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Executive Summary

The report at hand has been elaborated within the work package "life cycle assessment" in the RENEW project (Renewable Fuels for Advanced Powertrains). The project investigates different production routes for so called biomass-to-liquid (BTL) automotive fuels made from biomass. This report describes the goal and scope of the LCA study for BTL-fuels.

Introduction to life cycle assessment methodology

This report provides an introduction into the methodology of life cycle assessment (LCA). The LCA method aims to investigate and compare environmental impacts of products or services that occur from cradle to grave. The method has been standardized by the International Organization for Standardization (ISO). This introduction forms the basis for the further communication on LCA issues in the RENEW project. Important terms and methodological phases are explained according to the ISO standards.

Production routes developed in the RENEW project

Within the RENEW project, different production routes for BTL-fuels, which are produced by gasification of biomass followed by a synthesis process, are further developed. These are:

- production of Fischer-Tropsch-fuel (FT) by two-stage gasification (pyrolytic decomposition and entrained flow gasification) of wood, gas treatment and synthesis (SP1);
- production of FT-fuel by two-stage gasification (flash pyrolysis and entrained flow gasification) of wood, straw and energy plants as well as CFB-gasification (circulating fluidized bed), gas treatment and synthesis, (SP2);
- BTL-DME (dimethylether) and methanol production by entrained flow gasification of black liquor from a kraft pulp mill, gas treatment and synthesis, (SP3). Biomass is added to the mill to compensate for the withdrawal of black liquor energy
- bioethanol production in different processes from different feedstock (SP4).

Goal of this LCA

The goal of the LCA is to compare different production routes for BTL-fuels (FT-diesel and BTL-DME) from an environmental point of view. The two production routes for ethanol have been excluded from the LCA because of lack of sufficient data for an analysis. The assessment includes all process stages from well-to-tank (WTT) for BTL-fuels. A well-to-wheel study has been performed in WP 5.4 The following questions are addressed in the LCA study:

- Which production route for BTL-fuels, investigated within the RENEW project, is the one with the lowest environmental impacts[1]?
- If there is a choice between different biomass inputs, which one is the environmentally best for the different conversion processes?
- What are the relative shares of contribution to the environmental impacts in different stages of production for the investigated fuels?
- Where are the potentials for improvement?

[1] For this question probably more than one answer will be given, because a certain fuel can have the lowest environmental impacts for e.g. acidification but not necessarily for another category indicator.

- How does the environmental profile of a certain fuel change if the scenario is changed (e.g. different efficiency in fuel production process; different external energy supply)?

The answers to these questions should support the decision on the most promising production routes for BTL-fuels that should be supported by politics and automobile manufactures in the future. The goal of this study implies a comparative assertion of different options, which is disclosed to the public.

It is important to note that several questions are out of the scope of the LCA in the RENEW project and that it will not be possible to answer these questions with data nor analysis made during this LCA study. Such questions are for example:

- What are the environmental impacts of using the fuels investigated in this study (well-to-wheel - WTW)? [2]
- Are there better possible uses for the biomass, e.g. as a material or a fuel for power plants and heating devices?
- Does it make sense to produce the BTL-fuels investigated in this study and to support this in agricultural policy or would it be better to use the available land resources for other purposes?[3]
- Are there better options to reduce greenhouse gas emissions or environmental impacts caused by road traffic?
- What are social and economic impacts of the investigated production chains?[4]
- Are BTL-fuels sustainable?

Stakeholders and audience

The stakeholders and audience of this study are defined as follows: The LCA study is elaborated for all people involved in the development of conversion processes for BTL-fuels. The results of the LCA can be used to improve the BTL-fuel production from an environmental point of view. Further parties, which might be interested in the results, are producers of biomass resources and distributors of BTL-fuels.

Reference flow and functional unit

The reference flow describes in a physical unit the final product or service delivered by the investigated product systems. It is the appropriate unit for analysing different products or production routes.

The function of interest in this study is the supply of chemical bound energy to powertrains. Different types of liquid fuels can provide this function. The fuels are burned in the powertrain in order to be converted to mechanical energy that can be used for traction of vehicles.

The reference flow for the comparison of BTL-fuel production routes is defined as the energy content expressed as the "lower heating value of the fuel delivered to the tank".

2 This question is addressed in other SP5 work packages (WP4) of the project.

3 This question is addressed in other SP5 work packages (WP 3, WP4) of the project.

4 This question is addressed in other SP5 work packages (WP3) of the project.

Product system

Figure 1 shows the major stages of the product system, which are investigated as unit processes. The LCA within the RENEW project investigates the life cycle from biomass provision to the tank and excludes the actual use of the fuel in the powertrain (well-to-tank).[5] The conversion processes are divided into different sub-processes (e.g. gasification, gas treatment, synthesis, etc.) and are modelled in several unit processes.

Inputs of materials, energy carriers, resource uses, etc. to the shown unit processes are followed up as far as possible. To achieve this, the recursively modelled background data of the ecoinvent database[6] are used. There are no cut-off criteria in terms of a specific percentage of mass or energy inputs to the system. Data gaps due to lack of data are filled as far as possible with approximations. The product system is modelled in a way that all inputs and outputs at its boundaries are elementary flows.

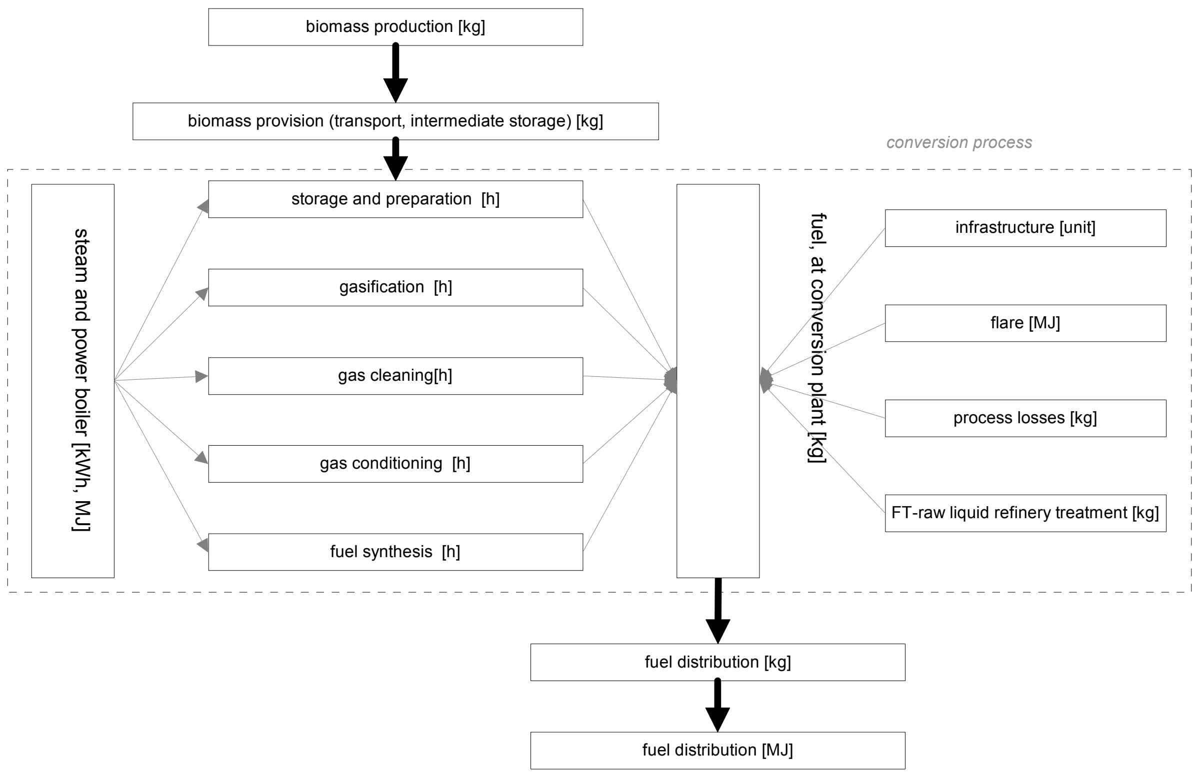

Figure 1 Flowchart of the product system for BTL-fuel with individual unit processes. The conversion process is described with nine sub-processes

Attributional LCA

The LCA assigns the environmental impacts of foreseen production chains to the produced products. The attributional approach is used for the RENEW project. The attributional methodology aims at describing the environmentally relevant physical flows to and from a life cycle and its subsystems. Thus it considers only impacts of the running process and not what would have happened if the process had not taken place. Results are stable over time and resistant to changes in other parts of economy. This type of analysis does not reflect that due to a decision supported by the LCA production patterns might be changed.

[5] Tank-to-wheel investigations will be part of WP 5.4. They are shown separately from the ISO LCA parts of the report.

[6] www.ecoinvent.org

Multi-output process modelling

So far, there is no standardized way or best solution how to solve problems of by-products and further functions in life cycle inventory modelling. The ISO standard leaves different choices for the problem. Depending on the chosen solution, the results of an LCA might be quite variable.

Multi-output processes are divided in this study into subsystems (where possible). If this is not possible, the approach of allocation based on different causality principles is used as far as possible. The procedure has to be decided for the concrete multi-output process based on causalities and available data. It is intended that material balances are correct in all cases.

Scenarios

Two different scenarios are considered in the modelling of the process chains. These scenarios are defined in cooperation with other work packages of SP5 in the RENEW project. These scenarios are described in a separate document, which is published on the RENEW homepage.[7]

Life cycle impact assessment

The elementary flows from the life cycle inventory analysis are characterised according to commonly accepted methodologies. This life cycle impact assessment will evaluate the use of primary energy resources, the emission of greenhouse gasses and the potential contribution of elementary flows to photo oxidant formation, acidification and eutrophication. Other category indicators, e.g. describing impacts due to pesticide or heavy metal emissions as well as potential impacts on biodiversity are not included in the analysis.

Critical review

The goal of this study implies a comparative assertion of different options that is disclosed to the public. Because of this, a critical review by three external LCA experts is foreseen. The review will ensure that all stages of the LCA are conducted according to the ISO standards developed for the methodology of LCA.

[7] See www.renew-fuel.com

Abbreviations and Glossary

a	annum (year)
AMF	automotive fuels, e.g. methanol and DME
AP	acidification potential
biodiesel	vegetable oil methyl ester, liquid product from esterification of vegetable oils
biogas	product gas produced by bio-chemical digestion
BLG	black liquor gasification
BLGMF	black liquor gasification with motor fuel production
BTL	biomass-to-liquid fuel including FT-fuel, methanol and DME produced from synthesis gas
CFB	circulating fluidized bed
CFBR	Circulating-Fluidized-Bed-Reactor
CH2	compressed hydrogen
CNG	compressed natural gas
CSL	by-product of corn production, abbreviation not specified in the original study
DME	dimethylether
dt	dezitonnen (=100 kg)
E-1	Exponential description of figures. The information 1.2E-2 has to be read as 1.2 * 10-2 = 0.012
EEE	Europäischen Zentrum für Erneuerbare Energie Güssing
ETBE	ethyl-tertio-butyl-ether (ethyl-tertiary-butyl-ether)
EtOH	ethanol
FAME	fatty acid methyl ester
FICFB	Fast internal circulating fluidized bed (Güssing plant)
FT	Fischer-Tropsch (synthesis)
GH2	gaseous hydrogen
GHG	green house gas
GWP	global warming potential
H	hierarchist
HA	hybrid analysis
HHV	higher (upper) heating value
high caloric gas	product gas with a lower heating value of LHV >15 MJ/m^3, also called “rich gas”
I	individualist
ICE	internal combustion engine
ISO	International Organization for Standardization
LCA	life cycle assessment
LCI	life cycle inventory analysis
LH2	liquefied hydrogen
LHV	lower heating value
low caloric gas	product gas with a lower heating value <9 MJ/mÂ^3; also called poor gas

ME	methyl ester
MeOH	methanol
middle caloric gas	product gas with a lower heating value of 9<LHV<15 MJ/m^3, also called middle gas
MTBE	methyl-tertio-butyl-ether
n.a.	not available
NG	natural gas
NGO	non governmental organisation
LTV	low temperature gasifier
PM	particulate matter
POCP	photochemical ozone creation potential
pure gas	product gas after removal of impurities for a special application (e. g. gas engine)
raw gas	product gas at the outlet of the gasifiers, i. e. before gas cooling or cleaning.
RENEW	Renewable Fuels for Advanced Powertrains
RER	Europe
RME	rape seed methyl ester (Rapsölmethylester)
SETAC	Society of Environmental Toxicology and Chemistry
SME	sun flower methyl ester (Sonnenblumenölmethylester)
SP	Sub-Project in RENEW. SP5 deals with the assessment of different BTL-fuel production processes
synthetic gas, synthesis gas or syngas	mixture of hydrogen, carbon monoxide (and possibly nitrogen) with a H2/CO-ration suitable for a special synthesis (e. g. methanol synthesis)
TS	Technical specification
ULS	Ultra Low Sulphur
WP	Work package
WP5.1	Biomass potential assessment
WP5.2	Life cycle assessment for BTL-fuel production routes
WP5.3	Economic assessment of BTL-fuel production
WP5.4	Technical assessment
WP5.5	Analysis of gasification processes for gaseous fuels

Contents

1 Introduction

1.1 Background

The study at hand has been elaborated within the project RENEW – Renewable Fuels for Advanced Powertrains. On January 1st, 2004 a consortium from industry, universities and consultants started to investigate production routes for automotive fuels made from biomass. The production of BTL-fuels by gasification of biomass followed by a synthesis process will be investigated and a life cycle assessment (LCA) of several technologies will be performed.

Representatives of 31 institutions from 9 countries work together. Automotive and mineral oil companies, energy suppliers, plant builders and operators joined a consortium together with universities, consultants and research institutes. Supported by the European Union and Swiss federal authorities, the partners will contribute to increase the use of BTL-fuels made from biomass.

ESU-services Ltd., Switzerland is responsible for a work package where different production routes for biomass-to-liquid (BTL) fuels will be investigated in an LCA from well to tank. Four different conversion processes and 3 biomass products are investigated. Two different scenarios for the BTL-fuel chains are considered in the LCA. The aim of the LCA is to compare and improve the different production routes dealt with in the project.

