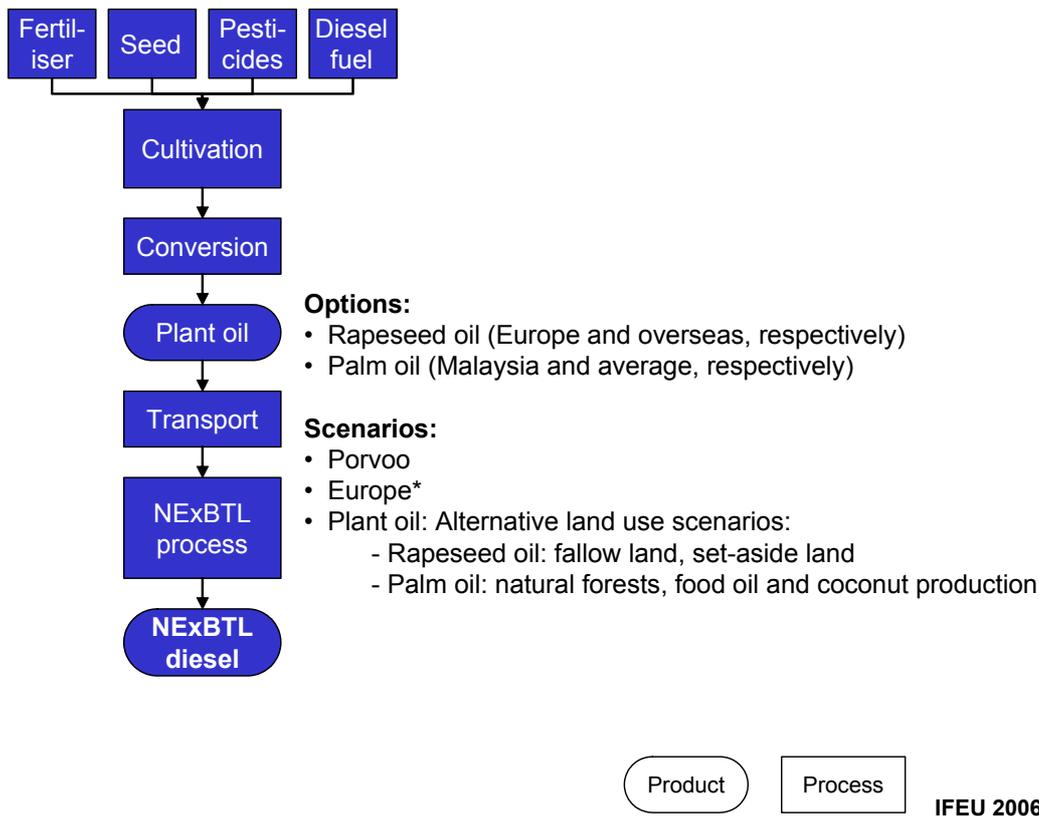
From the differentiated figures, the following can be concluded:

- Production of hydrogen leads to the most relevant energy and greenhouse gas expenditure. But results don't differ significantly if hydrogen is produced with different steam reformer types or different fossil fuel and feedstock inputs.
- The differences between the Porvoo and the Europe (as Porvoo) scenario are mainly due to differences in the origin of the natural gas (see chapter 2). Balance differences are small for energy consumption, but relevant for greenhouse gas emission.
- The use of fuel gas (alternative fuel gas use) within the process only marginally affects the balance results for the NExBTL process. The "low efficiency" scenario leads to only slightly higher expenditures compared to the standard Europe (as Porvoo) scenario.
- There are only marginal differences in the results if rapeseed oil or palm oil is used as the feedstock (Note: this is only true for the NExBTL process itself). This is because differences in the amount of sludge don't have a significant influence on the results.

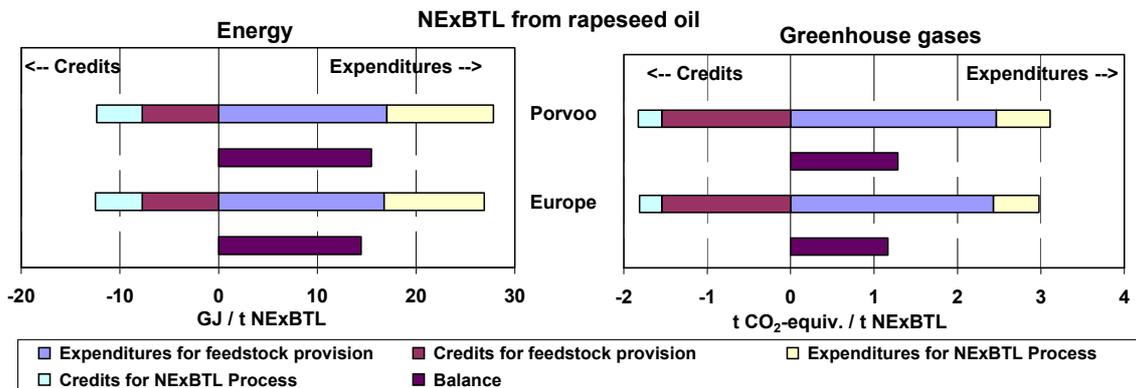
Obviously, there are only small differences between the considered sensitivities in the energy and greenhouse gas results of the **NExBTL process** compared to the overall **provision of NExBTL**. Therefore, the results on the NExBTL process itself can be regarded as quite reliable and it is not necessary to consider these sensitivities in detail in the following chapters.

