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Life Cycle Assessment of BTL-fuel production: Inventory Analysis

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Executive Summary “Life Cycle Inventory Analysis”

Introduction

The report at hand was 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.

The LCA method aims to investigate and compare environmental impacts of products or services that occur along their supply chain from cradle to grave. The method is standardized by the International Organization for Standardization (ISO).

Within the RENEW project, different production routes of 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 and straw, gas treatment and synthesis;
- 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;
- BTL-DME (dimethylether) and methanol production by entrained flow gasification of black liquor from a kraft pulp mill, gas treatment and synthesis. Biomass is added to the mill to compensate for the withdrawal of black liquor energy;
- Bioethanol production by different processes from different feedstock.

This report describes the life cycle inventory analysis (LCI) for the LCA study of different conversion technologies.

Goal of the study

The goal of the LCA is to compare different production routes of BTL-fuels (FT-diesel and dimethylether) from an environmental point of view. The environmental impacts of different conversion routes developed in the RENEW project are investigated for that purpose. The different conversion concepts are compared. Emissions from using the fuel are not taken into account in this analysis. A comparison with fossil fuels is not made here. A detailed description of the goal and scope definition of this LCA can be found in a separate report of this project (Jungbluth et al. 2007a).

Scope and system boundaries

The life cycle inventory includes all process stages from well-to-tank for BTL-fuels. This includes resource extraction or biomass production, transportation, storage, fuel conversion and distribution. The functional unit for the comparison of BTL-fuel production routes is defined as the energy content delivered to the tank. The reference flow is 1 MJ fuel, expressed by the lower heating value.

The inventory within the LCA considers all relevant environmental flows according to the attributional modelling principle. Thus the results show the environmental impacts caused by the production processes. The modelling does not consider changes introduced by the extension of the market share of these production processes or increased production of biofuels.

The environmental impacts of multi-output processes are allocated based on different principles that reflect best the causalities of material and energy flows.

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 (SP5-Partners 2007).

Starting point calculation

The so-called “starting point calculation” addresses the possible production route in the near future. Average data representing agricultural and harvesting technology of today are used for these production systems. Farms with very small production volumes, which are not supplied to the market, are not considered in the assessment. The inventory of the conversion processes is based on the actual development state of the different technologies. In a nutshell this means “assuming we would erect such a plant today, what would the plant look like?” In this scenario the operation of the biomass to biofuel plant is self-sufficient, which means that the plant uses energy only out of biomass. Thus, no direct external electricity or other non-renewable energy supply is considered in the process models.

Scenario 1

In scenario 1 a modelling of a maximized fuel production is made. The supply chain is supposed to be as efficient as possible regarding biofuel production. One of the highest criteria of the evaluation is the ratio of biofuel production to needed agricultural land. The use of hydrogen improves the carbon/hydrogen-ration and thus leads to a higher conversion rate of biomass to fuel. External conventional electricity input into the production system is used in most of the conversion concepts for providing the necessary hydrogen.

A quite crucial point in scenario 1 is the assumption on the hydrogen supply for the biomass conversion. The way in which the electricity for the water electrolysis is produced has important consequences for the costs and the environmental performance of the conversion concept. Here we assume that the external electricity is provided with wind power plants. This is assumed by the project team as one option for a maximized fuel production based on renewable energy.

It is not realistic to get such a renewable electricity supply until 2020 for more than a small number of conversion plants, but this scenario describe a direction that might be worth going. Only if there would be the possibility in 2020 for hydrogen from wind power, the conversion rate biomass to fuel could be increased in the way modelled here. Due to the limited production capacity until 2020, this scenario does not describe a general improvement option, but an option for special locations. The influence of using the average electricity in Europe is shown in a sensitivity analysis.

For biomass production, it is assumed that inputs of fertilizers and pesticides are higher than for today. In addition, the yield are higher than today.

Biomass production

Three types of biomass inputs are studied for the conversion to BTL-fuels. These are short rotation wood (willow-salix or poplar), miscanthus and wheat straw. The life cycle inventory data of biomass production are based on regional data investigated for Northern, Eastern, Southern and Western Europe. The data were collected by regional partners from the RENEW project. The main assumptions about the intermediate storage of biomass are harmonized with partners from WP5.3 of the RENEW project.

Table 1 shows some key figures from the life cycle inventory analysis of biomass products and intermediate storage. A critical issue in the inventory of wheat straw is the allocation between wheat straw and wheat grains. In the base case, this allocation is made with today market prices. This gives an allocation factor of about 10% to the produced straw. A sensitivity analysis is calculated based on the energy content, which leads to an allocation factor of 43% to the produced straw.

Several influencing factors are taken into account for the modelling in scenario 1. These are e.g. intensified agriculture in Eastern Europe, improvements in plant species and agricultural technology, achievements of maximized yields by higher inputs of fertilizers and pesticides. The different requirements give not one direction of development. Scenario 1 also does not give a clear picture of the average biomass production in the year 2020 compared to the situation investigated for today in the starting point calculation.

Table 1 Key figures of the life cycle inventory of biomass production, allocation between wheat straw and grains based on today market price

		bundles, short-rotation wood	bundles, short-rotation wood	miscanthus-bales	miscanthus-bales	wheat straw, bales	wheat straw, bales
		starting point	scenario 1	starting point	scenario 1	starting point	scenario 1
N-fertilizer	g/kg DS	5.2	6.3	4.0	5.6	2.2	1.8
P2O5-fertilizer	g/kg DS	4.0	3.5	3.1	2.8	1.1	0.8
K2O-fertilizer	g/kg DS	6.4	5.4	5.1	4.3	0.9	1.5
Lime	g/kg DS	6.5	5.9	3.6	2.4	4.4	2.8
diesel use	g/kg DS	5.1	4.9	4.3	3.3	2.3	1.4
yield, bioenergy resource	kg DS/ha/a	10'537	12'630	14'970	20'504	4'900	6'719
yield, wheat grains	kg DS/ha/a	-	-	-	-	3'718	4'428
energy content of biomass	MJ/kg DS	18.4	18.4	18.8	18.8	17.2	17.2
losses during storage	%	7%	4%	6%	3%	6%	3%

DS dry substance

Data analysis for conversion processes

Data for the conversion processes were provided by different plant developers in the RENEW project. The data are mainly based on technical modelling of such plants, which is based on experiences and knowledge gained from the research work done in the RENEW project. The data are crosschecked as far as possible with project partners doing the technical assessment of the conversion concepts. Further details about the data quality check can be found in the WP5.4-reports.

Where so far no reliable first-hand information is available (e.g. emission profiles of power plants, concentration of pollutants in effluents or the use of catalysts) assumptions are based on literature data. Thus, sometimes it is difficult to distinguish between different process routes because differences could not be investigated. Table 2 provides an overview on the data provided by different partners and the generic assumptions used for modelling of the conversion processes.

We like to emphasise that the different conversion processes investigated in this study, have different development degrees. That means that the data presented in this report represent the current development status of the respective technology. A lot of effort was put to produce LCI data as best as possible.

All conversion concepts are based on their optimal technology. Four concepts are investigated on a scale of 500 MW biomass input and one was investigated based on 50 MW biomass input. Some conversion concepts might be improved by increasing the plant size to up to 5 GW. This has not been considered in this study.

The products produced by the different process chains are not 100% identical with regard to their physical and chemical specifications. Therefore, a possible further use of the data in other studies or investigations has to be reflected under these circumstances. Interpretations and especially comparisons based on the data developed in this study must consider the herewith-linked technology background.

Table 2 Overview on data provided by different conversion plant developers

Concept	Centralized Entrained Flow Gasification	Centralized Autothermal Circulating Fluidized Bed Gasification	Decentralized Entrained Flow Gasification	Allothermal Circulating Fluidized Bed Gasification	Entrained Flow Gasification of Black Liquor for DME-production
Abbreviation	cEF-D	CFB-D	dEF-D	ICFB-D	BLEF-DME
Developer	UET	CUTEC	FZK	TUV	CHEMREC
Biomass input	Amount and type	Amount and type	Amount and type	Amount and type	Amount and type
Biomass type	Wood, straw	Wood, straw	Straw	Wood, miscanthus	Wood, black liquor
Heat and electricity use	Provided	Provided	Provided and own assumptions	Provided	Provided
Auxiliary materials	Hydrogen, Fe(OH)2	Filter ceramic, RME, silica sand, quicklime, iron chelate	Nitrogen, silica sand	Nitrogen, RME, quicklime, silica sand	No auxiliaries reported
Catalysts	Literature	Literature	Literature	Amount of zinc catalyst	Literature
Emission profile	Literature for gas firing and plant data for CO	Literature for gas firing	Literature for gas firing, plant data for H_2S and own calculations	Literature for gas firing and plant data for CO, CH_4, NMVOC	Literature for wood firing and plant data for CO, H_2S, CH_4
Amount of air emissions	Calculated with emission profile and CO_2 emissions	Calculated with emission profile and CO_2 emissions	Calculated with emission profile and own assumptions on CO_2.	Calculated with emission profile and CO_2 emissions	Calculated with emission profile and CO_2 emissions
Effluents	Amount and concentrations	Only amount. Rough assumption on pollutants	Only amount. Rough assumption on pollutants	Only amount. Rough assumption on pollutants	Amount and TOC concentration. Rough assumption on pollutants
Wastes	Amount and composition	Only amount	Only amount	Only amount	Only amount
Fuel upgrading	Included in process data	Standard RENEW model for upgrading	Standard RENEW model for upgrading	Standard RENEW model for upgrading	Included in process data
Products	BTL-FT, electricity	FT-raw product, electricity	FT-raw product, electricity	FT-raw product, electricity	BTL-DME

Key figures for starting point calculation on conversion concepts

Key figures on the starting point calculation are summarized in Table 3. Here we show the conversion rate from biomass to fuel in terms of energy, the plant capacity and the production volume per hour. The BLEF-DME[1] process has the highest conversion rate followed by the cEF-D process. The ICFB-D process has a rather low conversion rate (biomass to fuel) because it produces large amounts of electricity as a by-product. The electricity is only burdened with the direct air emissions from the power plant, but not with the production of biomass. This is a worst case assumption for the BTL-fuel and reflects the project idea of mainly producing fuel.

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[1] BLEF-DME stands for Entrained Flow Gasification of Black Liquor for DME (dimethylether)-production, see Table 3 for further abbreviations of production processes.

Table 3 Starting point calculation. Key figures of conversion processes: conversion rate between biomass input and BTL-fuel output in terms of energy

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

toe tonnes oil equivalent with 42.6 MJ/kg

Key figures for Scenario 1 on conversion concepts

The idea of scenario 1 is to maximize the biomass conversion rates. Due, to external inputs of electricity it is even possible to achieve biomass to fuel conversion rates higher than 100%. We summarize the key figures for scenario 1 in Table 4.

The conversion rates vary quite a lot between the different processes. The conversion rate of the ICFB-D process is in the range of the figures presented by other plant operators for the starting point calculation. There is no external hydrogen input for this conversion process.

According to the data provided and used, the cEF-D process has the highest conversion rate. The process CFB-D has a similar conversion rate like the ICFB-D process, but with quite different amount of hydrogen input. The differences and reasons for the technical differences are further analysed in WP5.4 of the RENEW project.

The demand on external electricity ranges between 135 and 515 MW. With an installed capacity of 1.5 MW per wind power plant, a wind park with 100 to 400 units of wind power plants is required for one conversion plant. The production of biofuels would be quite dependent on the actual supply situation. The dEF-D process is strictly speaking not mainly producing a fuel from biomass, but from wind energy as more than half of the energy input is electricity.

Table 4 Scenario 1. Key figures of conversion processes. Ratio biomass input to BTL-fuel output in terms of energy and hydrogen input

	Biomass	Wood	Wood	Straw	Straw	Wood	Miscanthus
	Process	Centralized Entrained Flow Gasification	Centralized Autothermal Circulating Fluidized Bed Gasification	Centralized Autothermal Circulating Fluidized Bed Gasification	Decentralized Entrained Flow Gasification	Allothermal Circulating Fluidized Bed Gasification	Allothermal Circulating Fluidized Bed Gasification
	Product	BTL-FT	BTL-FT	BTL-FT	BTL-FT	BTL-FT	BTL-FT
	Code	cEF-D	CFB-D	CFB-D	dEF-D	ICFB-D	ICFB-D
	Developer	UET	CUTEC	CUTEC	FZK	TUV	TUV
conversion rate (biomass to all liquids)	energy	108%	57%	56%	91%	55%	57%
capacity biomass input (MW)	power	499	485	464	455	518	498
external electricity, including H2 production	MW	489	135	149	515	-	-
hydrogen input conversion	kg/kg product	0.24	0.13	0.13	0.34	-	-
all liquid products (diesel, naphtha, DME)	toe/h	45.6	23.4	21.9	34.9	24.1	24.0

toe tonnes oil equivalent with 42.6 MJ/kg

Sensitivity analysis

A sensitivity analysis within the life cycle inventory analysis covers the following most important issues:

Wheat grains and wheat straw are produced as together. In the base case, we assume an allocation of all inputs and outputs based on the today market price. This attributes only a small part (10%) of the mass and energy flows to the production of straw. A sensitivity analysis is performed with an allocation based on the energy content, which is similar to the amount of dry matter of straw and grains harvested.

The ICFB-D process has a plant layout designed for the cogeneration of electricity and heat together with BTL-FT production. In the base-case, all environmental impacts of biomass provision are allocated to the fuel production. A sensitivity analysis is performed that takes into account that biomass is also a necessary input for the electricity delivered to the grid.

A crucial point in scenario 1 is the provision of electricity for the production of hydrogen. In the base case, a supply from wind power plants is assumed. This is not realistic for a large-scale production in Europe due to capacity limitations. Thus, a sensitivity analysis is performed taking into account the average central European electricity mix.

Electronic data format and background data

All inventory data investigated in this report are recorded in the EcoSpold data format. The format follows the ISO-TS 14048 recommendations for data documentation and exchange formats. It can be used with all major LCA software products.

All background data, e.g. on fertilizer production or agricultural machinery are based on the ecoinvent database. This has been investigated following the same methodological rules as used in this study. The quality of background data and foreground data is on a comparable and consistent level and all data are fully transparent.

Next steps

The interpretation and main findings of the comparative LCA study of RENEW can be found in deliverable 5.2.10 (Jungbluth et al. 2007b).

The goal of this study implies a comparative assertion of different options that are disclosed to the public. Because of this, a critical review by three external LCA experts is performed. The review evaluates whether that all stages of the LCA are conducted according to the LCA ISO standards.

Abbreviations and Glossary

a	annum (year)
AGR	Acid Gas Removal which is the same as Gas cleaning used to take out the acidic gases CO2 and H2S.
ASU	air separation unit
BFW	Boiler Feed Water and is de-ionized water of quality suitable to be added into a steam system
biodiesel	vegetable oil methyl ester, liquid product from esterification of vegetable oils
biogas	product gas produced by bio-chemical digestion
BLEF-DME	Entrained Flow Gasification of Black Liquor for DME-production
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
cEF-D	Centralized Entrained Flow Gasification
CFB	circulating fluidized bed
CFB-D	Centralized Autothermal Circulating Fluidized Bed Gasification
CFBR	Circulating-Fluidized-Bed-Reactor
CH	Switzerland
conf	confidential
DE	Germany
dEF-D	Decentralized Entrained Flow Gasification
DME	dimethylether
DS	dry substance or dry matter
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
FCC	fluid catalytic cracking
FICFB	Fast internal circulating fluidized bed (Güssing plant)
FT	Fischer-Tropsch (synthesis)
GR	Greece
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”
ICE	internal combustion engine
ICFB-D	Allothermal Circulating Fluidized Bed Gasification
ISO	International Organization for Standardization
LCA	life cycle assessment
LCI	life cycle inventory analysis
LHV	lower heating value
low caloric gas	product gas with a lower heating value <9 MJ/m^3; also called poor gas
LTV	low temperature gasifier

middle caloric gas	product gas with a lower heating value of $9<LHV<15$ MJ/m³, also called middle gas
nd	no data
NG	natural gas
PL	Poland
PM	particulate matter
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	Country code for Europe
RME	rape seed methyl ester (Rapsölmethylester)
sc1	Scenario 1
SE	Sweden
SETAC	Society of Environmental Toxicology and Chemistry
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)
toe	tonnes oil equivalent with 42.6 MJ/kg
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 is investigated and a life cycle assessment (LCA) of several technologies is performed.

Representatives of 32 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. Different scenarios for the BTL-fuel chains will be considered in the LCA. The aim of the LCA is to compare and to give recommendations for improvements of the different production routes from an environmental point of view.

The LCA is one work package (WP5.2) out of five in the subproject 5 (SP5). Work package 1 (WP5.1) investigates the potential of 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

In this chapter, you will find helpful information for understanding the following modelling approach for the life cycle of BTL-fuels. The life cycle inventory for the production of biomass can be found in chapter 2. The conversion processes are investigated in chapter 3. Finally, chapter 4 investigates the distribution of the fuels to the final consumer. Each chapter includes also a more detailed definition of the system boundaries of the life cycle inventory analysis.

1.3 Description of the electronic data format according to ISO 14048

In accordance with the goal and scope definition, the inventory analysis has been conducted as far as possible in an electronic format in compliance with the technical specification ISO/TS 14048. The EcoSpold format has been used for this purpose. The format has been developed in the ecoinvent project (Frischknecht et al. 2004b). It is based on the Spold format for LCA. All unit process data are available in electronic format as XML files. These files can be directly imported and used with all major LCA software products, e.g. GaBi, SimaPro or Umberto. The format is considered to comply also with the technical specification ISO/TS 14048.

Thus, the data are presented quite often in form of tables, which are a direct printout of the electronic format. Some reading guidance is given in this section. The so called EcoSpold data format is briefly described in this chapter. For a more extensive description, we refer to Hedemann & König (2003) and to the three dataset schemas available via the Internet.[2]

A process, its products and its life cycle inventory data are documented using the ecoinvent data format (EcoSpold) with the basic structure shown in Tab. 1.1.

Tab. 1.1 Structure of the EcoSpold data format

Meta information			
	Process		
		ReferenceFunction	defines the product or service output to which all emissions and requirements are referred to
		TimePeriod	defines the temporal validity of the dataset
		Geography	defines the geographical validity of the dataset
		Technology	describes the technology(ies) of the process
		DataSetInformation	defines the kind of process or product system, and the version number of the dataset
	Modelling and validation		
		Representativeness	defines the representativeness of the data used
		Sources	describes the literature and publications used
		Validations	lists the reviewers and their comments
	Administrative information		
		DataEntryBy	documents the person in charge of implementing the dataset in the database
		DataGenerator AndPublication	documents the originator and the published source of the dataset
		Persons	lists complete addresses of all persons mentioned in a dataset
Flow data			
		Exchanges	quantifies all flows from technical systems and nature to the process and from the process to nature and to other technical systems
		Allocations	describes allocation procedures and quantifies allocation factors, required for multi-function processes

1.3.1 Unit process description (Meta Information)

The following Tab. 1.2 shows an example of the data documentation. Column A provides some additional description for structuring the different lines. It is not part of the XML-files. In column C one can find the data field names. The following columns provide information for one unit process. In the report several such columns for similar processes might be shown together.

In this example, the information refers to the unit process “diesel, used by tractor”. The process has been investigated for the location “RER”. This stands for Europe. Two character location codes like DE, PL, etc. stand for countries and they are similar to the country abbreviations used for internet addresses. They are based on an ISO standard. Three character abbreviations stand for regions like Europe (RER), Global (GLO), Oceans (OCE), etc. A full list of abbreviations can be found on http://www.ecoinvent.ch/en/publikationen.htm#list%20of%20ecoinvent%20names.

The following line 4 (*InfrastructureProcess*) defines whether the unit process is an infrastructure process (1) or not (0). Some LCA software generally neglect infrastructure processes and thus this information is necessary for a clear identification.

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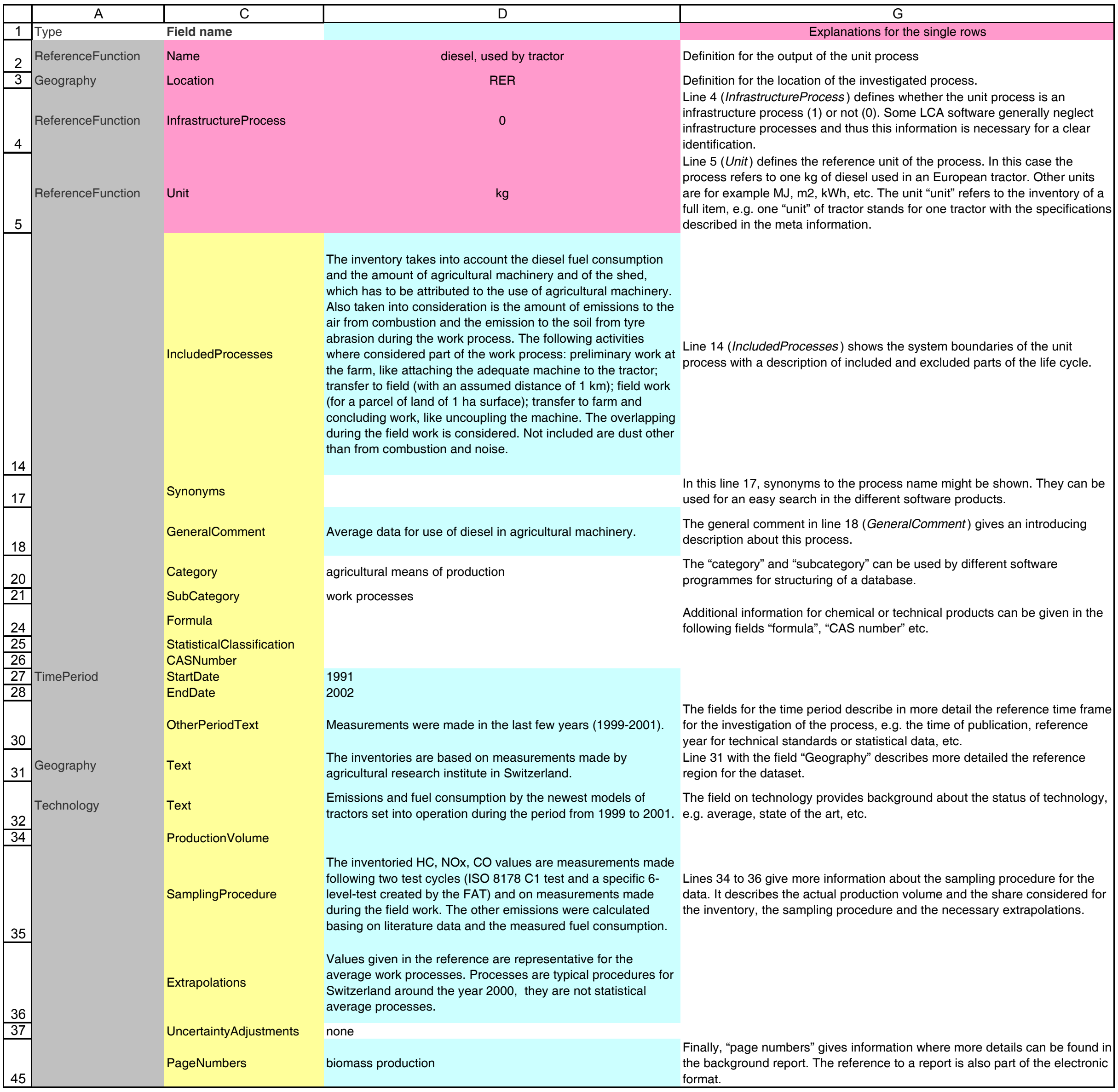
[2] www.ecoinvent.ch → Publications → ecoinvent Documents and Technical Specifications → Data exchange format (EcoSpold)

Line 5 (*Unit*) defines the reference unit of the process. In this case the process refers to one kg of diesel used in a European tractor. Other units are for example MJ, m^2, kWh, etc. The unit "unit" refers to the inventory of a full item, e.g. one "unit" of a tractor stands for one tractor with the specifications described in the meta information.

For all following rows an explanation is provided in column G of Tab. 1.2. These explanations are not part of the electronic format.

As one can recognize from the numbering of the lines, several rows of the format, which are not of interest for the common reader but for the software developer, have been excluded from this simplifying description. Detailed and complete information is available by Hedemann & König (2003).

Tab. 1.2 Example for the documentation of a unit process



	A	C	D	G
1	Type	**Field name**		Explanations for the single rows
2	ReferenceFunction	Name	diesel, used by tractor	Definition for the output of the unit process
3	Geography	Location	RER	Definition for the location of the investigated process.
4	ReferenceFunction	InfrastructureProcess	0	Line 4 (*InfrastructureProcess*) defines whether the unit process is an infrastructure process (1) or not (0). Some LCA software generally neglect infrastructure processes and thus this information is necessary for a clear identification.
5	ReferenceFunction	Unit	kg	Line 5 (*Unit*) defines the reference unit of the process. In this case the process refers to one kg of diesel used in an European tractor. Other units are for example MJ, m2, kWh, etc. The unit "unit" refers to the inventory of a full item, e.g. one "unit" of tractor stands for one tractor with the specifications described in the meta information.
14		IncludedProcesses	The inventory takes into account the diesel fuel consumption and the amount of agricultural machinery and of the shed, which has to be attributed to the use of agricultural machinery. Also taken into consideration is the amount of emissions to the air from combustion and the emission to the soil from tyre abrasion during the work process. The following activities where considered part of the work process: preliminary work at the farm, like attaching the adequate machine to the tractor; transfer to field (with an assumed distance of 1 km); field work (for a parcel of land of 1 ha surface); transfer to farm and concluding work, like uncoupling the machine. The overlapping during the field work is considered. Not included are dust other than from combustion and noise.	Line 14 (*IncludedProcesses*) shows the system boundaries of the unit process with a description of included and excluded parts of the life cycle.
17		Synonyms		In this line 17, synonyms to the process name might be shown. They can be used for an easy search in the different software products.
18		GeneralComment	Average data for use of diesel in agricultural machinery.	The general comment in line 18 (*GeneralComment*) gives an introducing description about this process.
20		Category	agricultural means of production	The "category" and "subcategory" can be used by different software programmes for structuring of a database.
21		SubCategory	work processes	
24		Formula		Additional information for chemical or technical products can be given in the following fields "formula", "CAS number" etc.
25		StatisticalClassification		
26		CASNumber		
27	TimePeriod	StartDate	1991	
28		EndDate	2002	
30		OtherPeriodText	Measurements were made in the last few years (1999-2001).	The fields for the time period describe in more detail the reference time frame for the investigation of the process, e.g. the time of publication, reference year for technical standards or statistical data, etc.
31	Geography	Text	The inventories are based on measurements made by agricultural research institute in Switzerland.	Line 31 with the field "Geography" describes more detailed the reference region for the dataset.
32	Technology	Text	Emissions and fuel consumption by the newest models of tractors set into operation during the period from 1999 to 2001.	The field on technology provides background about the status of technology, e.g. average, state of the art, etc.
34		ProductionVolume		
35		SamplingProcedure	The inventoried HC, NOx, CO values are measurements made following two test cycles (ISO 8178 C1 test and a specific 6-level-test created by the FAT) and on measurements made during the field work. The other emissions were calculated basing on literature data and the measured fuel consumption.	Lines 34 to 36 give more information about the sampling procedure for the data. It describes the actual production volume and the share considered for the inventory, the sampling procedure and the necessary extrapolations.
36		Extrapolations	Values given in the reference are representative for the average work processes. Processes are typical procedures for Switzerland around the year 2000, they are not statistical average processes.	
37		UncertaintyAdjustments	none	
45		PageNumbers	biomass production	Finally, "page numbers" gives information where more details can be found in the background report. The reference to a report is also part of the electronic format.

1.3.2 Unit process inventory (Flow Data)

The unit process inventory is an inventory of energy and material flows (in- and outputs), which are used or emitted by a 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, waste management services or seeds) or outputs (e.g. the product). 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 from a technical process to the environment, e.g. the emission of a certain amount of SO_2.

Fig. 1.1 shows the unit process flow chart of 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.