The LCA is one work package (WP5.2) out of five in the subproject 5 (SP5). Work package 1 (WP5.1) investigates the potential for biomass supply in Europe. WP5.3 calculates economic aspects of the BTL-fuel production. A further technical assessment of the different supply routes including also use aspects of the fuels will be elaborated in WP5.4. The production of gaseous fuels from biomass via gasification is investigated in WP5.5.

1.2 Reading guide

Chapter 2 of this report explains the methodology of life cycle assessment (LCA) in detail. This description is based on ISO standards and nomenclature. The description is used as a basis for terms and expressions used in the goal and scope definition.

The goal definition in chapter 3 starts with the definition of questions and stakeholders to be addressed by the study and defines how the results will be published. Chapter 4 describes the scope of the LCA study. This includes further information on the reference flow for the comparison, on system boundaries and modelling principles within the life cycle inventory analysis. The products and processes which are of interest for the RENEW project are defined in chapter 5 of this report. This description includes a more detailed definition of the system boundaries of the life cycle inventory analysis.

2 Life cycle assessment (LCA) methodology

The method of life cycle assessment (LCA) will be used for the environmental evaluation within the RENEW project and is explained here in detail. This chapter is intended as a first introduction for co-workers within the RENEW project which are not very familiar with the methodology of LCA. Experts can use it as a reference, but might skip it in the first reading. All important terms are explained. These definitions and explanations will form the basis for further communication on LCA issues. The LCA within the RENEW project shall be elaborated according to ISO standards 14040 ff. Important issues and the nomenclature from these standards are introduced here.

2.1 Introduction

The method of life cycle assessment (LCA) (some authors use the older term life cycle analysis or ecobalance, the latter is derived from the German “Ökobilanz”) aims to investigate and compare environmental impacts of products or services that occur from cradle to grave. This means that the whole life cycle from resource extraction to final waste treatment is investigated.

The International Organization for Standardization (ISO) (1997-2000) standardizes the basic principles. LCA is used for hot spot analysis, product or process improvement, comparative assertion, marketing and environmental policy. The following description is based on the ISO standard series 14040-14049 (International Organization for Standardization (ISO) 2006) and the most recent and complete guidelines provided by Guinée *et al.* (2001a; 2001b).

2.2 Conceptual background in ISO 14040ff for LCA

LCA studies systematically and adequately address the environmental aspects of product systems, from raw material acquisition to final disposal (from "cradle to grave"). The analysis normally includes the full life cycle of a product from cradle to grave including the life cycle of all pre-products and energy carriers used. Many kinds of environmental interventions, e.g. emissions into water, air and soil as well as resource uses (primary energy carriers, land, etc.) are accounted for. Some authors include also additional effects, e.g. the direct health hazards for employees in the production facilities.

The method distinguishes four main phases, namely (1) goal and scope definition, (2) inventory analysis, (3) impact assessment, and (4) interpretation (see Fig. 2.1). The “Goal and scope definition” describes the underlying questions, the target audience, the system boundaries and the definition of a reference flow for the comparison of different alternatives. The inputs of resources, materials and energy as well as outputs of products and emissions are investigated and recorded in the “Life cycle inventory analysis”. Its result is a list of resources consumed and pollutants emitted along the life cycle of a product or system. These elementary flows (emissions and resource consumptions) are described, characterized and aggregated during the “Impact assessment”. Conclusions are drawn during the “Interpretation”. Normally LCA aims at analysing and comparing different products, processes or services that fulfil the same utility (e.g. 1kg of synthetic ethanol against 1kg of ethanol from sugar beets).

The ISO standards are not mandatory in any way for conducting LCA studies. However, it is strongly recommendable to follow the guidelines of the ISO standards as far as possible for LCA studies disclosed to the public in order to increase the credibility of these LCA studies. This is especially important for comparative assertions that are disclosed to the public.

The different phases of the methodology are explained in more detail in the following chapters. They are not necessarily executed in a step by step procedure, but they might be refined in an iterative manner throughout the study.

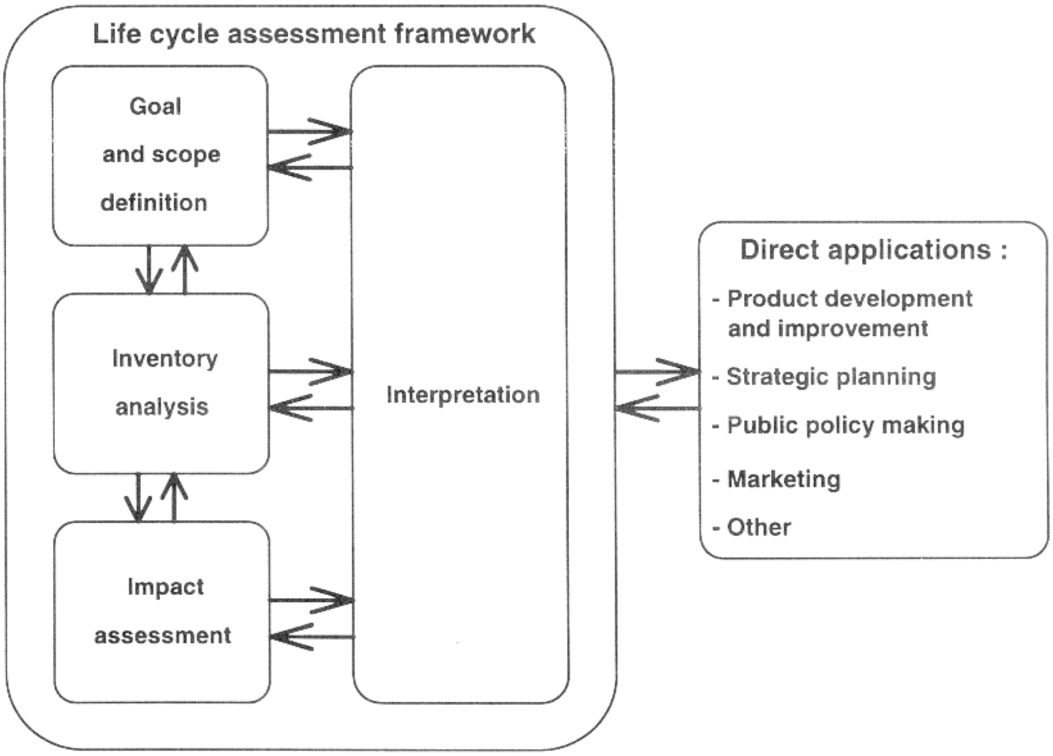

Fig. 2.1 Phases of an LCA (International Organization for Standardization (ISO) 1997-2000)

2.3 Goal and scope definition

The ISO 14041 (International Organization for Standardization (ISO) 1998) describes the procedure for the goal and scope definition. Some key aspects are described in the following section.

2.3.1 Goal

The goal of an LCA study shall unambiguously state the intended application, the reasons for carrying out the study and the intended audience, i.e. to whom the results of the study are intended to be communicated (International Organization for Standardization (ISO) 1998:5.2).

An important question is if the study shall evaluate the environmental impacts of an existing system (attributional LCA) or if consequences due to the change of production patterns shall be analysed (see Jungbluth et al. 2004 for further explanation). The ISO standard does not give hints on this issue.

2.3.2 Functional unit and reference flow

The functions of the investigated system shall be clearly defined. Products or services are defined as a functional output. The functional unit is a measure of the performance of the functional outputs of the product system. The reference flow is a measure of the needed outputs from the product system that are required to fulfil the function expressed by the functional unit (International Organization for Standardization (ISO) 1998:5.3.2).

2.3.3 System boundaries and cut off rules

The system boundaries define the unit processes to be included in the product system. The analysis of technical processes required to manufacture products and deliver services is based on environmental process chain analysis. In many cases there will not be sufficient time, data, or resources to conduct a fully comprehensive study (International Organization for Standardization (ISO) 2000b:5.3.3). According to ISO 14041 (International Organization for Standardization (ISO) 2000b) several criteria are used to decide which inputs to be studied, including a) mass, b) energy, and c) environmental relevance. Any decisions to omit life cycle stages, processes or inputs/outputs shall be clearly stated and justified. The criteria used in setting the system boundaries dictate the degree of confidence in ensuring that the results of the study have not been compromised and that the goal of the study will be met.

An important question for agricultural products is the definition of system boundaries between the technosphere system (agricultural production) and nature (e.g. agricultural soil or ground water). Here it has to be clearly defined which part of agricultural soil and groundwater system belongs to the technical system and which to the natural system.

2.3.4 Data quality requirements

According to ISO 14041 (1998) some descriptions of data quality requirements should be included in the goal and scope definition. These descriptions should cover the following parameters:

- time-related coverage;
- geographical coverage;
- technology coverage.

Furthermore, for studies that intend to make a comparative assertion that is disclosed to the public, the following additional data quality requirements shall be considered:

- precision: measure of the variability of the data values for each data category expressed;
- completeness: percentage of locations reporting primary data from the potential number in existence for each data category unit process;
- representativeness: qualitative assessment of the degree to which the data set reflects the true population of interest;
- consistency: qualitative assessment of how uniformly the study methodology is applied to the various components of the analysis;
- reproducibility: qualitative assessment of the extent to which information on the methodology and data values allows an independent practitioner to reproduce the results reported in the study.

2.4 Life cycle inventory analysis

The second stage of an LCA is the life cycle inventory analysis (LCI) or short inventory analysis. This involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system. An intermediate result of an LCA is the life cycle inventory analysis result with cumulative data for the emission of hundreds of individual substances and for many resource uses. These data constitute the input to the life cycle impact assessment. The inventory analysis is standardized in ISO 14041 (International Organization for Standardization (ISO) 2006).

Normally, data investigation is the most time consuming step of an LCA. In the last years, the situation has been continuously improved due to the set up of standardized background databases (e.g. ecoinvent Centre 2006) and LCA software products that include these background data.

The agricultural production stage is more difficult to model in LCA than technical systems such as e.g. coal power plants due to a number of specific methodological problems and less frequent measurements of emissions. Cattle raising results for example in milk, meat, fertilizer, leather, etc. and it is difficult to assign or allocate emissions due to fodder production to the single products. Agricultural products are produced by thousands of producers while technical products are often produced in a few facilities. Thus it is difficult to determine the average production parameters such as e.g. fertilizer use for so many actors, because they are hardly monitored sufficiently (Cowell et al. 1999).

The following sections will look deeper into some challenges of the life cycle inventory analysis.

2.4.1 Product system and unit process

The unit process describes the smallest portion of a product system for which data are collected when performing a life cycle assessment. Fig. 2.2 shows the main processes of the product system for the transportation with a truck that uses ethanol. The product system is divided into unit processes, e.g. potatoes production or fermentation to ethanol, in order to facilitate and structure the further analysis.

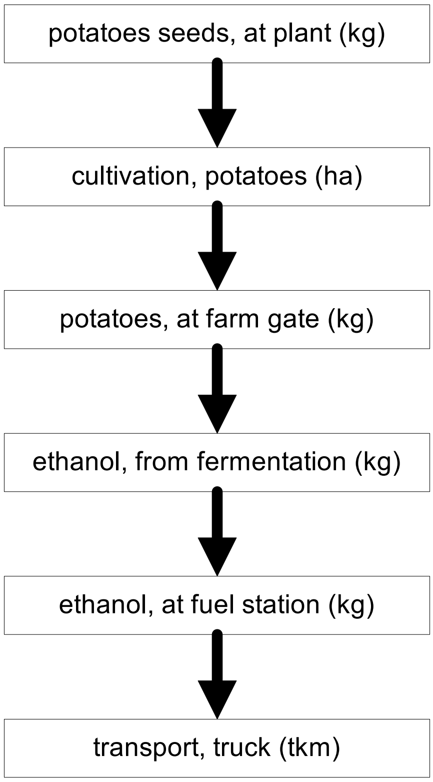

Fig. 2.2 Product system from well to wheel for truck fuelled with ethanol from potatoes that is divided into unit processes

2.4.2 Unit process inventory

The unit process inventory is an inventory of energy and material flows (in- and outputs) which are used or emitted by an unit process. It is also termed as unit process raw data. There are two classes of inputs and outputs: technosphere flows and elementary flows. Technosphere flows take place between different processes which are controlled by humans, e.g. the delivery of ethanol from the plant to the fuel station. They can be physical or service inputs (e.g. electricity, fertilizer or seeds) or outputs (e.g. the product or wastes that have to be treated). Elementary flows in this context are all emissions of substances to the environment (output) and resource uses (inputs, e.g. of fresh water or land). An emission is a single output of a technical process to the environment, e.g. the emission of a certain amount of SO_2.

Fig. 2.3 shows the unit process for potatoes cultivation with some inputs and outputs as an example. Potato seeds are the direct input, potatoes are the major output (product or reference flow) of this unit process. Besides, further inputs, e.g. fertilizer, machinery hours or pesticides are necessary. The unit process causes also some emissions, e.g. pesticides to water or N_2O to air.

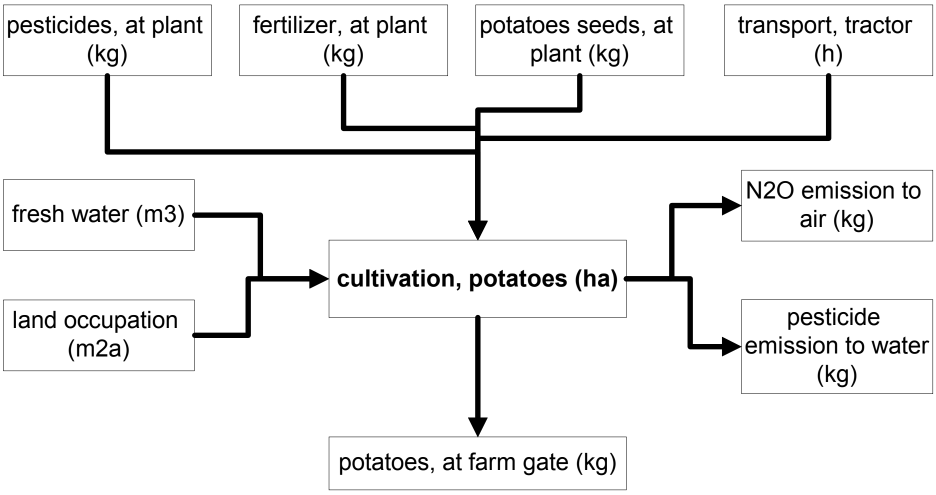

Fig. 2.3 Unit process for the cultivation of potatoes including some examples of inputs and outputs

Tab. 2.1 shows some unit process raw data for the production of 1kg potatoes in Switzerland with integrated production technology (excerpt from Nemecek et al. 2004). Only a part of the recorded 67 inputs and outputs is shown in this table. One can first see some examples for the input of fertilizers, pesticides and transport services. These technosphere inputs are linked to other unit processes that are described in similar tables. Then resource uses of carbon dioxide and land are recorded (input flow from nature). Emissions are distinguished according to the compartments (air, water, soil) and sub compartments (e.g. river, groundwater). They are recorded for different outputs. Finally the technosphere output or reference flow of the process is defined as 1kg potatoes from integrated production in Switzerland.