### 3.4 NExBTL-Production

As a synthesis of the preceding chapters, energy consumption and greenhouse gas emissions of the entire NExBTL production chain “from cradle to gate” are presented and analysed in this chapter. The presented balances include the provision of the respective feedstock as well as the respective NExBTL process and consider all applicable credits. Also, both feedstock options, rapeseed and palm oil, and the reference systems within the scope of this study are compared (for details see chapters 3.1 to 3.3).



\* Detailed flow charts can be found in the Annex

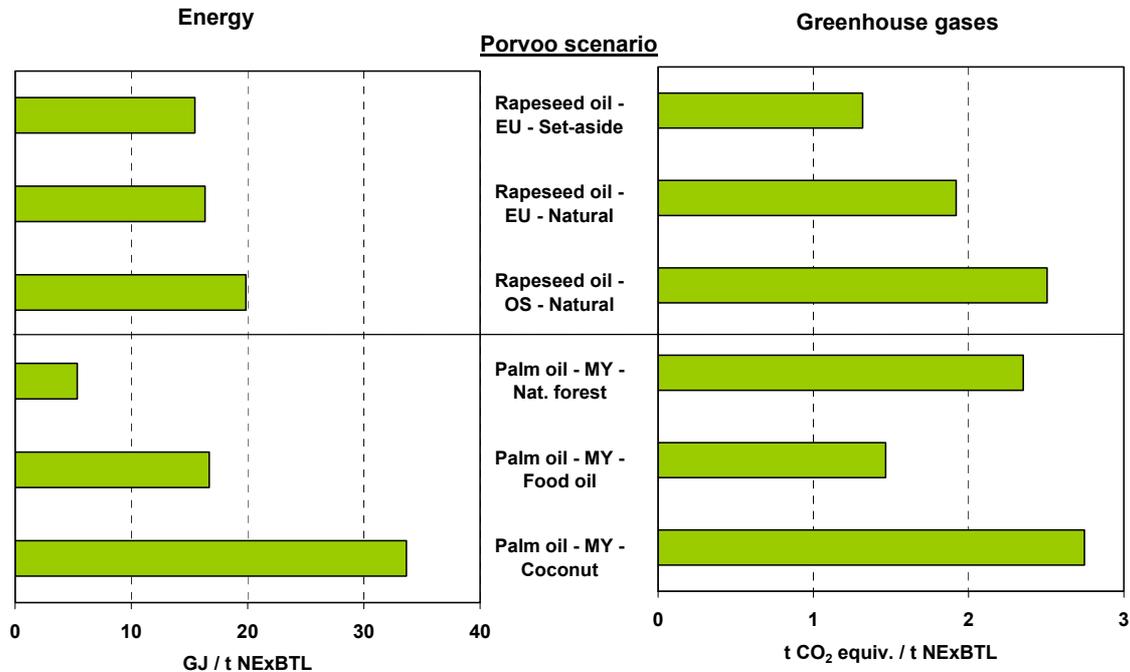


**Example how to read the left diagram:**

The bars show the energy expenditures to the right and credits to the left, differentiated by feedstock provision (rapeseed) and the NExBTL process, followed by the balance below. To provide 1 ton of NExBTL from rapeseed oil “from cradle to gate”, about 15 GJ of fossil primary energy is consumed and about 1.2 t of greenhouse gases are emitted.

The results for the Porvoo and Europe scenario follow exact the same pattern and the differences are quite small. Therefore, the detailed results are presented for the Porvoo scenario, but also give a good indication of the results for the European scenario.

The feedstock reference areas are overseas (OS) and Europe (EU) for rapeseed oil and Malaysia for palm oil. Malaysian palm oil is analysed in reference to the different alternative land uses as described in chapter 3.2.



#### Example how to read the diagrams:

The bars show the energy (left diagram) and greenhouse gas (right diagram) balance for the provision of one tonne of NExBTL from “cradle to gate” at Porvoo. The bars in the first row are the same as the balance bars in the previous diagram.

From the balances for the NExBTL production, the following can be concluded:

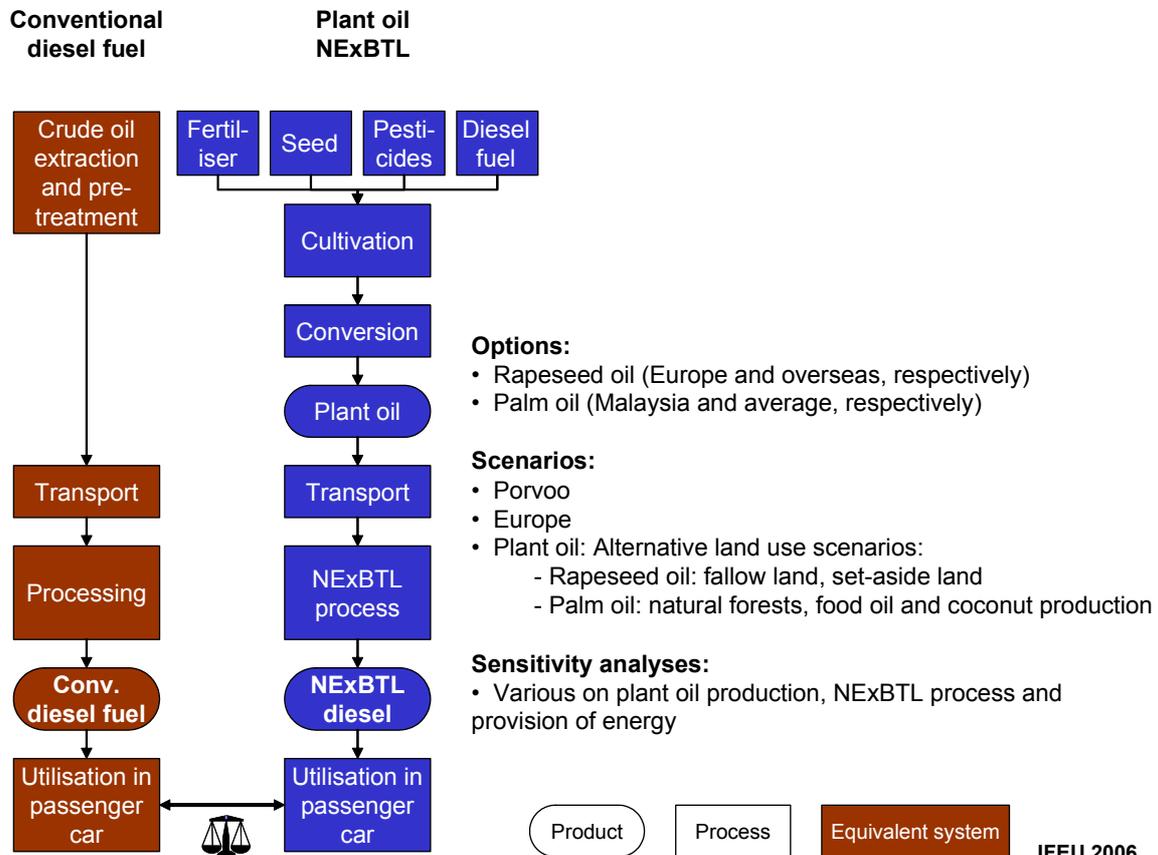
- Energy consumption and greenhouse gas emissions are lowest for rapeseed oil from Europe and palm oil in reference to natural forest or for food oil production.
- The result differences due to the provision of feedstock are much higher than those for the NExBTL process.
- The differences in the results for rapeseed are mainly due the transportation distance (Europe or overseas) and the reference system (natural or set-aside land)
- The differences in the results for palm oil are mainly due to expenditures for the substitution of products from the reference system.
- **The results are mainly influenced by provisions of feedstock in general and the reference system in particular.**