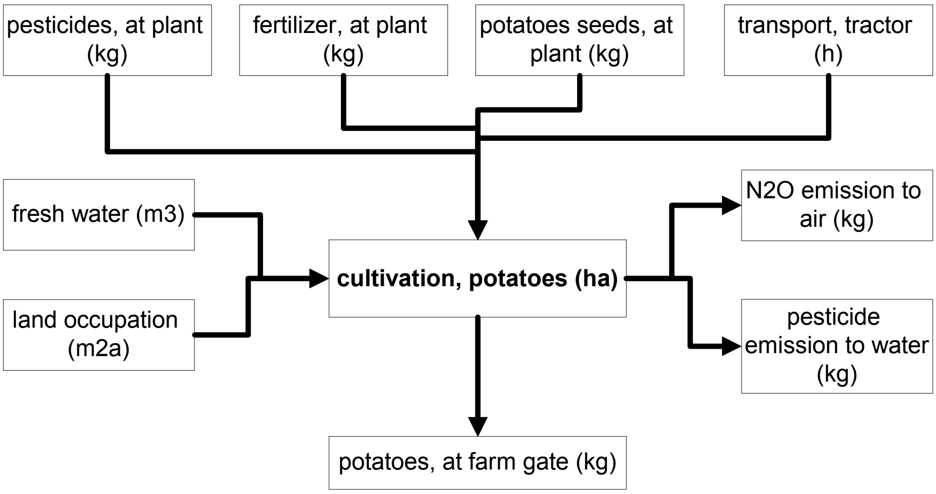


Fig. 1.1 Unit process flow chart of the cultivation of potatoes including some examples of inputs and outputs

Tab. 1.3 shows an example for some unit process raw data. In the first four lines of column L, there is again a description of the reference flow for this unit process. The description equals the structure of the process information shown before (Tab. 1.2). This example refers to the production of 1 kg potatoes in Switzerland (CH) with integrated production (IP) technology (excerpt from Nemecek et al. 2004). Only a part of the recorded 67 inputs and outputs is shown in this table.

Column B is not part of the electronic format, but it helps to structure the information about different inputs and outputs. In column F, G, J and K the different inputs and outputs to and from the unit process are described in detail. For technosphere inputs the nomenclature equals the description for the reference flow. Line 7, for instance, defines the input of a fertilizer (ammonium nitrate, as N, at regional storage). The fertilizer has been produced in Europe (RER). It is not an infrastructure process and the actual amount per kg potatoes in column L is provided with the unit “kg”. Or in other words line 7 can be read as follows: For the production of 1 kg potatoes one needs 0.44 grams of nitrogen in the form of ammonium nitrate fertilizer.

Tab. 1.3 shows some further 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.

In lines 49-53 resource uses of carbon dioxide and land are recorded (input flow from nature). The description of flows from and to nature differs a little bit from technosphere flows. There is no necessity for defining the location or the “infrastructure” field. Emissions are distinguished according to the compartments (air, water, soil) and sub compartments (e.g. river, groundwater). We show here different examples.

Finally, the technosphere output or reference flow of the process is defined as 1 kg potatoes from integrated production in Switzerland. This is not shown for all datasets as it is always equal to "1".

This inventory table also provides information on the uncertainty of the recorded amount of the flows. In this case, the uncertainty type 1 (column M) stands for a lognormal distribution. The standard deviation in column N records the square value for the 95% geometric standard deviation. The mean value multiplied or divided by the 95% squared geometric standard deviation gives the 97% maximum or the 2.5% minimum value, respectively.

The general comment in column R provides information about the estimation or calculation of each flow. In this example, the amounts of fertilizer are based on statistical data while different air emissions have been calculated with models.

Quite often, a simplified approach has been used for the estimation of uncertainties. The pedigree matrix in the field "general comment" provides the background information about this approach. Here different sources of uncertainty (Reliability, Completeness, Temporal correlation, Geographical correlation, Further technological correlation, Sample size) are estimated with scores between 1 and 5. The higher the single scores the higher is the estimated uncertainty. This means for the example (4,4,1,1,1,5) i.e. that reliability and completeness are rather poor while temporal, geographical and technological correlations of the used data source are good. This assessment of the sources of information is used to calculate the standard deviation in column N. For detailed information, please refer to Frischknecht *et al.* (2004b).

Tab. 1.3 Example of unit process raw data of 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	R
3	Explanations	Name	Location	Infrastructure-Process	Unit	potatoes IP, at farm	uncertaintyType	StandardDeviation95%	GeneralComment
4		Location				CH			
5		InfrastructureProcess				0			
6		Unit				kg			
7	Technosphere	ammonium nitrate, as N, at regional storehouse	RER	0	kg	4.35E-4	1	1.07	(2,1,1,1,1,na) statistical data
17		[sulfonyl]urea-compounds, at regional storehouse	CH	0	kg	2.69E-7	1	1.13	(2,2,3,1,1,na) statistical data
23		potato seed IP, at regional storehouse	CH	0	kg	6.78E-2	1	1.07	(2,1,1,1,1,na) statistical data
25		fertilising, by broadcaster	CH	0	ha	8.08E-5	1	1.07	(2,1,1,1,1,na) statistical data
26		harvesting, by complete harvester, potatoes	CH	0	ha	2.69E-5	1	1.07	(2,1,1,1,1,na) statistical data
40		transport, lorry 28t	CH	0	tkm	1.57E-3	1	2.71	(4,5,na,na,na,na) standard assumption
49	resource, in air	Carbon dioxide, in air			kg	3.42E-1	1	1.07	(2,2,1,1,1,na) calculation
50	resource, biotic	Energy, gross calorific value, in biomass			MJ	3.87E+0	1	1.07	(2,2,1,1,1,na) measurement
51	resource, land	Occupation, arable, non-irrigated			m2a	1.27E-1	1	1.77	(2,1,1,1,1,na) statistical data
52		Transformation, from arable, non-irrigated			m2	2.69E-1	1	2.67	(2,1,1,1,1,na) statistical data
53		Transformation, to arable, non-irrigated			m2	2.69E-1	1	2.67	(2,1,1,1,1,na) statistical data
54	air, low population density	Ammonia			kg	4.36E-4	1	1.30	(2,2,1,1,1,na) modell calculation
55		Dinitrogen monoxide			kg	1.29E-4	1	1.61	(2,2,1,1,1,na) modell calculation
57	soil, agricultural	Cadmium			kg	2.62E-8	1	1.77	(2,2,1,1,1,na) modell calculation
58		Chlorothalonil			kg	8.83E-5	1	1.32	(2,2,1,1,1,na) modell calculation
71	water, ground-	Nitrate			kg	9.36E-3	1	1.77	(2,2,1,1,1,na) modell calculation
72		Phosphate			kg	3.06E-6	1	1.77	(2,2,1,1,1,na) modell calculation
73	water, river	Phosphate			kg	1.06E-5	1	1.77	(2,2,1,1,1,na) modell calculation
75	Outputs	potatoes IP, at farm	CH	0	kg	1.00E+0			

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

1.4 System boundaries of modelling

Fig. 1.2 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).[3] The conversion processes are di-

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[3] 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.

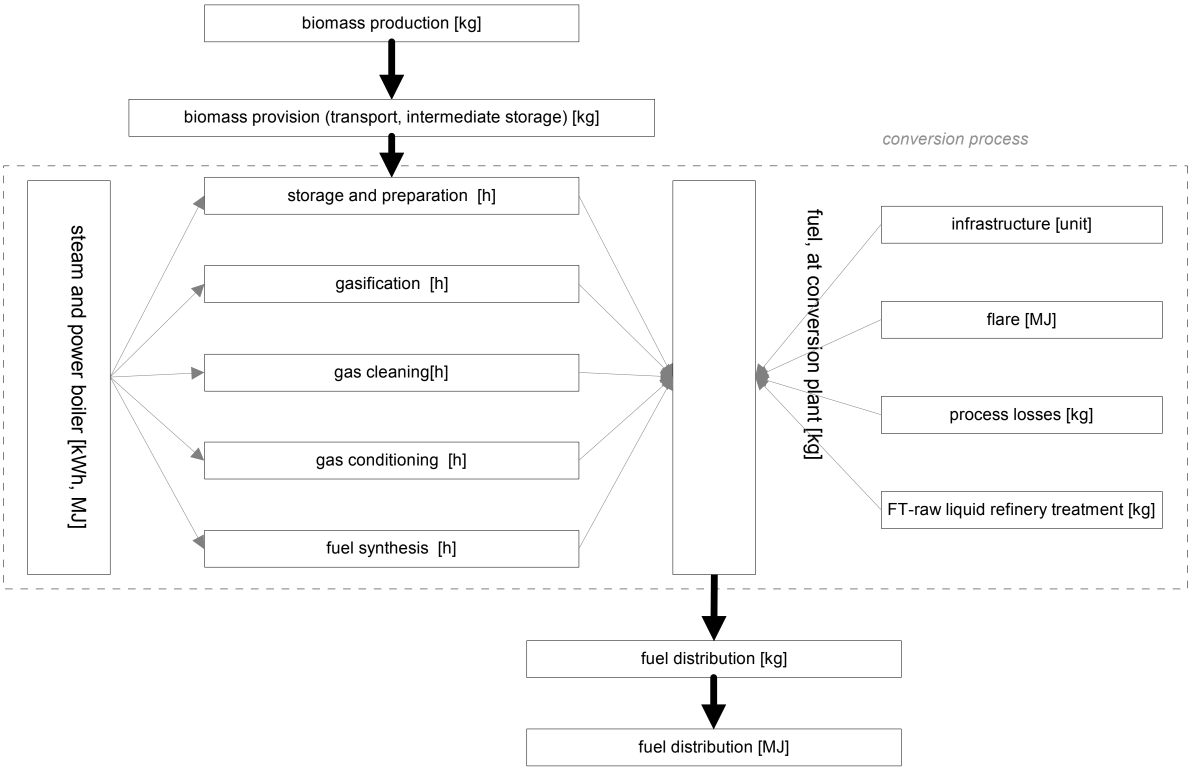

Fig. 1.2 Flowchart of the product system for BTL-fuel with individual unit processes. The conversion process is described with nine sub-processes

1.5 Application of scenarios

Data of biomass production and conversion are investigated for two different cases according to the common project document (SP5-Partners 2007):

Today	Starting point of scenario definitions with description of today's production systems
Sc1	Scenario 1 (Maximized biofuel production) describing production technology with highest conversion rate that can be achieved using hydrogen produced with electricity.

Scenario 2 (self-sufficient production) has been excluded from the analysis because it has been considered by the conversion plant developers to be very similar to the starting point scenario.[4]

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[4] Decision of the RENEW Coordination Committee, Stuttgart, March 2006.

The project team has further elaborated the necessary assumptions for the consideration of the scenarios. The following assumptions were crucial for the investigation of biomass production and conversion.

1.5.1 Starting point

The so-called “starting point calculation” addresses the possible production route in the near future. For these production systems, average data for agricultural and harvesting technology of today are used. Farms with very small production volumes that is not available for the market, are not considered in the assessment. Biomass is the major energy carrier for the supply of internal energy and for the production of the fuel. The inventory for the conversion processes is based on the actual development state of the different technologies. In a nutshell this means “assuming we would erect such a plant today, what would the plant look like?” In this scenario the operation of the biomass to biofuel plant is self-sufficient, which means that the plant produces all electricity, energy and necessary inputs out of biomass. Thus, no direct external electricity supply or other non-renewable energy is considered for the modelling.

1.5.2 Scenario 1

In scenario 1 a modelling for a maximized fuel production is made. The supply chain is supposed to be as efficient as possible regarding biofuel production. One of the highest criteria of the evaluation is the biofuel production to needed surface area for biomass production ratio. External conventional electricity input into the production system is used in most of the conversion concepts. The use of hydrogen improves the carbon/hydrogen-ration and thus lead to a higher conversion rate of biomass to fuel.

A quite crucial point for scenario 1 is the assumption for the hydrogen supply for the biomass conversion. The way in which the electricity is produced has important consequences for the costs and the environmental performance of the conversion concept. Here we assume that the external electricity is provided with wind power plants. It is not realistic to get such a renewable electricity supply until 2020 for more than a very small number of conversion plants, but this scenario describes a direction that might be worth going. Only if there would be the possibility in 2020 for hydrogen from wind power, the conversion rate biomass to fuel could be increased. Due to the limited production capacity until 2020 this will not lead to a considerable share of biofuel production. Therefore this scenario does not describe a general improvement option, but an option for special locations or lucky circumstances.

It is probable that inputs of fertilizers and pesticides are higher than for today biomass production. In addition, the yield should be higher than today. Possible improvements in the production of items like fertilizers or conventional diesel until 2020 have not been investigated in the analysis.

2 Life cycle inventory of biomass production and provision

2.1 Introduction

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[5]);
- 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 detailed data of biomass production in Poland, Sweden and Greece have been investigated in subtasks of this project. This document provides and summarizes the results from the three LCI reports on biomass (Ganko 2005; Lantz 2005; Nikolaou 2005). The different partners investigate the inventories indicated in Tab. 2.1. The data are as far as possible specific for a region. The origin of the data (e.g. literature sources used, etc.) is specified in the reports. Data of Western Europe have been investigated roughly based on literature data. They are described in this chapter.

The data investigated in the reports mentioned above have been harmonized and translated to the format necessary for the life cycle inventory analysis by ESU-services Ltd.. However, a detailed description of the production processes in the three countries can be found in the three reports mentioned above, which are provided as annexes to this report on request.

Tab. 2.1 Distribution of LCI data collection between different partners in the RENEW project

Region	Northern Europe	Central Europe	Southern Europe	Western Europe
Country	Sweden	Poland	Greece	Germany
Location Code	SE	PL	GR	DE
willow-salix or poplar salix	x	x	x	x
miscanthus	-	x	x	x
wheat and wheat straw	x	x	x	x
Responsible partner	LUND	EC BREC	CRES	ESU

All assumptions are based on the goal and scope definition of this LCA (Jungbluth et al. 2007a) and on the scenario document (SP5-Partners 2007).

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 consid-

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[5] 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.

ered 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. 2.2 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. 2.2 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

2.2 Methodology

In general, the life cycle inventory analysis follows the methodology applied in the ecoinvent project (Frischknecht et al. 2004a) if not stated otherwise in the goal and scope definition for this LCA. Thus LCI data are investigated consistent with the background data used.

2.2.1 Average production data of Europe

In the analysis, one average inventory of the production of the three types of biomass in Europe is established. Therefore, it is necessary to define the share of different countries and regions contributing to the assumed average.

The assumptions on the shares are based on the forecast of the biomass potentials for the crops listed in chapter 2.1 in different regions (Pisarek et al. 2004) are shown in Tab. 2.3. Such data were not available for all three biomasses and for the two scenarios. LCI data have not been investigated for all six regions, but only for Northern, Eastern, Western and Southern Europe. UK, Ireland and the alpine regions have only a small potential for the total possible biomass production.

Tab. 2.3 Share of different regions and countries for the biomass potential (Pisarek et al. 2004)

starting point	**Norther Europe**	**Eastern Europe**	**Alpine regions**	**Western Europe**	**UK and Ireland**	**Southern Europe**
energy crops	6%	23%	1%	32%	9%	28%
Straw	7%	23%	1%	32%	15%	22%

Scenario 1	**Norther Europe**	**Eastern Europe**	**Alpine regions**	**Western Europe**	**UK and Ireland**	**Southern Europe**
energy crops	5%	21%	2%	27%	10%	34%

The LCI data are available for four countries from different regions in Europe (Sweden, Poland, Greece and Germany/Switzerland). The averages in Tab. 2.4 have been recalculated based on the information available. The very small share of alpine regions has been neglected. No data were available for production patterns in the UK and Ireland and thus no specific data have been considered for calculating the averages. The shares shown in Tab. 2.4 have been used to calculate the average inventories from the specific data of four countries.

Tab. 2.4 Calculation of average LCI data of Europe in this study based on the availability of inventory data

starting point	Norther Europe	Eastern Europe	Alpine regions	Western Europe	UK and Ireland	Southern Europe
Willow-Salix	7%	26%	0%	36%	0%	31%
Miscanthus	0%	28%	0%	38%	0%	34%
Straw	9%	27%	0%	38%	0%	26%

Scenario 1	Norther Europe	Eastern Europe	Alpine regions	Western Europe	UK and Ireland	Southern Europe
Willow-Salix	7%	26%	0%	36%	0%	31%
Miscanthus	0%	26%	0%	33%	0%	41%
Straw	9%	27%	0%	38%	0%	26%

2.2.2 Biomass properties

The project team has defined the biomass properties in a separate report (SP5-Partners 2007). Tab. 2.5 shows the main properties, which are also used in the inventory analysis. The assumptions for heating values per MJ dry mass were not defined by the project team. They had to be recalculated for this inventory. Please note that some of the parameters are provided on a wet mass basis while others are provided on a dry mass basis. Not all of the parameters from the cited document are necessary for the following calculations of the LCI.

Tab. 2.5 Chemical and physical properties of investigated biomass products (SP5-Partners 2007)

Kind of biomass		Willow-Salix	Miscanthus	Wheat Straw
Trading Form		bundles	bales	bales
Bulk density [kg dry substance/m^3]		200-400	119.00	119.00
Bulk density [kg wet substance/m^3]		285-571	148.00	140.00
Proximate analysis [wt % wet]				
Water content	average	30.00	20.00	15.00
Ash content	average	1.40	3.20	5.53
sum proximate analysis		100.05	88.88	98.78
Elemental analysis [wt % dry]				
	C	48.02	47.04	45.66
	H	6.08	6.14	5.75
	S	0.05	0.19	0.30
	N	0.49	0.67	0.50
	O	43.12	42.24	40.59
Ash content	average	2.00	4.00	6.50
	sum (C. H. O. N. S Ash)	99.78	100.48	99.30
Ash & Trace Elements				
	Cl [wt % dry]	0.03	0.19	0.70
Trace Components	Al	149	200	50
[mg/kg dry]	Ca	5000	3500	4000
	Fe	100	600	100
	K	3000	15000	10000
	Mg	500	1700	700
	Mn	97		
	Na	139	1000	500
	P	800	3000	1000
	Si	220	15000	10000
	Ti	10		
	As	0.05	0.1	0.05
	Cd	0.61	0.2	0.1
[mg/kg dry]	Cr	1	1	10
[mg/kg dry]	Cu	3	5	2
[mg/kg dry]	Hg	0.015	0.01	0.02
[mg/kg dry]	Ni	0.5	2	1
[mg/kg dry]	Pb	0.1	1	0.5
[mg/kg dry]	V		3	3
[mg/kg dry]	Zn	70	25	10
Ash Composition[1]	SiO2	2.35	33.8	
	Al2O3	1.41	4.3	
	Fe2O3	0.73	2.5	
	CaO	41.2	9.9	
	MgO	2.47	7.6	
	P2O5	7.4		3.6
	Na2O	0.94	2.2	
	K2O	15	19.7	0.2
Caloric Values [MJ/kg wet]				
Lower	average	12.16	13.64	13.1
Higher	average	13.46	15.05	14.5
Caloric Values [MJ/kg dry]				
Lower	average	18.80	18.40	17.2
Higher	average	19.80	19.80	19.0

2.2.3 Fertilizer use

In all scenarios, we only consider the use of artificial fertilizers. Manure and dung will not be available for the production of energy crops under the precondition that food and fibre production is not affected. Inventory data of fertilizer production have been investigated by (Nemecek et al. 2004).

The use of sewage sludge might be restricted due to health concerns. Thus, it is not considered here. The use of ash from the conversion plants might be one option to close the nutrient cycle for the biofuel production. However, detailed information about a possible use of ashes are not available so far. It has to be considered that legal restriction for the heavy metal content of fertilizers might hinder such an application.

Specific data on the amount of N, P2O5 and K2O used in agriculture are provided. The average mix of N, P2O5 and K2O-fertilizers is based on these key figures. This mix is based on the current situation in Switzerland (Nemecek et al. 2004). The mix of fertilizer is important for calculating subsequent emissions from their application.

Due to the differences in the quality of soil, the use of potassium (K2O) is higher in Poland in certain cases. This has been considered in the inventories of this country.

2.2.4 Water use

The water use in agriculture and water scarcity is an important environmental issue in some European countries. Water can be used in quite different forms and from different sources. So far there is no characterisation method for different types of water use nor a common agreement how to inventory such uses.

Irrigation is only necessary in Southern Europe. Abstraction from surface waters (lakes or rivers) accounts for more than 80% of irrigation abstractions in Greece and for 68% in Spain. In Portugal abstraction is mainly from groundwater sources. Many coastal Mediterranean regions depend largely on groundwater sources for irrigation. In Italy, the northern regions source their irrigation mainly from groundwater, while in the south the use of surface water is widespread and large-scale surface-water transfers are found (Baldock et al. 2000).

Irrigation water is inventoried in this study as water from rivers. The amount of rain is considered as well in the inventory analysis of all three countries. Thus, the total amount of water used for the production of different BTL-fuels can be evaluated.

2.2.5 Emission from agricultural processes

Comparison of published models

There are several direct emissions due to the agricultural production. Ammonia, dinitrogen oxide and nitrogen oxide are the main emissions to air. Phosphate and nitrate are emitted to ground and surface waters. Pesticides are emitted to soil.

There are several models proposed by different authors (Basset-Mens & van der Werf 2005; Brentrup 2003; Jungbluth 2000; Milà i Canals 2003; Nemecek et al. 2004). Some models are very simple, e.g. just a linear relationship between fertilizer input and pollutant emission (Jungbluth 2000). Others include several factors like actual nutrient uptake of plants, degradation, soil qualities, slope, etc (Nemecek et al. 2004).

In Tab. 2.6 we compare the outcome of the several models of the calculation of agricultural field emissions of wheat cultivation per hectare and year. The input of fertilizers is the same for all models and shown in the first part of the table.

The results for ammonia are quite similar for the three models shown on the left side of Tab. 2.6. Only (Basset-Mens & van der Werf 2005) do not provide factors for mineral fertilizers and thus show quite lower emission.

Nitrate emissions vary by a factor of two. The complex model of (Nemecek et al. 2004) takes into account monthly data of fertilization, degradation and plant uptake of nitrogen while the model of (Basset-Mens & van der Werf 2005) only provides a simple factor per hectare of cultivation. However the specific emission rate is very similar in this example.

Calculated emissions of N_2O vary considerably. One important factor is the calculation of secondary emissions due to primary emissions of nitrate. The nitrate is degraded in rivers and lakes and thus contributes also to N_2O emissions (only considered by Basset-Mens & van der Werf 2005; Nemecek et al. 2004). This is not considered in the methodology used by the IPCC (Albritton & Meira-Filho 2001) for calculating national greenhouse gas inventories. For such calculations a linear factor of 1.25% N_2O-N emitted from the nitrogen application is used. This linear relationship gives the figure of 2.6 kg N_2O in the shown example of Tab. 2.6. Even with the newer methodologies the uncertainty range can be considered as quite high because of the many influencing factors and the difficulties to make reliable measurements.

NO_x emissions are calculated as a share of N_2O emissions or in relation to fertilizer input. The results vary considerably, but this emission is normally not very critical in the LCIA.

Most of the models did not provide recommendations for different phosphorous emissions.

Tab. 2.6 Comparison of field emissions of wheat cultivation calculated with different models for agricultural LCA

	Name	Unit	Nemecek 2004	Brentrup 2003	Milà i Canals 2003	Basset-Mens 2005	Jungbluth 2000
	Location		CH	RER	RER	FR	CH
	Unit		ha	ha	ha	ha	ha
technosphere	ammonium nitrate, as N, at regional storehouse	kg	67.1	67.1	67.1	67.1	67.1
	ammonium sulphate, as N, at regional storehouse	kg	5.1	5.1	5.1	5.1	5.1
	calcium ammonium nitrate, as N, at regional storehouse	kg	33.7	33.7	33.7	33.7	33.7
	diammonium phosphate, as N, at regional storehouse	kg	7.0	7.0	7.0	7.0	7.0
	urea, as N, at regional storehouse	kg	23.6	23.6	23.6	23.6	23.6
	potassium chloride, as K2O, at regional storehouse	kg	44.9	44.9	44.9	44.9	44.9
	potassium sulphate, as K2O, at regional storehouse	kg	2.9	2.9	2.9	2.9	2.9
	diammonium phosphate, as P2O5, at regional storehouse	kg	18.5	18.5	18.5	18.5	18.5
	single superphosphate, as P2O5, at regional storehouse	kg	1.1	1.1	1.1	1.1	1.1
	thomas meal, as P2O5, at regional storehouse	kg	3.3	3.3	3.3	3.3	3.3
	triple superphosphate, as P2O5, at regional storehouse	kg	26.2	26.2	26.2	26.2	26.2
	phosphate rock, as P2O5, beneficiated, dry, at plant	kg	15.3	15.3	15.3	15.3	15.3
	slurry spreading, by vacuum tanker	m3	3.3	3.3	3.3	3.3	3.3
	solid manure loading and spreading, by hydraulic loader and spreader	kg	111.0	111.0	111.0	111.0	111.0
emission air, low population density	Ammonia	kg	9.0	8.8	8.8	2.1	14.4
	Dinitrogen monoxide	kg	4.2	2.6	2.6	7.9	2.8
	Nitrogen oxides	kg	0.9		0.3		1.2
emission water, ground-	Nitrate	kg	125.3	87.3	108.8	131.4	75.0
	Phosphate	kg	0.2				
emission water, river	Phosphate	kg	0.5				2.0
	Phosphorus	kg	0.3				2.6

Methodology for this study

The methodology used to calculate the field emissions in this study follows one of the most elaborated models available at present. All assumptions are in accordance with the methodology developed for the ecoinvent database. Direct contacts with the authors ensure a proper implementation. This method includes for example the parameters fertilizer input, degradation, fall out, average mix of fertilizer used, nitrogen uptake of plants in every month and others. Detailed information is available from this publication (Nemecek et al. 2004). The basic idea can be described as follows:

NH_3: Ammonia emissions are calculated with linear factors (Nemecek et al. 2004: Tab. 4.2) for each type of nitrogen fertilizer applied.

Nitrate: The complex model of (Nemecek et al. 2004) takes into account monthly data for amount and type of nitrogen fertilization, nitrogen mineralization from decomposing plant material (Nmin, m) and plant uptake (N upt m) of nitrogen. Further factors, like depth of roots, cultivation intensity and slope of the field are considered in the calculation formulas.

N_2O: Dinitrogen oxide emissions are calculated with a linear factor for the total amount of nitrogen applied. Secondary emissions are added and they are calculated from the direct emissions of ammonia and nitrate.

NO_x to air: Linear calculation with the amount of N_2O emissions.

Phosphate and phosphorus: The calculation takes into account the amount and type of phosphate fertilizer, the type of land use and the type and duration of soil cover (important for emissions due to erosion). Leaching of soluble phosphate to groundwater, run-off of soluble phosphate to surface water and erosion of soil particles containing phosphorous are distinguished.

Emissions of heavy metals are calculated with an input-output balance of the field. Inputs are due to application of fertilizers and pesticides. Outputs are the uptake of plants withdrawn during the harvest (Nemecek et al. 2004). Emissions of heavy metals are not considered in the LCIA of this study (Jungbluth et al. 2007a).

All applications of pesticides have been modelled in the inventory as well as their emissions to agricultural soil. This is in line with the methodology applied (Nemecek et al. 2004). Pesticide emissions are also not considered in the LCIA of this study.

2.2.6 NMVOC emissions from plants

"Isoprene (also known as 2-methyl-1,3-butadiene), an unsaturated C-5 hydrocarbon, is emitted in vast amounts from photosynthesizing leaves of many plant species, particularly by trees. With a global atmospheric carbon flux of approximately 450 million tons of carbon per year, isoprene emissions are a major contributor to the total biogenic volatile organic compound (BVOC) flux of 1,200 million tons of carbon per year. Current interest in understanding the biochemical and physiological mechanisms controlling isoprene formation in plants comes from the important role isoprene plays in atmospheric chemistry. Isoprene rapidly reacts with hydroxyl radicals in the atmosphere. In the presence of nitric oxides (NO_X), the oxidation of isoprene contributes significantly to the formation of ozone, a dominant tropospheric air pollutant. Moreover, isoprene also contributes to the regulation of tropospheric hydroxyl radicals concentration and thus plays an important role in determining the abundance of atmospheric methane, an important greenhouse gas."[6] On a sunny day the isoprene emission of 10,000 trees can be up to 10 kilograms per hour.