This inventory table provides also information on the uncertainty for the recorded amount of the flows. In this case the uncertainty type 1 means a lognormal distribution. The standard deviation records the square value for the 95% percentile. The mean value multiplied or divided by the 95% standard deviation gives the 97.%% maximum or the 2.5% minimum value, respectively.

Tab. 2.1 Example of unit process raw data for the production of 1kg potatoes in Switzerland with integrated production technology (excerpt from Nemecek et al. 2004)

	B	F	G	J	K	L	M	N
3	Explanations	Name	Location	Infrastructure-Process	Unit	potatoes IP, at farm	uncertaintyType	StandardDeviation95%
4		Location				CH		
5		InfrastructureProcess				0		
6		Unit				kg		
7	Technosphere	ammonium nitrate, as N, at regional storehouse	RER	0	kg	4.4E-4	1	1.07
17		[sulfonyl]urea-compounds, at regional storehouse	CH	0	kg	2.7E-7	1	1.13
23		potato seed IP, at regional storehouse	CH	0	kg	6.8E-2	1	1.07
25		fertilising, by broadcaster	CH	0	ha	8.1E-5	1	1.07
26		harvesting, by complete harvester, potatoes	CH	0	ha	2.7E-5	1	1.07
40		transport, lorry 28t	CH	0	tkm	1.6E-3	1	2.71
49	resource, in air	Carbon dioxide, in air			kg	3.4E-1	1	1.07
50	resource, biotic	Energy, gross calorific value, in biomass			MJ	3.9E+0	1	1.07
51	resource, land	Occupation, arable, non-irrigated			m2a	1.3E-1	1	1.77
52		Transformation, from arable, non-irrigated			m2	2.7E-1	1	2.67
53		Transformation, to arable, non-irrigated			m2	2.7E-1	1	2.67
54	air, low population density	Ammonia			kg	4.4E-4	1	1.3
55		Dinitrogen monoxide			kg	1.3E-4	1	1.61
57	soil, agricultural	Cadmium			kg	2.6E-8	1	1.77
58		Chlorothalonil			kg	8.8E-5	1	1.32
71	water, ground-	Nitrate			kg	9.4E-3	1	1.77
72		Phosphate			kg	3.1E-6	1	1.77
73	water, river	Phosphate			kg	1.1E-5	1	1.77
75	Outputs	potatoes IP, at farm	CH	0	kg	1.0E+0		

RER – Europe; CH – Switzerland; IP – Integrated Production

2.4.3 Multi-output processes and allocation rules

Some processes do not only have one single technosphere output, but several outputs which might have different uses in the technosphere. The planting of wheat on an agricultural area leads to two products: wheat grains and wheat straw (see Fig. 2.4). During one year 6420 kg grain and 3910 kg straw are produced in Switzerland per hectare (Nemecek et al. 2004).

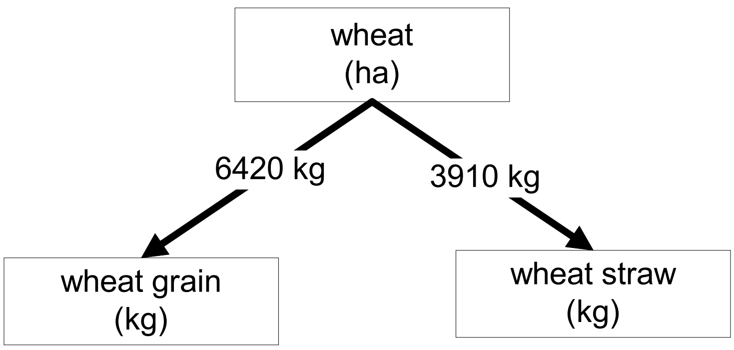

Fig. 2.4 Wheat production its co-products as an example of a multi-output process (data from Nemecek et al. 2004)

Multi-output processes are ubiquitous in LCA product systems. They are present in the energy industry (e.g., combined oil and gas production, oil refineries producing different fuels, combined heat and power production), in the mining industry (e.g., platinum group metals), in agriculture (e.g. production of wheat and straw), in the chemical industry (e.g., phosphoric acid production), in forestry (e.g., sawing of timber) or in the electronics industry (silicon purification with $SiCl_4$ as a by-product).

Principles according to ISO 14041

The environmental impacts of the process have to be shared between the different products (allocation). The following stepwise procedure shall be applied according to ISO 14041 in the LCI for multi-output processes (International Organization for Standardization (ISO) 1998:6.5.3):

- Wherever possible, allocation should be avoided by dividing the subprocesses to be allocated into two or more subprocesses and collecting the data related to these subprocesses or,
- expanding the product system to include the additional functions related to the co products. [8] The ISO-standard does not specify how the system expansion has to be made and two possibilities can be distinguished:
  - Expansion of the functional unit in order to investigate a basket of benefits for the systems under investigation.
  - Subtraction of avoided burdens for the co-products which are not of interest for the study at hand.

  In principle there are two possibilities for the choice of the additional products or services included in the system (see also Jungbluth et al. 2004):

  - Average products can be assumed to be included for determining further functions of the system (attributional LCA), or
  - the system expansion is based on the principle that marginal products are identified and included in the product system (consequential LCA).
- If allocation cannot be avoided the inputs and outputs of the system should be partitioned between its different products or functions in a way which reflects the underlying physical relationships between them.
- If physical relationship cannot be established the inputs should be allocated between the products and functions in a way which reflects other relationships between them. For example, input and output data might be allocated in proportion to the economic value of the products.

Whenever several alternative allocation procedures seem applicable, a sensitivity analysis shall be conducted to illustrate the consequences of the departure from the selected approach.

Context-specific allocation criteria

The problem of allocation has first been dealt with in economics. Here costs of the production process have to be allocated to the different valuable products. J.S. Mill is often mentioned as one of the first economists who raised the question of an adequate procedure to allocate (private) costs to two jointly produced goods (Mill 1848). Criteria used today for the allocation of costs are for instance given in Horngren (1991). They differentiate between the following criteria:

a) cause and effect,

b) benefits received,

c) fairness or equity, and

[8] It is debatable whether this approach really avoids the allocation problem as stated by ISO. Frischknecht (1998) showed that this approach assumes a 100% allocation of benefits to the process of interest while other processes, which are not investigated in the foreground system, are burdened with the full environmental load of the process considered additionally for the system expansion.

d) ability to bear.

Ad a) The criterion "cause and effect" relies on physical, chemical or biological causation. It may be applied for the analysis of combined production where the output of co-products can be varied independently such as an oil refinery producing oil products (light fuel oil, gasoline, bitumen, et cetera). This criterion corresponds to the second step of the ISO 14041 procedure and is not applicable to joint production processes.

Ad b) The criterion of "benefits received" is used to allocate common costs according to the individual profits achieved by spending these common costs. The costs of common marketing activities, for example, may be allocated to the respective goods according to their individual increase in turnover due to these common activities. The criterion may be applied in cases where no market determines the price (value) of products (goods and services).

Ad c) A fair allocation of common costs is required when several decision-makers are involved in a joint production process. It implies that there is a problem of decision-making which includes negotiations in view of a commonly accepted and supported solution. This may be necessary for investments in a dam, for instance, that is used for electricity production, flood protection, drinking water supply and irrigation, and where several decision-makers and profiteers are concerned. In life cycle assessment such a situation may occur in voluntary coalitions, e.g., in the waste treatment sector. Waste "producers" may look for companies being interested in using the waste as a secondary raw material. The criterion "fairness or equity" is not provided by the ISO procedure.

Ad d) The criterion "ability to bear" allocates costs according to the co-product's capacity to bear production costs. The gross sales value and the estimated net realisable value method are representatives of an operationalised concept relying on this criterion. They consider the competitiveness of jointly produced products and result in a price structure that is optimal for the company's profit maximisation.

This short overview shows that different positions and situations may lead to the application of completely different allocation principles and approaches.

System expansion with the avoided burden approach

The following description for the procedure of system expansion with the avoided burden approach (in a consequential LCA) is based on a case study for rape seed methyl ester (Calzoni et al. 2000). It is assumed that extracted rape seed meal is used as protein component in livestock feed and substitutes soy meal. The system expansion is based on the preconditions that:

- soy meal is the marginal protein fodder and rape seed oil is the marginal edible oil on the market;
- rape seed contains 40% oil and 20% raw protein in the dry matter and that soy bean contains 17% oil and 34% raw protein in the dry matter, and
- the raw protein and the oil in both rape seed and soy bean are substitutable in the marginal application.

Per 5 kg rape seed produced an additional production of 1.66 kg rape seed is added. Then a system expansion with 3.91 kg soy bean is made (see Fig. 2.5). In this case results of the balance are valid only for the functional unit of interest, which is 2 kg of rape seed oil.

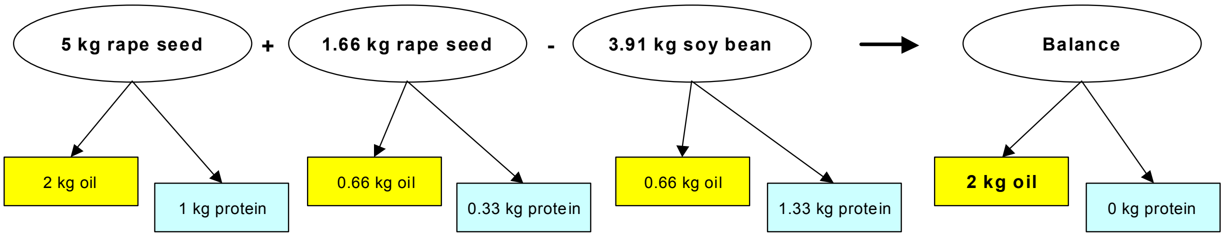

Fig. 2.5 Example for system expansion with the avoided burden approach for rape seed with the purpose of avoiding allocation regarding soy bean oil and protein (Calzoni et al. 2000)

System expansion with the basket of benefits approach

The basic idea for the system expansion with a basket of benefits for the functional unit is quite similar to the example made before (Fig. 2.5). In this case the comparison is made between a system, which delivers several benefits with one multi-output process, and a system, which delivers these benefits with different separate production processes. The results show the impacts for the whole expanded product system and not for the individual products.

Applied on the example in Fig. 2.5, one would define the functional unit of rape seed production as "2 kg oil and 1 kg protein". This could be compared with an alternative system which produces the same amount of oil and protein in a different way (e.g. oil from crude oil and protein from biomass).

Allocation by partitioning of inputs and outputs

The procedure for an allocation is explained in more detail with an example from the ecoinvent database. According to ISO 14041, "the sum of the allocated inputs and outputs of a unit process shall equal the unallocated inputs and outputs of the unit process" (International Organization for Standardization (ISO) 1998:6.5.2). This is also known as the 100% rule.

The allocation procedures shall be uniformly applied to similar inputs and outputs of the systems under consideration (International Organization for Standardization (ISO) 1998). This is especially important if a product is an output for one process and an input for another process. Residues without value that are used by other processes have to be treated in a consistent way for the processes delivering them and the processes that makes use of them.

Each multi-output dataset includes information on the allocation factors for all inputs and outputs. Each pollutant, each working material or raw material input may have its individual allocation factor, if adequate or necessary. Allocation factors need not to be between 0 and 100%. They may well be negative and above 100%. However, the sum of the set of allocation factors of one particular input or output needs to add up to exactly 100%.

Tab. 2.2 shows an excerpt of the inputs and outputs of the wheat production process and the allocation factors as modelled in the ecoinvent database. First some examples of inputs from technosphere and elementary flows are shown. The column "wheat IP" gives the amounts used or emitted per hectare. In this example 67 kg of nitrogen in ammonium nitrate are required and 3.9 grams of cadmium are emitted to agricultural soil per hectare and year. The allocation factors for the two products shown in the columns AG and AH define the share of this total which is allocated to the specific product. These shares (allocation factors) can be determined based on different properties, e.g. product value, carbon or energy content. For carbon dioxide uptake (line 44) 61% of the total amount are allocated to the wheat grains because this equals the amount of carbon found in this product.

Tab. 2.2 Excerpt of the multi-output process raw data of the wheat production and allocation factors used for the grains and straw (example from Nemecek et al. 2004)

	B	F	G	J	K	Z	AG	AH
3	Explanations	Name	Location	Infrastructure-Process	Unit	wheat IP	wheat grains IP, at farm	wheat straw IP, at farm
4		Location				CH	CH	CH
5		InfrastructureProcess				0	0	0
6		Unit				ha	kg	kg
7	Technosphere	ammonium nitrate, as N, at regional storehouse	RER	0	kg	6.7E+1	92.5	7.5
26		grain drying, low temperature	CH	0	kg	7.6E+1	100.0	-
44	resource, in air	Carbon dioxide, in air			kg	1.4E+4	61.3	38.7
45	resource, biotic	Energy, gross calorific value, in biomass			MJ	1.7E+5	59.1	40.9
46	resource, land	Occupation, arable, non-irrigated			m2a	7.9E+3	92.5	7.5
53	soil, agricultural	Cadmium			kg	3.9E-3	42.2	57.9
54		Chlormequat			kg	2.3E-1	92.5	7.5
72	Outputs	wheat grains IP, at farm	CH	0	kg	6.4E+3	100.0	
73		wheat straw IP, at farm	CH	0	kg	3.9E+3		100.0

Unit process raw data can be derived from the information shown in Tab. 2.2. For instance, the input of 67 kg "Ammonium nitrate" is multiplied with the allocation factor 92.5% and divided by 6420 (the amount of wheat grains per hectare). Hence, 9.7 g ammonium nitrate input is attributed to the production of 1 kg of wheat grains. Only 1.3 g is attributed to the production of 1 kg of wheat straw. Tab. 2.3 shows the results of this multiplication.