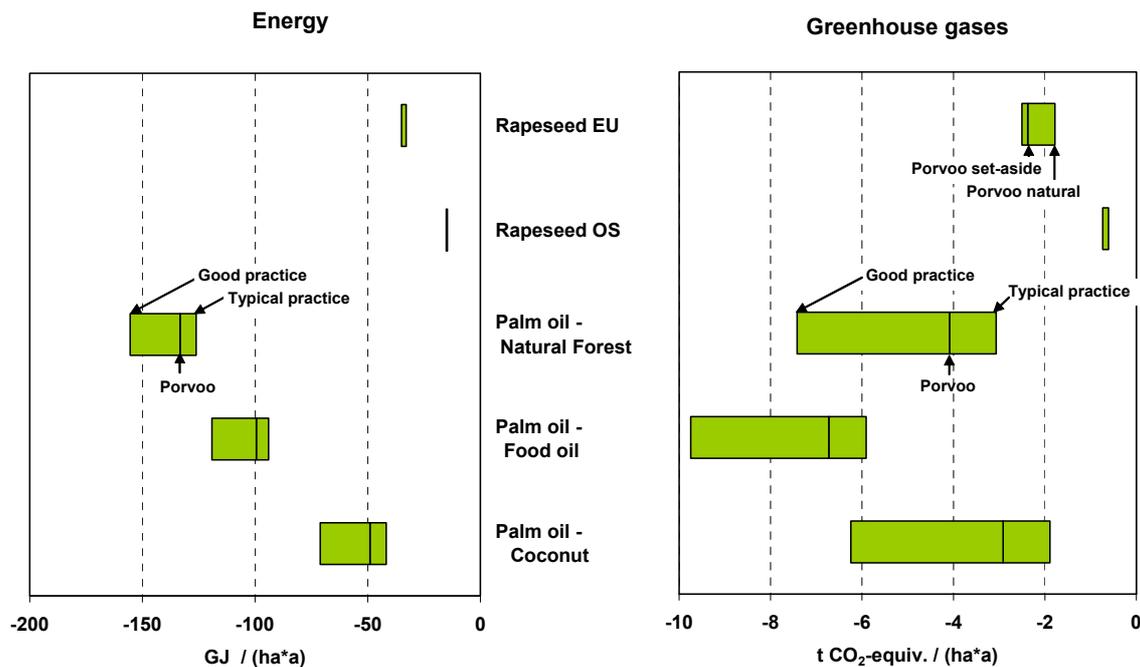
## 4 Results: Life-cycle comparisons

An interpretation of energy consumption and greenhouse gas emissions associated with the production of NExBTL calls for a comparison with the use of alternative products. This chapter therefore compares the life cycle of NExBTL with the equivalent life cycle of conventional diesel fuel and thus leads to an assessment of the advantages and disadvantages of NExBTL compared to conventional diesel fuel.

For both fuels, the entire life-cycle expenditures and credits have been taken into account (see simplified flow chart below). The basic systems for NExBTL have been described in detail in the preceding chapters. For conventional diesel fuel, the life-cycle includes crude oil extraction and pre-treatment as well as transport and further processing. For the use stage, use of both fuels in a vehicle has been assumed.

The presentation of results is undertaken differentiated by selected parameters which have the most considerable influence on the results. These parameters are the feedstock options rapeseed oil and palm oil as well as the various references systems for feedstock provisions within the scope of this study. The results are first presented per hectare and year to allow an analysis from the perspective of agricultural land use. Afterwards, results are also presented for the production of 170,000 t of NExBTL, which corresponds to the annual output of the Porvoo plant.





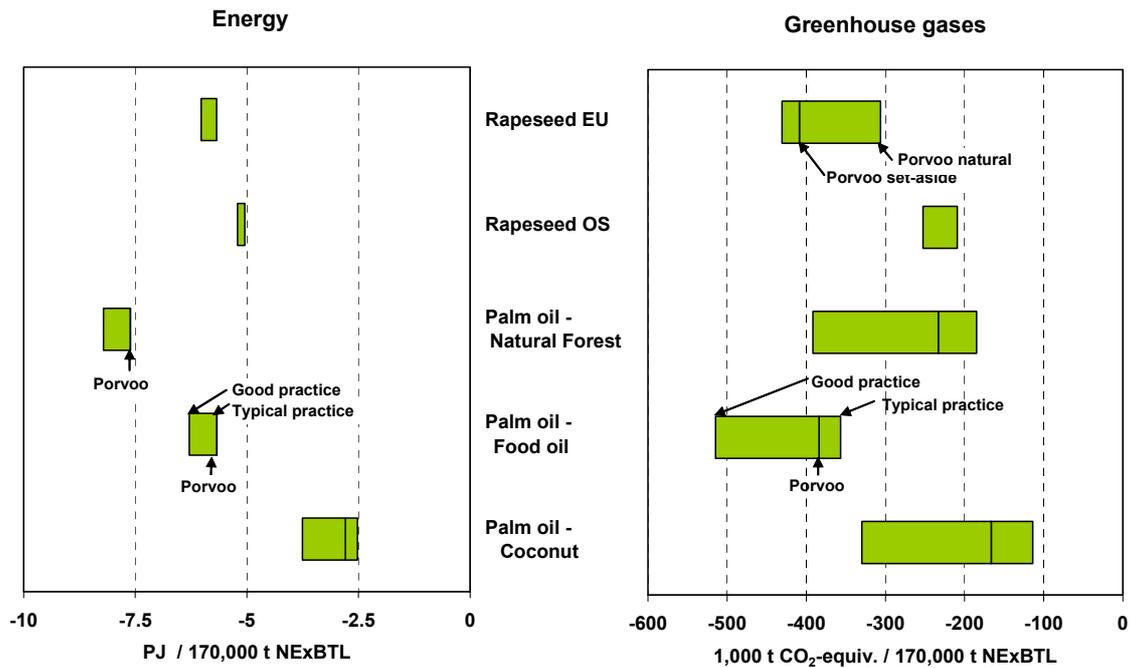
\* Rapeseed results include the complete bandwidths of the Porvoo and Europe scenarios including all sensitivity analyses and different reference systems

**Example how to read the left diagram:**

Each bar shows the bandwidth of life-cycle comparison results for the respective feedstock option. The advantage for NExBTL compared to conventional diesel is displayed to the left side and the disadvantage to the right. The top left bar, for instance, shows that the substitution of conventional diesel fuel with NExBTL produced from rapeseed from one hectare land, saves about 32 GJ primary energy over the entire life-cycle comparison.

From the comparative results per hectare and year, the following can be concluded:

- All investigated options show a clear advantage for NExBTL over conventional diesel fuel. The degree of this advantage, however, is very different.
- NExBTL from rapeseed has advantages in energy consumption and greenhouse gas emissions compared to conventional diesel fuel. If grown in Europe, the net energy savings are about 32 GJ and the respective saving of greenhouse gases is about 2 t of CO<sub>2</sub> equivalents per hectare and year. The advantage of overseas rapeseed is lower due to the lower per hectare yield and longer transportation distance.
- The results for NExBTL from palm oil are mainly influenced by the reference system: All reference systems within the scope of this study show a considerable advantage over conventional diesel fuel. This advantage can be up to three to four times higher than the advantage for rapeseed oil due to the higher per hectare yield but it also can meet the same level (coconut/typical practice).
- The difference of the results for palm oil between typical and good practice is considerable compared to the small bandwidth for rapeseed oil. It does not significantly change the ranking of advantages and disadvantages but gives a clear indication of possibilities to improve the results: biogas recovery and energy sell out.