So far such biogenic emissions are only rarely accounted for in LCA. There is a modelling uncertainty due to several influencing factors like type of plant, temperature or irradiation of the sun. Also it has been shown that there is a large seasonal variation with the main emissions soon after budbreak in the summer and quite lower emissions in the winter. No information could be found about the influence of different cultivation intensities (e.g. fields with lower or higher annual yields). Nevertheless, according to the today knowledge, these emissions are quite important with respect to the formation of summer smog and thus they should be accounted for in the LCI.

The difficulties with estimating such emissions are also visible from showing some results for the annual emissions per hectare. Tab. 2.7 shows an overview of results from selected studies that vary by several orders of magnitude.

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[6] Information from http://www.plantphysiol.org/cgi/content/full/135/1/152 retrieved on 11.2005.

Tab. 2.7 Estimation of NMVOC emissions in different studies (kg/ha/year)

Pollutant	Plant	Range	Mean	Reference
Isoprene	Poplar	189-1600	476	(Mann & Spath 1997)
Monoterpene	Swiss forest	Factor 5	29	(Spirig & Neftel 2002)
VOC	Swiss agriculture	-	4	(Spirig & Neftel 2002)
VOC	Swiss grasslands	-	3.6	(Spirig & Neftel 2002)
NMVOC	German area	5-25	-	(UMEG 2000)

The emission rates are normally measured as microgram of isoprene emission per gram of dry matter leaves per hour under standardized temperature and irradiation conditions. This factor is multiplied with the leaf mass and a correction factor accounting for the regional available amount of sunlight. Tab. 2.8 provides the estimation used in this study based on the model of Richardson (2002:B1101-1-19). This model allows accounting for regional differences in Europe and for plant specific factors.

Leaf weight (kg/ha) and emission factors for miscanthus and wheat (kg/kg leaf/h) are estimated based on (Sanderson 2002). The amount of harvested biomass is taken from the inventories in the next sections. The leaf weights are only available as averages for different types of biomass and thus do not account for different amounts of harvest. This has been corrected by multiplying the emission factor with the actual harvest divided by the average harvest of these cultures. An “environmental correction factor” accounts for the differences e.g. in irradiation, sunshine hours or temperature (Sanderson 2002). The factors for different countries are shown in Tab. 2.9, Tab. 2.13, Tab. 2.17).

Influencing factors for differences between different scenarios are not known. Thus, differences in the results for the comparison of scenarios are not a valid estimation. The general difference between emissions from forests and agriculture is known and thus the higher amount of emissions from willow-salix can be assumed correct. In contrast, the difference between wheat and miscanthus is too small and considered insignificant.

This best estimation cannot take into account several biomass specific factors. Data of a period take into account a full cultivation period for perennial crops. Tab. 2.8 shows that the average amount of emissions per hectare and year is about 20 to 50 kg. These figures are in the order of magnitude of other publications as shown in Tab. 2.7. The overall uncertainty is estimated with 5.

Tab. 2.8 Emission rate for isoprene and monoterpene emissions

	leaf weight (kg/ha)	biomass harvest (kg dry matter/ha/period)	Isoprene (kg/kg leaf/h)	other NMVOC (kg/kg leaf/h)	Isoprene (kg/ha/a)	Monoterpene (kg/ha/a)
Willow-Salix	1500	176'844	3.40E-05	1.70E-06	53.1	2.7
Miscanthus	1250	15'547	1.60E-05	8.00E-07	21.6	1.1
Wheat	1250	8'618	1.60E-05	8.00E-07	20.1	1.0

Exclusion of biogenic NMVOC from the LCIA

In the base case such emissions from plants are excluded from the LCIA. The reasoning is that there are still some uncertainties for the correct modelling. Furthermore it is questionable if such natural emissions should be included in the LCIA because the main conclusion would be that all plants have a very high negative impact on the environment and thus it would be preferable to have no plants. The inventoried emissions will be included in an LCIA for a sensitivity analysis.

2.3 Short-rotation wood plantation

Elaboration of LCI: Niels Jungbluth, ESU-services Ltd., Uster
Data provider Ewa Ganko, Mikael Lantz, Natasa Nikolaou, Niels Jungbluth

Short rotation wood is an agricultural product that is cultivated over a period of several years. The wood is harvested in bundles. These bundles are stored and pre-dried near the field edge. Chipping is taking place at the conversion plant. It is not included in the inventory of this biomass. Here we investigated poplar as the most suitable short-rotation wood for the Southern European countries and willow-salix as a species recommended for plantation in other parts of Europe.

Today there is no commercial production of willow-salix in Poland. Data were available only for a plantation with a manual harvesting. Thus, data are assumed for a machinery-based production (Ganko 2005).

The nursery of planting stocks for willow-salix is investigated only with the starting point scenario. The influences of variations due to different scenarios on the results are considered negligible. Thus, the same inventory data of planting stocks are used for the scenario 1.

Tab. 2.9 shows the key figures on short rotation wood production in the different countries (Germany, Greece, Poland and Sweden) based on the three reports with regional inventory data. The data of Western Europe have been assessed based on the data provided by (FNR 2005; Rosenqvist & Lantz 2006). The first lines show the amount of different types of fertilizers used per hectare of cultivation over a period of cultivation (Duration of plantation between 8 and 22 years). The table also shows data of the diesel use in agricultural machinery. The data include the establishment of the plantation and the harvesting over a full plantation period. The next line gives the amount of yield in kg dry matter. Further details on the use of water and pesticides are provided in the reports with the regional inventory data.

The emission factors show the actual percentage of different emissions in relation to the fertilizer application. Thus, e.g. about 4% to 13% of the applied nitrogen are emitted in the form of nitrate. The calculation of NMVOC emissions and the necessary environmental correction factors have been explained in chapter "NMVOC emissions from plants".

As outlined before, there are no simple or linear relationships for the different scenarios. Different influencing factors like region, present status of technology and forecast of future developments had to be levelled out. Thus, there is no comparable trend in the scenarios for certain key factors like the diesel consumption.

Tab. 2.9 Key figures on short-rotation wood production (duration of plantation) in different countries for one hectare and a full plantation period (regional life cycle inventory data and own assumptions)

		bundles, short-rotation wood, at field	bundles, short-rotation wood, scenario 1, at field	planting stocks, short-rotation wood, at field	poplar	poplar, sc1	willow	willow, sc1	willow	willow, sc1	willow	willow, sc1
		RER	RER	RER	GR	GR	PL	PL	SE	SE	DE	DE
		ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
N-fertilizer, tot	kg	997	1'298	636	792	1'342	881	1'761	1'801	1'801	1'101	826
P2O5-fertilizer, tot	kg	772	731	229	724	724	1'322	1'322	553	553	461	347
K2O-fertilizer, min	kg	1'224	1'117	556	720	720	1'760	1'760	1'615	1'615	1'205	904
Lime	kg	1'241	1'209	1'112	-	-	3'000	3'000	4'800	4'800	360	270
diesel use	kg	982	1'004	139	1'289	1'289	673	654	897	1'037	950	1'000
yield	kg DS/ha/period	191'144	206'532	86'231	102'000	120'000	286'000	363'000	198'000	308'000	200'000	150'000
yield, planting stocks	units	-	-	3'448'543								
amount of harvests	-	6	6	7	6	6	7	7	6	6	5	5
Duration of plantation period	a	18	16	8	12	12	22	22	22	22	20	15
Pesticide use	kg	9.9	9.7	33.4	3.9	3.9	28.5	28.6	2.2	3.3	3.4	2.6
NO3-N emission factor	%	8%	6%	9%	10%	6%	5%	4%	8%	4%	9%	9%
N2O-N emission factor	%	1.5%	1.5%	1.1%	1.6%	1.5%	1.4%	1.4%	1.5%	1.4%	1.5%	1.5%
NH3-N emission factor	%	4.5%	4.5%	2.9%	4.5%	4.5%	4.5%	4.5%	4.6%	4.6%	4.5%	4.5%
Emission factor isoprene	kg/ha/period/h	0.051	0.055	0	0.027	0.032	0.076	0.097	0.053	0.082	0.053	0.040
Emission factor NMVOC	kg/ha/period/h	0.003	0.003	0	0.0014	0.0016	0.0038	0.0048	0.0026	0.0041	0.0027	0.0020
environmental correction factor	h	1'041	1'041	723	1'440	1'440	912	912	508	508	890	890
environmental correction factor	period	17'748	16'157	6'840	17'280	17'280	20'064	20'064	11'176	11'176	17'800	13'350

sc1 Scenario 1

The description of the dataset is documented in Tab. 2.10. The life cycle inventory analysis results are calculated and elaborated based on these key figures. Tab. 2.11 and Tab. 2.12 provide the detailed information about all elementary flows, data uncertainties and the way in which these data are calculated.

Tab. 2.10 Documentation of the average short-rotation wood production

ReferenceFunction	Name	bundles, short-rotation wood, at field	bundles, short-rotation wood, scenario 1, at field	planting stocks, short-rotation wood, at field
Geography	Location	RER	RER	RER
ReferenceFunction	InfrastructureProcess	0	0	0
ReferenceFunction	Unit	kg	kg	unit
	IncludedProcesses	The inventory includes the processes of soil cultivation, sowing, weed control, fertilisation, pest and pathogen control, harvest and balling. Machine infrastructure and a shed for machine sheltering is included. Inputs of fertilisers, pesticides and planting stocks as well as their transports to the farm are considered. The direct emissions on the field are also included. The system boundary is the field.	The inventory includes the processes of soil cultivation, sowing, weed control, fertilisation, pest and pathogen control, harvest and balling. Machine infrastructure and a shed for machine sheltering is included. Inputs of fertilisers, pesticides and planting stocks as well as their transports to the farm are considered. The direct emissions on the field are also included. The system boundary is the field.	The inventory includes the processes of soil cultivation, sowing, weed control, fertilisation, pest and pathogen control, harvest and balling. Machine infrastructure and a shed for machine sheltering is included. Inputs of fertilisers, pesticides and planting stocks as well as their transports to the farm are considered. The direct emissions on the field are also included. The system boundary is the field.
	Synonyms	whole shoot	whole shoot	
	GeneralComment	Inventory refers to the production of 1 kg dry matter short rotation wood (willow-salix in Poland and Sweden, salix-poplar in Greece) bundles.	Inventory refers to the production of 1 kg dry matter short rotation wood (willow-salix in Poland and Sweden, salix-poplar in Greece) bundles.	Inventory refers to the production of 1 planting stock (1 unit) with a length of about 25 cm.
	Category	agricultural production	agricultural production	agricultural production
	SubCategory	plant production	plant production	plant production
TimePeriod	StartDate	2000	2000	2000
	EndDate	2000	2020	2000
	OtherPeriodText	Starting point scenario for average agricultural and harvesting technology in the year 2004.	Scenario 1 for maximized biofuel production in the year 2020	Starting point scenario for average agricultural and harvesting technology in the year 2004.
Geography	Text	Refers to an average production in Europe. Calculation based on inventory data for SE, PL, DE and GR. Production shares based on expert guess.	Refers to an average production in Europe. Calculation based on inventory data for SE, PL, DE and GR. Production shares based on expert guess.	Refers to an average production in Europe. Calculation based on inventory data for SE, PL, DE and GR. Production shares based on expert guess.
Technology	Text	Average production of today	Expert guess data for agricultural and harvesting technology in 2020	Integrated production
	ProductionVolume	So far only limited experiences.	So far only limited experiences.	So far only limited experiences.
	SamplingProcedure	Data were compiled by experts from Poland, Greece, Germany and Sweden from statistics, pilot network, fertilising recommendations, documents from extension services, information provided by retailers, literature and expert knowledge. The production data were verified and adjusted by the project team.	Data were compiled by experts from Poland, Greece, Germany and Sweden from statistics, pilot network, fertilising recommendations, documents from extension services, information provided by retailers, literature and expert knowledge. The production data were verified and adjusted by the project team.	Data were compiled by experts from Poland, Greece, Germany and Sweden from statistics, pilot network, fertilising recommendations, documents from extension services, information provided by retailers, literature and expert knowledge. The production data were verified and adjusted by the project team.
	Extrapolations	none	based on scenario definitions	Average of two literature sources.
	UncertaintyAdjustments	none	none	none

Tab. 2.11 Life cycle inventory analysis and unit process raw data of average short-rotation wood production (technosphere inputs and outputs)

	Name	Location	InfrastructureProcess	Unit	bundles, short-rotation wood, at field	bundles, short-rotation wood, scenario 1, at field	planting stocks, short-rotation wood, at field	UncertaintyType	StandardDeviation 95%	GeneralComment
	Location				RER	RER	RER			
	InfrastructureProcess				0	0	0			
	Unit				kg	kg	unit			
fertilizer	ammonium nitrate, as N, at regional storehouse	RER	0	kg	2.78E-3	3.50E-3	4.55E-4	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	ammonium sulphate, as N, at regional storehouse	RER	0	kg	2.14E-4	2.69E-4	3.50E-5	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	calcium ammonium nitrate, as N, at regional storehouse	RER	0	kg	1.39E-3	1.75E-3	2.27E-4	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	diammonium phosphate, as N, at regional storehouse	RER	0	kg	4.84E-4	4.13E-4	3.53E-5	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	urea, as N, at regional storehouse	RER	0	kg	9.64E-4	1.21E-3	1.57E-4	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	potassium chloride, as K2O, at regional storehouse	RER	0	kg	6.14E-3	5.32E-3	3.34E-4	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	potassium sulphate, as K2O, at regional storehouse	RER	0	kg	3.92E-4	3.40E-4	2.13E-5	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	lime, from carbonation, at regional storehouse	CH	0	kg	5.06E-3	3.87E-3	1.10E-4	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	diammonium phosphate, as P2O5, at regional storehouse	RER	0	kg	1.24E-3	1.05E-3	9.01E-5	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	single superphosphate, as P2O5, at regional storehouse	RER	0	kg	8.84E-5	7.53E-5	6.44E-6	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	thomas meal, as P2O5, at regional storehouse	RER	0	kg	2.21E-4	1.88E-4	1.61E-5	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	triple superphosphate, as P2O5, at regional storehouse	RER	0	kg	1.81E-3	1.54E-3	1.32E-4	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	phosphate rock, as P2O5, beneficiated, dry, at plant	MA	0	kg	1.06E-3	9.04E-4	7.72E-5	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
seeds	planting stocks, short-rotation wood, at field	RER	0	unit	8.07E-2	7.99E-2	7.91E-3	1	1.32	(4,4,1,1,1,5); establishment of the plantation
pesticides	[sulfonyl]urea-compounds, at regional storehouse	CH	0	kg	0	0	0	1	1.32	(4,4,1,1,1,5); pesticide use
	cyclic N-compounds, at regional storehouse	CH	0	kg	0	0	7.17E-7	1	1.32	(4,4,1,1,1,5); pesticide use
	dinitroaniline-compounds, at regional storehouse	RER	0	kg	2.06E-7	1.75E-7	2.01E-6	1	1.32	(4,4,1,1,1,5); pesticide use
	diphenylether-compounds, at regional storehouse	RER	0	kg	1.54E-6	1.31E-6	1.67E-6	1	1.32	(4,4,1,1,1,5); pesticide use
	nitrile-compounds, at regional storehouse	CH	0	kg	3.79E-8	4.18E-8	2.41E-6	1	1.32	(4,4,1,1,1,5); pesticide use
	triazine-compounds, at regional storehouse	RER	0	kg	2.16E-5	1.70E-5	8.93E-7	1	1.32	(4,4,1,1,1,5); pesticide use
	linuron, at regional storehouse	RER	0	kg	1.54E-6	1.31E-6	1.26E-6	1	1.32	(4,4,1,1,1,5); pesticide use
	metolachlor, at regional storehouse	RER	0	kg	5.24E-6	4.45E-6	4.28E-6	1	1.32	(4,4,1,1,1,5); pesticide use
	organophosphorus-compounds, at regional storehouse	RER	0	kg	1.09E-5	1.00E-5	3.11E-7	1	1.32	(4,4,1,1,1,5); pesticide use
	pesticide unspecified, at regional storehouse	CH	0	kg	3.47E-6	2.95E-6	3.22E-6	1	1.32	(4,4,1,1,1,5); pesticide use
machinery	diesel, used by tractor	RER	0	kg	6.60E-3	6.46E-3	8.34E-4	1	1.32	(4,4,1,1,1,5); machinery use
	transport, lorry 32t	RER	0	tkm	4.52E-3	0	4.58E-4	1	2.09	(4,5,na,na,na,na); standard distances for transport of materials
	transport, lorry 32t, Euro 5, diesel	RER	0	tkm	0	4.53E-3	0			
	transport, van <3.5t	RER	0	tkm	3.16E-5	3.11E-5	5.03E-7	1	2.09	(4,5,na,na,na,na); standard distances for transport of materials
	transport, barge	RER	0	tkm	2.59E-2	2.80E-2	3.20E-3	1	2.09	(4,5,na,na,na,na); standard distances for transport of materials
	transport, freight, rail	RER	0	tkm	3.61E-3	3.76E-3	8.26E-4	1	2.09	(4,5,na,na,na,na); standard distances for transport of materials

Tab. 2.12 Life cycle inventory analysis and unit process raw data of average short-rotation wood production (eco-sphere inputs and outputs)

	Name	Location	InfrastructureProcess	Unit	bundles, short-rotation wood, at field	bundles, short-rotation wood, scenario 1, at field	planting stocks, short-rotation wood, at field	UncertaintyType	StandardDeviation 95%	GeneralComment
	Location				RER	RER	RER			
	InfrastructureProcess				0	0	0			
	Unit				kg	kg	unit			
resource, in air	Carbon dioxide, in air	-	-	kg	1.76E+0	1.76E+0	0	1	1.26	(3,4,1,1,1,5); carbon uptake of plants
resource, biotic	Energy, gross calorific value, in biomass	-	-	MJ	1.88E+1	1.88E+1	0	1	1.26	(3,4,1,1,1,5); energy content of harvested product
resource, water	Water, rain	-	-	m3	7.28E-1	6.53E-1	4.23E-2	1	1.26	(3,4,1,1,1,5); average rainfall in the region during the plantation
	Water, river	-	-	m3	7.77E-2	6.60E-2	5.28E-3	1	1.32	(4,4,1,1,1,5); water used for irrigation
resource, land	Occupation, forest, intensive, short-cycle	-	-	m2a	1.00E+0	8.78E-1	8.24E-2	1	1.59	(3,4,1,1,1,5); land use
	Transformation, from pasture and meadow, extensive	-	-	m2	6.13E-2	5.94E-2	2.55E-2	1	1.34	(3,4,1,1,1,5); transformation of set aside land
	Transformation, to forest, intensive, short-cycle	-	-	m2	6.13E-2	5.94E-2	2.55E-2	1	2.07	(3,4,1,1,1,5); land use
emission air, low population density	Ammonia	-	-	kg	3.21E-4	3.94E-4	5.03E-5	1	1.48	(4,4,1,5,3,5); model calculation for emissions based on fertilizer application
	Dinitrogen monoxide	-	-	kg	1.33E-4	1.57E-4	2.63E-5	1	1.70	(4,4,1,5,3,5); model calculation for emissions based on fertilizer application
	Isoprene	-	-	kg	4.74E-3	4.31E-3	8.95E-5	1	5.36	(5,na,1,3,3,5); model calculation for biogenic emissions based on literature
	Terpenes	-	-	kg	2.37E-4	2.16E-4	4.47E-6	1	5.36	(5,na,1,3,3,5); model calculation for biogenic emissions based on literature
	Nitrogen oxides	-	-	kg	2.80E-5	3.30E-5	5.51E-6	1	1.70	(4,4,1,5,3,5); model calculation for emissions based on fertilizer application
emission soil, agricultural	Cadmium	-	-	kg	-2.05E-7	-2.65E-7	-1.81E-9	1	1.70	(4,4,1,5,3,5); input-output balance for seeds, products and fertilizer
	Chromium	-	-	kg	4.20E-6	3.45E-6	3.30E-7	1	1.70	(4,4,1,5,3,5); input-output balance for seeds, products and fertilizer
	Copper	-	-	kg	-2.32E-6	-2.38E-6	-9.87E-8	1	1.70	(4,4,1,5,3,5); input-output balance for seeds, products and fertilizer
	Lead	-	-	kg	1.68E-7	1.36E-7	1.29E-8	1	1.70	(4,4,1,5,3,5); input-output balance for seeds, products and fertilizer
	Mercury	-	-	kg	-1.43E-8	-1.43E-8	-6.93E-10	1	1.70	(4,4,1,5,3,5); input-output balance for seeds, products and fertilizer
	Nickel	-	-	kg	1.06E-7	7.79E-8	3.11E-8	1	1.70	(4,4,1,5,3,5); input-output balance for seeds, products and fertilizer
	Zinc	-	-	kg	-6.40E-5	-6.47E-5	-3.18E-6	1	1.70	(4,4,1,5,3,5); input-output balance for seeds, products and fertilizer
	Atrazine	-	-	kg	2.16E-5	1.70E-5	8.93E-7	1	1.48	(4,4,1,5,3,5); pesticide application, Azotop 50 WP
	Chlorotoluron	-	-	kg	0	0	3.57E-7	1	1.48	(4,4,1,5,3,5); pesticide application, Faworyt 300 SE, Chlopyralid
	Chlorpyrifos	-	-	kg	0	0	3.02E-7	1	1.48	(4,4,1,5,3,5); pesticide application, Metolaclor
	Cypermethrin	-	-	kg	0	0	3.02E-8	1	1.48	(4,4,1,5,3,5); pesticide application
	Dichlobenil	-	-	kg	3.79E-8	4.18E-8	2.41E-6	1	1.48	(4,4,1,5,3,5); pesticide application, Casaron 6.75 GR
	Fenpropimorph	-	-	kg	0	0	7.17E-7	1	1.48	(4,4,1,5,3,5); pesticide application, assumption for fenitrhothion
	Fluazifop-P-butyl	-	-	kg	1.54E-6	1.31E-6	1.67E-6	1	1.48	(4,4,1,5,3,5); pesticide application, Metolaclor
	Glyphosate	-	-	kg	1.09E-5	1.00E-5	9.33E-9	1	1.48	(4,4,1,5,3,5); pesticide application
	Linuron	-	-	kg	1.54E-6	1.31E-6	1.26E-6	1	1.48	(4,4,1,5,3,5); pesticide application, Linuron
	Metolachlor	-	-	kg	5.24E-6	4.45E-6	4.28E-6	1	1.48	(4,4,1,5,3,5); pesticide application, Metolaclor
	Pendimethalin	-	-	kg	2.06E-7	1.75E-7	2.01E-6	1	1.48	(4,4,1,5,3,5); pesticide application, Pendimethalin
	Pyridate	-	-	kg	3.47E-6	2.95E-6	2.83E-6	1	1.48	(4,4,1,5,3,5); pesticide application, Pyridate
emission water, ground-	Nitrate	-	-	kg	2.17E-3	1.97E-3	9.45E-4	1	1.70	(4,4,1,5,3,5); model calculation for emissions based on fertilizer application
	Phosphate	-	-	kg	1.54E-5	1.35E-5	1.26E-6	1	1.70	(4,4,1,5,3,5); model calculation for emissions based on fertilizer application
emission water, river	Phosphate	-	-	kg	8.75E-5	7.20E-5	3.54E-6	1	1.70	(4,4,1,5,3,5); model calculation for emissions based on fertilizer application
	Phosphorus	-	-	kg	1.58E-6	1.53E-6	6.58E-7	1	1.70	(4,4,1,5,3,5); emission due to erosion

2.4 Miscanthus plantation

Elaboration of LCI: Niels Jungbluth, ESU-services Ltd., Uster
Data provider Ewa Ganko, Mikael Lantz, Natasa Nikolaou, Niels Jungbluth

Miscanthus[7] is a genus of about 15 species of perennial grasses native to subtropical and tropical regions of Africa and southern Asia, with one species (M. sinensis) extending north into temperate eastern Asia. The sterile hybrid between M. sinensis and M. sacchariflorus, Miscanthus giganteus or "E-grass", has been trialed as a biofuel in Europe since the early 1980s. It can grow to heights of more than 3.5 m in one growth season. Its dry weight annual yield can reach 25t/ha (10t/acre). It grows over a period of several years and can be harvested once every year.

Tab. 2.13 shows the key figures[8] on miscanthus production in the different countries based on the three reports with regional inventory data. The data of Western Europe have been investigated with literature data. Data of the starting point scenario are assessed with (FNR 2005; Rosenqvist & Lantz 2006). Data of scenario 1 have been assessed roughly (Mehlin et al. 2003). The pesticide use has been approximated with the data provided by (Wolfensberger & Dinkel 1997).

These data are investigated for one average year of production. The data of the establishment of the plantation are divided by the number of harvest during the plantation. The data include the establishment of the plantation and the harvesting over a full plantation period. Further details for the use of water and pesticides are provided in the reports with the regional inventory data.

The nursery of planting stocks for miscanthus is investigated only with the starting point scenario. The influences of variations due to different scenarios on the results are considered negligible. Thus, the same inventory data are used for the scenarios 1.

Tab. 2.13 Key figures of miscanthus production in different countries per ha and year (regional life cycle inventory data and own assumptions)

		miscanthus-bales, at field	miscanthus-bales, scenario 1, at field	planting stocks, miscanthus, at field	miscanthus, planting stocks	miscanthus, planting stocks	miscanthus	miscanthus, sc1	miscanthus	miscanthus, sc1	miscanthus	miscanthus, sc1
		RER	RER	RER	GR	PL	GR	GR	PL	PL	DE	DE
		ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
N-fertilizer, tot	kg	60	115	68	75	60	75	150	60	80	48	100
P2O5-fertilizer, tot	kg	46	57	63	50	80	50	50	80	80	18	48
K2O-fertilizer, min	kg	76	87	109	100	120	100	100	120	120	23	45
Lime	kg	53	49	71	-	158	-	-	158	158	25	25
diesel use	kg	64	69	61	67	53	67	67	53	57	70	80
yield	kg DS	14'970	20'504	14'325	15000	13'500	15000	25000	13500	16500	16000	18000
amount of harvests	-	19	19	9	1	19	19	19	19	19	19	19
Duration of plantation	a	20	20	11	3	20	20	20	20	20	20	20
Pesticides	kg	1.19	1.40	1.81	3.08	0.26	3.08	3.08	0.26	0.26	0.19	0.19
Water content	%	16%	16%	16%	16%	16%	16%	16%	16%	16%	16%	16%
NO3-N emission factor	%	54%	40%	51%	46%	56%	46%	32%	50%	47%	64%	43%
N2O-N emission factor	%	2.8%	2.1%	2.7%	2.6%	2.9%	2.6%	1.5%	2.7%	2.6%	3.1%	2.5%
NH3-N emission factor	%	4.5%	3.6%	4.5%	4.5%	4.5%	4.5%	2.3%	4.5%	4.5%	4.6%	4.5%
Emission factor isoprene (kg/ha/period/h)	-	0.020	0.027	0.019	0.02004	0.01804	0.02004	0.0334	0.01804	0.02204	0.02138	0.02405
Emission factor NMVOC (kg/ha/period/h)	-	0.001	0.001	0.001	0.0010	0.0009	0.0010	0.0017	0.0009	0.0011	0.0011	0.0012
environmental correction factor	h	1'082	1'123	1'203	1'440	912	1'440	1'440	912	912	890	890

sc1 Scenario 1

The life cycle inventory analysis is calculated and elaborated based on these key figures. Tab. 2.15 and Tab. 2.16 provide the detailed information on all elementary flows, data uncertainties and the way in which these data are calculated. The description of the datasets is documented in Tab. 2.14.

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[7] Chinaschilf in German.

[8] See Tab. 2.9 for a more detailed description.