Tab. 2.3 Example for the derived unit process raw data for the two co-products of "wheat IP". Input and output flow of the multi-output process times allocation factor divided by co-product output equals input and output flows of the derived unit processes (excerpt from Nemecek et al. 2004)

Explanations	Name	Location	Infrastructure-Process	Unit	wheat grains IP, at farm	wheat straw IP, at farm
	Location				CH	CH
	InfrastructureProcess				0	0
	Unit				kg	kg
Technosphere	ammonium nitrate, as N, at regional storehouse	RER	0	kg	9.7E-3	1.3E-3
	grain drying, low temperature	CH	0	kg	1.2E-2	
resource, in air	Carbon dioxide, in air			kg	1.3E+0	1.4E+0
resource, biotic	Energy, gross calorific value, in biomass			MJ	1.5E+1	1.8E+1
resource, land	Occupation, arable, non-irrigated			m2a	1.1E+0	1.5E-1
soil, agricultural	Cadmium			kg	2.6E-7	5.8E-7
	Chlormequat			kg	3.3E-5	4.4E-6
	wheat grains IP, at farm	CH	0	kg	1.0E+0	
	wheat straw IP, at farm	CH	0	kg		1.0E+0

Summary

The ISO methodology for the allocation procedure still leaves a range of possible choices. These choices might have an important influence on the final results and they have a subjective component in any case. Thus special attention has to be paid to explain these choices in an LCA study. For the choice of the approach the specific goals of the study have to be considered.

2.4.4 Uncertainty considerations in LCI

Within the life cycle inventory of a unit process the amounts of the inputs and outputs are described with single figures (the mean values). This quantitative description of the unit process includes uncertainty because the mean values are uncertain. In reality there might be a difference between the value that has been investigated (or measured and reported) and the "real" value.

Different types of uncertainty are present in the life cycle inventory data of a process:

- Variability and stochastic error of the figures which describe the inputs and outputs due to e.g. measurement uncertainties, process specific variations, temporal variations, etc.
- Appropriateness of the input or output flows. Sometimes an input or output does not perfectly match with the input or output observed in reality. This may be due to temporal and / or spatial approximations. For instance, the electricity consumption of a process that takes place in Nigeria might have been approximated with the dataset of the electricity supply mix of the European network.
- Model uncertainty: the model used to describe a unit process may be inappropriate (using for instance linear instead of non-linear modelling).
- Neglecting important flows. Sometimes not all relevant information is available to completely describe a process. Such unknown inputs and outputs are missing in the inventory.

So far there is no standardized procedure how to document and analyse different types of uncertainties in the LCI. It has to be noted that the impact assessment introduces further uncertainties to the analysis which might be even more important than the inventory uncertainties.

2.4.5 Life cycle inventory analysis result

The LCI result is the outcome of a life cycle inventory analysis. It includes all elementary flows crossing the boundaries of the product system under investigation. Thus all inputs of resources and outputs of emissions are summed up over the life cycle (cradle to gate or cradle to grave). Tab. 2.4 shows an excerpt of the LCI results for potatoes (Nemecek et al. 2004). Only some of over 1000 elementary flows are shown in this table.

One can see that the cumulative results are higher than the unit process raw data shown in Tab. 2.1 due to further inputs from the life cycle. The direct uptake of carbon dioxide for potatoes growing was about 340 grams. Another 30 grams are added in the life cycle e.g. for the growing of potatoes seeds. The table shows also some examples for emissions to air and soil. It has to be noted that the LCI analysis does not show any inputs and outputs to the technosphere, but only the flows between technosphere and environment. This LCI table provides the starting point for life cycle impact assessment.

Tab. 2.4 Example for selected LCI results for potatoes (excerpt from Nemecek et al. 2004)

		Name		potatoes IP, at farm
		Location		CH
		Unit	Unit	kg
		Infrastructure		0
resource	Occupation, arable, non-irrigated	land	m2a	3.3E-1
resource	Carbon dioxide, in air	in air	kg	3.7E-1
air	Carbon dioxide, fossil	high population density	kg	1.3E-2
air	Carbon dioxide, fossil	low population density	kg	2.0E-2
air	Nitrogen oxides	low population density	kg	2.8E-4
soil	Cadmium	agricultural	kg	2.8E-8
soil	Cadmium	unspecified	kg	4.8E-11

2.5 Impact assessment

The life cycle impact assessment (LCIA) phase of the LCA aims at evaluating the significance of potential environmental impact using the results of the LCI analysis. This procedure involves associating inventory data with specific environmental impacts and attempting to understand those impacts. The level of detail, choice of impacts evaluated and methodologies used depend on the goal and scope definition of the study (International Organization for Standardization (ISO) 2006). The term impact assessment is used for all steps of aggregation.

LCIA consists of standardized procedures for one or more of the following elements (International Organization for Standardization (ISO) 2000a:4). Mandatory according to ISO 14042 are:

- Selection of impact categories, category indicators and characterization models.
- Classification – Assigning of inventory data to impact categories.
- Characterization – Different elementary flows are multiplied with a flow specific characterization factor that describes their potential contribution to the same environmental problem. Afterwards the characterized figures are summed up to the category indicator result. The gases CO_2, CH_4, N_2O are for example classified as greenhouse gases, because they contribute to global warming. It is possible to determine characterisation factors based on the global warming potential of these gases. The characterisation compares different elementary flows on a midpoint level.

Optional elements according to ISO or specific LCIA methodologies are:

- Normalization – The total emission of a pollutant or the characterization value related to the product is compared with the total emissions or the total characterisation value caused in a certain region and within a certain period of time.
- Grouping – Sorting and possibly ranking of the impact categories. The latter is based on value judgements.
- Weighting – The characterized and normalized results for different environmental problems are aggregated based on a weighting principle that reflects for example principles of environmental policy or value judgements expressed by a panel. It should be noted that ISO 14042 states that weighting shall not be used for comparative assertions disclosed to the public.

Finally life cycle impact category indicators are derived. An indicator describes a single emission or the aggregation of different single emissions, compounds of an element and/or resource uses. These indicators are used for the following interpretation.

It is necessary to choose appropriate impact assessment methodologies with regard to special emissions in the life cycle (e.g. agricultural chemicals), the region under study (e.g. Europe) and the decision-makers addressed. Often LCA studies use different impact assessment methodologies simultaneously in order to see and discuss differences in the outcome.

Every LCIA involves some subjectivity such as choice, modelling and evaluation of the impact categories. Therefore transparency is critical to LCIA to ensure that assumptions are clearly described and reported (International Organization for Standardization (ISO) 2006:8).

An important requirement of International Organization for Standardization (ISO) (2000a) is that weighting shall not be used for comparative assertions which are disclosed to the public. In such studies a sufficiently comprehensive set of category indicators shall be employed. Thus the aggregated results of LCIA methods (e.g. single scores from Brand et al. 1998; Goedkoop & Spriensma 2000) shall only be used for internal studies or studies without comparative assertions (e.g. for hot spot analysis). Intermediate results of these LCIA methodologies, e.g. on the level of safeguard subjects, can also be used for comparative assumptions if available.

There is a range of different approaches for the damage assessment of the characterisation. These methods can be grouped according to the major problems which are assessed. Tab. 2.5 shows a short description of the most important category indicators for LCIA. Different areas of protection are of concern. They have a recognisable value for the society. Human health describes damages on human beings. Natural resources can be depleted and the opportunities of future generations may be influenced. The natural environment can be affected by man-made interventions, but also the man made environment, e.g. buildings might be damaged due to human activities (Guinée et al. 2001a).

Life cycle impact assessment (LCIA) methodologies, which are used for the aggregation of the inventory analysis results, have been developed by different authors (Brand et al. 1998; Goedkoop & Spriensma 2000; Guinée et al. 2001a; Hauschild & Wenzel 1997; Huijbregts 1999; Steen 1999).

Tab. 2.5 Short description of important category indicators in LCIA and areas of protection (partly from Guinée et al. 2001a)

Category indicator	Description	Area of protection
Depletion of abiotic resources	Abiotic resources (including energy resources) such as iron ore, crude oil, etc. which are regarded as non-living. There is a wide variety of methods available for characterising contributions to this category. Many studies focus on energy resources. The cumulative energy demand (CED) quantifies the entire energy demand, valued as primary energy. Different types of primary energy uses (i.e. fossil, nuclear, hydro, sun, wind, biomass) have to be described and characterised.	NR, HH, NE
Depletion of biotic resources	These are resources that are regarded as living, e.g. rainforests, animals, etc. Not many LCA studies account for these impacts.	NR, HH, NE, ME
Land use	This category covers a range of consequences of human land use patterns. Different impact on e.g. the resource aspect, biodiversity or life support functions might be considered.	NR, ME
Climate change	This is defined as the impact of human made emissions on the radiative forcing of the atmosphere. This is also referred to as the "greenhouse effect" because in many parts of the earth the emissions might cause rising temperatures of the earth's surface.	HH, NE, ME
Stratospheric ozone depletion	This category refers to the thinning of the stratospheric ozone layer as a result of anthropogenic emissions. This causes a greater fraction of solar UV-B radiation to reach the earth's surface, with potentially harmful impacts on living beings.	HH, NE, ME, NR
Human toxicity	Impact of toxic substances on human health are covered in this category. Some LCA also include the exposure at workplace in this category.	HH
Ecotoxicity	This category covers the impacts of toxic substances on aquatic, terrestrial and sediment ecosystems. Further subcategories are freshwater aquatic, marine, freshwater sediment and marine sediment ecotoxicity.	NE, NR
Photo oxidant formation	This describes the formation of reactive chemical compounds such as ozone by the action of sunlight on certain primary air pollutants. These reactive educts may be injurious to human health and ecosystems.	HH, ME, NE, NR
Acidification	Acidifying pollutants have a wide variety of impacts on soil, groundwater, surface waters and materials. The major pollutants are SO_2, NO_x and NHx.	NE, ME, HH, NR
Eutrophication	This covers all impacts of excessively high environmental levels of macronutrients, the most important of which are nitrogen and phosphorus. Nutrient enrichment may cause an undesirable shift in species composition and elevated biomass production in both aquatic and terrestrial ecosystems. Increased biomass production in aquatic ecosystems may lead to depressed oxygen levels.	NE, NR, ME
Waste heat	Waste heat may increase temperatures on a local scale.	NE, NR
Ionising radiation	This covers the impacts arising from releases of radioactive substances as well as direct exposure to radiation.	HH, NE, NR

Areas of protection: HH – human health, NR – natural resources, NE – natural environment, ME – man made environment

2.6 Interpretation

Within the interpretation part, a final discussion of the LCI and the LCIA results is made. This should be done according to the defined goal and scope of the study in order to reach consistent conclusions and recommendations. The interpretation phase may involve the iterative process of reviewing and revising the scope of the LCA. It is checked whether the nature and quality of the data collected is consistent with the defined goal. The findings of sensitivity analyses should also be reflected in the interpretation (International Organization for Standardization (ISO) 2006).

2.7 Critical review

A critical review facilitates the understanding and enhances the credibility of LCA studies. This is especially important if comparative assertions raise special concerns. The critical review is done by one or more external experts. The specification of the review process in the ISO documents is rather general. Some basic requirements for the nominations of the experts are listed (such as familiarity of the expert with the ISO 14040ff standards as well as his or her technical and scientific expertise and publication of the review report within the LCA report). The critical review process shall ensure that (International Organization for Standardization (ISO) 2006):

- the methods used for the LCA are consistent with the international standard;
- the methods are scientifically and technically valid;
- the data used are appropriate and reasonable in relation to the goal of the study;
- the interpretation reflects the limitations identified and the goal of the study;
- the study report is transparent and consistent.

2.8 Data documentation and exchange format

ISO/TS 14048 gives a technical specification for Life Cycle Inventories (LCI) data documentation format (International Organization for Standardization (ISO) 2002). The specification intends to support a transparent reporting, interpretation and review of data collection, data calculation and data quality, as well as facilitating data exchange. This format can serve as a guideline for collecting and reporting data according to ISO 14041, independent of the media used (paper or electronic), independent of any specific software, and independent of the industrial context. Attention has been given to keep it compatible with the subsequent steps of impact assessment (ISO 14042) and interpretation (ISO 14043) and to facilitate these phases of an LCA.

Some data exchange formats have been developed internationally, such as SPINE (CPM 2000) and EcoSpold (ecoinvent Centre 2006; Hedemann & König 2003). Looking at these formats, they can be considered to be in compliance with the technical specification ISO/TS 14048. However, they turn out to be more comprehensive and show some differences, in regard to the intended purpose, their structure and to individual data fields. These differences might turn out to be an obstacle when trying to exchange information between the data formats and for implementing the required interfaces in LCA software tools. So far no electronic format for data exchange has been standardized by ISO.

ISO 14048 as a technical specification is not mandatory for an LCA according to ISO 14040ff. A data documentation according to ISO/TS 14048 is rather straightforward as none of the data fields is classified mandatory and because ISO/TS 14048 allows for various interpretations.

3 Goal of the study

The LCA methodology according to ISO 14040ff does not provide a detailed procedure for each step in the LCA. Thus at several points of a study, decisions have to be made by the researcher or the project team. The goal and scope definition of an LCA is the most important phase. All subsequent assumptions and decisions in the analysis have to be made according to the goal of the study.

Within the RENEW project the focus is laid on the comparison of different production routes for BTL-fuels that are developed and investigated within the project. The following sections elaborate the goal and scope definition in more detail.