\* Rapeseed results include the complete bandwidths of the Porvoo and Europe scenarios including all sensitivity analyses and different reference systems

#### Example how to read the left diagram:

Each bar shows the bandwidth of life-cycle comparison results for the respective option and scenario. The advantage for NExBTL compared to conventional diesel is displayed to the left side and the disadvantage to the right. The top left bar, for instance, shows that the substitution of conventional diesel fuel with 170,000 t of NExBTL produced from rapeseed, saves over 6 PJ of primary energy over the entire life-cycle.

In general, the results follow the same pattern as the results per hectare on the previous page. The only difference is that the advantage differences between rapeseed oil and palm oil are smaller than on a per hectare basis, because yield differences are less significant on a mass related basis.

## 5 Conclusions

The comparison of NExBTL with conventional diesel fuel shows an advantage for NExBTL in terms of energy consumption and greenhouse gas emissions for the options and scenarios considered in this study.

All results mainly depend on feedstock provision in general and the reference system in particular. Variations within the NExBTL process itself, including the provision of hydrogen for the NExBTL process, are only of minor importance.

The results in this chapter can be regarded as very robust for the considered boundary conditions. However, the results show that they can not be directly transferred to other feedstocks such as other plant oils, animal fats or used food oils. The same applies if other than the investigated plantations for food oil and coconut production would occupy the area of the palm oil plantation. Furthermore, from other LCAs for bio-fuels it can be concluded by analogy, that the results can not be transferred to other environmental impacts acidification and eutrophication. Additionally, the question of biodiversity arises if tropical rain forest has to be cut for the production of palm oil. This might be important since this scenario shows the best results for savings of energy and greenhouse gases.

## 6 References

- /BORKEN ET AL. 1999/ Borken, J., Patyk, A., Reinhardt, G.A.: Basisdaten für ökologische Bilanzierungen. (Base data for ecological balances) Verlag Vieweg, Braunschweig-Wiesbaden 1999
- /FRANKE 1994/ Franke, G.: Nutzpflanzen der Tropen und Subtropen. Band 3: Spezieller Pflanzenbau – Genusmittel liefernde Pflanzen, Kautschuk liefernde Pflanzen, Gummi liefernde Pflanzen, Öl und Fett liefernde Pflanzen, Knollenpflanzen, Zucker liefernde Pflanzen. Ulmer, Stuttgart 1994
- /GÄRTNER AND REINHARDT 2003/ Gärtner, S.O., Reinhardt, G.A: Life-cycle assessment of biodiesel: Update and new aspects. By order of the Union for the Promotion of Oil and Protein Plants, Berlin 2003
- /HANSEN AND YUSOFF 2005/ Hansen, S.B., Yusoff, S.: Feasibility study of performing a life cycle assessment on crude palm oil production in Malaysia. In: International Journal of LCA 2005 (OnlineFirst): 1-9. Landsberg 2005
- /HIRSINGER 1999/ Hirsinger, F.: Status paper 'oil palm'. By order of the German Federal Environmental Agency, Berlin 1999
- /IFEU 2006/ Internal IFEU Database. Continuously updated. Heidelberg 2006.
- /IPCC 2002/ International Panel on Climate Change: IPCC Guidelines for National Greenhouse Gas Inventories – Workbook Draft, 2002
- /ISO 14040-43/ DIN German Institute for Standardization (Ed.): DIN EN ISO 14040 to 14043. Deutsche Normen. (German and English version) Beuth Verlag, Berlin 1997 – 2000
- /ISTA MIELKE 2004/ Oil World Annual 2004. Hamburg 2004
- /JUNGK AND REINHARDT 2000/ Jungk, N.C., Reinhardt, G.A.: Landwirtschaftliche Referenzsysteme in ökologischen Bilanzierungen (Agricultural reference systems in ecological balances). By order of the Federal Ministry for Agriculture, Food and Forestry, FKZ 99 NR 009, Bonn, 2000
- /MPOB 2006/ Choo, Y.M., Subramaniam, V., Malaysian Palm Oil Board: Personal communication as of March 2006
- /MUTERT AND FAIRHURST 1999/ Mutert, E.W., Fairhurst, T.H.: Oil palm – The great crop of South East Asia: Potential, nutrition and management. Paper presented at the IFA Regional Conference for Asia and the Pacific, Kuala Lumpur, Malaysia, 14-17 November 1999
- /NESTE 2006/ Gust, S., Neste Oil Corporation, Porvoo, Finland: personal communication as of February 2006
- /OHLER 1999/ Ohler, J.G. (ed.) Modern Coconut Management. Palm cultivation and products. ITDG Publishing, London 1999
- /PATEL ET AL. 1999/ M. Patel, G. A. Reinhardt, G. Zemanek: Vegetable Oils for Biofuels versus Surfactants: an Ecological Comparison for Energy and Greenhouse Gases. Fett/Lipid 101 (1999), No. 9, S. 314-320
- /PCA 2006/ Philippine Coconut Authority. Coconut Statistics. Online: <http://pca.da.gov.ph/cocostat.html>
- /REHM AND ESPIG 1996/ Rehm, S., Espig, G.: Die Kulturpflanzen der Tropen und Subtropen. Anbau, wirtschaftliche Bedeutung, Verwertung. Ulmer, Stuttgart 1996
- /REINHARDT ET AL. 1999/ Reinhardt, G.A., Borken, J., Patyk, A., Vogt, R., Zemanek, G.: Ressourcen- und Emissionsbilanzen: Rapsöl und RME im Vergleich zu Dieselkraftstoff. (Resource and Emission balances: rapeseed oil and RME in comparison with diesel fuel) in: Umweltbundesamt (eds.): Kraus, K., Niklas, G., Tappe, M.: Aktuelle Bewertung des Einsatzes von Rapsöl/RME im Vergleich zu Dieselkraftstoff. UBA-Texte 97/99, Berlin 1999
- /UNIFEI 2006/ Lova, E.S., Universidade Federal de Itajubá, Brazil: personal communication as of March 2006