Tab. 2.14 Documentation of the average miscanthus production

ReferenceFunction	Name	miscanthus-bales, at field	miscanthus-bales, scenario 1, at field	planting stocks, miscanthus, at field
Geography	Location	RER	RER	RER
ReferenceFunction	InfrastructureProcess	0	0	0
ReferenceFunction	Unit	kg	kg	unit
	IncludedProcesses	The inventory includes the processes of soil cultivation, sowing, weed control, fertilisation, pest and pathogen control, harvest and balling. Machine infrastructure and a shed for machine sheltering is included. Inputs of fertilisers, pesticides and planting stocks as well as their transports to the farm are considered. The direct emissions on the field are also included. The system boundary is the field.	The inventory includes the processes of soil cultivation, sowing, weed control, fertilisation, pest and pathogen control, harvest and balling. Machine infrastructure and a shed for machine sheltering is included. Inputs of fertilisers, pesticides and planting stocks as well as their transports to the farm are considered. The direct emissions on the field are also included. The system boundary is the field.	The inventory includes the processes of soil cultivation, sowing, weed control, fertilisation, pest and pathogen control, harvest and balling. Machine infrastructure and a shed for machine sheltering is included. Inputs of fertilisers, pesticides and planting stocks as well as their transports to the farm are considered. The direct emissions on the field are also included. The system boundary is the field.
	Synonyms			
	GeneralComment	Inventory refers to the production of 1 kg dry matter miscanthus-bales.	Inventory refers to the production of 1 kg dry matter miscanthus-bales.	Inventory refers to the production of 1 planting stock (1 unit).
	Category	agricultural production	agricultural production	agricultural production
	SubCategory	plant production	plant production	plant production
TimePeriod	StartDate	2000	2000	2000
	EndDate	2000	2020	2000
	OtherPeriodText	Starting point scenario for average agricultural and harvesting technology in the year 2004.	Scenario 1 for maximized biofuel production in the year 2020	Starting point scenario for average agricultural and harvesting technology in the year 2004.
Geography	Text	Refers to an average production in Europe. Calculation based on inventory data for SE, PL, DE and GR. Production shares based on expert guess.	Refers to an average production in Europe. Calculation based on inventory data for SE, PL, DE and GR. Production shares based on expert guess.	Refers to an average production in Europe. Calculation based on inventory data for SE, PL, DE and GR. Production shares based on expert guess.
Technology	Text	Average production of today	Expert guess data for agricultural and harvesting technology in 2020	Integrated production
	ProductionVolume	So far only limited experiences.	So far only limited experiences.	So far only limited experiences.
	SamplingProcedure	Data were compiled by experts from Poland, Greece, Germany and Sweden from statistics, pilot network, fertilising recommendations, documents from extension services, information provided by retailers, literature and expert knowledge. The production data were verified and adjusted by the project team.	Data were compiled by experts from Poland, Greece, Germany and Sweden from statistics, pilot network, fertilising recommendations, documents from extension services, information provided by retailers, literature and expert knowledge. The production data were verified and adjusted by the project team.	Data were compiled by experts from Poland, Greece, Germany and Sweden from statistics, pilot network, fertilising recommendations, documents from extension services, information provided by retailers, literature and expert knowledge. The production data were verified and adjusted by the project team.
	Extrapolations	none	based on scenario definitions	Average of two literature sources.
	UncertaintyAdjustments	none	none	none

Tab. 2.15 Life cycle inventory analysis and unit process raw data of average miscanthus production (technosphere inputs and outputs)

	Name	Location	InfrastructureProcess	Unit	miscanthus-bales, at field	miscanthus-bales, scenario 1, at field	planting stocks, miscanthus, at field	Uncertainty	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER			
	InfrastructureProcess				0	0	0			
	Unit				kg	kg	unit			
fertilizer	ammonium nitrate, as N, at regional storehouse	RER	0	kg	1.92E-3	1.98E-3	1.32E-4	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	ammonium sulphate, as N, at regional storehouse	RER	0	kg	1.48E-4	1.53E-4	1.02E-5	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	calcium ammonium nitrate, as N, at regional storehouse	RER	0	kg	9.62E-4	9.92E-4	6.60E-5	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	diammonium phosphate, as N, at regional storehouse	RER	0	kg	3.37E-4	3.05E-4	1.87E-5	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	urea, as N, at regional storehouse	RER	0	kg	6.66E-4	6.87E-4	4.57E-5	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	potassium chloride, as K2O, at regional storehouse	RER	0	kg	4.77E-3	4.00E-3	4.26E-4	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	potassium sulphate, as K2O, at regional storehouse	RER	0	kg	3.04E-4	2.55E-4	2.72E-5	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	lime, from carbonation, at regional storehouse	CH	0	kg	3.56E-3	2.40E-3	3.55E-4	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	diammonium phosphate, as P2O5, at regional storehouse	RER	0	kg	8.62E-4	7.81E-4	4.77E-5	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	single superphosphate, as P2O5, at regional storehouse	RER	0	kg	6.16E-5	5.58E-5	3.41E-6	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	thomas meal, as P2O5, at regional storehouse	RER	0	kg	1.54E-4	1.39E-4	8.52E-6	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	triple superphosphate, as P2O5, at regional storehouse	RER	0	kg	1.26E-3	1.14E-3	6.99E-5	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	phosphate rock, as P2O5, beneficiated, dry, at plant	MA	0	kg	7.39E-4	6.69E-4	4.09E-5	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
seeds	planting stocks, miscanthus, at field	RER	0	unit	3.46E-2	2.51E-2	2.10E-3	1	1.32	(4,4,1,1,1,5); establishment of the plantation
pesticides	benzimidazole-compounds, at regional storehouse	RER	0	kg	3.50E-7	2.40E-7	4.26E-8	1	1.32	(4,4,1,1,1,5); pesticide use
	cyclic N-compounds, at regional storehouse	CH	0	kg	1.31E-6	9.00E-7	1.60E-7	1	1.32	(4,4,1,1,1,5); pesticide use
	triazine-compounds, at regional storehouse	RER	0	kg	4.52E-5	4.03E-5	3.67E-6	1	1.32	(4,4,1,1,1,5); pesticide use, Atrazine
	organophosphorus-compounds, at regional storehouse	RER	0	kg	3.24E-5	2.69E-5	2.36E-6	1	1.32	(4,4,1,1,1,5); pesticide use
machinery	diesel, used by tractor	RER	0	kg	4.28E-3	3.35E-3	2.42E-4	1	1.32	(4,4,1,1,1,5); machinery use
	transport, lorry 32t	RER	0	tkm	3.22E-3	0	2.44E-4	1	2.09	(4,5,na,na,na,na); standard distances for transport of materials
	transport, lorry 32t, Euro 5, diesel	RER	0	tkm	0	3.47E-3	0			
	transport, van <3.5t	RER	0	tkm	9.81E-6	7.45E-6	1.87E-7	1	2.09	(4,5,na,na,na,na); standard distances for transport of materials
	transport, barge	RER	0	tkm	1.80E-2	2.17E-2	1.25E-3	1	2.09	(4,5,na,na,na,na); standard distances for transport of materials
	transport, freight, rail	RER	0	tkm	4.12E-3	4.26E-3	3.33E-4	1	2.09	(4,5,na,na,na,na); standard distances for transport of materials

Tab. 2.16 Life cycle inventory analysis and unit process raw data of average miscanthus production (ecosphere inputs and outputs)

	Name	Location	InfrastructureProcess	Unit	miscanthus-bales, at field	miscanthus-bales, scenario 1, at field	planting stocks, miscanthus, at field	Uncertainty	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER			
	InfrastructureProcess				0	0	0			
	Unit				kg	kg	unit			
resource, in air	Carbon dioxide, in air	-	-	kg	1.72E+0	1.72E+0	9.98E-2	1	1.26	(3,4,1,1,1,5); carbon uptake of plants
resource, biotic	Energy, gross calorific value, in biomass	-	-	MJ	1.84E+1	1.84E+1	1.06E+0	1	1.26	(3,4,1,1,1,5); energy content of harvested product
resource, water	Water, rain	-	-	m3	4.92E-1	3.44E-1	2.40E-2	1	1.26	(3,4,1,1,1,5); average rainfall in the region during the plantation
	Water, river	-	-	m3	1.36E-1	1.21E-1	1.10E-2	1	1.32	(4,4,1,1,1,5); water used for irrigation
resource, land	Occupation, arable	-	-	m2a	6.68E-1	4.88E-1	4.08E-2	1	1.28	(3,4,1,1,1,5); land occupation
	Transformation, from pasture and meadow, extensive	-	-	m2	3.34E-2	2.44E-2	7.24E-3	1	1.34	(3,4,1,1,1,5); transformation of set aside land
	Transformation, to arable	-	-	m2	3.34E-2	2.44E-2	7.24E-3	1	1.34	(3,4,1,1,1,5); transformation to energy crops
emission air, low population density	Ammonia	-	-	kg	2.22E-4	2.27E-4	1.50E-5	1	1.48	(4,4,1,5,3,5); model calculation for emissions based on fertilizer application
	Dinitrogen monoxide	-	-	kg	1.67E-4	1.68E-4	1.11E-5	1	1.70	(4,4,1,5,3,5); model calculation for emissions based on fertilizer application
	Isoprene	-	-	kg	1.45E-3	1.57E-3	8.99E-5	1	5.32	(5,na,na,3,3,3); model calculation for biogenic emissions based on literature
	Terpenes	-	-	kg	7.23E-5	5.28E-5	4.42E-6	1	5.32	(5,na,na,3,3,3); model calculation for biogenic emissions based on literature
	Nitrogen oxides	-	-	kg	3.51E-5	3.52E-5	2.33E-6	1	1.70	(4,4,1,5,3,5); model calculation for emissions based on fertilizer application
emission soil, agricultural	Cadmium	-	-	kg	8.22E-8	5.54E-8	1.57E-8	1	1.70	(4,4,1,5,3,5); input-output balance for seeds, products and fertilizer
	Chromium	-	-	kg	2.62E-6	2.28E-6	2.02E-7	1	1.70	(4,4,1,5,3,5); input-output balance for seeds, products and fertilizer
	Copper	-	-	kg	-4.52E-6	-4.57E-6	3.00E-8	1	1.70	(4,4,1,5,3,5); input-output balance for seeds, products and fertilizer
	Lead	-	-	kg	-8.08E-7	-8.37E-7	1.44E-8	1	1.70	(4,4,1,5,3,5); input-output balance for seeds, products and fertilizer
	Mercury	-	-	kg	-9.51E-9	-9.54E-9	3.56E-11	1	1.70	(4,4,1,5,3,5); input-output balance for seeds, products and fertilizer
	Nickel	-	-	kg	-1.58E-6	-1.61E-6	2.60E-8	1	1.70	(4,4,1,5,3,5); input-output balance for seeds, products and fertilizer
	Zinc	-	-	kg	-2.08E-5	-2.14E-5	3.03E-7	1	1.70	(4,4,1,5,3,5); input-output balance for seeds, products and fertilizer
	Atrazine	-	-	kg	4.52E-5	4.03E-5	3.67E-6	1	1.48	(4,4,1,5,3,5); pesticide application, 500g/l
	Carbendazim	-	-	kg	3.50E-7	2.40E-7	4.26E-8	1	1.48	(4,4,1,5,3,5); pesticide application, sportak alpha 380 EC
	Glyphosate	-	-	kg	3.24E-5	2.69E-5	2.36E-6	1	1.48	(4,4,1,5,3,5); Roundup 360 SL, 360g/l
	Prochloraz	-	-	kg	1.31E-6	9.00E-7	1.60E-7	1	1.48	(4,4,1,5,3,5); pesticide application, sportak alpha 380 EC
emission water, ground-	Nitrate	-	-	kg	9.40E-3	9.47E-3	6.17E-4	1	1.70	(4,4,1,5,3,5); model calculation for emissions based on fertilizer application
	Phosphate	-	-	kg	1.23E-5	8.97E-6	7.51E-7	1	1.70	(4,4,1,5,3,5); model calculation for emissions based on fertilizer application
emission water, river	Phosphate	-	-	kg	4.00E-5	2.99E-5	2.42E-6	1	1.70	(4,4,1,5,3,5); model calculation for emissions based on fertilizer application
	Phosphorus	-	-	kg	3.08E-7	2.25E-7	1.88E-8	1	1.70	(4,4,1,5,3,5); emission due to erosion

2.5 Production of wheat and wheat straw

Elaboration of LCI: Niels Jungbluth, ESU-services Ltd., Uster
Data provider Ewa Ganko, Mikael Lantz, Natasa Nikolaou, Niels Jungbluth

Wheat and wheat straw are produced together on the field. This type of cultivation is an annual harvested crop.

The total amount of straw in the plant is not equal to the part that is actually usable for energy purposes. In the calculation for the life cycle inventory, we consider the yield to be the amount of straw actually harvested and transported to the farm. Thus, the yield does not include the remaining straw on the field.

It has to be noted that a part of this yield will be necessary for breeding of animals and thus the actual potential for energy uses is lower than the yield assumed in this study.

The data of Western Europe have been estimated based on (FNR 2005; Nemecek et al. 2004). Data of the (FNR 2005) have mainly been used for intensive production in scenario 1. While for today production also data of Swiss integrated production have been assumed.

For wheat production, we assume the production of wheat as food or fodder. This type of wheat production might be different from the production of wheat grains for the purpose of ethanol production because this type of wheat needs less protein and thus less input of nitrogen fertilizers.

Tab. 2.17 shows the key figures[9] on wheat production in the different countries. Data of machinery use are calculated as an average use of fuel per year. The higher figure for lime use in Poland is because soils have a lower pH value.

Tab. 2.17 Key figures on wheat production in different countries per ha and year (regional life cycle inventory data and own assumptions)

		wheat straw, bales, at field RER ha	wheat straw, bales, scenario 1, RER ha	wheat GR ha	wheat, sc1 GR ha	wheat PL ha	wheat, sc1 PL ha	wheat SE ha	wheat, sc1 SE ha	wheat DE ha	wheat, sc1 DE ha
N-fertilizer, tot	kg	109	144	100	150	85	140	158	158	120	140
P2O5-fertilizer, tot	kg	55	68	50	75	60	70	46	46	57	66
K2O-fertilizer, min	kg	47	116	-	30	80	120	84	84	48	181
Lime	kg	221	221	-	-	750	750	180	180	-	-
Slurry and liquid manure	m3										
fuel use	kg	113	110	104	104	92	85	127	110	132	132
Grain yield	kg DS	4'900	6'719	3'000	6'000	4'250	7'250	6'000	6'000	6'420	7'000
Straw yield	kg DS	3'718	4'428	4'500	6'000	3'100	5'000	2'500	2'000	3'910	3'500
Duration of plantation (Period)	a	0.80	0.80	0.79	0.79	0.83	0.83	0.79	0.79	0.79	0.79
Number of pesticide applications	-	1.82	1.82	1.00	1.00	4.00	4.00	1.00	1.00	1.00	1.00
Pesticides	kg	2.22	2.35	1.50	2.00	2.78	2.78	0.86	0.86	2.64	2.64
Water content grain	%	16%	16%	15%	15%	17%	17%	15%	15%	15%	15%
Water content straw	%	16%	16%	15%	15%	17%	17%	15%	15%	15%	15%
NO3-N emission factor	%	35%	19%	44%	19%	46%	19%	21%	17%	23%	19%
N2O-N emission factor	%	2.5%	2.0%	2.7%	2.0%	2.8%	2.0%	2.0%	1.9%	2.1%	2.0%
NH3-N emission factor	%	4.5%	4.6%	5%	5%	5%	5%	5%	5%	5%	5%
Emission factor isoprene	g/ha/period/h	0.0200	0.0259	0.017	0.028	0.017	0.028	0.020	0.019	0.024	0.024
Emission factor NMVOC	g/ha/period/h	0.0010	0.0013	0.0009	0.0014	0.0009	0.0014	0.0010	0.0009	0.0012	0.0012
environmental correction factor	h	1'006	1'006	1'440	1'440	912	912	508	508	890	890
environmental correction factor	period	808	808	1'144	1'144	760	760	403	403	707	707

sc1 Scenario 1

There are several possibilities to allocate the inputs and outputs between straw and grains. The possibilities have been discussed by several authors (Audsley et al. 1997; Clift et al. 1995; Cowell et al. 1999; Nemecek et al. 2004). The LCAnet food recommends the use of system expansion (Cowell et al. 1999), which is not foreseen in this study. The most common approach in case studies considers the economic value of the products. Another possibility would be to allocate only those environmental impacts to straw that are directly necessary for the straw output (e.g. same nitrogen input as withdrawal of nitrogen with the straw). Thus, grains would be seen as a main product while straw is considered more as a by-product or waste.

Within the cost assessment, only these inputs are assigned to straw, which are fully necessary for its production. These are the machinery use for harvesting, but not the use for plugging, pesticide application, etc. Only the amount of nutrients finally harvested with the straw is included as an input in that calculation.

Tab. 2.18 shows the factors that can be used for the allocation between wheat straw and wheat grains. The allocation share for straw is much higher (about 43%) if the energy content is used than with an allocation by market price[10] (about 10%). Or in other words, the allocation by energy results in four

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[9] See Tab. 2.9 for a more detailed description.

[10] European prices by EUROSTAT for 2003 http://europa.eu.int/comm/agriculture/agrista/2004/table_en/index.htm

times the environmental impacts per kg of straw in comparison to using the economic value. The price for straw is also quite dependant at the point of sale because transports might be responsible for a large share of the costs. For the straw at the field edge, these transports have been excluded (Ganko et al. 2006).

Within this study, the price of the couple-products is used for the allocation between wheat and straw, because this seems to best reflect the assumption that straw can be used a by-product. The influence of this assumption on the results is assessed with a sensitivity analysis for an allocation by the energy content of the two products.

Tab. 2.18 Allocation between wheat and straw. Comparison of energy content and economic allocation based on European prices and yields in the starting point calculation

Allocation Straw/Wheat	Yield	Europe	Allocation factor	Price	Allocation factor
	kg/ha	MJ/kg	%	t	%
wheat, lower heating value	4'900	**17.0**	57%	€ 172.00	90%
straw, lower heating value	3'718	**17.2**	43%	€ 24.50	10%

The life cycle inventory analysis is calculated and elaborated based on the key figures shown in Tab. 2.17. Tab. 2.20 and Tab. 2.21 provide the detailed information on all inputs and outputs, data uncertainties and the way in which these data are calculated. The description of the datasets is documented in Tab. 2.19. The last two rows in Tab. 2.21 show the amount of straw and grains actually harvested. About 8% and 10% of the inputs and outputs per hectare are allocated to the amount of straw while the rest is allocated to the wheat grains in the starting point calculation and in scenario 1, respectively.

Tab. 2.19 Documentation of the average wheat straw production

ReferenceFunction	Name	wheat straw, bales, at field	wheat straw, bales, scenario 1, at field
Geography	Location	RER	RER
ReferenceFunction	InfrastructureProcess	0	0
ReferenceFunction	Unit	kg	kg
	IncludedProcesses	The inventory includes the processes of soil cultivation, sowing, weed control, fertilisation, pest and pathogen control, harvest and drying of the grains. Machine infrastructure and a shed for machine sheltering is included. Inputs of fertilisers, pesticides and seed as well as their transports to the farm are considered. The direct emissions on the field are also included. The system boundary is the field.	The inventory includes the processes of soil cultivation, sowing, weed control, fertilisation, pest and pathogen control, harvest and drying of the grains. Machine infrastructure and a shed for machine sheltering is included. Inputs of fertilisers, pesticides and seed as well as their transports to the farm are considered. The direct emissions on the field are also included. The system boundary is the field.
	Synonyms		
	GeneralComment	Inventory refers to the production of 1 kg dry matter wheat straw, with a moisture content of 15 %. Allocation between wheat and straw is based on the price of both couple products.	Inventory refers to the production of 1 kg dry matter wheat straw, with a moisture content of 15 %. Allocation between wheat and straw is based on the price of both couple products.
	Category	agricultural production	agricultural production
	SubCategory	plant production	plant production
TimePeriod	StartDate	2000	2000
	EndDate	2000	2020
	OtherPeriodText	Starting point scenario for average agricultural and harvesting technology in the year 2004.	Scenario 1 for maximized biofuel production in the year 2020
Geography	Text	Refers to an average production in Europe. Calculation based on inventory data for SE, PL, DE and GR. Production shares based on expert guess.	Refers to an average production in Europe. Calculation based on inventory data for SE, PL, DE and GR. Production shares based on expert guess.
Technology	Text	Average production of today	Expert guess data for agricultural and harvesting technology in 2020
	ProductionVolume	Not known	Not known
	SamplingProcedure	Data were compiled by experts from Poland, Greece, Germany and Sweden from statistics, pilot network, fertilising recommendations, documents from extension services, information provided by retailers, literature and expert knowledge. The production data were verified and adjusted by the project team.	Data were compiled by experts from Poland, Greece, Germany and Sweden from statistics, pilot network, fertilising recommendations, documents from extension services, information provided by retailers, literature and expert knowledge. The production data were verified and adjusted by the project team.
	Extrapolations	none	based on scenario definitions
	UncertaintyAdjustments	none	none

Tab. 2.20 Life cycle inventory analysis and unit process raw data of average wheat straw production (technosphere inputs and outputs)

	Name	Location	Unit	wheat straw, bales, at field	wheat straw, bales, scenario 1, at field	Uncertainty	StandardDeviation95%	GeneralComment
	Location			RER	RER			
	InfrastructureProcess			0	0			
	Unit			kg	kg			
fertilizer	ammonium nitrate, as N, at regional storehouse	RER	kg	1.40E-3	1.35E-3	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	ammonium sulphate, as N, at regional storehouse	RER	kg	1.08E-4	1.04E-4	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	calcium ammonium nitrate, as N, at regional storehouse	RER	kg	7.00E-4	6.73E-4	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	diammonium phosphate, as N, at regional storehouse	RER	kg	1.58E-4	1.40E-4	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	urea, as N, at regional storehouse	RER	kg	4.84E-4	4.66E-4	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	potassium chloride, as K2O, at regional storehouse	RER	kg	1.17E-3	2.07E-3	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	potassium sulphate, as K2O, at regional storehouse	RER	kg	7.45E-5	1.32E-4	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	lime, from carbonation, at regional storehouse	CH	kg	5.79E-3	4.17E-3	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	diammonium phosphate, as P2O5, at regional storehouse	RER	kg	4.04E-4	3.58E-4	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	single superphosphate, as P2O5, at regional storehouse	RER	kg	2.89E-5	2.56E-5	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	thomas meal, as P2O5, at regional storehouse	RER	kg	7.22E-5	6.40E-5	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	triple superphosphate, as P2O5, at regional storehouse	RER	kg	5.92E-4	5.25E-4	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
	phosphate rock, as P2O5, beneficiated, dry, at plant	MA	kg	3.46E-4	3.07E-4	1	1.32	(4,4,1,1,1,5); application of fertilizer and average consumption
seeds	wheat seed IP, at regional storehouse	CH	kg	3.98E-3	3.12E-3	1	1.32	(4,4,1,1,1,5); establishment of the plantation
pesticides	[sulfonyl]urea-compounds, at regional storehouse	CH	kg	1.45E-5	1.04E-5	1	1.32	(4,4,1,1,1,5); pesticide use
	cyclic N-compounds, at regional storehouse	CH	kg	9.63E-6	7.93E-6	1	1.32	(4,4,1,1,1,5); pesticide use
	nitrile-compounds, at regional storehouse	CH	kg	1.89E-6	1.36E-6	1	1.32	(4,4,1,1,1,5); pesticide use
	diphenylether-compounds, at regional storehouse	RER	kg	9.27E-8	6.69E-8	1	1.32	(4,4,1,1,1,5); pesticide use
	dicamba, at regional storehouse	RER	kg	7.08E-7	5.10E-7	1	1.32	(4,4,1,1,1,5); pesticide use
	pesticide unspecified, at regional storehouse	CH	kg	2.01E-5	1.45E-5	1	1.32	(4,4,1,1,1,5); Baytan Universal 19.5 WS (triadimenol, imazail, fuberydazol).
	phenoxy-compounds, at regional storehouse	CH	kg	1.35E-5	1.22E-5	1	1.32	(4,4,1,1,1,5); pesticide use
machinery	diesel, used by tractor	RER	kg	2.97E-3	2.08E-3	1	1.32	(4,4,1,1,1,5); machinery use
	transport, lorry 32t	RER	tkm	1.62E-3	0	1	2.09	(4,5,na,na,na,na); standard distances for transport of materials
	transport, lorry 32t, Euro 5, diesel	RER	tkm	0	1.68E-3	1	2.09	(4,5,na,na,na,na); standard distances for transport of materials
	transport, van <3.5t	RER	tkm	6.15E-5	4.82E-5	1	2.09	(4,5,na,na,na,na); standard distances for transport of materials
	transport, barge	RER	tkm	1.09E-2	1.04E-2	1	2.09	(4,5,na,na,na,na); standard distances for transport of materials
	transport, freight, rail	RER	tkm	1.32E-3	1.42E-3	1	2.09	(4,5,na,na,na,na); standard distances for transport of materials

Tab. 2.21 Life cycle inventory analysis and unit process raw data of average wheat straw production (ecosphere inputs and outputs)

	Name	Location	Unit	wheat straw, bales, at field	wheat straw, bales, scenario 1, at field	Uncertainty	StandardDeviation95%	GeneralComment
	Location			RER	RER			
	InfrastructureProcess			0	0			
	Unit			kg	kg			
resource, in air	Carbon dioxide, in air	-	kg	1.67	1.67	1	1.41	(4,4,1,5,3,5); carbon uptake of plants
resource, biotic	Energy, gross calorific value, in biomass	-	MJ	17.2	17.2		1.4	(4,4,1,5,3,5); energy content of harvested product
resource, biotic	Water, rain	-	m3	1.58E-1	1.14E-1	1	1.41	(4,4,1,5,3,5); average rainfall in the region during the plantation
	Water, river	-	m3	4.10E-3	2.96E-3	1	1.41	(4,4,1,5,3,5); water used for irrigation
resource, land	Occupation, arable	-	m2a	2.11E-1	1.52E-1	1	1.43	(4,4,1,5,3,5); land occupation
	Transformation, from arable	-	m2	1.86E-1	1.34E-1	1	1.48	(4,4,1,5,3,5); 71% of total transformation
	Transformation, from pasture and meadow, intensive	-	m2	7.61E-2	5.49E-2	1	1.48	(4,4,1,5,3,5); 29% of total transformation
	Transformation, to arable	-	m2	2.62E-1	1.89E-1	1	1.48	(4,4,1,5,3,5); land transformation for crop
emission air, low population density	Ammonia	-	kg	1.57E-4	1.51E-4	1	1.48	(4,4,1,5,3,5); model calculation for emissions based on fertilizer application
	Dinitrogen monoxide	-	kg	1.03E-4	8.08E-5	1	1.70	(4,4,1,5,3,5); model calculation for emissions based on fertilizer application
	Isoprene	-	kg	4.15E-4	4.04E-4	1	5.36	(5,na,1,3,3,5); model calculation for biogenic emissions based on literature
	Terpenes	-	kg	2.08E-5	2.02E-5	1	5.36	(5,na,1,3,3,5); model calculation for biogenic emissions based on literature
	Nitrogen oxides	-	kg	2.16E-5	1.70E-5	1	1.70	(4,4,1,5,3,5); model calculation for emissions based on fertilizer application
emission soil, agricultural	Cadmium	-	kg	9.96E-8	8.68E-8	1	1.70	(4,4,1,5,3,5); input-output balance for seeds, products and fertilizer
	Chromium	-	kg	1.66E-6	1.47E-6	1	1.70	(4,4,1,5,3,5); input-output balance for seeds, products and fertilizer
	Copper	-	kg	-6.02E-7	-5.91E-7	1	1.70	(4,4,1,5,3,5); input-output balance for seeds, products and fertilizer
	Lead	-	kg	-1.18E-7	-1.01E-7	1	1.70	(4,4,1,5,3,5); input-output balance for seeds, products and fertilizer
	Mercury	-	kg	-5.69E-9	-5.03E-9	1	1.70	(4,4,1,5,3,5); input-output balance for seeds, products and fertilizer
	Nickel	-	kg	1.77E-7	1.60E-7	1	1.70	(4,4,1,5,3,5); input-output balance for seeds, products and fertilizer
	Zinc	-	kg	-2.39E-6	-2.92E-6	1	1.70	(4,4,1,5,3,5); input-output balance for seeds, products and fertilizer
	MCPA	-	kg	1.02E-5	9.86E-6	1	1.48	(4,4,1,5,3,5); pesticide application
	Chlormequat	-	kg	1.48E-5	1.07E-5	1	1.48	(4,4,1,5,3,5); Terpal C 460 SL
	Chlorotoluron	-	kg	0	0	1	1.48	(4,4,1,5,3,5); pesticide application
	Cypermethrin	-	kg	0	0	1	1.48	(4,4,1,5,3,5); pesticide application
	Cyproconazole	-	kg	2.29E-7	1.65E-7	1	1.48	(4,4,1,5,3,5); Artea 330 EC
	Dicamba	-	kg	7.08E-7	5.10E-7	1	1.48	(4,4,1,5,3,5); Lintur 70 WG
	Diflufenican	-	kg	9.27E-8	6.69E-8	1	1.48	(4,4,1,5,3,5); pesticide application
	Difenoconazole	-	kg	1.79E-7	1.29E-7	1	1.48	(4,4,1,5,3,5); pesticide application
	Fenpropimorph	-	kg	6.52E-6	5.69E-6	1	1.48	(4,4,1,5,3,5); pesticide application
	Fluroxypyr	-	kg	1.62E-7	1.17E-7	1	1.48	(4,4,1,5,3,5); pesticide application
	Flusilazole	-	kg	3.58E-6	2.58E-6	1	1.48	(4,4,1,5,3,5); pesticide application
	Ioxynil	-	kg	1.89E-6	1.36E-6	1	1.48	(4,4,1,5,3,5); pesticide application
	Isoproturon	-	kg	1.43E-5	1.03E-5	1	1.48	(4,4,1,5,3,5); pesticide application
	Lamda-Cyhalothrin	-	kg	7.16E-8	5.16E-8	1	1.48	(4,4,1,5,3,5); Karate Zenon 050 CS, 10% active substance
	Mecoprop-P	-	kg	3.08E-6	2.22E-6	1	1.48	(4,4,1,5,3,5); pesticide application
	Metaldehyde	-	kg	2.98E-7	2.15E-7	1	1.48	(4,4,1,5,3,5); pesticide application
	Propiconazole	-	kg	7.16E-7	5.16E-7	1	1.48	(4,4,1,5,3,5); Artea 330 EC
	Triasulfuron	-	kg	1.37E-7	9.89E-8	1	1.48	(4,4,1,5,3,5); Lintur 70 WG, Apyros 75 WG
	Tridemorph	-	kg	6.50E-7	4.69E-7	1	1.48	(4,4,1,5,3,5); Folicur Plus 375 EC
	Tebuconazole	-	kg	2.89E-6	2.08E-6	1	1.48	(4,4,1,5,3,5); Folicur Plus 375 EC
emission water, ground-	Nitrate	-	kg	4.13E-3	2.25E-3	1	1.70	(4,4,1,5,3,5); model calculation for emissions based on fertilizer application
	Phosphate	-	kg	4.69E-6	3.38E-6	1	1.70	(4,4,1,5,3,5); model calculation for emissions based on fertilizer application
emission water, river	Phosphate	-	kg	1.33E-5	9.89E-6	1	1.70	(4,4,1,5,3,5); model calculation for emissions based on fertilizer application
	Phosphorus	-	kg	6.77E-6	4.88E-6	1	1.70	(4,4,1,5,3,5); emission due to erosion

2.6 Machinery use

Elaboration of LCI: Niels Jungbluth, ESU-services Ltd., Uster
Data provider ESU-services Ltd.