3.1 Questions

The goal of the LCA is to compare different production routes for BTL-fuels (FT-diesel and BTL-DME) from an environmental point of view. The assessment includes all process stages from well-to-tank (WTT) for BTL-fuels. The following questions are addressed in the LCA study (see chapter 2.3.1 for explanations):

- Which production route for BTL-fuels, investigated within the RENEW project, is the one with the lowest environmental impacts9?
- If there is a choice between different biomass inputs – addressing also different agricultural technologies -, which one is the environmentally best for the different conversion processes?
- Are there regional differences for the recommendations?
- What are the relative shares of contribution to the environmental impacts in different stages of production for the investigated fuels?
- Where are the potentials for improvement?
- How does the environmental profile of a certain fuel change if the scenario is changed (e.g. different efficiency in fuel production process; different external energy supply)?

The answers to these questions will support the decision on the most promising production routes for BTL-fuels that should be supported by politics and automobile manufactures in the future. The goal of this study implies a comparative assertion of different options, which will be disclosed to the public.

It is important to note that several questions are out of the scope of the LCA in the RENEW project and that it will not be possible to answer these questions with data nor analysis made during this LCA study. Such questions are for example:

- What are the environmental impacts of using the fuels investigated in this study (well-to-wheel - WTW)? 10
- Are there better possible uses for the biomass, e.g. as a material or a fuel for power plants and heating devices?
- Does it make sense to produce the BTL-fuels investigated in this study and to support this in agricultural policy or would it be better to use the available land resources for other purposes?11

[9] For this question probably more than one answer will be given, because a certain fuel can have the lowest environmental impacts for e.g. acidification but not necessarily for another category indicator.

[10] This question is addressed in other SP5 work packages (WP4) of the project.

[11] This question is addressed in other SP5 work packages (WP 3, WP4) of the project.

- Are there better options to reduce greenhouse gas emissions or environmental impacts caused by road traffic?
- What are social and economic impacts of the investigated production chains?12
- Are BTL-fuels sustainable?

3.2 Stakeholders

The stakeholders and audience of this study are defined as follows: The LCA study is elaborated for all people involved in the development of conversion processes for BTL-fuels. The results of the LCA can be used to improve the BTL-fuel production from an environmental point of view. Further parties, which might be interested in the results are producers of biomass resources and distributors of BTL-fuels. The following Tab. 3.1 shows the stakeholders addressed by the LCA study. The table describes also the kind of direct involvement in this study as well as possible uses of the study results.

Tab. 3.1 Stakeholders of the study, their involvement and own interest in the LCA study results

Stakeholder	Involvement in this study	Use of results
Resource suppliers	Suppliers of biomass resources (e.g. farmers, forest authorities) are not directly involved in the study. However, some biomass suppliers might have direct contacts to the process developers.	Assess their environmental competitiveness on the BTL-fuel market.
Conversion process developers	The conversion process developers are partners in the RENEW project. They will be included in the discussion on the goal and scope and other phases of the LCA. Furthermore they support the study directly with data.	Improve the environmental performance of their processes.
Fuel distributors	Two fuel distributors are partners in the RENEW project.	Assess their environmental competitiveness on the BTL-fuel market.
Automobile manufacturers	The automobile manufacturers VW, Daimler-Chrysler and VTEC are directly involved in the study via a monitoring committee for the LCA. All major decisions for the LCA are made in close cooperation with this committee.	Adopt their product decisions e.g. on powertrain concepts to the results.
Public users of LCI data	Not directly involved.	Use of LCI data for own studies.
Public decision makers, authorities and NGO's (non governmental organisations)	The study is financed by the European Commission, the Swiss Federal Office for Education and Science (Bundesamt für Bildung und Wissenschaft) and the Swiss Federal Office of Energy (Bundesamt für Energie). Other public decision makers or NGOs are not directly involved.	Support political decisions.
Investors and energy industry	Not directly involved.	Assess their environmental competitiveness on the BTL-fuel market.
Authors	The LCA is elaborated by ESU-services Ltd., Switzerland. This is a private consultancy specialized on LCA. Only 50% of the work is financed by Swiss authorities and the rest by own funds of the consultancy.	Make use of the knowledge developed within this project in future projects.

12 This question is addressed in other SP5 work packages (WP3) of the project.

Stakeholder	Involvement in this study	Use of results
Project partners of the LCA	Public and private research organisations from different countries support the work for the LCA (see Tab. 3.2). They contribute data and they are involved in the major decisions. The project partners are financed by the European Commission and by own funds.	Only limited own interests in the results of the study for further own research works.
Critical review panel	The critical review panel of three independent LCA experts reviews all four stages of the LCA. Its work is financed via the project funds.	Partly general interest in study results and methodology.

Tab. 3.2 shows the partners of the RENEW project directly involved in the LCA.

Tab. 3.2 RENEW partner directly involved in elaborating the LCA

Company	Abbreviation	Country
Volkswagen AG	VW	DE
Center for Renewable Energy Sources (CRES)	CRES	GR
DaimlerChrysler AG	DC AG	DE
EC Baltic Renewable Energy Centre (EC BREC)	EC Brec	PL
Lunds University	LU	SE
ESU-services Ltd.	ESU services	CH
Institute of Energy and Environment (IEE)	IEE	DE
Volvo Technology Corporation	VTEC	SE

3.3 Publication

There are three LCA reports that are worked out during the course of the project. They address the four stages of an LCA: goal and scope, inventory analysis, life cycle impact assessment and interpretation.

A final summary report based on these documents will be published. This final report will be in full accordance to the ISO 14040 series. A transparent and complete documentation of the LCA study is seen as a prerequisite for the public acceptance of the results.

The life cycle inventory results of the study can be used by the project partners to assess environmental impacts of fuel production in relation to its use in own further LCA studies. Therefore all life cycle inventory data are documented and published in a reproducible and transparent manner addressing confidentiality requirements in an adequate way.

In order to deliver a high quality public LCI database confidentiality requirements of data suppliers will be respected where necessary or requested. LCI data provided by ESU-services Ltd. or external data suppliers will be published separately and be disseminated on special conditions in order to keep the proprietary rights of the individual data owner.

4 Scope of the study

The scope definition, a detailed definition of the systems to be studied, its related boundaries and the reference flow is provided in this chapter.

4.1 Reference flow

The reference flow describes in a physical unit the final product or service delivered by the investigated product systems. It is the appropriate unit for analysing different products or production routes (see chapter 2.3.2 for explanations).

The function of interest in this study is the supply of chemical bound energy to powertrains. Different types of liquid fuels can provide this function. The fuels are burned in the powertrain in order to be converted to mechanical energy that can be used for traction of vehicles.

The reference flow for the comparison of BTL-fuel production routes is defined as the energy content expressed as the "lower heating value of the fuel delivered to the tank".

Different stages of BTL-fuel conversion will also be compared based on the energy content of the output. There will be no system expansion according to the basket of benefits approach for the reference flow in order to consider by-products.

The reference flow is the mass of different BTL-fuels (FT-diesel and BTL-DME) that correspond to 1MJ (reference flow).

Specifications of different BTL-fuels, i.e. the energy content per mass or volume, will be delivered by WP5.4. Additives, in order to achieve the usability of the respective fuel in power trains will be taken into account. Important for the LCA is the composition of chemical elements, e.g. carbon, hydrogen and oxygen, the lower and upper heating value and the density of the fuels. Tab. 4.1 shows the required data for the characterisation of fuel properties in the LCA. These data are used e.g. to calculate evaporative losses.

Tab. 4.1 Required data for the chemical composition of fuels (example)

Chemical composition		
Alkenes		%
n- Alkenes		%
Olefins		%
Aromatics		%
Poly-Aromatics		%
Methanol		%
Ethanol		%
DME / dimethylether		%
Higher alcohols		%
Ketenes / Aldehydes		%
Carboxylic acids		%
other analysed compounds ...		%
Water		%
Elemental composition		
Carbon		%
Hydrogen		%
Oxygen		%
Sulphur		%
Nitrogen		%
Potassium		%
Chlorine		%
Arsenic		%
Lead		%
Cadmium		%
Chromium		%
Mercury		%
Zinc		%
Other trace elements (as measured)		%
..		%
..		%
Physical properties		
Lower heating value		MJ / kg
Lower heating value		MJ / l
Upper heating value		MJ / kg
Upper heating value		MJ / l
Liquid density (15°C)		kg / l
Liquid density (30°C)		kg / l
Liquid density (40°C)		kg / l

4.2 System boundaries

Fig. 4.1 shows the major stages of the product system, which are investigated as unit processes. The LCA within the RENEW project investigates the life cycle from biomass provision to the tank and excludes the actual use of the fuel in the powertrain (well-to-tank).[13] The conversion processes are di-

[13] Tank-to-wheel investigations will be part of WP 5.4. They are shown separately from the ISO LCA parts of the report.

vided into different sub-processes (e.g. gasification, gas treatment, synthesis, etc.) and are modelled in several unit processes.

Inputs of materials, energy carriers, resource uses etc to the shown unit processes will be followed up as far as possible. To achieve this, the recursively modelled background data of the ecoinvent database (ecoinvent Centre 2006) will be used. There are no cut-off criteria in terms of a specific percentage of mass or energy inputs to the system. Data gaps due to lack of data will be filled as far as possible with approximations. The product system will be modelled in a way that all inputs and outputs at its boundaries are elementary flows.

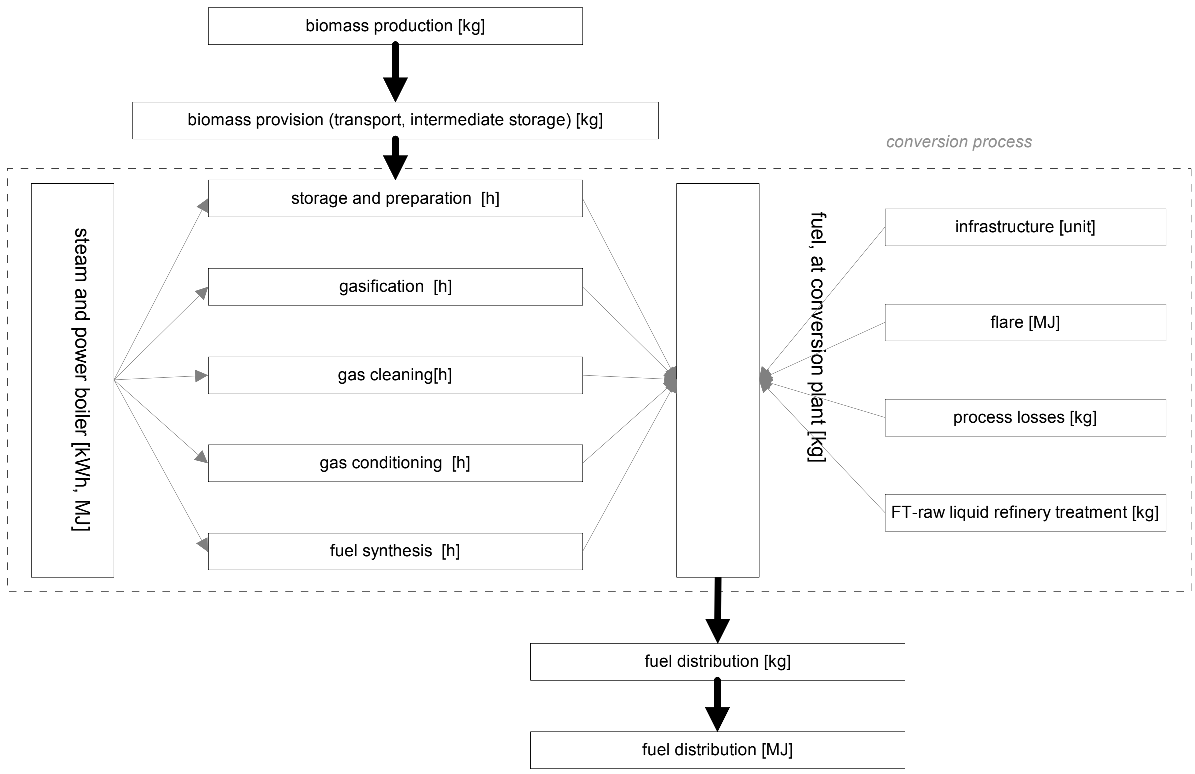

Fig. 4.1 Flowchart of the product system for BTL-fuel with individual unit processes. The conversion process is described with nine sub-processes

4.3 Data categories

The list of elementary flows, which have to be recorded in the inventory, is not limited to a certain catalogue now. The list of elementary flows developed by de Beaufort-Langeveld (2003) and further refined by Frischknecht *et al.* (2004a) will be used as a reference work. Land occupation and transformation are addressed according to the classes defined by Frischknecht *et al.* (2004a). Some LCIA methods proposed by CML will be used and partly adapted to the background data used, e.g. for use of energy resources.

Elementary flows that are not easy to address in the LCIA or for that data are only rarely available are not addressed. These are for example noise, vibration, non-ionization radiation and odour. Labour health and direct impacts on workers are not addressed. Wastes are not considered as an elementary flow. Waste management is considered as a part of the product system, thus emissions resulting from the waste management processes are included in the inventory.

Social and economic aspects of the life cycle are not addressed in the LCA study. They will be partly investigated in other work packages of the RENEW project, e.g. WP5.3. and WP5.4.

4.4 Modelling principle

4.4.1 Attributional LCA

The LCA will assign the environmental impacts of foreseen production chains to the produced products. The attributional approach will be used for the RENEW project. The attributional methodology aims at describing the environmentally relevant physical flows to and from a life cycle and its subsystems. Thus it considers only impacts of the running process and not what would have happened if the process had not taken place. Results are stable over time and resistant to changes in other parts of economy. This type of analysis does not reflect that due to a decision supported by the LCA production patterns might be changed (Ekvall et al. 2004; Jungbluth et al. 2004).

4.4.2 Multi-output process modelling

So far there is no standardized way or best solution how to solve problems of by-products and further functions in life cycle inventory modelling. The ISO standard leaves different choices for the problem. Depending on the chosen solution, the results of an LCA might be quite variable (see chapter 2.4.3 and Jungbluth et al. 2004).

Multi-output processes are divided into subsystems (where possible). If this is not possible the approach of allocation based on different causality principles will be used as far as possible. The procedure has to be decided for the concrete multi-output process based on causalities and available data. It is intended that material balances are correct in all cases. For some scenarios it might be useful to model the environmental impacts according to the avoided burden approach in order to take consequences of process development decisions into account (e.g. alternative fuel use if black liquor is used as a biomass input).