## Annex: Sensitivity data and process energy and mass flow charts

### Sensitivity data for the provision of palm oil:

Some important parameters which influence the results for the provision of palm oil, such as the reference system or transportation distance, have already been discussed in chapter 3.2. However, also a range of other factors and processes have a relevant influence on the results. Among these factors are the per hectare yields, methane emissions from palm oil mill effluent (POME), the location of the palm kernel oil mill and the option for energy sell out. Sensitivity analyses have therefore been undertaken for these factors, in order to illustrate their influence on the results.

The following parameters are used to characterise the sensitivity analyses in detail:

- In most cases, methane which arises during the storage of POME escapes unused into the air. First plants in Malaysia now recover the biogas and use it as a bio-energy carrier. On a global scale, however, this practice is not yet common. Therefore **bio-gas use** describes the share of biogas – by mass of palm oil produced – which is recovered and used as bio-energy.
- Shells and fibres are only partly used in a boiler to produce the energy required for the palm oil mill which is thus energy self sufficient. **Energy sell out** describes the share of surplus energy which is sold out. It consists either of power from the boiler which is fed into the grid or of shells and fibres being sold for external energy production.
- If a **palm kernel oil mill** is located next to a palm oil mill, its energy input can also be provided through the use of shells and fibres. In this case also the palm kernel oil mill is energy self sufficient. The parameter describes the share of palm oil mills – by mass of kernels processed – for which this applies. Other palm kernel oil mills purchase external electricity.

Palm oil for the Porvoo plant is assumed to be produced under average Malaysian conditions. For the European scenario, typical and good practice palm oil from the world market is considered. Both options use the same value for the palm kernel oil mills, because this parameter is rather depending on the infrastructure, but not a specific indicator for good practice. The following table summarises the main differences between the options for palm oil production:

Option:	Malaysia	Typical practice	Good practice
Biogas use	10%	0%	100%
Energy sell out	10%	0%	100%
Yield	3.7 t/ ha	3.5 t/ ha	4.0 t/ ha
Palm kernel oil mill *	10%	5%	5%

\* Note: this parameter is due to infrastructure and not related to typical or good practice

Source: IFEU estimates and calculations based on /ISTA MIELKE 2004/, /PCA 2006/, /MPOB 2006/, /HIRSINGER 1999/, /UNIFEI 2006/

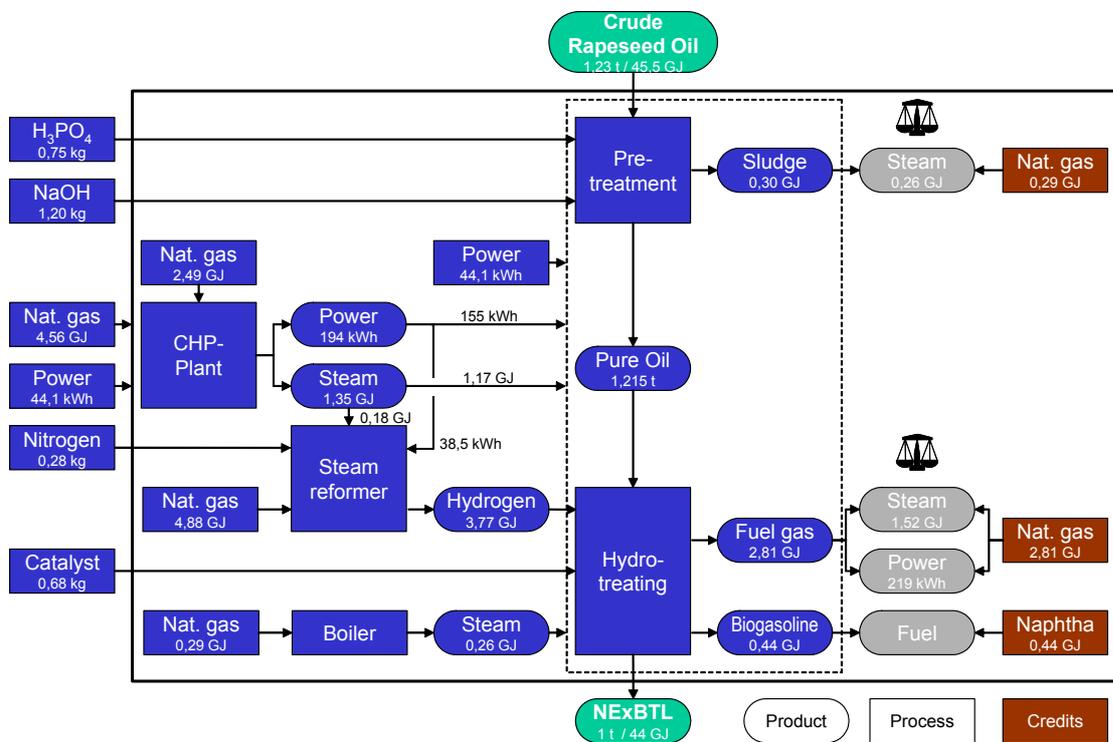
### Process energy and mass flow charts:

The following section presents detailed energy and mass flow charts for different scenarios and sensitivities. The following variations are presented:

- Porvoo (*Standard - simplified*)
- Porvoo (*Standard - detailed*)
- Porvoo (*Equal Power*)
- Europe (*as Porvoo*)
- Europe (*as Porvoo - Low Efficiency*)
- Europe (*Alternative Fuel Gas*)

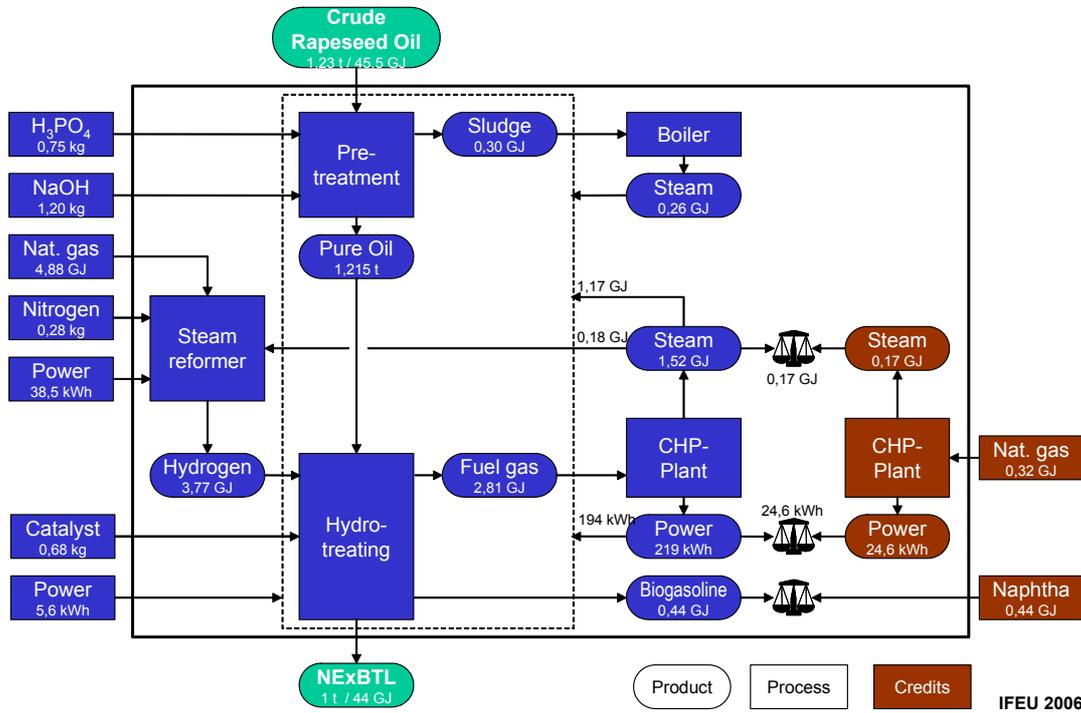
### Porvoo (*Standard – simplified*)

This simplified presentation corresponds to the presentation in chapter 3.3 and illustrates the credits given to NExBTL. This chart additionally includes the energy and mass flows.