Case studies on machinery use for agricultural products show that the fuel usage and emissions due to fuel combustion are the most important factor for this input. The data of machinery usage are provided in a simplified form. Key parameters are the diesel use per hour, the working hours on the field and the total diesel use for one culture.

Average emission factors have been calculated with data from (Nemecek et al. 2004). The emission factors per kg of diesel are shown in Tab. 2.23.

Tab. 2.22 Documentation of the use of diesel fuel in agricultural machinery

	A	C	D
2	ReferenceFunction	Name	diesel, used by tractor
3	Geography	Location	RER
4	ReferenceFunction	InfrastructureProcess	0
5	ReferenceFunction	Unit	kg
14		IncludedProcesses	The inventory takes into account the diesel fuel consumption and the amount of agricultural machinery and of the shed, which has to be attributed to the use of agricultural machinery. Also taken into consideration is the amount of emissions to the air from combustion and the emission to the soil from tyre abrasion during the work process. The following activities where considered part of the work process: preliminary work at the farm, like attaching the adequate machine to the tractor; transfer to field (with an assumed distance of 1 km); field work (for a parcel of land of 1 ha surface); transfer to farm and concluding work, like uncoupling the machine. The overlapping during the field work is considered. Not included are dust other than from combustion and noise.
17		Synonyms	
18		GeneralComment	Average data for use of diesel in agricultural machinery.
20		Category	agricultural means of production
21		SubCategory	work processes
24		Formula	
25		StatisticalClassification	
26		CASNumber	
27	TimePeriod	StartDate	1991
28		EndDate	2002
30		OtherPeriodText	Measurements were made in the last few years (1999-2001).
31	Geography	Text	The inventories are based on measurements made by agricultural research institute in Switzerland.
32	Technology	Text	Emissions and fuel consumption by the newest models of tractors set into operation during the period from 1999 to 2001.
34		ProductionVolume	
35		SamplingProcedure	The inventoried HC, NOx, CO values are measurements made following two test cycles (ISO 8178 C1 test and a specific 6-level-test created by the FAT) and on measurements made during the field work. The other emissions were calculated basing on literature data and the measured fuel consumption.
36		Extrapolations	Values given in the reference are representative for the average work processes. Processes are typical procedures for Switzerland around the year 2000, they are not statistical average processes.
37		UncertaintyAdjustments	none
45		PageNumbers	biomass production

Tab. 2.23 Life cycle inventory of the use of diesel fuel in agricultural machinery

Explanations	Name	Location	Infrastructure-Process	Unit	diesel, used by tractor	uncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kg			
Technosphere	shed	CH	1	m2	1.20E-3	1	3.83	average of literature data and deviation
	agricultural machinery, general, production	CH	1	kg	1.60E-1	1	5.92	average of literature data and deviation
	tractor, production	CH	1	kg	1.29E-1	1	2.13	average of literature data and deviation
	diesel, at regional storage	RER	0	kg	1.00E+0	1	1.11	average of literature data and deviation
	trailer, production	CH	1	kg	1.17E-2	1	22.04	average of literature data and deviation
	harvester, production	CH	1	kg	8.60E-3	1	22.04	average of literature data and deviation
	agricultural machinery, tillage, production	CH	1	kg	1.12E-1	1	5.12	average of literature data and deviation
air, low population density	Ammonia			kg	2.00E-5	1	1.56	average of literature data and deviation
	Benzene			kg	7.30E-6	1	1.56	average of literature data and deviation
	Benzo(a)pyrene			kg	3.00E-8	1	5.05	average of literature data and deviation
	Cadmium			kg	1.00E-8	1	5.05	average of literature data and deviation
	Carbon dioxide, fossil			kg	3.11E+0	1	1.21	average of literature data and deviation
	Carbon monoxide, fossil			kg	6.32E-3	1	5.92	average of literature data and deviation
	Chromium			kg	5.00E-8	1	5.05	average of literature data and deviation
	Copper			kg	1.70E-6	1	5.05	average of literature data and deviation
	Dinitrogen monoxide			kg	1.20E-4	1	1.56	average of literature data and deviation
	Heat, waste			MJ	4.54E+1	1	1.11	average of literature data and deviation
	Methane, fossil			kg	1.29E-4	1	1.56	average of literature data and deviation
	Nickel			kg	7.00E-8	1	5.05	average of literature data and deviation
	Nitrogen oxides			kg	4.41E-2	1	1.64	average of literature data and deviation
	NMVOC, non-methane volatile organic compounds, unspecified origin			kg	3.17E-3	1	2.16	average of literature data and deviation
	PAH, polycyclic aromatic hydrocarbons			kg	3.29E-6	1	3.05	average of literature data and deviation
	Particulates, < 2.5 um			kg	3.79E-3	1	3.32	average of literature data and deviation
	Selenium			kg	1.00E-8	1	1.56	average of literature data and deviation
	Sulfur dioxide			kg	1.01E-3	1	1.21	average of literature data and deviation
	Zinc			kg	1.00E-6	1	5.05	average of literature data and deviation
soil, agricultural	Cadmium			kg	7.27E-8	1	2.21	average of literature data and deviation
	Lead			kg	3.22E-7	1	2.26	average of literature data and deviation
	Zinc			kg	1.91E-4	1	2.18	average of literature data and deviation
Outputs	diesel, used by tractor	RER	0	kg	1.00E+0			

2.7 Pre-treatment and intermediate storage of biomass

Elaboration of LCI: Niels Jungbluth, ESU-services Ltd., Uster
Data provider ESU-services Ltd., (Ganko et al. 2006), J. Witt, Kevin McDonnell

A further pre-treatment of the biofuel might be necessary at the plant prior to the gasification. 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 for the biomass supply are of special interest. These depend on the actual size of conversion plants and the projected production capacities of biomass in the surrounding area.

Tab. 2.24 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. 2.24 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	-

So far, not much information is available about biomass preparation between harvest and the plant gate. Different possibilities of biofuel pre-treatment and intermediate storage are studied in WP3 of SP5 (draft, Ganko et al. 2006).

All conversion plants have only a very limited onsite storage capacity. All biomass types are only harvested during a short period of the year. Thus, an intermediate storage between harvest and actual delivery to the conversion plant is necessary. Normally the farmer will be responsible for this storage. It is assumed that miscanthus and straw are stored as silage bales at the edge of the field.

The storage of biomass is associated with a natural substance loss because of biological decomposition processes (due to fungi and bacteria). Among other things, the biomass substance losses are mainly depending on raw material (e.g. round wood, wood chips, straw), the kind and place of storage (e.g. indoor or outside). The C-loss is included in the substance loss but is generally not considered separately.[11]

First results from Ireland for poorly constructed outdoor stacks show product losses of up to 30% of the straw, because of fouling or wet parts that cannot be used for incineration.[12] These losses can be reduced considerable with improved storage systems.

The following values for substance loss factors (relating to dry mass) have been defined by RENEW experts for the systems investigated for the scenarios:[13]

- Round wood or wood bundles by indoor storage: 3-5% / by outside storage: 5-8%
- Straw bales by indoor storage: 2-3% / by outside storage: 8%

The modelling for the conversion plants is based on given moisture content. This has to be maintained by the type of intermediate storage, because pre-drying at the conversion plant is not included in these data. The assumption for losses and storage facilities is based on these data. For miscanthus, a similar situation as for straw has been assumed because the same type of storage facilities is discussed.

The life cycle inventory analysis and unit process raw data are shown in the following tables. Tab. 2.26 shows also the assumption used for transports and storage facilities.

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[11] Email communication J. Witt, IE Leipzig, 20.7.2006

[12] WP5.3 discussion during project meeting in Stuttgart, 03/2006.

[13] Email communication J. Witt, IE Leipzig, 20.7.2006

Tab. 2.25 Documentation of the inventory data of the biomass treatment

ReferenceFunction	Name	miscanthus-bales, at intermediate storage	miscanthus-bales, scenario 1, at intermediate storage	bundles, short-rotation wood, at intermediate storage	bundles, short-rotation wood, scenario 1, at intermediate storage	wheat straw, bales, at intermediate storage	wheat straw, bales, scenario 1, at intermediate storage
Geography	Location	RER	RER	RER	RER	RER	RER
ReferenceFunctic	InfrastructureProcess	0	0	0	0	0	0
ReferenceFunctic	Unit	kg	kg	kg	kg	kg	kg
	IncludedProcesses	Transport to 1st gathering point, baling material, storage capacity, land use open ground, product losses during storage.	Transport to 1st gathering point, baling material, storage capacity, land use open ground, product losses during storage.	Transport to 1st gathering point, baling material, storage capacity, land use open ground, product losses during storage.	Transport to 1st gathering point, baling material, storage capacity, land use open ground, product losses during storage.	Transport to 1st gathering point, baling material, storage capacity, land use open ground, product losses during storage.	Transport to 1st gathering point, baling material, storage capacity, land use open ground, product losses during storage.
	Synonyms			whole shoot	whole shoot		
	GeneralComment	Inventory for the intermediate storage of biomass between harvest and actual delivery to the conversion plant.	Inventory for the intermediate storage of biomass between harvest and actual delivery to the conversion plant.	Inventory for the intermediate storage of biomass between harvest and actual delivery to the conversion plant.	Inventory for the intermediate storage of biomass between harvest and actual delivery to the conversion plant.	Inventory for the intermediate storage of biomass between harvest and actual delivery to the conversion plant.	Inventory for the intermediate storage of biomass between harvest and actual delivery to the conversion plant.
	InfrastructureIncluded	1	1	1	1	1	1
	Category	agricultural production	agricultural production	agricultural production	agricultural production	agricultural production	agricultural production
	SubCategory	plant production	plant production	plant production	plant production	plant production	plant production
	Formula						
	StatisticalClassification						
	CASNumber						
TimePeriod	StartDate	2000	2000	2000	2000	2000	2000
	EndDate	2000	2020	2000	2020	2000	2020
	OtherPeriodText	Most information for the year 2000.	Most information for the year 2000.	Most information for the year 2000.	Most information for the year 2000.	Most information for the year 2000.	Most information for the year 2000.
Geography	Text	Estimation for Europe	Estimation for Europe	Estimation for Europe	Estimation for Europe	Estimation for Europe	Estimation for Europe
Technology	Text	Storage of biomass products.	Storage of biomass products.	Storage of biomass products.	Storage of biomass products.	Storage of biomass products.	Storage of biomass products.
	ProductionVolume						
	SamplingProcedure	Literature.	Literature.	Literature.	Literature.	Literature.	Literature.
	Extrapolations	From single data to average data.	From single data to average data.	From single data to average data.	From single data to average data.	From single data to average data.	From single data to average data.
	UncertaintyAdjustments	none	none	none	none	none	none
	PageNumbers	Pre-treatment	Pre-treatment	Pre-treatment	Pre-treatment	Pre-treatment	Pre-treatment

Tab. 2.26 Life cycle inventory analysis and unit process raw data of the biomass treatment

	Name	Location	InfrastructureProcess	Unit	miscanthus-bales, at intermediate storage	miscanthus-bales, scenario 1, at intermediate storage	bundles, short-rotation wood, at intermediate storage	bundles, short-rotation wood, scenario 1, at intermediate storage	wheat straw, bales, at intermediate storage	wheat straw, bales, scenario 1, at intermediate storage	UncertaintyType	StandardDeviation 95%
	Location				RER	RER	RER	RER	RER	RER		
	InfrastructureProcess				0	0	0	0	0	0		
	Unit				kg	kg	kg	kg	kg	kg		
technosphere	miscanthus-bales, at field	RER	0	kg	1.06E+0	-	-	-	-	-	1	1.12
	miscanthus-bales, scenario 1, at field	RER	0	kg	-	1.03E+0	-	-	-	-	1	1.12
	bundles, short-rotation wood, at field	RER	0	kg	-	-	1.07E+0	-	-	-	1	1.12
	bundles, short-rotation wood, scenario 1, at field	RER	0	kg	-	-	-	1.04E+0	-	-	1	1.12
	wheat straw, bales, at field	RER	0	kg	-	-	-	-	1.06E+0	-	1	1.12
	wheat straw, bales, scenario 1, at field	RER	0	kg	-	-	-	-	-	1.03E+0	1	1.12
	baling, material	CH	0	unit	5.45E-3	5.89E-4	-	-	5.45E-3	5.89E-4	1	1.12
	transport, tractor and trailer	CH	0	tkm	1.69E-2	1.59E-2	1.72E-2	1.62E-2	1.69E-2	1.59E-2	1	2.09
	dried roughage store, non ventilated, operation	CH	0	kg	1.06E-1	9.27E-1	1.07E-1	9.36E-1	1.06E-1	9.27E-1	1	1.30
resource, land	Occupation, industrial area	-	-	m2a	1.19E-3	1.29E-4	1.20E-3	1.30E-4	1.19E-3	1.29E-4	1	1.56
air, low population density	Carbon dioxide, biogenic	-	-	kg	1.03E-1	5.17E-2	1.23E-1	7.04E-2	1.00E-1	5.02E-2	1	1.21
	Heat, waste	-	-	MJ	8.19E-1	4.09E-1	8.51E-1	4.87E-1	7.86E-1	3.93E-1	1	1.21
assumptions	biomass losses during storage			%	6%	3%	7%	4%	6%	3%		
	water content of biomass			%	30%	30%	20%	20%	15%	15%		15
	share of bales with plastic foil			%	90%	10%	0%	0%	90%	10%		175
	share of closed storage			%	10%	90%	10%	90%	10%	90%		
	share on open ground			%	90%	10%	90%	10%	90%	10%		400
	carbon content			%	47%	47%	48%	48%	46%	46%		
	lower heating value			MJ	13.64	13.64	12.16	12.16	13.10	13.10		

Different possibilities for bailing are discussed in a RENEW report (Ganko et al. 2006). The materials for making of bales are quantified with a specific dataset. The dataset includes the production of the bailing material and its disposal after use (own calculation based on Nemecek et al. 2004).

Tab. 2.27 Documentation of the dataset for baling materials

ReferenceFunction	401	Name	baling, material
Geography	662	Location	CH
ReferenceFunction	493	InfrastructureProcess	0
ReferenceFunction	403	Unit	unit
	402	IncludedProcesses	Material, transport, disposal, manufacturing of films for biomass bales
	491	Synonyms	
	492	GeneralComment	Rough estimation based on agricultural dataset. Amount refers to one hay bale with about 1.4 m3 or 175 kg dry matter
	495	Category	agricultural means of production
	496	SubCategory	work processes
	499	Formula	
	501	StatisticalClassification	
	502	CASNumber	
TimePeriod	601	StartDate	2000
	602	EndDate	2004
	611	OtherPeriodText	
Geography	663	Text	Data from Switzerland but also valid for Europe.
Technology	692	Text	Materials for bale pressing
	724	ProductionVolume	unknown
	725	SamplingProcedure	unknown
	726	Extrapolations	none
	727	UncertaintyAdjustments	none
	762	PageNumbers	background data

Tab. 2.28 Life cycle inventory of baling materials

	Name	Location	InfrastructurePro	Unit	baling, material	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				CH			
	InfrastructureProcess				0			
	Unit				unit			
product	baling, material	CH	0	unit	1			
technosphere	polyethylene, HDPE, granulate, at plant	RER	0	kg	1.00E+0	1	1.09	(2,3,2,2,1,na); literature
	transport, lorry 32t	RER	0	tkm	1.00E-1	1	2.09	(4,5,na,na,na,na); standard
	transport, freight, rail	RER	0	tkm	2.00E-1	1	2.09	(4,5,na,na,na,na); standard
	extrusion, plastic film	RER	0	kg	1.00E+0	1	1.09	(2,3,2,2,1,na); literature
	disposal, polyethylene, 0.4% water, to municipal incineration	CH	0	kg	1.00E+0	1	1.09	(2,3,2,2,1,na); standard

3 Life cycle inventory of conversion processes

3.1 Introduction

Several conversion technologies for the production of biomass-to-liquid fuels (BTL) are further developed within the project. These are:

- production of Fischer-Tropsch-fuel (FT) by two-stage gasification (pyrolytic decomposition and entrained flow gasification) of wood, gas treatment, synthesis and product upgrading (SP 1);
- production of FT-fuel by two-stage gasification (flash pyrolysis and entrained flow gasification) of wood, straw and energy plants as well as two types of fluidized bed gasification (CFB), gas treatment and synthesis, (SP2);
- BTL-DME (dimethylether) 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).[14]

These concepts represent different development status. This could result in a different quality and reliability of the calculated LCI results. The data given here represents the status of BtL technology in the year 2006. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by the respective technology partner.

These concepts have been further developed in the course of the project. A technical assessment of 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.

The description of the different processes in this report is based on information from the respective subprojects.

3.2 Overview of fuel conversion processes

Fig. 3.1 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.

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[14] Due to the fact that no data for the bioethanol production was delivered within the respective deadlines, the bioethanol production is not part of WP 52.

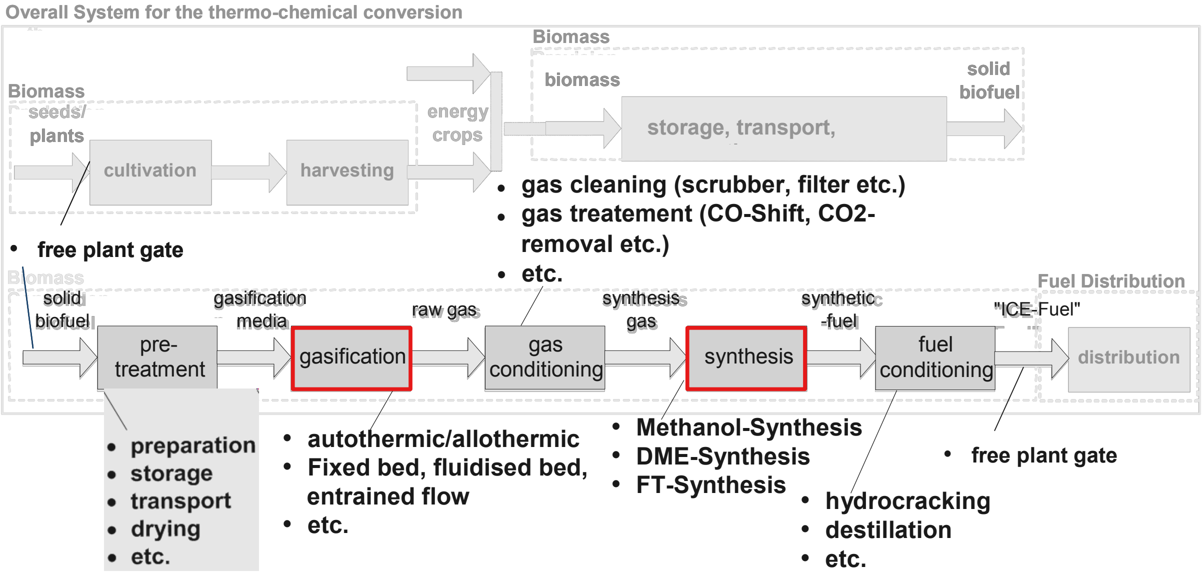

Fig. 3.1 Flow chart of generic conversion process and different process routes for the production of BTL-fuels

3.2.1 Pre-treatment

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

3.2.2 Gasification of solid biomass

The next stage in the production chain is the gasification of the biomass. Tab. 3.1 shows an overview of the gasification processes investigated within RENEW. The output of these processes is raw gas.

Tab. 3.1 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

3.2.3 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).

3.2.4 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).

3.2.5 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.

3.3 Outline of data investigation

Four different BTL-routes and one DME-route are investigated. The concepts are described in detail in a separate working package of this project (Vogel 2007; Vogel et al. 2007). The concepts are classified according to the main technological characteristics, e.g. the type of gasification and the BTL-output (Tab. 3.2). Within label these concepts with a short abbreviation and/or with the project partner responsible for the investigation of data.

For each of these routes different scenarios (see scenario document SP5-Partners 2007) are applied as far as data are available from the respective subprojects.

The following Tab. 3.2 shows the actual data delivery until the end of the data collection period (June 2006). All process routes and biomass resources in green are included in the further analysis. Due to time constraints, possible process routes and scenarios have been excluded from the further analysis if data were not available until the end of the data collection period. These combinations are marked in red. CHEMREC has not provided data for Scenario 1. Abengoa has not provided any data.

Tab. 3.2 Overview of investigated process routes, scenarios and biomass resources (planning and actual investigation)

Project partner	***UET***	***FZK***	***Cutec***	***TUV***	***Chemrec***	***Abengoa***
Concept	Centralized Entrained Flow Gasification	Decentralized Entrained Flow Gasification	Centralized Autothermal Circulating Fluidized Bed Gasification	Allothermal Circulating Fluidized Bed Gasification	Entrained Flow Gasification of Black Liquor for DME-production	Circulating Fluidized Bed Ethanol
Abbreviation	***cEF-D***	***dEF-D***	***CFB-D***	***ICFB-D***	***BLEF-DME***	***CFB-E***
Starting point	X	X	X	X	X	
Scenario 1 "Maximized biofuel production"	X	X	X	X	nd	nd
Investigated biomass						
Willow-salix	X		X	X	X	nd
Miscanthus	a)		a)	X		
Straw	X	X	X			

nd	no data available
D	FT-diesel
E	Ethanol

a) The use of this biomass would be possible, data have not been modelled because it would be quite similar to the use of straw.

The production routes investigated for BTL-fuels in the RENEW project are a combination of the subprocesses described above in chapter 3.2.1 to 3.2.5. 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. 3.3 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. 3.3 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	-

3.4 Generic inventory data and methodology applied on conversion processes

Author:	Niels Jungbluth, ESU-services Ltd., Uster
Data provider	ESU-services Ltd. if not mentioned otherwise in the see single chapters
Last changes:	2006-03-07

The life cycle inventory analysis is based on data provided by the RENEW partners. Literature data have been used to fill in remaining data gaps.

In this chapter, we describe the generic data and assumptions that are used for all conversion processes. With generic data, it has been checked if these inputs are particularly relevant for the results of the life cycle impact assessment. If not, it has been decided not to investigate these inventories more specifically. In some cases it was not possible to investigate more specific data, e.g. for the emission profiles of off-gases. However, also here the absolute amount of off-gases is known for each conversion concept. Thus, important parameters for the evaluation of the conversion concepts are investigated according to the actual development state.

3.4.1 Product properties

Three products are considered as a functional unit or as a output of the conversion processes: DME: 28.84 MJ/kg, FT diesel: 44,0 MJ/kg and Naphtha: 43,7 MJ/kg. For some calculations we use oil equivalents as a unit. This is equal to 42.6 MJ/kg.

3.4.2 Conversion rates

Conversion rates in this report are only provided for informational reasons and as a yardstick to compare the results of the inventory analysis with the assumptions used in the technical assessment of RENEW. The conversion rate has been defined in collaboration with RENEW partners from SP5 as follows:

conversion rate (biomass to all liquids), energy =
sum of lower heating value (diesel + naphtha + DME + EtOH) at refinery or conversion plant (MJ/h)
/ sum of lower heating value of biomass used in the conversion plant (MJ/h).

and

conversion rate (biomass to all liquids), mass =
mass (diesel + naphtha + DME + EtOH) at refinery or conversion plant (MJ/h)
/ mass of biomass dry matter used in the conversion plant (MJ/h).

3.4.3 Biomass transport to conversion plant

Elaboration of LCI: Niels Jungbluth, ESU-services Ltd., Uster
Data provider Chemrec, IE-Leipzig

A typical uptake area for biomass (wood) in Swedish paper manufacturing plants of this size is about 150-200 km, using a slightly conservative estimate.[15]

Experiences in Germany show that semi-trailers are mainly used for the biomass transport. They can transport a volume of 90 m^3 or 27t of freight. For wood chips the maximum capacity is thus about 22t. For short rotation wood and the plant capacities used in this study, a transport distance of 200 km including both ways is a realistic assumption. The direct transport distances are estimated between 50 and 85 km.[16]

Within WP5.1 transport distances of 30 km with a small truck to an intermediate storage and 150 km by large truck or train are considered.

In this study, the average one-way transport distance of biomass to the conversion plant is estimated with 150km by truck (50% load, class 32t) for all process routes except the FZK-route due to the decentralized approach of FZK. For the FZK-process a transport distance of 30 km with tractor is assumed. This includes all transports from the field and intermediate storages to the plant.

For the future scenario 1, the transport distance is reduced to 125 km. This considers that the yields per hectare have been increased and more farmers are involved in the raw biomass production. Also more efficient collection systems should have been installed.

3.4.4 Plant construction

Elaboration of LCI: Niels Jungbluth, ESU-services Ltd., Uster
Data provider UET, FZK, CHEMREC, CUTEC

The inventory data of the construction of the conversion plant are estimated as an average of the information available from different plant developers. All plants have only very small storage capacities for 1-2 weeks. Thus, most of the biomass has to be stored elsewhere between harvest and use. This is investigated in chapter 2.7.

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[15] Personal communication with Chemrec, 2006.