4.4.3 Scenarios for the assessment

The scenarios defined within SP5 for the different assessment studies will be considered for the LCA (SP5-Partners 2007). The scenarios define different system boundaries for the biofuel input, the technology type, the time frame and the plant size. Three scenarios are foreseen:

- Starting point
- Maximized biofuel production

The detailed description of these scenarios as given in (SP5-Partners 2007) will be used in the LCA.

4.5 Data quality requirements

4.5.1 Time horizon for inventory modelling

The analysis in the LCA has to be based on a certain reference year. The time horizon for the LCA defines some boundary conditions. The time horizon is defined in the different assessment scenarios for SP5 (SP5-Partners 2007).

Another point for the discussion of the time horizon is the inclusion of future environmental impacts. Greenhouse gas emissions can be assessed for a time frame of 20, 100 or 500 years. Most studies used the perspective of 100 years to evaluate these impacts. Emissions from landfills might be spread over very long time frames of several ten thousand years and it questionable whether this time frame is considered in decision-making. Also the modelling of some LCIA methods considers possible damages over very long time frames. This introduces normally higher uncertainties to the results than just taking into account today and near future impacts. According to the recommendations of a recent Swiss discussion forum on this issue, long-term emissions will be calculated separately from emissions taking place within 100 years after the time of analysis.

4.5.2 Geographical scope

The geographical scope of the RENEW project covers the member states of the European Union in mid 2004 and Switzerland (Fig. 4.2). The analysis will consider and distinguish different possible production places. The following countries are included in the assessment (ISO abbreviations used in this study):

AT	Austria	DE	Germany	NL	Netherlands
BE	Belgium	GR	Greece	PL	Poland
CH	Switzerland	HU	Hungary	PT	Portugal
CY	Cyprus	IE	Ireland	SK	Slovakia
CZ	Czech Republic	IT	Italy	SI	Slovenia
DK	Denmark	LV	Latvia	ES	Spain
EE	Estonia	LT	Lithuania	SE	Sweden
FI	Finland	LU	Luxembourg	GB	United Kingdom
FR	France	MT	Malta		

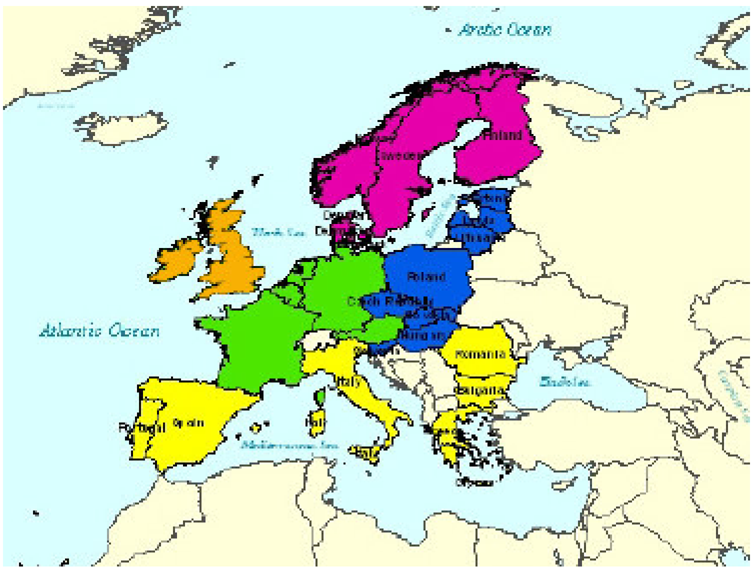

Fig. 4.2 Map of European countries covered in the RENEW project

4.5.3 Technology coverage

Until today many biomass resources and most of the biomass fuels are not produced in a large scale. Data are available only for feasibility studies, laboratory or small-scale plants. An investigation of the ecological effects of different fuel supply chains must therefore be related to the future. Many of the regarded technologies are still in the state of demonstration and testing. It is difficult to carry out an

LCA on future systems, because a great number of processes occur within the system boundaries that have not been analysed for the time being.

A systematic overview of different methodologies of forecasting future developments has been elaborated by Pehnt (2003). He distinguished six different methodologies:

- Subjective assessment methods, which are based on expert judgements (e.g. opinion survey, brainstorming, experts' consultation). These methods are very common in LCA because they require little resources.
- Adaptation methods use the empiric knowledge of completed projects. Thus databases of comparable projects or processes are applied to forecast the relevant components. The processes may be disaggregated into sub-processes for which information is available.
- Input-output coefficients (see Jungbluth et al. 2004 for explanations) can be applied using average energy requirements, emissions, etc. per monetary unit. Thus data from a cost assessment can be used to derive environmental information.
- Regression analysis is a common forecasting method that starts from a function, which correlates on one dependent, and one or more independent variables using coefficients. These are minimised, for instance, using least-square methods.
- Modelling the system can be a powerful alternative if no empirical data is available. This can be applied on different kinds of product systems.
- Scenarios can be used as a forecasting method for an assessment of the data ranges.

Tab. 4.2 shows the criteria proposed by Pehnt (2003) for selecting forecasting methods in LCA.

Tab. 4.2 Criteria for selecting forecasting methods in LCA (Pehnt 2003)

Criteria / Method		Subjective	Adaption	IO coeff.	Regression	Modelling	Scenario
Time horizon		SML	SM	SM	SM	SML	SML
Required ressources	Required information	+	–/o	+	–/+ #	o	–
	Required user qualification	–	o	+	+	–	–
	Speed of usage	+/– *	+	+	o	–	–
Quality of results	Reliability	–	–/o	+	+	+	irr
	Information content	+	+/o	o	+/o	+	+
	Systematic errors?	o/+	o	–	+	+	+
Flexibility	Spectrum of applicability	+	+	+	o	+	+
	Adaptability towards changes	+/o	+	+	o	o	o

S short term; M medium term; L long term
+ advantage of the method • o neutral • – disadvantage of the method • irr: not relevant
* + for single expert interviews, – for Delphi method
# + if regression equation is available in literature, – if regression equation needs to be researched

In general it seems to be difficult to define a good procedure how to assess future technologies in LCA case studies. For the actual study, data to model the conversion processes will be delivered from SP 1, 2, 3 and 4 according to the scenarios developed in SP5 (SP5-Partners 2007).

4.5.4 Foreground and background data

The direct investigation of data will be focused on the product system described in Fig. 4.1. Data for these unit processes will be investigated as far as possible on up-to-date information from production sites and statistics. These data will be investigated by means of questionnaires and direct contacts to plant operators.

All supplies of materials, electricity, energy carriers, services, etc. are modelled as far as possible with available background data from the ecoinvent database (ecoinvent Centre 2006) or other published LCI data sources. These data describe for example the production of fertilizers, transport or waste management services or the supply of electricity in nearby all European countries. Thus it is not necessary to investigate such LCI data again. Specifications made for the scenarios will be considered (SP5-Partners 2007).

4.5.5 Uncertainties

An important aspect of the LCA studies of biomass fuels is the assessment of data uncertainties and variations (see chapter 2.4.4 for further explanations). Several procedures have been applied until now (see Tab. 4.3 and Jungbluth et al. 2004). Data for biomass production show quite often a high variability due to differing natural conditions and farming practices.

Uncertainties have to be investigated in the context of the study and under consideration of the relevant questions. For the RENEW project assessments via sensitivity analysis or variation of parameters in scenarios will be applied in order to address the data uncertainties and variations. This aims to clarify the rule of uncertainties for the outcome of the study and to assess whether the results are reliable or not. Furthermore the data quality will be described according to the points mentioned in chapter 2.3.4.

Tab. 4.3 Assessment of uncertainties and data variations in LCA case studies

Method	Description
Standard deviation	Beer (2001) assessed the percent range of uncertainties of selected tail pipe emissions with their standard deviation found in measurements.
Square root of the sum of squares	The uncertainty ranges have been combined as variances i.e. as the square root of the sum of squares (Edwards 2004).
Scenario modelling	Different scenarios can be modelled e.g. for the system expansion in order to assess the uncertainty introduced by modelling assumptions (e.g. used by Calzoni et al. 2000).
Sensitivity analysis	Use of extreme maximum or minimum input data in order to calculate the maximum or minimum environmental impacts (e.g. used by Calzoni et al. 2000; van den Broek et al. 2003).
Pedigree matrix for standard deviation	Within the background database ecoinvent standard deviations are assessed for each individual flow in the database. These figures can be used to calculate the 95% range of results in a Monte-Carlo simulation (Frischknecht et al. 2004a).
Monte-Carlo analysis for selected parameter uncertainties	In SimaPro it is possible to calculate the uncertainty range of selected parameters (ecoinvent Centre 2006; PRé Consultants 2007).

4.5.6 Calculation routines

A commercial LCA software (SimaPro) is used to calculate the life cycle inventory analysis and to document the data. The product uses the ecoinvent background database (ecoinvent Centre 2006). The life cycle inventory analysis of the RENEW project is transferred to GaBi plans and is published in Del. 5.2.9 (IKP & PE Europe 2004; Jungbluth & Schmutz 2007).

4.6 Critical review

According to the goals described in chapter 3, this study can be considered as a comparative assertion that is disclosed to the public. For such LCA studies a critical review is mandatory according to the ISO standards (see chapter 2.7). The study will be reviewed by a critical review panel of three persons. These person are well known experts in the field of LCA methodology or with regard to LCA case studies for BTL-fuels. They have been selected at the beginning of the project and they are paid from the project funds. Consolidated critical review comments will be received intermediately on the four main stages of the LCA. The following persons have been appointed as members of the critical review panel:

- Prof. W. Klöpffer, Germany (Chair);
- R. van den Broek, The Netherlands (Co-reviewer);
- L.G. Lindfors, Sweden (Co-reviewer).

4.7 Life cycle impact assessment

The life cycle impact assessment (LCIA) will be made in the third year of the project. For the evaluation of fuel production routes some category indicators (see Tab. 2.5 for description) are of specific interest.

The last column of Tab. 4.4 shows the foreseen LCIA methodologies to be applied. The inclusion or exclusion of category indicators has been discussed within the project team. The main clauses for the choice of category indicators were the reliability and acceptance of the existing LCIA methods. The relevance for the life cycles of interest was also assessed based on the present knowledge.

Further category indicators might be assessed in more detail if they turn out to be important after the finalisation of the inventory analysis and if reliable LCIA methods are available. The data collection should facilitate the use of different methods. This makes it possible to take into account the latest scientific developments and to use the most suited methods.

In all cases, different characterisation models are available. The methods are chosen according to the baseline proposal from Guinée *et al.* (2001a). All methods will be linked to the elementary flows in the inventory data according to the implementation rules defined for the ecoinvent database by (Frischknecht et al. 2004b) and provided with the software SimaPro. New elementary flows will be assessed according to the factors provided in the original method and the implementation rules described for ecoinvent data.

Tab. 4.4 Important category indicators in LCIA and their consideration for this study

Category indicator	Relevance	Assessed
Depletion of abiotic resources, energy	Important is the use of energy resources. The cumulative demand of biomass, other renewable, fossil and nuclear energy resources will be assessed.	(Frischknecht et al. 2004b)
Depletion of abiotic resources, water	Water is a scare resource especially in Southern European countries.	No LCIA method. Amount will be quantified in the LCI.
Depletion of biotic resources	The biomass resources used for the processes all stem from artificial production processes. Thus it does not seem to be relevant to include biotic resources in the assessment.	Not relevant
Land use	Most important resource for production of biomass and important differences between different biomass types.	No accepted LCIA method. Assessment on the level of inventory data for the land occupation.
Climate change	Main reason for promotion of BTL-fuels.	(IPCC 2001, 100 years time frame for integration)
Stratospheric ozone depletion	No direct relevance in the product systems.	N_2O contributes to ODP, but no model to quantify this ODP contribution is currently available. For other emissions from the direct life cycle not relevant
Human toxicity	Some relevance for air and soil emissions from agriculture and background processes.	No accepted method
Ecotoxicity	High relevance for forestry and agricultural processes, e.g. use of pesticides and fertilizers.	No accepted method
Photo oxidant formation	Some relevance because of air emissions from production processes and agriculture.	(Guinée et al. 2001a, high NO_x POCP)
Acidification	Relevance because of air emissions from agriculture and fuel combustion.	(Guinée et al. 2001a, average European AP)
Eutrophication	High relevance due to use of fertilizers in agricultural processes.	(Guinée et al. 2001a, generic EP)
Waste heat	No direct relevance. Interesting for analytical reasons.	Not relevant
Ionising radiation	Relevant only if nuclear or coal power are important for the electricity supply.	No accepted method

5 Description of process routes

In the LCI report we give some information about the products and processes of interest within the RENEW project (Jungbluth et al. 2007). Several conversion technologies for the production of biomass-to-liquid fuels (BTL) are further developed in the project. These are:

- production of Fischer-Tropsch-fuel (FT) by two-stage gasification (pyrolytic decomposition and entrained flow gasification) of wood, gas treatment and synthesis (SP1);
- production of FT-fuel by two-stage gasification (flash pyrolysis and entrained flow gasification) of wood, straw and energy plants as well as CFB-gasification (circulating fluidized bed), gas treatment and synthesis, (SP2);
- BTL-DME (dimethylether) and methanol production by entrained flow gasification of black liquor from a kraft pulp mill, gas treatment and synthesis, (SP3).Biomass is added to the mill to compensate for the withdrawal of black liquor energy
- bioethanol production in different processes from different feedstock (SP4).

Fig. 5.1 shows an overview of the main biomass conversion routes investigated and developed within the RENEW project (status 2003). These concepts will be further developed in the course of the project. A technical assessment for gaseous fuels (methane) which can be derived by gasification of biomass is prepared in the working packaging WP5.5. This fuel will not be addressed in the LCA.

A detailed technical description, which will also form the basis for the LCA, will be elaborated in WP 5.4 of the RENEW project.

Four different BTL-routes and one DME-route route are investigated.