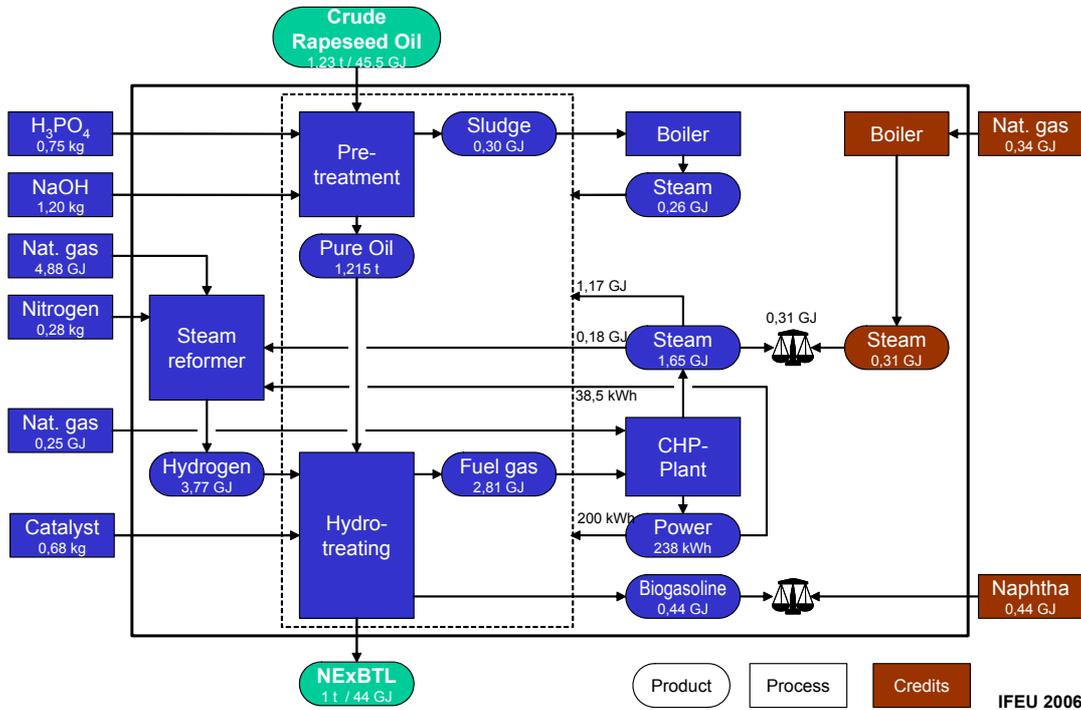
**Porvoo (Standard – detailed)**

This is the same process as presented above. In contrast to the schematic presentation, however, credits are presented as effective internal energy flows.



**Porvoo (Equal Power)**

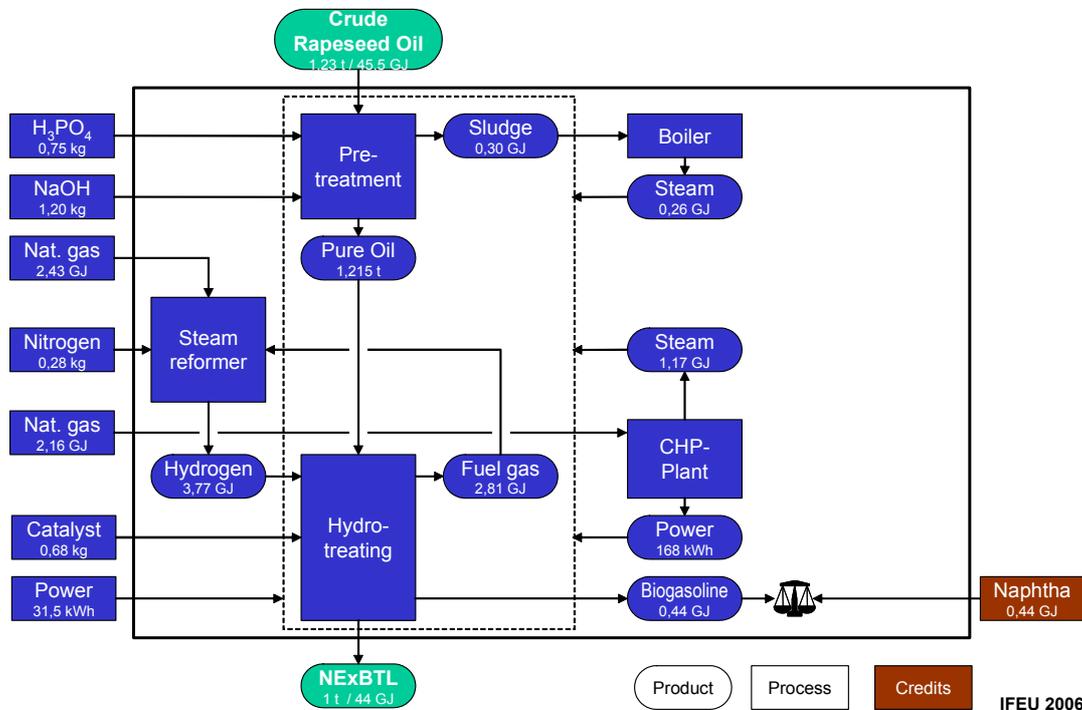
This process is not presented in chapter 3.3, but presented here as an additional sensitivity. The parameters correspond to the Porvoo plant, but the CHP produces the exact amount of power required for the process. The steam difference is assumed to be produced in a boiler.





**Europe (Alternative Fuel Gas)**

This process assumes that all fuel gas is used in the steam reformer instead of the CHP-Plant. Thus less natural gas from outside is required in the steam reformer, but additional natural gas is required for the CHP-Plant.



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