[16] Personal communication Stephanie Frick, Institut für Energetik und Umwelt, 12.05.

Tab. 3.4 Documentation of the inventory data of the conversion plant construction

ReferenceFunction	Name	fuel synthesis plant
Geography	Location	RER
ReferenceFunct	InfrastructureProcess	1
ReferenceFunct	Unit	unit
	IncludedProcesses	Land occupation and transformation, buildings, chemical facilities.
	Synonyms	
	GeneralComment	Infrastructure of the fuel synthesis plant, average of investigated sites.
	Category	biomass
	SubCategory	fuels
	Formula	
	StatisticalClassification	
	CASNumber	
TimePeriod	StartDate	2005
	EndDate	2006
	OtherPeriodText	Starting point scenario
Geography	Text	Europe
Technology	Text	actual development state for biofuel conversion
	ProductionVolume	202250000
	SamplingProcedure	average of questionnaires
	Extrapolations	none
	UncertaintyAdjustments	none
	PageNumbers	conversion plants

Tab. 3.5 Life cycle inventory analysis and unit process raw data of the conversion plant construction, Starting point calculation

	Name	Location	Infrastruct ureProces	Unit	fuel synthesis plant	Uncertaint yType	Standard Deviation 95%	GeneralComment	Plant	Plant, wheat	storage and plant	Plant
	Location				RER				UET	UET	FZK	CHEMREC
	InfrastructureProcess				1							
	Unit				unit				unit	unit	unit	unit
product	fuel synthesis plant	RER	1	unit	1							
resource	Occupation, industrial area, built up	-	-	m2a	1.67E+6	1	3.00	(1,1,1,1,1,1); average of questionnaires	1.00E+6	1.00E+6	4.00E+5	4.28E+6
	Occupation, industrial area, vegetation	-	-	m2a	1.78E+6	1	3.00	(1,1,1,1,1,1); average of questionnaires	2.60E+6	3.00E+6	0	1.52E+6
	Transformation, from unknown	-	-	m2	1.73E+5	1	1.05	(1,1,1,1,1,1); average of questionnaires	1.80E+5	2.00E+5	2.00E+4	2.90E+5
	Transformation, to industrial area, built up	-	-	m2	8.35E+4	1	1.05	(1,2,1,1,1,1); average of questionnaires	5.00E+4	5.00E+4	2.00E+4	2.14E+5
	Transformation, to industrial area, vegetation	-	-	m2	8.90E+4	1	1.24	(2,4,1,1,1,5); average of questionnaires	1.30E+5	1.50E+5	0	7.60E+4
material	facilities, chemical production	RER	1	kg	2.04E+7	1	3.09	(4,5,na,na,na,na); Assumption for technical equipment	0	0	0	0
	building, multi-storey	RER	1	m3	8.75E+4	1	3.06	(2,4,1,1,1,5); average of questionnaires	4.00E+4	1.10E+5	2.00E+5	0
	building, hall, steel construction	CH	1	m2	5.35E+4	1	3.06	(2,4,1,1,1,5); average of questionnaires	0	0	0	2.14E+5

	life time	a	20
	capacity	kg/a	2.02E+8
	operation time	h/a	8'000

Tab. 3.6 Life cycle inventory analysis and unit process raw data of the conversion plant construction, Scenario 1

	Name	Location	Infrastruct ureProces	Unit	fuel synthesis plant	Uncertaint yType	Standard Deviation 95%	GeneralComment	Plant, wood	Plant, wheat	storage and plant
	Location				RER				UET	UET	FZK
	InfrastructureProcess				1						
	Unit				unit				unit	unit	unit
product	fuel synthesis plant	RER	1	unit	1						
resource	Occupation, industrial area, built up	-	-	m2a	8.00E+5	1	3.00	(1,1,1,1,1,1); average of questionnaires	1.00E+6	1.00E+6	4.00E+5
	Occupation, industrial area, vegetation	-	-	m2a	1.87E+6	1	3.00	(1,1,1,1,1,1); average of questionnaires	2.60E+6	3.00E+6	0
	Transformation, from unknown	-	-	m2	1.33E+5	1	1.05	(1,1,1,1,1,1); average of questionnaires	1.80E+5	2.00E+5	2.00E+4
	Transformation, to industrial area, built up	-	-	m2	4.00E+4	1	1.05	(1,2,1,1,1,1); average of questionnaires	5.00E+4	5.00E+4	2.00E+4
	Transformation, to industrial area, vegetation	-	-	m2	9.33E+4	1	1.24	(2,4,1,1,1,5); average of questionnaires	1.30E+5	1.50E+5	0
material	facilities, chemical production	RER	1	kg	2.18E+7	1	3.09	(4,5,na,na,na,na); Assumption for technical equipment	0	0	0
	building, multi-storey	RER	1	m3	1.17E+5	1	3.06	(2,4,1,1,1,5); average of questionnaires	4.00E+4	1.10E+5	2.00E+5
	building, hall, steel construction	CH	1	m2	0	1	3.06	(2,4,1,1,1,5); average of questionnaires	0	0	0

	life time	a	20
	capacity	kg/a	2.17E+8
	operation time	h/a	8'000

3.4.5 Internal flows

The flows of gases, steam, electricity and products inside the conversion plant are quite complex. Fig. 3.2 shows a simplified flow chart of these internal flows. Tail and off-gases in different qualities as well as steam of different pressure and temperature levels are produced in the sub-processes of the conversion plants. These flows are partly fed to the power plant (e.g. a steam and power boiler). Gases are burned here. The power plant itself delivers steam and electricity to different stages in the conversion plant.

Sometimes there are several output streams of one sub-process in the conversion plant. These flows do not have economic values and they are used inside the production plant within other production stages. A modelling with allocating all elementary flows between these internal flows would be quite complicated without giving additional information relevant for the environmental assessment of the final product. Internal flows of steam, water and gases between sub-processes and to the power plant are disregarded in the modelling of the LCI. Thus, all internally used outputs do not bear any environmental burdens. All air emissions of the electricity and steam production at the power plant are allocated between heat and electricity based on the exergy provided. The full amount of heat and the main part of this electricity is used inside the conversion plant. In some cases, a part of the electricity might be delivered to the grid bearing also its share of the air emissions. This is a worst-case assumption for the fuel products, because none of the biomass input to the plant is allocated to electricity used outside the plant.

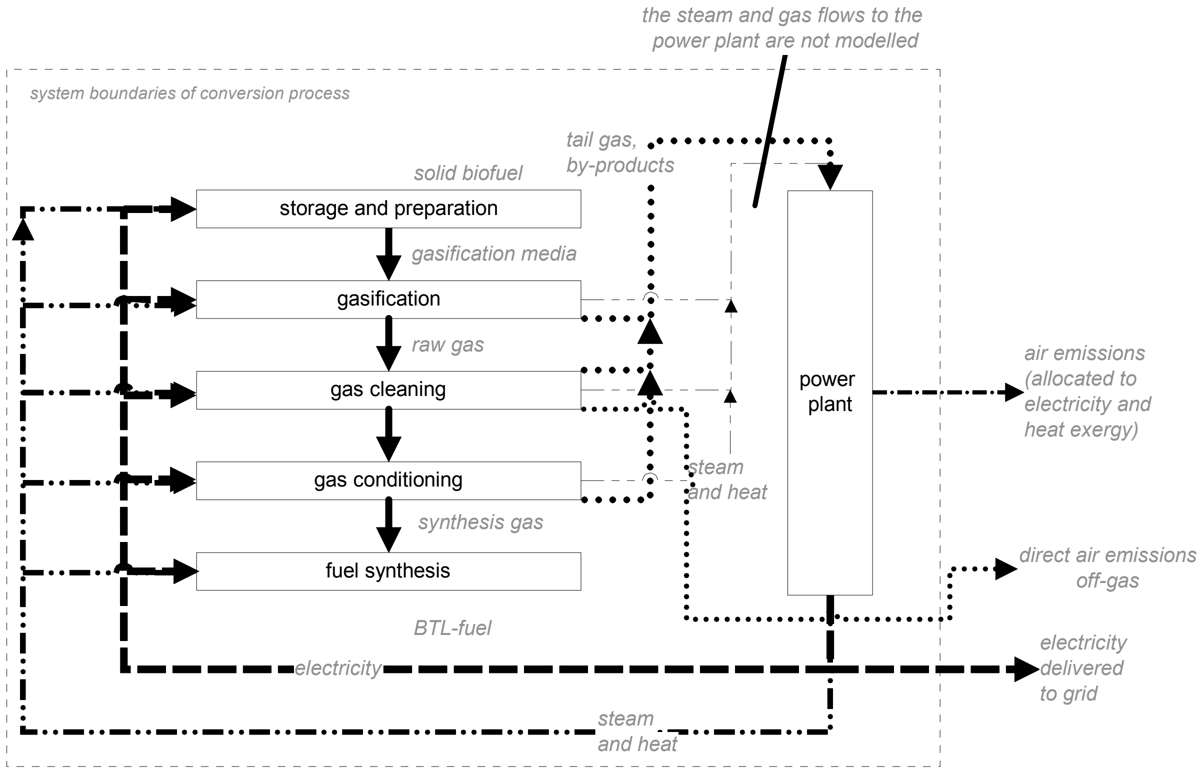

Fig. 3.2 **Simplified flow chart showing internal flows of steam, gases, electricity and products between sub-processes in the conversion process**

3.4.6 Missing information on the amount of chemicals used

For some chemicals, the amount used per hour is not known. In such cases, the amount is estimated with 1 g/h. In general, such inputs are considered as not very important with respect to the caused environmental impacts. With this assumption, it is ensured that the item is not forgotten. The inputs shown in Tab. 3.7 are treated with this approach.

Tab. 3.7 Inputs for certain processes with an unknown amount

Process	Input
CUTEC	iron chelate
CUTEC	Filter ceramic for the hot gas filtration
CUTEC	silica sand (small amounts)

3.4.7 Steam and Power generation

Elaboration of LCI: Niels Jungbluth, ESU-services Ltd., Uster
Data provider Literature, UET, FZK, CHEMREC, CUTEC, TUV

Data on the emission profile from the power plants are rarely available. The power plants burn tail gases, synthesis gases or charcoal from the biomass gasification. Thus, the emissions profile is regarded as comparable with the emissions from a modern gas fired power plant. Data available from the questionnaires have been considered for the assessment. The yardstick for the extrapolation of the emissions is the amount of CO_2 released from the power plants.

One of the boundary conditions in the scenario document is a design of the conversion plants for fuel production. Thus, electricity and heat are considered as by-products of the plant. It has to be noted that for electricity, used outside the plant, the necessary input of biomass to gasification is not considered. Thus, all biomass going to the conversion plant is fully allocated to the production of BTL-fuels. However, direct emissions from the power plant are also allocated partly to the share of electricity delivered to the grid

All steam must be used on the production site according to the boundary conditions. There is no input or output to external places. The environmental impacts are allocated between internally used heat and electricity based on the exergy content of both products. The standard assumption if the actual amounts are not known, is a share of 39% of provided energy in the form of electricity and the rest as heat. With an exergy factor for heat of 0.182, this results in an average allocation factor of about 78% for electricity and 22% for heat.

Data for the emissions in the FZK concept were only roughly available. In scenario 1 it was necessary to use own assumptions in order to maintain an approximately correct carbon balance.

The following tables show the life cycle inventory analysis for the power and steam generation.

Tab. 3.8 Documentation of the inventory data of gas turbines and power plants used in the conversion processes, starting point calculation

ReferenceFunction	Name	electricity, biomass, at gas turbine and ORC cycle	electricity, biomass, at steam and power boiler	electricity, biomass, at power station	electricity, biomass, at steam and power boiler	electricity, biomass, at gas and steam turbine
Geography	Location	TUV	Chemrec	UET	FZK	CUTEC
ReferenceFunct	InfrastructureProcess	0	0	0	0	0
ReferenceFunct	Unit	kWh	kWh	kWh	kWh	kWh
	IncludedProcesses	Emissions from the gas turbine and ORC cycle. Provision of biomass is not included.	Emissions from the steam boiler (back-pressure mode) and power boiler (condensing mode), provision of wood chips is not included.	Emissions from the steam turbine, consumption of natural gas, provision of biomass is not included.	Emissions from the gas turbine and ORC cycle. Provision of biomass is not included.	Emissions from the gas turbine and ORC cycle. Provision of biomass is not included.
	Synonyms					
	GeneralComment	Calculation for the emissions from the gas turbine and ORC cycle. The turbine uses process steam and synthesis gasses. Allocation is based on electricity production and internally used heat. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use	Calculation for the emissions from the boiler. The boiler uses wood chips. Allocation is based on exergy for electricity and internally used heat. A part of the electricity is used for the paper production plant. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future	Calculation for the emissions from the steam turbine. The turbine uses natural gas, process steam and synthesis gasses. Allocation is based on exergy for electricity and internally used heat. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by the	Calculation for the emissions from the gas turbine and ORC cycle. The turbine uses process steam and synthesis gasses. Allocation is based on exergy for electricity and internally used heat. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future	Calculation for the emissions from the gas turbine and ORC cycle. The turbine uses process steam and synthesis gasses. Allocation is based on exergy for electricity and internally used heat. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future
	Category	biomass	biomass	biomass	biomass	biomass
	SubCategory	power plants	power plants	power plants	power plants	power plants
	Formula					
	StatisticalClassification					
	CASNumber					
TimePeriod	StartDate	2005	2005	2005	2005	2005
	EndDate	2006	2006	2006	2006	2006
	OtherPeriodText	Starting point scenario	Starting point scenario	Starting point scenario	Starting point scenario	Starting point scenario
Geography	Text	Europe	Europe	Europe	Europe	Europe
Technology	Text	Simulation with IPSEpro by plant developers for a 50MW plant.	actual development state for biofuel conversion	actual development state for biofuel conversion	actual development state for biofuel conversion	actual development state for biofuel conversion
	ProductionVolume	9509	180000	37934	50000	69262
	SamplingProcedure	questionnaire and own assumptions with similar emission profiles	questionnaire and own assumptions with similar emission profiles	questionnaire and own assumptions with similar emission profiles	questionnaire and own assumptions with similar emission profiles	questionnaire and own assumptions with similar emission profiles
	Extrapolations	emission profile per kg of CO2 from a natural gas power plant	emission profile per kg of CO2 from a wood chips power plant	emission profile per kg of CO2 from a natural gas power plant	emission profile per kg of CO2 from a natural gas power plant	emission profile per kg of CO2 from a natural gas power plant
	UncertaintyAdjustments	none	none	none	none	none
	PageNumbers	power generation	power generation	power generation	power generation	power generation

Tab. 3.9 Life cycle inventory analysis and unit process raw data of gas turbines and power plants used in the conversion processes, starting point calculation

	Name	Location	InfrastructureProcess	Unit	electricity, biomass, at power station	electricity, biomass, at gas turbine and ORC cycle	electricity, biomass, at steam and power boiler	electricity, biomass, at gas and steam turbine	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				UET	TUV	FZK	CUTEC			
	InfrastructureProcess				0	0	0	0			
	Unit				kWh	kWh	kWh	kWh			
Technosphere	natural gas, high pressure, at consumer	RER	0	MJ	8.17E-1	0	0	0	1	1.05	(1,2,1,1,1,1); Questionnaire
	gas power plant, 100MWe	RER	1	unit	1.26E-10	4.71E-10	4.71E-10	1.20E-10	1	3.00	(1,2,1,1,1,1); Generic data
	disposal, ash from paper prod. sludge, 0% water, to residual material landfill	CH	0	kg	3.18E-6	2.92E-5	2.92E-5	1.77E-5	1	1.05	(1,2,1,1,1,1); Questionnaire, ashes from the use of biomass fuel
	Water, cooling, unspecified natural origin	-	-	m3	1.91E-2	1.75E-1	1.75E-1	1.06E-1	1	3.00	(1,2,1,1,1,1); Questionnaire
	water, decarbonised, at plant	RER	0	kg	6.37E-1	5.83E+0	5.83E+0	3.54E+0	1	1.05	(1,1,1,1,1,1); Questionnaire
	lubricating oil, at plant	RER	0	kg	9.55E-5	8.75E-4	8.75E-4	5.31E-4	1	1.05	(1,1,1,1,1,1); Generic data
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	9.55E-5	8.75E-4	8.75E-4	5.31E-4	1	1.31	(2,3,1,1,3,5); Generic data
Emission	Acenaphthene	-	-	kg	2.52E-12	2.30E-11	2.30E-11	1.40E-11	1	1.31	(2,3,1,1,3,5); Emission profile of gas power plant and questionnaire
	Acetaldehyde	-	-	kg	2.55E-9	2.33E-8	2.33E-8	1.42E-8	1	1.31	(2,3,1,1,3,5); Emission profile of gas power plant and questionnaire
	Acetic acid	-	-	kg	3.82E-7	3.50E-6	3.50E-6	2.12E-6	1	1.31	(2,3,1,1,3,5); Emission profile of gas power plant and questionnaire
	Benzene	-	-	kg	2.96E-9	2.71E-8	2.71E-8	1.65E-8	1	3.10	(2,3,1,1,3,5); Emission profile of gas power plant and questionnaire
	Benzo(a)pyrene	-	-	kg	1.69E-12	1.54E-11	1.54E-11	9.38E-12	1	1.31	(2,3,1,1,3,5); Emission profile of gas power plant and questionnaire
	Butane	-	-	kg	2.96E-6	2.71E-5	2.71E-5	1.65E-5	1	1.31	(2,3,1,1,3,5); Emission profile of gas power plant and questionnaire
	Carbon dioxide, fossil	-	-	kg	4.58E-2	0	0	0	1	1.31	(2,3,1,1,3,5); Share of natural gas
	Carbon dioxide, biogenic	-	-	kg	1.33E-1	1.63E+0	1.63E+0	9.91E-1	1	1.31	(2,3,1,1,3,5); Calculated CO2 emission
	Carbon monoxide, fossil	-	-	kg	2.31E-4	0	0	0	1	1.31	(2,3,1,1,3,5); Share of natural gas
	Carbon monoxide, biogenic	-	-	kg	6.69E-4	8.24E-3	8.24E-3	5.00E-3	1	1.31	(2,3,1,1,3,5); Emission profile of a conversion plant
	Dinitrogen monoxide	-	-	kg	1.59E-5	1.46E-4	1.46E-4	8.84E-5	1	1.31	(2,3,1,1,3,5); Emission profile of gas power plant and questionnaire
	Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	-	-	kg	9.24E-17	8.45E-16	8.45E-16	5.13E-16	1	3.10	(2,3,1,1,3,5); Emission profile of gas power plant and questionnaire
	Ethane	-	-	kg	4.46E-6	4.08E-5	4.08E-5	2.48E-5	1	3.10	(2,3,1,1,3,5); Emission profile of gas power plant and questionnaire
	Formaldehyde	-	-	kg	1.05E-7	9.62E-7	9.62E-7	5.84E-7	1	1.31	(2,3,1,1,3,5); Emission profile of gas power plant and questionnaire
	Heat, waste	-	-	MJ	2.29E+0	2.10E+1	2.10E+1	1.27E+1	1	1.31	(2,3,1,1,3,5); Emission profile of gas power plant and questionnaire
	Hexane	-	-	kg	2.52E-6	2.30E-5	2.30E-5	1.40E-5	1	1.31	(2,3,1,1,3,5); Emission profile of gas power plant and questionnaire
	Mercury	-	-	kg	9.55E-11	8.75E-10	8.75E-10	5.31E-10	1	1.31	(2,3,1,1,3,5); Emission profile of gas power plant and questionnaire
	Methane, biogenic	-	-	kg	2.55E-4	1.18E-4	1.18E-4	1.42E-3	1	1.31	(2,3,1,1,3,5); Emission profile of gas power plant and questionnaire
	Nitrogen oxides	-	-	kg	1.40E-4	3.49E-3	3.49E-3	7.78E-4	1	3.10	(2,3,1,1,3,5); German standard TA Luft
	PAH, polycyclic aromatic hydrocarbons	-	-	kg	2.55E-8	2.33E-7	2.33E-7	1.42E-7	1	3.10	(2,3,1,1,3,5); Emission profile of gas power plant and questionnaire
	Particulates, < 2.5 um	-	-	kg	4.78E-7	8.49E-6	8.49E-6	2.65E-6	1	1.31	(2,3,1,1,3,5); Emission profile of gas power plant and questionnaire
	Pentane	-	-	kg	3.82E-6	3.50E-5	3.50E-5	2.12E-5	1	3.10	(2,3,1,1,3,5); Emission profile of gas power plant and questionnaire
	Propane	-	-	kg	2.26E-6	2.07E-5	2.07E-5	1.26E-5	1	1.31	(2,3,1,1,3,5); Emission profile of gas power plant and questionnaire
	Propionic acid	-	-	kg	5.10E-8	4.66E-7	4.66E-7	2.83E-7	1	1.62	(2,3,1,1,3,5); Emission profile of gas power plant and questionnaire
	Sulfur dioxide	-	-	kg	1.59E-6	3.91E-5	3.91E-5	8.84E-6	1	1.31	(2,3,1,1,3,5); Emission profile of gas power plant and questionnaire
	Toluene	-	-	kg	4.78E-9	4.37E-8	4.37E-8	2.65E-8	1	1.31	(2,3,1,1,3,5); Emission profile of gas power plant and questionnaire
info	electricity			kWh/h	3.79E+4	9.51E+3	5.00E+4	6.93E+4			
	internal electricity use			kWh/h	3.11E+4	2.75E+3	3.35E+4	6.73E+4			
	heat			MJ/h	1.04E+5	7.83E+3	2.82E+5	3.56E+5			
	Allocation (exergy) share electricity			%	87%	94%	78%	70%			
	exergy factor heat			-	0.192	0.277	0.182	0.298			
	temperature Tm			K	583	618	383	418			

The power plant for the CHEMREC process burns directly wood chips. Thus, the emission profile of a modern wood cogeneration unit with emission control is used for the assessment of missing data for air pollutants and other inputs.

Tab. 3.10 Life cycle inventory analysis and unit process raw data of wood cogeneration unit with emission control used by CHEMREC, starting point calculation

Explanations	Name	Location	Infrastructure-Process	Unit	electricity, biomass, at steam and power boiler				electricity, biomass, at steam and power boiler	electricity, at cogen 6400kWth, wood, emission control, allocation exergy
	Location				Chemrec				Chemrec	CH
	InfrastructureProcess				0					0
	Unit				kWh				h	kWh
Technosphere	ammonia, liquid, at regional storehouse	CH	0	kg	5.63E-8	1	1.20	general assumption	1.30E-2	8.76E-8
	chlorine, liquid, production mix, at plant	RER	0	kg	2.25E-6	1	1.20	general assumption	5.21E-1	3.50E-6
	sodium chloride, powder, at plant	RER	0	kg	2.82E-5	1	1.20	general assumption	6.51E+0	4.38E-5
	chemicals organic, at plant	GLO	0	kg	3.94E-5	1	1.20	general assumption	9.12E+0	6.13E-5
	lubricating oil, at plant	RER	0	kg	2.25E-5	1	1.10	general assumption	5.21E+0	3.50E-5
	urea, as N, at regional storehouse	RER	0	kg	1.84E-4	1	1.20	general assumption	4.26E+1	2.86E-4
	transport, lorry 16t	CH	0	tkm	3.29E-2	1	1.20	general assumption	7.61E+3	5.12E-2
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	2.25E-5	1	1.20	general assumption	5.21E+0	3.50E-5
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	2.25E-5	1	1.20	general assumption	5.21E+0	3.50E-5
	disposal, wood ash mixture, pure, 0% water, to sanitary landfill	CH	0	kg	3.03E-3	1	1.05	homogeneous fuel	7.00E+2	2.83E-3
	treatment, sewage, to wastewater treatment, class 2	CH	0	m3	1.67E-5	1	1.20	general assumption	3.86E+0	8.41E-6
	water, decarbonised, at plant	RER	0	kg	5.41E-3	1	1.20	general assumption	1.25E+3	8.41E-3
	cogen unit 6400kWth, wood burning, building	CH	1	unit	1.66E-9	1	1.20	uncertainty on lifetime and material	3.84E-4	2.59E-9
	cogen unit 6400kWth, wood burning, common components for heat+electricity	CH	1	unit	6.65E-9	1	1.20	uncertainty on lifetime and material	1.54E-3	1.03E-8
	cogen unit 6400kWth, wood burning, components for electricity only	CH	1	unit	2.83E-8	1	1.20	essentially uncertainty of assignment of reference system	6.54E-3	4.40E-8
	Water, cooling, unspecified natural origin	-	-	m3	1.67E-2				3.86E+3	
air, high population density	Acetaldehyde			kg	4.19E-7	1	3.70	extrapolation	9.69E-2	6.52E-7
	Ammonia			kg	1.17E-4	1	3.70	extrapolation	2.70E+1	1.82E-4
	Arsenic			kg	6.87E-9	1	3.70	extrapolation	1.59E-3	1.07E-8
	Benzene			kg	6.25E-6	1	3.70	extrapolation	1.45E+0	9.72E-6
	Benzene, ethyl-			kg	2.06E-7	1	3.70	extrapolation	4.77E-2	3.20E-7
	Benzene, hexachloro-			kg	4.95E-14	1	3.70	extrapolation	1.14E-8	7.69E-14
	Benzo(a)pyrene			kg	3.44E-9	1	3.70	extrapolation	7.94E-4	5.34E-9
	Bromine			kg	4.12E-7	1	3.70	extrapolation	9.53E-2	6.41E-7
	Cadmium			kg	4.81E-9	1	3.70	extrapolation	1.11E-3	7.48E-9
	Calcium			kg	4.02E-5	1	3.70	extrapolation	9.29E+0	6.25E-5
	Carbon dioxide, biogenic			kg	8.52E-1	1	1.05	uncertainty of carbon content in the wood	1.97E+5	1.32E+0
	Carbon monoxide, biogenic			kg	8.65E-4	1	2.20	measurements	2.00E+2	7.48E-5
	Chlorine			kg	1.24E-6	1	3.70	extrapolation	2.86E-1	1.92E-6
	Chromium			kg	2.72E-8	1	3.70	extrapolation	6.29E-3	4.23E-8
	Chromium VI			kg	2.75E-10	1	4.00	range of data	6.36E-5	4.27E-10
	Copper			kg	1.51E-7	1	3.70	extrapolation	3.50E-2	2.35E-7
	Dinitrogen monoxide			kg	5.19E-5	1	1.90	measurements and assumption, based on literature	1.20E+1	2.35E-4
	Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin			kg	2.13E-13	1	3.70	extrapolation	4.93E-8	3.31E-13
	Fluorine			kg	3.44E-7	1	3.70	extrapolation	7.94E-2	5.34E-7
	Formaldehyde			kg	8.93E-7	1	3.70	extrapolation	2.07E-1	1.39E-6
	Heat, waste			MJ	6.81E+0	1	1.05	own estimation, based on uncertainty of upper heating value and electricity production	1.57E+6	1.06E+1
	Hydrocarbons, aliphatic, alkanes, unspecified			kg	6.25E-6	1	3.70	extrapolation	1.45E+0	9.72E-6
	Hydrocarbons, aliphatic, unsaturated			kg	2.13E-5	1	3.70	extrapolation	4.93E+0	3.31E-5
	Lead			kg	1.71E-7	1	3.70	extrapolation	3.96E-2	2.66E-7
	Magnesium			kg	2.48E-6	1	3.70	extrapolation	5.74E-1	3.86E-6
	Manganese			kg	1.17E-6	1	3.70	extrapolation	2.72E-1	1.83E-6
	Mercury			kg	2.06E-9	1	3.70	extrapolation	4.77E-4	3.20E-9
	Methane, biogenic			kg	2.98E-6	1	3.70	extrapolation	6.90E-1	4.64E-6
	m-Xylene			kg	8.24E-7	1	3.70	extrapolation	1.91E-1	1.28E-6
	Nickel			kg	4.12E-8	1	3.70	extrapolation	9.53E-3	6.41E-8
	Nitrogen oxides			kg	2.46E-4	1	1.45	measurements and assumption, based on	5.70E+1	4.70E-4
	NMVOC, non-methane volatile organic compounds, unspecified origin			kg	4.19E-6	1	3.70	extrapolation	9.69E-1	6.52E-6
	PAH, polycyclic aromatic hydrocarbons			kg	7.56E-8	1	3.70	extrapolation	1.75E-2	1.18E-7
	Particulates, < 2.5 um			kg	2.16E-6	1	1.10	measurements	5.00E-1	5.34E-5
	Phenol, pentachloro-			kg	5.57E-11	1	3.70	extrapolation	1.29E-5	8.65E-11
	Phosphorus			kg	2.06E-6	1	3.70	extrapolation	4.77E-1	3.20E-6
	Potassium			kg	1.61E-4	1	3.70	extrapolation	3.72E+1	2.50E-4
	Sodium			kg	8.93E-6	1	3.70	extrapolation	2.07E+0	1.39E-5
	Sulfur dioxide			kg	1.71E-5	1	3.70	extrapolation	3.96E+0	2.66E-5
	Toluene			kg	2.06E-6	1	3.70	extrapolation	4.77E-1	3.20E-6
	Zinc			kg	2.06E-6	1	3.70	extrapolation	4.77E-1	3.20E-6