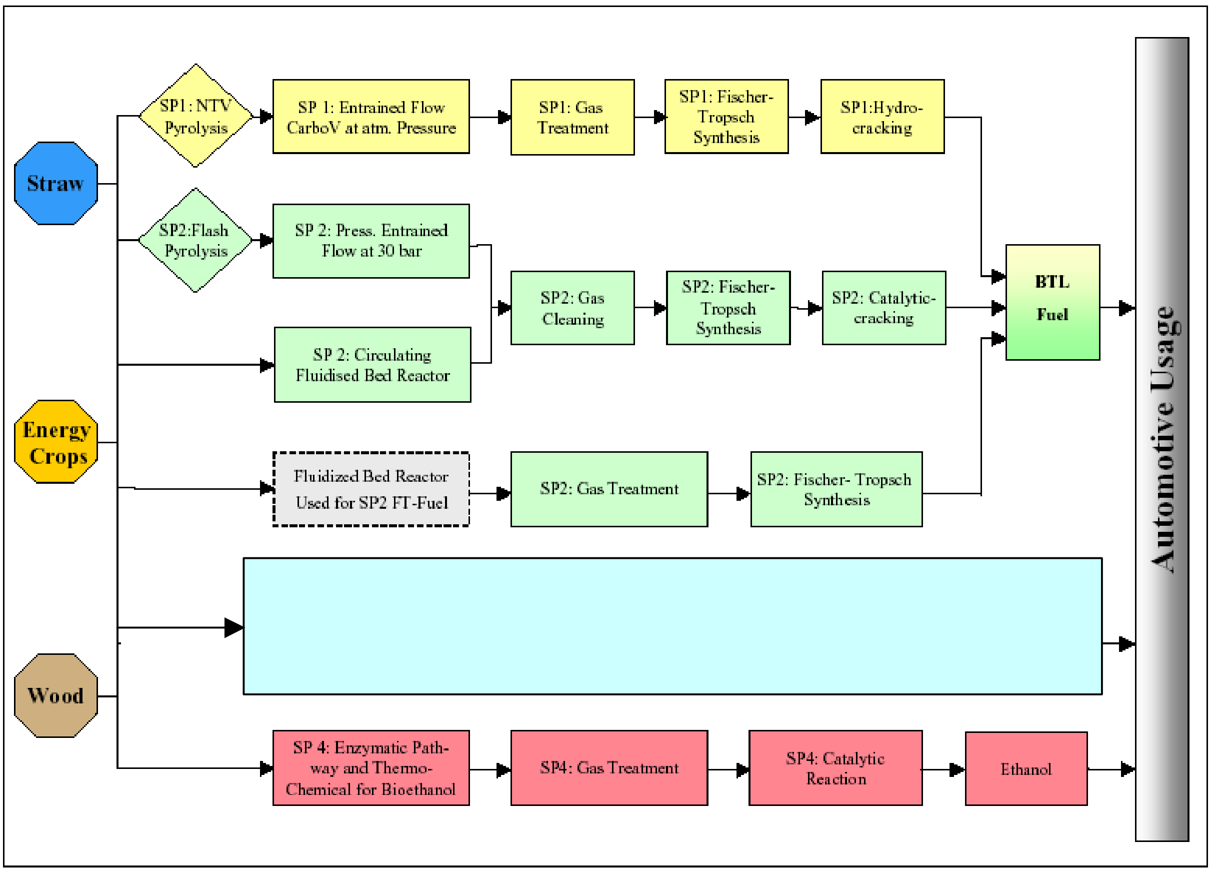

Fig. 5.1 Overview of subprojects and conversion routes developed within the RENEW project (RENEW 2003)

5.1 Biomass production and provision

Biomass can be specifically produced for the purpose of BTL-fuel production or it might arise as a by-product or residue from different types of technical processes. The following materials are proposed to be used and tested for the conversion technologies (Pisarek et al. 2004):

- Wood and forest residues (also used indirectly via black liquor[14]);
- Agricultural residues (corn stalks), by-products (straw),
- Energy crops (barley, wheat, sorghum, Jerusalem artichokes).

The biomass production or provision itself is not further developed within the RENEW project. However, the LCA includes the biomass provision. For that purpose LCI data for three types of biomass (short-rotation wood, straw and miscanthus) are investigated for different regions.

The inventory of the biomass inputs represents the average state of the art production of marketable products. Thus, small-scale farms are not included in the analysis. Organic production is only considered if there are good reasons to believe that these products will be used for BTL-fuel production and that they can be purchased at competitive prices.

Tab. 5.1 shows an overview of the system boundaries of the unit processes investigated for biomass production. The different types of flows and their inclusion or exclusion in the study are outlined. Biomass residues are not investigated as an input for conversion processes. According to a decision taken by the project team during the meeting in Engelberg intensive and extensive production are not distinguished.

Tab. 5.1 Overview on system boundaries of the unit processes investigated for biomass production

Flow	Included	Excluded
Technosphere inputs	Seeds, machinery, fuels, electricity, pesticides, fertilizer, transport services, waste management services.	Positive and negative effects on subsequent crops, consequences of shifts in production patterns.
Inputs from nature	Water, land, carbon	Soil quality, erosion, change of carbon content in soil
Outputs to nature	Emissions to air, water and soil, Emissions of NMVOC from plants (not included in LCIA).	O_2
Outputs to technosphere	Agricultural and forestry products and by-products.	Positive side effects of farm lands and forests, e.g. avalanche protection, habitat protection, provision of leisure possibilities, protection of the cultural landscape

5.2 Biomass preparation

Biomass has to be transported, stored and processed (e.g. dried) before it is delivered as a biofuel to the plant of the conversion process. The transport distance and transport modes are of special interest for the biomass supply. This depends on the actual size of conversion plants and the projected production capacities for biomass in the surrounding area.

[14] Black liquor is an internal product of pulp mills, resulting from the cooking of wood chips in digesters. The cooking produces a fibre, used for paper production, and an energy-rich black liquor stream. The use of black liquor for other purposes than steam production, implies that an energy substitution is required where wood is used for the steam production.

Tab. 5.2 shows an overview of the system boundaries of the biomass preparation. The different types of flows and their inclusion or exclusion within the study are outlined.

Tab. 5.2 Overview on system boundaries of the unit processes investigated for biomass preparation

Flow	Included	Ex-cluded
Technosphere inputs	Biomass, machinery, fuels, electricity, further consumables, storage facilities, transport services, waste management services.	-
Inputs from nature	Land occupation	-
Outputs to nature	Emissions to air and water from combustion and due to the process	-
Outputs to technosphere	Biofuel, marketable by-products	-

5.3 Overview of fuel conversion processes

Fig. 5.2 shows an overview of the process routes that can be used for BTL-fuel production. It consists of five major steps. In the first stage of gasification, different types of beds and process types are possible. The necessary energy for the process can be delivered allotherm (energy input from outside the reactor) or autotherm (oxidation of the biomass input in the reactor). In the automotive fuel synthesis different types of reactors and catalysts are used. The conditioning process of the fuel differs depending on the fuel.

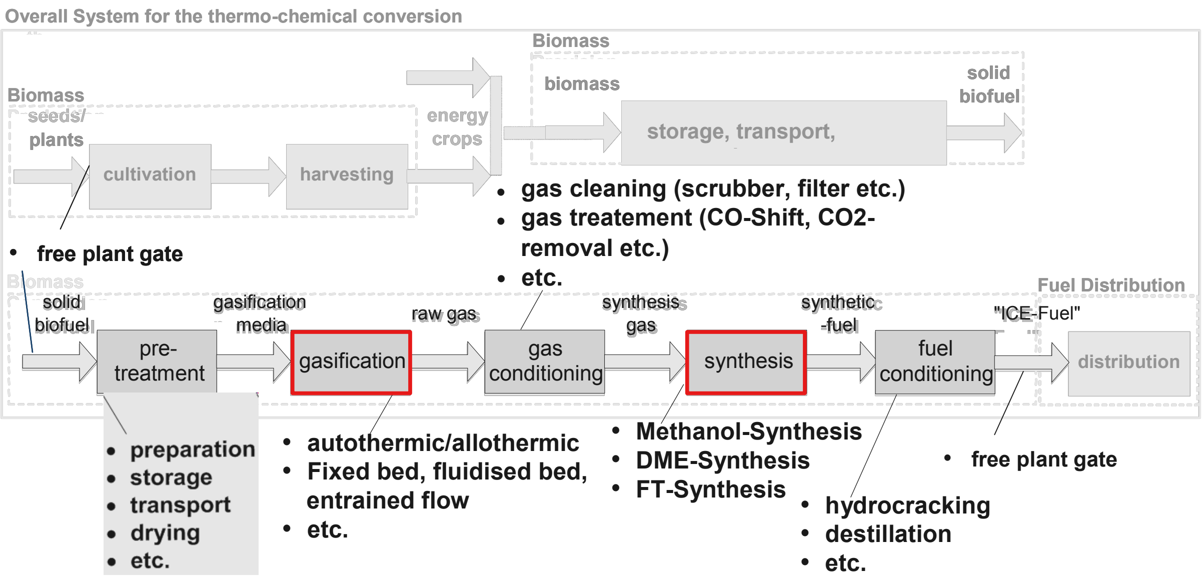

Fig. 5.2 Flow chart of generic conversion process and different process routes for the production of BTL-fuels

5.3.1 Pre-treatment

Pre-treatment of biomass at the conversion plant includes handling, short-intermediate storage and were necessary also pre-drying.

5.3.2 Gasification of solid biomass

The next stage in the production chain is the gasification of the biomass. Tab. 5.3 shows an overview of the gasification processes investigated within RENEW. The output of these processes is raw gas.

Tab. 5.3 Overview on gasification processes developed within the RENEW project

Work package, partner	Gasification process	Biomass	Energy input
SP1, UET	Choren/UET CARBO V®, Combined gasification: Low temperature gasification (pyrolysis) + entrained flow gasifier	Wood (other feedstocks possible)	Autotherm
SP2, CUTEC	Circulating fluidised bed steam gasification with steam and oxygen	Wood, grains, oil plants	Autotherm
SP2, FZK	Two-step fast pyrolysis followed by the pressurised entrained flow gasification for bio-oil slurries at 30 bar	Straw	Autotherm
SP2, TUV	Gasification with FICFB gasifier (Fast internal circulating fluidized bed)	Wood	Allotherm
SP3, Chemrec	Pressurized gasification of black liquor with oxygen in entrained flow reactor	Black liquor	Autotherm
SP4, WP2	Bubbling fluidised bed gasifier	Olive Waste, Black Poplar	Autotherm

5.3.3 Raw gas treatment

Downstream the gasifier the raw gases are conditioned and cleaned. The following pollutants are of interest: particles, halogen-compounds, sulphur-compounds, nitrogen-compounds, alkali-metals and tar. Conditioning may include one or several sub-processes e.g. tar removal, water gas-shift, COS hydrolysis, acid gas removal, methanation. The gases have to be treated in order to avoid a contamination of the catalysts and to derive the correct stoichiometry for the synthesis in the following fuel production stage (FNR 2004).

5.3.4 Fuel synthesis

The next stage of the fuel production is the synthesis of fuels from the purified synthesis gases. The process differs depending on the fuel in consideration, e.g. Fischer-Tropsch synthesis or others. The formulation of catalysts is an important factor for the process design. Cobalt and iron catalysts can be used for the synthesis. Iron-based catalysts have to be replaced periodically while cobalt-based catalysts have a longer life time (FNR 2004).

5.3.5 Fuel conditioning

Fuels are conditioned by hydro cracking, catalytic cracking, distillation and/or stabilisation. The synthetic fuel is mixed with additives and conditioned for further distribution to the final consumer. In some concepts, an external refinery treatment of FT-raw products is foreseen and modelled for this sub-process.

5.4 Investigated process routes for conversion processes

The production routes investigated for BTL-fuels in the RENEW project are a combination of the sub-processes described above. The different stages of biomass conversion to the BTL-fuel are investigated in individual unit processes. Data on biomass preparation, gasification, raw gas treatment, fuel synthesis and conditioning will not be compared among different conversion processes.

Tab. 5.4 shows an overview of the system boundaries of the unit processes investigated for the conversion of biomass to BTL-fuels. The different types of flows and their inclusion or exclusion within the study are outlined. Plant sizes will be considered for the modelling in the LCI according to the scenario definition (SP5-Partners 2007).

Tab. 5.4 Overview of system boundaries of the unit processes investigated for BTL-synthesis sub-processes

Flow	Included	Excluded
Technosphere inputs	Biomass, machinery, plant infrastructure, fuels, steam, electricity, catalysts, chemicals (e.g. hydrogen, acids), further consumables, transport services, waste management services.	Inputs for business management, marketing, plant maintenance and research are excluded because they are difficult to investigate. No data for additives.
Inputs from nature	Water, land	Oxygen, nitrogen, etc. in ambient air.
Outputs to nature	Emissions to air and water from combustion, processes and waste management	-
Outputs to technosphere	BTL-fuel, usable by-products	-

5.5 Fuel distribution

BTL-fuels are distributed to the end consumer. Within the RENEW project the use in powertrains is considered. Existing distribution chains might be used, but it is possible that they are reconsidered in order to be tailored for the BTL-fuels. The development of distribution chains is not part of the RENEW project. Nevertheless, the LCA will include the distribution in the analysis based on available generic data.

Prior to distribution, additives are added to the fuels. For all conversion processes the type and amount of chemicals used for this purpose was not known. In the LCA for refineries, these additives have only a minor contribution. Thus, they are neglected in the assessment.

Tab. 5.5 shows an overview of the system boundaries of the unit processes investigated for the distribution of BTL-fuels. The different types of flows and their inclusion or exclusion within the study are outlined.

Tab. 5.5 Overview on system boundaries of the unit processes investigated for BTL-fuel distribution

Flow	Included	Excluded
Technosphere inputs	BTL-fuel, storage facilities, fuel station infrastructure, electricity, further consumables, transport services, waste management services.	Inputs for business management, marketing, plant maintenance and research. Other activities of fuel stations, e.g. shops, garage, car washing, fuel additives.
Inputs from nature	Water, land	-
Outputs to nature	Emissions to air and water due to evaporative losses and cleaning activities.	-
Outputs to technosphere	BTL-fuel delivered to the tank	-

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Critical Review

(next pages)

RENEW
Renewable fuels for advanced powertrains

Critical Review

According to ISO 14040

by

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and

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June 2007

1 Procedural Aspects of the Critical Review

The Life Cycle Assessment (LCA) study to be reviewed is part of a larger EU-project (Sixth Framework Programme: Sustainable Energy Systems, co-financed by Switzerland) aiming at the technological feasibility of producing automotive fuels from biomaterials. The LCA has been performed by ESU-services Ltd. Uster (Switzerland), the practitioner, in collaboration with partners from European research institutes (LUND, ECBREC, CRES). The data collection and the work was co-ordinated by a consortium of European automotive manufacturers (Volkswagen, Daimler Chrysler, and Volvo) together with ESU-services. The whole RENEW consortium was coordinated by VW, Wolfsburg, Germany.

Originally it was planned (Klöpffer 2004) to review the 4 components of the LCA according to ISO 14040 (ISO 1997, 2006a) separately, starting in 2004:

- Scope and goal definition document (1st year)
- Inventory document (2nd year)
- Impact assessment document (3rd year)
- Interpretation and conclusions and final report (4th year)

The critical review was commissioned in March 2005. The official kick-off meeting took part 18th June 2005 in Berlin. The main aim of this meeting was the discussion of the Goal and Scope chapter of the LCA (delivery 5.2.2) submitted for review in March 2005. At that time it was decided that the inventory and impact assessment document (delivery 5.2.7) should be reviewed 2006 and the final Interpretation and conclusions document (delivery 5.2.10) should be reviewed 2007.

Unfortunately, due to delays in data acquisition, the inventory part could not be delivered in time, but rather – together with the final report – in March 2007. As a consequence, the critical review could not – or only partly – be performed in an interactive way, which is the preferred way to conduct a critical review (Klöpffer 2005). The critical review panel was in a position to comment the Goal and Scope part, but not the inventory part early enough to give advice for the further course of this important LCA. Actually, there was no communication between the practitioner team and the critical review panel for one and a half year. The advantage of a truly interactive critical was thus missed.

The second and final critical review meeting took part in Berlin the 14th of May 2007. The aim of this meeting was to discuss the final draft reports submitted in March 2007 and to plan the finalizing of both the LCA report and the critical review report.

This critical review is based on the three deliveries 5.2.2, 5.2.7 and 5.2.10 in their final versions, i.e. after corrections made by the practitioner according to the suggestions made by the review panel. The critical review process took place in a constructive atmosphere and under conditions of confidentiality. The resulting critical review report is consensus between the reviewers in all essential items.

2 General Impressions

The LCA-study under review is a comprehensive LCA in an emerging technological field whose political importance increased during the work to an unexpected degree. The environmental topic “Climate change” surfaced in the public awareness after years of nearly total neglect and also the second component – the limited availability of fossil resources – became a public topic (again) due to increasing oil prizes. The development of the fuels studied here is more recent compared to the established fuels bio-ethanol and bio-diesel. Originally it was planned to include bio-ethanol for comparison, but this part of the study was cancelled, because data could not be provided by the respective project partner. The Goal & Scope has been changed accordingly.

The three deliverables 5.2.2, 5.2.7 and 5.2.10, to be united into one report and containing this critical review as integral part, constitute doubtlessly an impressive work within the limits set by the goal & scope. We found the following general items worth to highlight:

- Comprehensiveness
- Transparent data format
- Use of original foreground data whenever possible (i.e. if delivered by the partners)
- Use of recent background data (ecoinvent)
- Excellent graphical presentation (except often very small letters)
- Realistic basis scenario

Less positive general items concern:

- Scenario 1 is not primarily based on environmental priorities
- The Life Cycle Impact Assessment (LCIA) using a restricted set of impact categories (no eco-toxicology) favours high efficiency models without a measure of negative ecological consequences
- "Island solution" for wind-parks delivering electrical power for hydrogen production to increase the efficiency

Despite these few restrictive items, the whole picture is a positive one. Most details which have been criticized by the reviewers in the first draft of the final report(s) have been taken into account in the final version. The study in its present form may serve as the basis of future LCAs and sustainability assessments as discussed in section 5.

3 Statements by the reviewers as required by ISO 14040

According to the LCA-framework standard ISO 14040 (ISO 1997, 2006a)
"The critical review process shall ensure that:

- *the methods used to carry out the LCA are consistent with the international Standard;*
- *the methods used to carry out the LCA are scientifically and technically valid;*
- *the data used are appropriate and reasonable in relation to the goal of the study;*
- *the interpretations reflect the limitations identified and the goal of the study;*
- *the study report is transparent and consistent."*

In the following sections 3.1 to 3.5 these items are discussed and answered to our best judgement in the light of the final report(s) and applying the international LCA-standards as the yardstick.

3.1 Are the methods used to carry out the LCA consistent with the international Standard?

During the work on this LCA-study (2004-2007), the first series of international LCA standards 14040-43 (ISO 1997, 1998, 2000a, 2000b) was replaced by a slightly modified set of two standards 14040 and -44 (ISO 2006a, 2006b). Since the new norms superseded the old ones in October 2006, they also constitute the yardstick for the final report. The actual differences are, however, so small (Finkbeiner et al. 2006) that the consequences for the critical review are minor. The critical review according to the panel method is more demanding according to new set of standards, requiring at least three experts. This is evidently fulfilled in the actual case. The structure of the LCA, which should be reflected in the structure of the study report, remained unchanged. Although the structure of the report does not follow exactly the structure of LCA, the essential components “Goal and scope definition”, “Inventory analysis”, “Impact assessment” and “Interpretation” are clearly recognizable and dealt with sufficient detail.

With regard to the system boundaries, which are described with enough details, we have to make the objection that no clear cut-off criteria are given; this is against the requirement set by the norm (ISO 14044, §4.2.3.3.3). Since we did not find that major processes were left out of the analysis of the systems, we think that – despite the evident lack of criteria - no significant asymmetries should occur in the systems studied.

With the exception of the points mentioned, no major deviation from the rules laid down in the standards were detected. We can therefore state **that the methods used are consistent with the international standard.**

3.2 Are the methods used to carry out the LCA scientifically and technically valid?

The methods used for collecting original data, to construct the systems and to calculate the inventory tables seem to be scientifically and technically up to date. It has to be noted, however, that the systems studied are defined from “well-to-tank” (roughly corresponding to “cradle-to-factory gate”). Systems without use and end-of-life phases are truncated and, therefore, cannot claim to analyse the systems “from cradle-to-grave”. This is not claimed in the study, however, and the conclusions which can be drawn are restricted. Since only different production routes for fuels were compared on the basis of their energy content (1 MJ), this truncation can be tolerated. The results do **not** allow, however, to prove the environmental superiority of one or the other fuel during use! For such assertions, “well-to-wheel” studies have to be done in the future, corresponding to “cradle-to-grave” in ordinary LCA language. The main reason for this restriction, beyond formal requirements by the standards, is the possible formation of environmentally problematic emissions by some of the fuels during combustion in the engines.

The general framework of this LCA is the attributional (i.e. classical) one which is the basis of the guidelines and standards by SETAC (SETAC 1993) and ISO. This method is valid as long as the introduction of a new technology does not alter the economy or technosphere in such a way that other important technologies (such as food production) are not significantly altered due to the competition with the new one.

The analysis uses two scenarios (a third one foreseen originally was cancelled), a status quo scenario and a "Scenario 1" which strives for optimal efficiency and includes electrical energy produced in wind parks to produce hydrogen used for increasing the amount of fuel. This scenario describes fuel production from biomass **and** wind power. The wind parks are treated as "islands", i.e. not connected with the European electricity grid in the main scenario. The electricity grid is used in a sensitivity analysis, however.

The impact assessment method used is essentially based on standard CML methodology (Guinée et al. 2002) using midpoint indicators (e.g. the Global Warming Potential, time horizon 100 years - GWP_{100} - for the impact category "Climate change"). A similar midpoint method, using slightly different impact indicators, EDIP (Wenzel et al. 1997; Hauschild and Wenzel 1997) was used as a sensitivity analysis in several cases. Furthermore, the Cumulative Energy Demand, CED (VDI 1997) has been used as an additional category in order to measure the total primary energy demand per MJ, the reference flow used for all fuels studied. This "impact category" does not perfectly fit into the ISO LCIA scheme (ISO 2000a, 2006b), but it is a very useful energy accounting method compatible with LCA and included in the Dutch guidelines and in the Swiss ecoinvent data base and LCA method (Guinée et al. 2002; Jungbluth & Frischknecht 2004).

The LCIA-relevant ISO standards (ISO 2000a, 2006b) do not prescribe a list of impact categories or specific indicator models, characterisation factors etc. It is only required to give the reasons for the selection of a specific set of categories and indicators. In LCA studies dealing with agriculture, forestry etc. it is advisable to include eco-toxicology as an impact category in addition to the traditional categories (e.g. acidification, eutrophication and photo-oxidation). This is not the case in this study, since no consensus was obtained in the project team. This omission is seen as a missed chance to improve LCIA and finally the results of the comparative studies. Land use is included using inventory data for land occupation (m^2 a). Since an internationally accepted method for assessing all aspects of land use is missing (Udo de Haes et al. 2002), the use of inventory data is certainly a good compromise. The same is true for the use of the resource water, which is also expressed by unweighed inventory data. Precipitation is lumped together with irrigation, however, the latter being only distinguished by the additional use of energy for pumping. The scarcity of this resource in the southern countries, in contrast to the rest of Europe, is therefore not clearly indicated.

Despite these deficiencies, the methods used are clearly within the limits of the standards and of the international practice. It can therefore be stated that **the methods used are scientifically and technically valid** within the limited framework of this study. Using modern LCIA methods (e.g. Jolliet et al. 2004) would have given signals for further, more advanced work in this area.

3.3 Are the data used appropriate and reasonable in relation to the goal of the study?

In order to assess the quality of the data used in this study it is necessary to distinguish between the foreground system, which is within the (future) producers sphere of influence and the background system which is not. Regarding to foreground, the quality of the data strongly depend of the status of development of the different methods. These data have been provided by the project partners. In some cases there are already pilot plants from which realistic extrapolations can be done; in others only small-scale (more or less laboratory-type) production is available. A third class of data consists of estimates and calculations.

Overall, data are well documented and of reasonable quality.

In general we consider the scales of the future plants (scenario 1) as realistic. What is less clear is to what extent improvement options in the whole chain have been included, both in the direct processes in the plants itself and in the indirect processes. Some examples of the latter where reasonably to be expected improvements have at least not been included

explicitly are e.g. with N_2O emissions during N-fertiliser production or with the relation between future crop yields and the amount of nitrogen required for this.
Summing up, the foreground data provided by the project partners are of differing quality.

The background data are taken from the ecoinvent data bank (Frischknecht 2005), the most advanced European data bank which is 100% compatible with the LCI method used in this LCA study.

Taking in mind the deficiencies with some foreground data, for which the practitioner cannot be blamed, it can be stated **that the data used are appropriate and reasonable in relation to the goal of the study.**

3.4 Do the interpretations reflect the limitations identified and the goal of the study?

The interpretations are in general cautious. Since no weighting is used, as required by the ISO standards for studies in which comparative assertions intended to be made available to the public are made, the results of the comparisons are often not unambiguous. There is one general result, however, namely the efficiency of the biomaterial production "at the field (or forest)" is of prime importance and seems to overrule the technical details of the different industrial production processes. Since a better efficiency is obtained with intense agriculture – as opposed to the organic one – it will be a great challenge to improve this modern agriculture in such a way that it can compete the more extensive ways of agriculture proposed with good reasons for the production food.

The main limitations of this study are the restriction to "well-to-tank" and the attributional mode of conducting the LCAs. No conclusions are drawn surpassing these limitations, e.g. by speculating about the further fate of the new production methods once they will be fully developed and contribute significantly to the European automotive fuel market.

Considering the early development status of the systems studied, it can be stated **that the interpretations reflect the limitations identified and the goal of the study.**

3.4 Is the study report transparent and consistent?

The report has been improved considerably and most comments by the reviewers were taken into account. It is well readable, illustrated with coloured diagrams and the length seems to be appropriate for the systems covered.

The four components of LCA are presented and discussed in due detail. The component "Interpretation" could be better separated from "Impact Assessment", since the report should mirror the basic structure of LCA with four components.

Although not all data could be presented, it can be said the data structure is exemplary. The results are given in great detail, using tables and figures. The letter size in the tables is too small, however.

Each of the three parts is preceded by an excellent executive summary. No major discrepancies between the different parts of the reports could be found.

Finally, it can be stated **that the report is transparent and consistent.**

4 Résumé and recommendations

First of all, we should clearly state what this LCA is **not**. Most importantly, it is not a full (cradle-to-grave or well-to-wheel) LCA, in full accordance with Goal & scope. Therefore, no conclusions can be drawn on the relative virtues of the fuels investigated **as fuels for use in automotive transport.** It is also not a comparative study of the type "fossil- versus biomass-based" fuels. Actually this topic is hardly mentioned and even the more established biofuels (bio-ethanol and bio-diesel) are not treated, although the former had been on the agenda originally. No comparative energy balances, no CO_2-balances (relative to fossil fuels). These comparisons are, of course, very interesting from the point of view "climate change" and should be done in the near future.

Within the limitations of this study, which are clearly stated, **the requirements by ISO 14040/44 are fulfilled.**

This study should not be an end in itself, but rather a starting point for more comprehensive studies aiming at the urgent questions whether or not biomass-based fuels will be able to replace at least part of the fossil fuels in Europe. This automatically leads to the next problem, since the classical ("attributive") LCA is clearly not suited for studies involving a drastic change of the economic and technological background. Will the more recent "consequential" LCA (Ekvall 1999; Weidema et al. 1999; Weidema 2002), which in principle takes into account changes brought about by a new technology, be suitable for systems of that size? Or should these problems dealt with using other instruments? The review panel cannot yet give a clear recommendation.

In future work, the LCIA should be extended in order to recognise and finally prevent problem shifting. This is the foremost duty of the instrument LCA.

It is strongly recommended that the three "deliveries" should be transformed into one final report and published without cuttings. The critical review is part the report. Practitioner and commissioner have the right to comment the critical review. These comments, if there are any, are also part of the report.

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