Tab. 3.11 Life cycle inventory analysis and unit process raw data of gas turbines and power plants used in the conversion processes, scenario 1

	Name	Location	InfrastructureProcess	Unit	electricity, biomass, at power station	electricity, biomass, at gas turbine and ORC cycle	electricity, biomass, at steam and power boiler	electricity, biomass, at gas and steam turbine	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				UET	TUV	FZK	CUTEC			
	InfrastructureProcess				0	0	0	0			
	Unit				kWh	kWh	kWh	kWh			
Technosphere	natural gas, high pressure, at consumer	RER	0	MJ	6.75E-1	0	6.75E-1	0	1	1.05	(1,2,1,1,1,1); Questionnaire
	gas power plant, 100MWe	RER	1	unit	4.06E-11	7.19E-11	4.06E-11	8.15E-11	1	3.00	(1,2,1,1,1,1); Generic data
	disposal, ash from paper prod. sludge, 0% water, to residual material landfill	CH	0	kg	1.29E-6	2.89E-5	1.29E-6	1.20E-5	1	1.05	(1,2,1,1,1,1); Questionnaire, ashes from the use of biomass fuel
	Water, cooling, unspecified natural origin	-	-	m3	7.76E-3	1.74E-1	7.76E-3	7.20E-2	1	3.00	(1,2,1,1,1,1); Questionnaire
	water, decarbonised, at plant	RER	0	kg	2.59E-1	5.79E+0	2.59E-1	2.40E+0	1	1.05	(1,1,1,1,1,1); Questionnaire
	lubricating oil, at plant	RER	0	kg	3.88E-5	8.68E-4	3.88E-5	3.60E-4	1	1.05	(1,1,1,1,1,1); Generic data
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	3.88E-5	8.68E-4	3.88E-5	3.60E-4	1	1.31	(2,3,1,1,3,5); Generic data
Emission	Acenaphthene	-	-	kg	1.02E-12	2.29E-11	1.02E-12	9.47E-12	1	1.31	(2,3,1,1,3,5); Emission profile of best technologie and questionnaire
	Acetaldehyde	-	-	kg	1.03E-9	2.32E-8	1.03E-9	9.59E-9	1	1.31	(2,3,1,1,3,5); Emission profile of best technologie and questionnaire
	Acetic acid	-	-	kg	1.55E-7	3.47E-6	1.55E-7	1.44E-6	1	1.31	(2,3,1,1,3,5); Emission profile of best technologie and questionnaire
	Benzene	-	-	kg	1.20E-9	2.69E-8	1.20E-9	1.12E-8	1	3.10	(2,3,1,1,3,5); Emission profile of best technologie and questionnaire
	Benzo(a)pyrene	-	-	kg	6.85E-13	1.53E-11	6.85E-13	6.36E-12	1	1.31	(2,3,1,1,3,5); Emission profile of best technologie and questionnaire
	Butane	-	-	kg	1.20E-6	2.69E-5	1.20E-6	1.12E-5	1	1.31	(2,3,1,1,3,5); Emission profile of best technologie and questionnaire
	Carbon dioxide, fossil	-	-	kg	3.78E-2	0	3.78E-2	0	1	1.31	(2,3,1,1,3,5); Share of natural gas
	Carbon dioxide, biogenic	-	-	kg	3.46E-2	1.62E+0	3.46E-2	6.72E-1	1	1.31	(2,3,1,1,3,5); Calculated CO2 emission
	Carbon monoxide, fossil	-	-	kg	1.35E-5	0	1.35E-5	0	1	1.31	(2,3,1,1,3,5); Share of natural gas
	Carbon monoxide, biogenic	-	-	kg	1.24E-5	5.16E-4	1.24E-5	2.40E-4	1	1.31	(2,3,1,1,3,5); Emission profile of a conversion plant
	Dinitrogen monoxide	-	-	kg	1.29E-6	2.89E-5	1.29E-6	1.20E-5	1	1.31	(2,3,1,1,3,5); Emission profile of best technologie and questionnaire
	Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	-	-	kg	3.75E-17	8.40E-16	3.75E-17	3.48E-16	1	3.10	(2,3,1,1,3,5); Emission profile of best technologie and questionnaire
	Ethane	-	-	kg	1.81E-6	4.05E-5	1.81E-6	1.68E-5	1	3.10	(2,3,1,1,3,5); Emission profile of best technologie and questionnaire
	Formaldehyde	-	-	kg	4.27E-8	9.55E-7	4.27E-8	3.96E-7	1	1.31	(2,3,1,1,3,5); Emission profile of best technologie and questionnaire
	Heat, waste	-	-	MJ	9.31E-1	2.08E+1	9.31E-1	8.63E+0	1	1.31	(2,3,1,1,3,5); Emission profile of best technologie and questionnaire
	Hexane	-	-	kg	1.02E-6	2.29E-5	1.02E-6	9.47E-6	1	1.31	(2,3,1,1,3,5); Emission profile of best technologie and questionnaire
	Hydrogen chloride	-	-	kg	1.72E-5	3.85E-4	1.72E-5	1.59E-4	1	1.31	(2,3,1,1,3,5); Questionnaire
	Mercury	-	-	kg	3.88E-11	8.68E-10	3.88E-11	3.60E-10	1	1.31	(2,3,1,1,3,5); Emission profile of best technologie and questionnaire
	Methane, biogenic	-	-	kg	1.03E-4	2.32E-3	1.03E-4	9.59E-4	1	1.31	(2,3,1,1,3,5); Emission profile of best technologie and questionnaire
	Nitrogen oxides	-	-	kg	3.36E-5	1.82E-3	3.36E-5	3.12E-4	1	3.10	(2,3,1,1,3,5); Standard TA Luft
	PAH, polycyclic aromatic hydrocarbons	-	-	kg	1.03E-8	2.32E-7	1.03E-8	9.59E-8	1	3.10	(2,3,1,1,3,5); Emission profile of best technologie and questionnaire
	Particulates, < 2.5 um	-	-	kg	1.94E-7	9.52E-6	1.94E-7	1.80E-6	1	1.31	(2,3,1,1,3,5); Emission profile of best technologie and questionnaire
	Pentane	-	-	kg	1.55E-6	3.47E-5	1.55E-6	1.44E-5	1	3.10	(2,3,1,1,3,5); Emission profile of best technologie and questionnaire
	Propane	-	-	kg	9.18E-7	2.06E-5	9.18E-7	8.51E-6	1	1.31	(2,3,1,1,3,5); Emission profile of best technologie and questionnaire
	Propionic acid	-	-	kg	2.07E-8	4.63E-7	2.07E-8	1.92E-7	1	1.62	(2,3,1,1,3,5); Emission profile of best technologie and questionnaire
	Sulfur dioxide	-	-	kg	6.47E-7	1.45E-5	6.47E-7	6.00E-6	1	1.31	(2,3,1,1,3,5); Emission profile of best technologie and questionnaire
	Toluene	-	-	kg	1.94E-9	4.34E-8	1.94E-9	1.80E-8	1	1.31	(2,3,1,1,3,5); Emission profile of best technologie and questionnaire
info	electricity			kWh/h	5.64E+4	6.59E+4	1.00E+5	8.02E+4			
	internal electricity use			kWh/h	5.63E+4	3.28E+4	1.00E+5	8.02E+4			
	heat			MJ/h	4.25E+4	5.35E+3	5.63E+5	3.00E+5			
	Allocation (exergy) share electricity			%	96%	99%	78%	68%			
	exergy factor heat			-	0.192	0.240	0.182	0.457			
	temperature Tm			K	583	602	383	540			

The supply of heat is directly calculated with the datasets of electricity supply (Tab. 3.12). The calculation takes into account the allocated shares based on the exergy content.

Tab. 3.12 Life cycle inventory analysis and unit process raw data of heat supplied by gas turbines and power plants used in the conversion processes, starting point calculation

	Name	Location	InfrastructureProcess	Unit	heat, biomass, at power station	heat, biomass, at gas turbine and ORC cycle	heat, biomass, at steam and power boiler	heat, biomass, at steam and power boiler	heat, biomass, at gas and steam turbine	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				UET	TUV	Chemrec	FZK	CUTEC			
	InfrastructureProcess				0	0	0	0	0			
	Unit				MJ	MJ	MJ	MJ	MJ			
Technosphere	electricity, biomass, at power station	UET	0	kWh	4.04E-2	0	0	0	0	1	1.05	(1,1,1,1,1,1); Calculation with exergy allocation
	electricity, biomass, at gas turbine and ORC cycle	TUV	0	kWh	0	1.76E-2	0	0	0	1	1.05	(1,1,1,1,1,1); Calculation with exergy allocation
	electricity, biomass, at steam and power boiler	Chemrec	0	kWh	0	0	7.91E-2	0	0	1	1.05	(1,1,1,1,1,1); Calculation with exergy allocation
	electricity, biomass, at steam and power boiler	FZK	0	kWh	0	0	0	7.91E-2	0	1	1.05	(1,1,1,1,1,1); Calculation with exergy allocation
	electricity, biomass, at gas and steam turbine	CUTEC	0	kWh	0	0	0	0	1.18E-1	1	1.05	(1,1,1,1,1,1); Calculation with exergy allocation

Tab. 3.13 Life cycle inventory analysis and unit process raw data of heat supplied by gas turbines and power plants used in the conversion processes, scenario 1

	Name	Location	InfrastructureProcess	Unit	heat, biomass, at power station	heat, biomass, at gas turbine and ORC cycle	heat, biomass, at steam and power boiler	heat, biomass, at gas and steam turbine	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				UET	TUV	FZK	CUTEC			
	InfrastructureProcess				0	0	0	0			
	Unit				MJ	MJ	MJ	MJ			
Technosphere	electricity, biomass, at power station	UET	0	kWh	1.11E-2	0	0	0	1	1.05	(1,1,1,1,1,1); Calculation with exergy allocation
	electricity, biomass, at gas turbine and ORC cycle	TUV	0	kWh	0	1.49E-3	0	0	1	1.05	(1,1,1,1,1,1); Calculation with exergy allocation
	electricity, biomass, at steam and power boiler	Chemrec	0	kWh	0	0	0	0	1	1.05	(1,1,1,1,1,1); Calculation with exergy allocation
	electricity, biomass, at steam and power boiler	FZK	0	kWh	0	0	7.91E-2	0	1	1.05	(1,1,1,1,1,1); Calculation with exergy allocation
	electricity, biomass, at gas and steam turbine	CUTEC	0	kWh	0	0	0	1.32E-1	1	1.05	(1,1,1,1,1,1); Calculation with exergy allocation

3.4.8 Off-gas emission profile

Elaboration of LCI: Niels Jungbluth, ESU-services Ltd., Uster
Data provider Literature, UET, FZK, CHEMREC, TUV

Air pollutants are released directly from the gas cleaning and from slurry production in some conversion concepts. A clear differentiation regarding pollutant concentration seems to be difficult with the present state of knowledge. Pollutant concentrations will also be mainly influenced by the filter technologies and not so much by process layouts. The use of filter technologies is dependent on economical and legal considerations.

Data on the emission profile from the conversion processes are rarely available. The emissions arise during the gas cleaning. They mainly consist of biogenic CO_2 and N_2. But, important are the emissions of many pollutants that occur only in small traces. Exhaust gases are oxidized with a catalyst at UET. Only few data are available for actual emissions profiles and concentrations.

The emission profile for all conversion plants has been assessed based on emission profiles from modern gas power plants (Faist Emmenegger et al. 2003). For methane emissions, a slightly higher figure has been used based on information available from the CHEMREC conversion plant. Tab. 3.15 shows all emissions of air pollutants emitted together with one kg of biogenic CO_2.

Tab. 3.14 Documentation of the emission profile for off-gas emissions from conversion processes

ReferenceFunction	Name	off-gas, per kg CO2 emission
Geography	Location	RER
ReferenceFunct	InfrastructureProcess	0
ReferenceFunct	Unit	kg
	IncludedProcesses	All emissions of air pollutants due to the emission of 1kg biogenic CO2 off-gas. No further inputs or outputs.
	Synonyms	
	GeneralComment	This data set describes the emission profile of off-gases from the biomass conversion process. The emission profile is calculated in relation to 1kg of CO2. Available information from conversion plants, legal limits (Technical Standards) and the emission profile from gas power plants have been taken into account for the estimation. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by the respective technology partner.
	Category	biomass
	SubCategory	fuels
	Formula	
	StatisticalClassification	
	CASNumber	
TimePeriod	StartDate	2005
	EndDate	2006
	OtherPeriodText	Starting point scenario
Geography	Text	Europe
Technology	Text	Biomass conversion in gasification and synthesis processes. Emissions due to cleaning of synthesis gas and extraction of CO2.
	ProductionVolume	no data
	SamplingProcedure	questionnaire, legal limits and emission profile of gas power plants
	Extrapolations	none
	UncertaintyAdjustments	none
	PageNumbers	conversion plants

Tab. 3.15 Life cycle inventory analysis and unit process raw data of off-gas emissions at the conversion plants (emissions per kg of biogenic CO_2 emission). Figures marked in yellow are used for the general assumptions

Name	Location	InfrastructureProcess	Unit	off-gas, per kg CO2 emission	UncertaintyType	StandardDeviation95%	GeneralComment	off-gas	CO2-off gas	CO2-off gas	tail gas, synthesis	CO-shift	emission limits TA Luft	natural gas combustion default
Location				RER				UET	UET	Chemrec	TUV	FZK	DE	RER
InfrastructureProcess				0										0
Unit				kg				kg CO2	kg CO2	kg CO2	kg CO2	kg CO2	kg CO2	kg CO2
Acenaphthene	-	-	kg	1.41E-11	1	1.23	(2,3,2,1,3,na); Average data of gas combustion							1.4E-11
Acetaldehyde	-	-	kg	1.43E-8	1	1.23	(2,3,2,1,3,na); Average data of gas combustion							1.4E-8
Acetic acid	-	-	kg	2.14E-6	1	1.23	(2,3,2,1,3,na); Average data of gas combustion							2.1E-6
Benzene	-	-	kg	1.66E-8	1	3.05	(2,3,2,1,3,na); Average data of gas combustion							1.7E-8
Benzo(a)pyrene	-	-	kg	9.46E-12	1	1.23	(2,3,2,1,3,na); Average data of gas combustion							9.5E-12
Butane	-	-	kg	1.66E-5	1	1.23	(2,3,2,1,3,na); Average data of gas combustion							1.7E-5
Carbon dioxide, biogenic	-	-	kg	1.0	1	1.23	(2,3,2,1,3,na); Reference value	*21.6%*	*83.2%*	*95.1%*	*29.1%*	*1*	*1*	*1*
Carbon monoxide, biogenic	-	-	kg	5.37E-4	1	3.05	(2,3,2,1,3,na); questionnaire	5.37E-4	1.39E-4	1.97E-3	1.06E-1		9.82E-4	1.8E-4
Dinitrogen monoxide	-	-	kg	1.79E-5	1	1.23	(2,3,2,1,3,na); Average data of gas combustion							1.8E-5
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	-	-	kg	5.18E-16	1	3.05	(2,3,2,1,3,na); Average data of gas combustion						3.93E-7	5.2E-16
Ethane	-	-	kg	2.50E-5	1	3.05	(2,3,2,1,3,na); Average data of gas combustion							2.5E-5
Formaldehyde	-	-	kg	5.89E-7	1	1.23	(2,3,2,1,3,na); Average data of gas combustion							5.9E-7
Hexane	-	-	kg	1.41E-5	1	1.23	(2,3,2,1,3,na); Average data of gas combustion							1.4E-5
Hydrogen sulfide	-	-	kg	3.19E-4	1	3.05	(2,3,2,1,3,na); Questionnaires			3.19E-4		1.67E-3		0
Mercury	-	-	kg	5.36E-10	1	1.23	(2,3,2,1,3,na); Average data of gas combustion						1.96E-7	5.4E-10
Methane, biogenic	-	-	kg	1.50E-3	1	3.05	(2,3,2,1,3,na); Questionnaires and own assumption			1.50E-3	1.76E-1			1.4E-3
Nitrogen oxides	-	-	kg	7.86E-4	1	3.05	(2,3,2,1,3,na); Standard TA Luft						7.86E-4	7.9E-4
PAH, polycyclic aromatic hydrocarbons	-	-	kg	1.43E-7	1	3.05	(2,3,2,1,3,na); Average data of gas combustion							1.4E-7
Particulates, < 2.5 um	-	-	kg	2.68E-6	1	1.23	(2,3,2,1,3,na); Average data of gas combustion						1.96E-5	2.7E-6
Pentane	-	-	kg	2.14E-5	1	3.05	(2,3,2,1,3,na); Average data of gas combustion							2.1E-5
Propane	-	-	kg	1.27E-5	1	1.23	(2,3,2,1,3,na); Average data of gas combustion							1.3E-5
Propionic acid	-	-	kg	2.86E-7	1	1.57	(2,3,2,1,3,na); Average data of gas combustion							2.9E-7
Sulfur dioxide	-	-	kg	9.82E-6	1	1.23	(2,3,2,1,3,na); Average data of gas combustion						7.86E-4	9.8E-6
Toluene	-	-	kg	2.68E-8	1	1.23	(2,3,2,1,3,na); Average data of gas combustion							2.7E-8
NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	0	1	1.23	(2,3,2,1,3,na); Specified for individual substances				6.02E-2		3.93E-4	0
Heat, waste	-	-	MJ	1.29E+1	1	1.23	(2,3,2,1,3,na); Average data of gas combustion							1.29E+1

3.4.9 Flaring

It can be expected that conversion plants of this size will use a flare in order to burn unused synthesis gas in case of e.g. shut-down of the operation or malfunctioning of certain installations. The amounts of gas sent to the flare and the emission profile is estimated with data investigated for oil refineries (Jungbluth 2004).

3.4.10 VOC emissions from plant operations.

It can be expected that conversion plants of this size emit NMVOC emissions, e.g. due to fuel handling, spillages, etc.. The amount and emission profile of such emissions is estimated with data investigated for oil refineries. The profile is based on the emission of 1kg NMVOC. Methane emissions are added to this profile. The amount of non-combustion NMVOC emissions is 268 g per tonne of produced fuel (Jungbluth 2004).

Tab. 3.16 Life cycle inventory analysis and unit process raw data of the VOC emissions from conversion plants

	Name	Location	InfrastructurePro	Unit	process specific emissions, conversion plant	UncertaintyType	StandardDeviati on95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kg			
product	process specific emissions, conversion plant	RER	0	kg	1			
emission air, high population density	Benzene	-	-	kg	2.0%	1	1.58	(2,3,3,1,3,na); average data of European refineries
	Benzene, ethyl-	-	-	kg	0.5%	1	1.58	(2,3,3,1,3,na); average data of European refineries
	Butane	-	-	kg	20.0%	1	1.58	(2,3,3,1,3,na); average data of European refineries
	Butene	-	-	kg	0.5%	1	1.58	(2,3,3,1,3,na); average data of European refineries
	Ethane	-	-	kg	5.0%	1	1.58	(2,3,3,1,3,na); average data of European refineries
	Ethene	-	-	kg	1.0%	1	1.58	(2,3,3,1,3,na); average data of European refineries
	Heptane	-	-	kg	5.0%	1	1.58	(2,3,3,1,3,na); average data of European refineries
	Hexane	-	-	kg	10.0%	1	1.58	(2,3,3,1,3,na); average data of European refineries
	Hydrocarbons, aliphatic, alkanes, unspecified	-	-	kg	5.0%	1	1.58	(2,3,3,1,3,na); average data of European refineries
	Pentane	-	-	kg	25.0%	1	1.58	(2,3,3,1,3,na); average data of European refineries
	Propane	-	-	kg	20.0%	1	1.58	(2,3,3,1,3,na); average data of European refineries
	Propene	-	-	kg	1.0%	1	1.58	(2,3,3,1,3,na); average data of European refineries
	Toluene	-	-	kg	3.0%	1	1.58	(2,3,3,1,3,na); average data of European refineries
	Xylene	-	-	kg	2.0%	1	1.58	(2,3,3,1,3,na); average data of European refineries
	Methane, biogenic	-	-	kg	1.11E-1	1	1.58	(2,3,3,1,3,na); average data of European refineries

3.4.11 Hydrogen production

In scenario 1 hydrogen is produced on-site or next to the plant site via electrolysis based on electricity produced with wind power plants. As this is not necessarily possible in all cases, a sensitivity analysis based on the average electricity mix for hydrogen production is performed for all different BtL routes.

The most important input of water electrolysis is the electricity use. Here we assume that the electricity is delivered as far as possible by the conversion plant itself. Only the demand not covered by the internal power generation is delivered from the grid. Thus, it is necessary to split up the inventory for hydrogen production. The electricity use for H_2 production is directly recorded with the unit process raw data of the conversion plant. Also the amount of H_2 is shown in these inventories. Here we only account for other inputs and outputs of the electrolysis and the necessary infrastructure.

The inventory analysis is based on literature data (Pehnt 2002; Röder 2001). The electricity use is 53.3 kWh/kg of H_2. Further specifications can be found in Tab. 3.18.

For 1kg of H_2 about 10.6 kg of deionised water are necessary (Tab. 3.17). Per kg of H_2 about 8 kg of O_2 are produced. The oxygen should be used as far as possible in the conversion plant.

For the allocation between H_2 and O_2 sold outside the plant we take the following assumption. The prices of hydrogen and oxygen are quite dependent on the electricity use. Oxygen can also be produced in an air separation unit. The electricity demand is in this case about 0.769 kWh/kg oxygen (Althaus et al. 2004). Thus, it can be concluded that about 86% of the electricity of the electrolysis (and thus also of the costs) are necessary for hydrogen production. All inputs and outputs of the process are allocated to H_2 production. If a part of the oxygen cannot be used by the conversion plant, a credit of 0.769 kWh/kg is subtracted from the electricity demand for H_2 production, because the oxygen might be used elsewhere.

Tab. 3.17 Products of the water electrolysis and allocation factors

			Input	Output	Electricity
H2		kg	1.19	1.00	86.4%
O2		kg	9.42	7.94	13.6%
H2O		kg	10.60	-	100.0%

Tab. 3.18 Documentation of the inventory data of the water electrolysis

ReferenceFunction	Name	hydrogen, liquid, from water electrolysis, at plant	water electrolysis plant
Geography	Location	RER	RER
ReferenceFunc	InfrastructureProcess	0	1
ReferenceFunc	Unit	kg	unit
	IncludedProcesses	Alkaline electrolysis, losses of transformation and equalizer, chemicals and infrastructure. The electricity use is not included, but directly accounted for at the conversion plant. All other inputs and outputs are allocated to H2, none to O2.	Materials and building process for the plant.
	Synonyms		
	GeneralComment	Production of hydrogen by alkaline electrolysis of water. Efficiency about 62%. Lower heating value is 119.9 MJ/kg. Higher Heating Value is 141.8 MJ/kg. Output pressure is 3 Mpa or 30 bar. The density is 0.084 kg/Nm3.	Plant infrastructure for the production of hydrogen. Life time 30a. Capacity 200 - 400 Nm3 H2 per hour. Availability 90%. Total production about 6000 t of H2.
	Category	chemicals	chemicals
	SubCategory	inorganics	inorganics
	Formula	H2	
	StatisticalClassification		
	CASNumber	001333-74-0	
TimePeriod	StartDate	1995	1995
	EndDate	2002	2002
	OtherPeriodText	Time of original publications.	Time of original publications.
Geography	Text	Plant operated in Europe	Plant operated in Europe
Technology	Text	alkaline electrolysis	plant infrastructure for the electrolysis of water
	ProductionVolume	unknown	unknown
	SamplingProcedure	Literature data.	Literature data.
	Extrapolations	Average of two literature sources.	Average of two literature sources.
	UncertaintyAdjustments	none	none
	PageNumbers	Hydrogen production	Hydrogen production

Tab. 3.19 Life cycle inventory analysis and unit process raw data of water electrolysis

	Name	Location	Infrastructur	Unit	hydrogen, liquid, from water electrolysis, at plant	water electrolysis plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER			
	InfrastructureProcess				0	1			
	Unit				kg	unit			
resource, in water	Water, cooling, unspecified natural origin	-	-	m3	9.52E-1	0	1	1.14	(2,3,3,3,1,na); literature data
technosphere	aluminium, production mix, at plant	RER	0	kg	0	4.10E+2	1	1.14	(2,3,3,3,1,na); literature data
	ferrochromium, high-carbon, 68% Cr, at regional storage	RER	0	kg	0	3.97E+4	1	1.14	(2,3,3,3,1,na); literature data
	chromium, at regional storage	RER	0	kg	0	4.74E+2	1	1.14	(2,3,3,3,1,na); literature data
	flat glass, uncoated, at plant	RER	0	kg	0	7.90E+1	1	1.14	(2,3,3,3,1,na); literature data
	sodium hydroxide, 50% in H2O, production mix, at plant	RER	0	kg	0	2.51E+3	1	1.14	(2,3,3,3,1,na); literature data
	nickel, 99.5%, at plant	GLO	0	kg	0	1.28E+3	1	1.14	(2,3,3,3,1,na); literature data
	polyethylene, HDPE, granulate, at plant	RER	0	kg	0	3.06E+2	1	1.14	(2,3,3,3,1,na); literature data
	chemicals inorganic, at plant	GLO	0	kg	3.04E-3	0	1	1.14	(2,3,3,3,1,na); literature data, KOH
	concrete, normal, at plant	CH	0	m3	0	7.47E+1	1	1.14	(2,3,3,3,1,na); literature data
	transport, lorry 32t	RER	0	tkm	3.04E-4	4.48E+3	1	2.09	(4,5,na,na,na,na); standard distance 100km
	transport, freight, rail	RER	0	tkm	6.07E-4	1.72E+4	1	2.09	(4,5,na,na,na,na); standard distance 200km
	water, completely softened, at plant	RER	0	kg	1.06E+1	0	1	1.14	(2,3,3,3,1,na); literature data
	electricity, medium voltage, production UCTE, at grid	UCTE	0	kWh	0	4.93E+3	1	1.14	(2,3,3,3,1,na); direct electricity use for electrolysis not included.
	diesel, burned in building machine	GLO	0	MJ	0	7.93E+4	1	1.14	(2,3,3,3,1,na); literature data
	light fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	0	7.93E+4	1	1.14	(2,3,3,3,1,na); literature data
	water electrolysis plant	RER	1	unit	1.68E-7	0	1	1.14	(2,3,3,3,1,na); literature data
	treatment, sewage, unpolluted, to wastewater treatment,	CH	0	m3	1.67E-3	1.64E+5	1	1.22	(4,3,1,1,1,na); based on efficiency for water use
	disposal, building, concrete gravel, to sorting plant	CH	0	kg	0	1.64E+5	1	1.14	(2,3,3,3,1,na); standard assumption for disposal
	disposal, building, glass sheet, to sorting plant	CH	0	kg	0	1.28E+3	1	1.14	(2,3,3,3,1,na); standard assumption for disposal
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg	0	7.90E+1	1	1.14	(2,3,3,3,1,na); standard assumption for disposal
emission air, high population density	Heat, waste	-	-	MJ	0	1.77E+4	1	1.14	(2,3,3,3,1,na); calculation
emission water, river	Potassium, ion	-	-	kg	2.12E-3	0	1	5.02	(2,3,3,3,1,na); rough estimation for emission of chemicals

3.4.12 Catalysts

Elaboration of LCI: Niels Jungbluth, ESU-services Ltd., Uster
Data provider Literature, CERTH

Gas treatment

During gasification, a zinc catalyst is used by some processes. The amount is estimated with 6 g zinc/kg of fuel produced based on information available from TUV if the actual amount is not known. Pure zinc has been used as a proxy in the life cycle inventory data.

Fischer-Tropsch synthesis

Information about used catalysts in the conversion processes is rarely available (Claeys 1997; Popp 1996; van Dijk 2001). Most Fischer-Tropsch synthesis processes use iron or cobalt based catalysts. Data on the material composition of such a catalyst has been estimated with available information from literature (Tab. 3.20). Missing inventories of some metals, are roughly approximated with inventories of metals with about the same price.

So far, there is also no information about the recycling or treatment possibilities for such catalysts. As a first rough guess, a disposal is included in the inventory. Further research and clarification is necessary about the amount, type and disposal of such catalysts.

Tab. 3.20 Life cycle inventory analysis and unit process raw data of the catalyst production for the Fischer-Tropsch synthesis

	Name	Location	InfrastructureProcess	Unit	catalyst, Fischer-Tropsch synthesis	UncertaintyType	StandardDeviation95%	GeneralComment	*iron catalyst, at plant*	*iron catalyst, FeAlCu, at plant*	*cobalt catalyst, atmospheric pressure, at plant*	*cobalt catalyst, CoZrRu-SiO2 at plant*	*cobalt catalyst, at plant*
	Location				RER				*RER*	*RER*	*RER*	*RER*	*RER*
	InfrastructureProcess				1				*0*	*0*	*0*	*0*	*0*
	Unit				kg				*kg*	*kg*	*kg*	*kg*	*kg*
technosphere	pig iron, at plant	GLO	0	kg	2.34E-1	1	1.24	(3,na,1,1,3,na); literature average	7.41E-1	4.28E-1	0	0	0
	cobalt, at plant	GLO	0	kg	1.81E-1	1	1.24	(3,na,1,1,3,na); literature average	0	0	3.19E-1	4.64E-1	1.20E-1
	palladium, at regional storage	RER	0	kg	9.72E-4	1	1.24	(3,na,1,1,3,na); rough assumption for ruthenium	0	0	0	0	0
	nickel, 99.5%, at plant	GLO	0	kg	1.71E-2	1	1.24	(3,na,1,1,3,na); rough assumption for thorium and zirconium	0	0	0	0	0
	zeolite, powder, at plant	RER	0	kg	3.52E-1	1	1.24	(3,na,1,1,3,na); Aerosil, Degussa, hochrein, SiO2	1.85E-1	4.73E-1	6.39E-1	4.64E-1	0
	magnesium oxide, at plant	RER	0	kg	5.11E-3	1	1.24	(3,na,1,1,3,na); literature average	0	0	2.56E-2	0	0
	aluminium oxide, at plant	RER	0	kg	1.11E-2	1	1.24	(3,na,1,1,3,na); literature average	0	5.57E-2	0	0	0
	titanium dioxide, production mix, at plant	RER	0	kg	1.76E-1	1	1.24	(3,na,1,1,3,na); literature average	0	0	0	0	8.78E-1
	copper, at regional storage	RER	0	kg	1.60E-2	1	1.24	(3,na,1,1,3,na); literature average	3.70E-2	4.28E-2	0	0	0
	potassium chloride, as K2O, at regional storehouse	RER	0	kg	7.41E-3	1	1.24	(3,na,1,1,3,na); literature average	3.70E-2	0	0	0	0
	disposal, catalyst for EDC production, 0% water, to underground deposit	DE	0	kg	1.00E+0	1	1.24	(3,na,1,1,3,na); rough assumption	1.00E+0	1.00E+0	9.84E-1	9.27E-1	9.98E-1
	Missing metals in database												
	Ruthenium			kg	9.72E-4	1	1.31	(2,3,1,1,3,5); Ruthenium	0	0	0	3.06E-3	1.80E-3
	Thorium (ThO2)			kg	3.19E-3	1	1.31	(2,3,1,1,3,5); Thorium (ThO2)	0	0	1.60E-2	0	0
	ZrO2			kg	1.39E-2	1	1.31	(2,3,1,1,3,5); ZrO2	0	0	0	6.96E-2	0

The amount of used catalysts is quite difficult to determine. The following table shows available information about catalysts uses and the assumption for this study.

Tab. 3.21 Information about the amount of catalysts used for the Fischer-Tropsch synthesis

Process	Amount (g/t product)	Source
Crude oil refinery	10	(Jungbluth 2004)
FCC	830	RENEW project team.[17]
Fischer-Tropsch	50-950	Rough estimation for laboratory data with (Popp 1996)
Fischer-Tropsch	**100**	**This study, rough assumption**

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[17] Discussion with CERTH: 300 t/h input to FCC, output 150 t/h diesel, the process uses 200t Zeolith A within 3 month or 3 t catalyst consumption per day, this is equal to 830g catalyst per tonne of diesel.

Tab. 3.22 Documentation of the inventory data of the catalyst production

ReferenceFunction	Name	catalyst, Fischer-Tropsch synthesis
Geography	Location	RER
ReferenceFunct	InfrastructureProcess	1
ReferenceFunct	Unit	kg
	IncludedProcesses	Average material composition for a catalyst, disposal, no manufacturing expenses nor emissions
	Synonyms	
	GeneralComment	Rough estimation for catalysts used in Fischer-Tropsch synthesis.
	Category	metals
	SubCategory	refinement
	Formula	
	StatisticalClassification	
	CASNumber	
TimePeriod	StartDate	2000
	EndDate	2000
	OtherPeriodText	Starting point scenario
Geography	Text	Europe
Technology	Text	Fischer-Tropsch synthesis
	ProductionVolume	not yet established
	SamplingProcedure	Literature
	Extrapolations	none
	UncertaintyAdjustments	none
	PageNumbers	conversion plants

3.4.13 Refinery treatment of FT-raw liquid

Elaboration of LCI: Niels Jungbluth, ESU-services Ltd., Uster
Data provider Literature

For the BtL concept producing raw FT wax, further processing in a conventional crude oil refinery would be needed to get final product to be used as FT transportation fuel. In most existing refineries, it would be difficult to find a unit suited to convert raw FT into a pure stream of high quality paraffinic FT diesel. Most probably, raw FT would be mixed with refinery intermediate streams, whose composition would depend on the refinery specific crude slate and process scheme. The input would end up in the diesel pool, without any quality specificity. In order to preserve its specific paraffinic quality, a dedicated upgrading unit would be needed, similar to the one included in the complete BtL schemes.[18]

The life cycle inventory of this sub-process is based on the inventory of fossil diesel production from raw crude oil investigated by (Jungbluth 2004) and further modelling in the RENEW project (Beiermann 2006). No advanced desulphurization is assumed, because the Fisher-Tropsch raw product shows already low sulphur content.

The transport to the refinery is considered with 100 km truck. All other inputs and outputs including the energy consumption are considered the same as for crude oil refining, but with a reduction factor of about 50% because the complexity and thus the energy use in this type of refinery is comparable low. It is assumed that 0.95 kg FT-fuel (70% diesel and 25% naphtha) can be produced with 1 kg FT-raw liquid (Beiermann 2006). The average heating value for the two products is 43.9 MJ/kg.

The rough assumption does not take into account differences in the quality of FT-raw products from different conversion plants. It can be assumed that FT-waxes are more complex to treat than FT-naphtha, because more hydrogen is necessary in order to produce a fuel.

The energy for the process is provided by burning light hydrocarbons from the processing in a power plant. About 0.05 kg light hydrocarbons can be burned per kg of FT-raw product input. This delivers heat and electricity for the process. Electricity is also used for the production of necessary hydrogen. Emissions from this process are modelled with data for refineries in Tab. 3.23. The heat demand is fully supplied with this process. A part of the electricity can be supplied to the grid. Thus, the actual amount of light hydrocarbons burned for the processing has been reduced to 0.031 kg/kg input (marked green in Tab. 3.23). The exergy content of the produced heat and electricity has been used to derive this figure.

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[18] Personal communication, Véronique Hervouet, Total, 1.2007.

Tab. 3.23 Life cycle inventory analysis and unit process raw data of the combustion of light hydrocarbons from processing FT-raw products in a refinery for providing process heat and electricity

	Name	Location	InfrastructureProcess	Unit	refinery gas, FT-processing, burned in power plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kg			
	refinery gas, FT-processing, burned in power plant	RER	0	kg	1.00E+0			
emission air, high population density	Heat, waste	-	-	MJ	3.45E+1	1	1.17	(3,3,3,3,1,3); Literature data, 75% waste heat to air
	Methane, biogenic	-	-	kg	2.50E-4	1	1.61	(3,4,4,3,1,4); Literature data
	Carbon monoxide, biogenic	-	-	kg	7.55E-4	1	5.09	(3,4,4,3,1,4); Literature data
	Carbon dioxide, biogenic	-	-	kg	2.82E+0	1	1.29	(3,4,4,3,1,4); Literature data
	Mercury	-	-	kg	7.00E-8	1	5.09	(3,4,4,3,1,4); Literature data
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	2.50E-4	1	2.09	(3,4,4,3,1,4); Literature data
	Nitrogen oxides	-	-	kg	2.27E-3	1	2.89	44.5% of Range for RER refineries
	Sulfur dioxide	-	-	kg	1.40E-3	1	14.14	Range for RER refineries, Share for combustion
	Particulates, < 2.5 um	-	-	kg	2.75E-4	1	2.03	(2,4,2,1,1,4); Literature data
	Radon-222	-	-	kBq	6.36E-3	1	2.03	(2,4,2,1,1,4); Literature data
emission water, river	Heat, waste	-	-	MJ	1.15E+1	1	1.29	(3,4,4,3,1,4); Literature data, 25% waste heat to cooling water

Tab. 3.24 Documentation of the inventory data of the treatment of FT-raw liquid in a refinery and the burning of refinery gases for steam and power production

ReferenceFunction	Name	refinery treatment, FT-raw liquid	refinery gas, FT-processing, burned in power plant
Geography	Location	RER	RER
ReferenceFunction	InfrastructureProcess	0	0
ReferenceFunction	Unit	kg	kg
	IncludedProcesses	All processes on the refinery site including the emissions from combustion facilities for the supply of electricity and thermal energy, including waste water treatment, process emissions and direct discharges to rivers. Not including throughput of FT-raw liquid. Energy is supplied by combustion of 0.05 kg C1-C4 fraction per kg of input.	Combustion emissions for the use of biogenic gas input from processing of FT-raw products.
	Synonyms		
	GeneralComment	Description of all flows of materials and energy due to the throughput of 1kg crude Fischer-Tropsch oil in the refinery. Out of this 0.95 kg of diesel and naphtha are produced. All inputs and outputs of the multi-output-process have been allocated between the co-products petrol, unleaded, bitumen, diesel, light fuel oil, heavy fuel oil, kerosene, naphtha, propane/ butane, refinery gas, secondary sulphur and electricity. The impacts of processing are allocated to the different products.	Description of the direct emissions due to the combustion of refinery gas in refinery furnaces and generators not including the infrastructure of the furnace.
	InfrastructureIncluded	1	
	Category	biomass	biomass
	SubCategory	fuels	heating systems
	Formula		
	StatisticalClassification		
	CASNumber		
TimePeriod	StartDate	2000	1980
	EndDate	2006	2006
	OtherPeriodText	Statistical data for the throughput and production volumes were available for the year 2000. The energy use has been based on actual modelling assumptions in the RENEW project. Other data and indicators have been estimated based on different environmental reports.	New European data from single plants for regulated emissions like biogenic CO2, NOx, SOx etc. have been provided in the literature. They have been compared and discussed with older literature data.
Geography	Text	Assumption for the European average.	Data for single European plants.
Technology	Text	Assumption for adopted technology used for the treatment of Fischer-Tropsch raw products.	Average technology in use. There might be large differences for single plants due to the technology used for the flue gas treatment.
	ProductionVolume	not known	It is estimated that 27 mio. tonnes of refinery gas were burned in 2000.
	SamplingProcedure	Reference document of the European Commission, environmental reports and literature data. Models developed in the RENEW project.	Environmental reports and literature data.
	Extrapolations	Many data were available only for 1 to 5 plants and have been extrapolated to the European situation. The energy use is modelled with a wood heating instead of using fossil fuels for energy production. All inputs and outputs have been reduced in comparison to the average refinery based on the reduced use of energy.	From single plants to average situation.
	UncertaintyAdjustments	none	none
	PageNumbers	refinery treatment	refinery treatment

Tab. 3.25 Life cycle inventory analysis and unit process raw data of the treatment of FT-raw liquid in a refinery

	Name	Location	Infrastruct	Unit	refinery treatment, FT-raw liquid	Uncertain tyType	Standard Deviation 95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kg			
product	refinery treatment, FT-raw liquid	RER	0	kg	1			
	cobalt, at plant	GLO	0	kg	1.59E-8	1	2.00	Range for RER refineries, Co/Mo Catalyst
resource, in water	Water, river	-	-	m3	3.64E-4	1	1.16	(3,3,1,3,1,4); Average of plant data
	Water, cooling, unspecified natural origin	-	-	m3	2.08E-3	1	1.12	(3,3,1,1,1,na); Average of plant data
transport	transport, lorry 32t	RER	0	tkm	5.44E-2	1	2.09	(4,5,na,na,na,na); Standard distance
	refinery gas, burned in flare	GLO	0	MJ	4.52E-2	1	1.34	(3,4,4,3,3,na); Literature
	refinery gas, FT-processing, burned in power plant	RER	0	kg	0.031378	1	1.07	(2,1,1,1,1,na); assumption for use of light hydrocarbons from FT-raw liquid input, excluding demand for electricity supply to the grid
water	tap water, at user	RER	0	kg	7.91E-3	1	1.10	(2,3,1,3,1,3); Average of plant data
chemicals	ammonia, liquid, at regional storehouse	RER	0	kg	1.05E-6	1	1.34	(3,4,4,3,3,na); Literature
	calcium chloride, CaCl2, at plant	RER	0	kg	8.44E-6	1	1.10	(2,3,1,3,1,3); Average of plant data
	chemicals organic, at plant	GLO	0	kg	2.32E-4	1	1.19	(3,4,2,1,1,4); IPPC European plant data
	hydrochloric acid, 30% in H2O, at plant	RER	0	kg	4.63E-5	1	1.14	(2,4,1,3,1,3); Env. reports DE
	iron sulphate, at plant	RER	0	kg	2.60E-5	1	1.34	(3,4,4,3,3,na); Literature, waste water treatment
	lime, hydrated, packed, at plant	CH	0	kg	1.82E-5	1	1.26	(3,4,1,3,3,na); Estimation based on literature
	lubricating oil, at plant	RER	0	kg	1.29E-5	1	1.14	(2,4,1,3,1,3); Env. reports DE
	naphtha, at regional storage	RER	0	kg	2.08E-2	1	1.10	(2,3,1,3,1,3); Calculation as input-output balance, not considered for transports
	nitrogen, liquid, at plant	RER	0	kg	4.29E-4	1	1.14	(2,4,1,3,1,3); Env. reports DE
	propylene glycol, liquid, at plant	RER	0	kg	2.99E-7	1	1.26	(3,4,1,3,3,na); Literature
	soap, at plant	RER	0	kg	1.39E-6	1	1.10	(2,3,1,3,1,3); Average of plant data
	sodium hypochlorite, 15% in H2O, at plant	RER	0	kg	2.60E-5	1	1.34	(3,4,4,3,3,na); Literature, waste water treatment
	sulphuric acid, liquid, at plant	RER	0	kg	6.20E-6	1	1.10	(2,3,1,3,1,3); Average of plant data
catalysts	molybdenum, at regional storage	RER	0	kg	8.59E-9	1	2.83	Range for RER refineries, Co/Mo Catalyst
	zeolite, powder, at plant	RER	0	kg	1.83E-6	1	1.34	Range for RER refineries
	zinc for coating, at regional storage	RER	0	kg	1.98E-8	1	1.00	Range for RER refineries, Zn Catalyst
transport	transport, lorry 32t	RER	0	tkm	3.68E-4	1	2.09	(4,5,na,na,na,na); Standard distance 100km
	transport, freight, rail	RER	0	tkm	2.21E-3	1	2.09	(4,5,na,na,na,na); Standard distance 600km
	refinery	RER	1	unit	1.50E-11	1	3.03	(3,3,1,1,1,4); Estimation
waste	disposal, refinery sludge, 89.5% water, to sanitary landfill	CH	0	kg	9.79E-5	1	1.10	(2,3,1,3,1,3); Average of plant data
	disposal, refinery sludge, 89.5% water, to hazardous waste incineration	CH	0	kg	1.04E-4	1	1.10	(2,3,1,3,1,3); Estimation
	disposal, catalytic converter NOx reduction, 0% water, to underground deposit	DE	0	kg	1.84E-7	1	1.10	(2,3,1,3,1,3); Estimation based on literature data
emission air, high population density	Heat, waste	-	-	MJ	2.81E-2	1	1.10	(2,3,1,3,1,3); Average of plant data
	Ammonia	-	-	kg	3.83E-8	1	1.54	(3,4,1,3,1,3); Plant data
	Benzene	-	-	kg	2.81E-6	1	1.65	(3,5,4,3,1,4); Literature
	Benzene, ethyl-	-	-	kg	7.01E-7	1	1.65	(3,5,4,3,1,4); Literature
	Butane	-	-	kg	2.81E-5	1	1.65	(3,5,4,3,1,4); Literature
	Butene	-	-	kg	7.01E-7	1	1.65	(3,5,4,3,1,4); Literature
	Dinitrogen monoxide	-	-	kg	5.10E-7	1	1.51	(2,3,1,3,1,3); Average of plant data
	Ethane	-	-	kg	7.01E-6	1	1.65	(3,5,4,3,1,4); Literature
	Ethene	-	-	kg	1.40E-6	1	1.65	(3,5,4,3,1,4); Literature
	Heptane	-	-	kg	7.01E-6	1	1.65	(3,5,4,3,1,4); Literature
	Hexane	-	-	kg	1.40E-5	1	1.65	(3,5,4,3,1,4); Literature
	Hydrocarbons, aliphatic, alkanes, unspecified	-	-	kg	2.34E-11	1	1.51	(2,3,1,3,1,3); Average of plant data
	Hydrocarbons, aliphatic, unsaturated	-	-	kg	1.29E-12	1	1.51	(2,3,1,3,1,3); Average of plant data
	Hydrocarbons, aromatic	-	-	kg	3.51E-13	1	1.51	(2,3,1,3,1,3); Average of plant data
	Methane, biogenic	-	-	kg	2.09E-5	1	1.41	(3,5,4,3,1,4); Literature
	Nitrogen oxides	-	-	kg	1.20E-5	1	2.89	11% of Range for RER refineries
	Particulates, > 10 um	-	-	kg	5.23E-6	1	2.12	(3,5,4,3,1,4); Literature
	Pentane	-	-	kg	3.51E-5	1	1.65	(3,5,4,3,1,4); Literature
	Propane	-	-	kg	2.81E-5	1	1.65	(3,5,4,3,1,4); Literature
	Propene	-	-	kg	1.40E-6	1	1.65	(3,5,4,3,1,4); Literature
	Sulfur dioxide	-	-	kg	9.10E-5	1	14.14	Range for RER refineries, Share for sulphur recovery and FCC
	Toluene	-	-	kg	4.21E-6	1	1.65	(3,5,4,3,1,4); Literature
	Xylene	-	-	kg	2.81E-6	1	1.65	(3,5,4,3,1,4); Literature
emission water, river	Aluminum	-	-	kg	6.64E-9	1	5.13	(3,5,4,3,1,4); Literature
	Ammonium, ion	-	-	kg	8.88E-7	1	6.32	Range for RER refineries
	AOX, Adsorbable Organic Halogen as Cl	-	-	kg	2.14E-9	1	3.16	Range for RER refineries
	Arsenic, ion	-	-	kg	1.32E-9	1	5.13	(3,5,4,3,1,4); Literature
	Barium	-	-	kg	1.33E-8	1	5.13	(3,5,4,3,1,4); Literature
	Benzene	-	-	kg	3.03E-9	1	44.72	Range for RER refineries
	Benzene, ethyl-	-	-	kg	2.63E-11	1	3.12	(3,5,4,3,1,4); Literature
	BOD5, Biological Oxygen Demand	-	-	kg	9.37E-7	1	3.16	Range for RER refineries
	Boron	-	-	kg	5.32E-8	1	1.65	(3,5,4,3,1,4); Literature
	Cadmium, ion	-	-	kg	1.32E-9	1	5.13	(3,5,4,3,1,4); Literature
	Calcium, ion	-	-	kg	6.64E-6	1	1.65	(3,5,4,3,1,4); Literature
	Chloride	-	-	kg	1.06E-5	1	5.02	(2,4,1,2,1,3); Average of CH plant, basic uncertainity = 5 estimated based on range
	Chromium, ion	-	-	kg	2.94E-8	1	2.24	Range for RER refineries

(…)

	Name	Location	Infrastruct	Unit	refinery treatment, FT-raw liquid	Uncertain tvTvpe	Standard Deviation 95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kg			
	COD, Chemical Oxygen Demand	-	-	kg	9.49E-6	1	2.04	Range for RER refineries
	Copper, ion	-	-	kg	1.32E-9	1	5.13	(3,5,4,3,1,4); Literature
	Cyanide	-	-	kg	2.30E-8	1	5.77	Range for RER refineries
	DOC, Dissolved Organic Carbon	-	-	kg	9.14E-9	1	1.53	(2,4,1,2,1,3); Average of CH plant
	Fluoride	-	-	kg	5.95E-7	1	4.47	Range for RER refineries
	Hydrocarbons, aromatic	-	-	kg	9.57E-8	1	3.01	(2,3,1,1,1,3); Average of plant data
	Hydrocarbons, unspecified	-	-	kg	1.26E-8	1	5.48	Range for RER refineries
	Iron, ion	-	-	kg	6.64E-8	1	5.13	(3,5,4,3,1,4); Literature
	Lead	-	-	kg	4.16E-8	1	5.02	(2,3,1,1,1,4); Range for RER refineries
	Magnesium	-	-	kg	3.32E-6	1	5.13	(3,5,4,3,1,4); Literature
	Manganese	-	-	kg	2.66E-8	1	5.13	(3,5,4,3,1,4); Literature
	Mercury	-	-	kg	1.33E-11	1	5.13	(3,5,4,3,1,4); Literature
	Molybdenum	-	-	kg	1.33E-9	1	5.13	(3,5,4,3,1,4); Literature
	Nickel, ion	-	-	kg	1.74E-9	1	5.02	(2,4,1,2,1,3); Average of CH plant
	Nitrate	-	-	kg	1.09E-6	1	1.65	(3,5,4,3,1,4); Literature
	Nitrogen, organic bound	-	-	kg	6.07E-7	1	2.65	Range for RER refineries
	Oils, unspecified	-	-	kg	1.22E-7	1	14.00	Range for RER refineries
	PAH, polycyclic aromatic hydrocarbons	-	-	kg	2.14E-9	1	3.16	Range for RER refineries
	Phenol	-	-	kg	2.03E-8	1	5.77	Range for RER refineries
	Phosphorus	-	-	kg	5.15E-8	1	3.87	Range for RER refineries
	Potassium, ion	-	-	kg	1.33E-6	1	1.65	(3,5,4,3,1,4); Literature
	Selenium	-	-	kg	1.99E-9	1	5.13	(3,5,4,3,1,4); Literature
	Silver, ion	-	-	kg	6.65E-9	1	5.13	(3,5,4,3,1,4); Literature
	Sodium, ion	-	-	kg	3.99E-5	1	1.65	(3,5,4,3,1,4); Literature
	Strontium	-	-	kg	9.21E-8	1	5.13	(3,5,4,3,1,4); Literature
	Sulfate	-	-	kg	2.71E-5	1	1.65	(3,5,4,3,1,4); Literature
	Sulfide	-	-	kg	1.33E-8	1	10.00	Range for RER refineries
	Suspended solids, unspecified	-	-	kg	1.33E-6	1	5.00	Range for RER refineries
	TOC, Total Organic Carbon	-	-	kg	3.70E-6	1	1.65	(3,5,4,3,1,4); Estimation
	Toluene	-	-	kg	1.33E-7	1	3.12	(3,5,4,3,1,4); Literature
	Vanadium, ion	-	-	kg	3.95E-9	1	5.13	(3,5,4,3,1,4); Literature
	Xylene	-	-	kg	1.33E-8	1	3.12	(3,5,4,3,1,4); Literature
	Zinc, ion	-	-	kg	2.27E-8	1	5.02	(2,4,1,2,1,3); Average of CH plant
emission water, ocean	Aluminum	-	-	kg	1.16E-8	1	5.13	(3,5,4,3,1,4); Literature
	Ammonium, ion	-	-	kg	1.54E-6	1	6.32	Range for RER refineries
	AOX, Adsorbable Organic Halogen as Cl	-	-	kg	3.72E-9	1	3.16	Range for RER refineries
	Arsenic, ion	-	-	kg	2.29E-9	1	5.13	(3,5,4,3,1,4); Literature
	Barium	-	-	kg	2.31E-8	1	5.13	(3,5,4,3,1,4); Literature
	Benzene	-	-	kg	5.26E-9	1	44.72	Range for RER refineries
	Benzene, ethyl-	-	-	kg	4.58E-11	1	3.12	(3,5,4,3,1,4); Literature
	BOD5, Biological Oxygen Demand	-	-	kg	1.63E-6	1	3.16	Range for RER refineries
	Boron	-	-	kg	9.25E-8	1	1.65	(3,5,4,3,1,4); Literature
	Cadmium, ion	-	-	kg	2.29E-9	1	5.13	(3,5,4,3,1,4); Literature
	Calcium, ion	-	-	kg	1.16E-5	1	1.65	(3,5,4,3,1,4); Literature
	Chloride	-	-	kg	1.84E-5	1	5.02	(2,4,1,2,1,3); Average of CH plant, basic uncertainity = 5 estimated based on range
	Chromium, ion	-	-	kg	5.12E-8	1	2.24	Range for RER refineries
	COD, Chemical Oxygen Demand	-	-	kg	1.65E-5	1	2.04	Range for RER refineries
	Copper, ion	-	-	kg	2.29E-9	1	5.13	(3,5,4,3,1,4); Literature
	Cyanide	-	-	kg	4.01E-8	1	5.77	Range for RER refineries
	DOC, Dissolved Organic Carbon	-	-	kg	1.59E-8	1	1.53	(2,4,1,2,1,3); Average of CH plant
	Fluoride	-	-	kg	1.03E-6	1	4.47	Range for RER refineries
	Hydrocarbons, aromatic	-	-	kg	1.66E-7	1	3.01	(2,3,1,1,1,3); Average of plant data
	Hydrocarbons, unspecified	-	-	kg	2.18E-8	1	5.48	Range for RER refineries
	Iron, ion	-	-	kg	1.16E-7	1	5.13	(3,5,4,3,1,4); Literature
	Lead	-	-	kg	7.24E-8	1	5.02	(2,3,1,1,1,4); Range for RER refineries
	Magnesium	-	-	kg	5.78E-6	1	5.13	(3,5,4,3,1,4); Literature
	Manganese	-	-	kg	4.63E-8	1	5.13	(3,5,4,3,1,4); Literature
	Mercury	-	-	kg	2.31E-11	1	5.13	(3,5,4,3,1,4); Literature
	Molybdenum	-	-	kg	2.31E-9	1	5.13	(3,5,4,3,1,4); Literature
	Nickel, ion	-	-	kg	3.02E-9	1	5.02	(2,4,1,2,1,3); Average of CH plant
	Nitrate	-	-	kg	1.90E-6	1	1.65	(3,5,4,3,1,4); Literature
	Nitrogen, organic bound	-	-	kg	1.06E-6	1	2.65	Range for RER refineries
	Oils, unspecified	-	-	kg	2.12E-7	1	14.00	Range for RER refineries
	PAH, polycyclic aromatic hydrocarbons	-	-	kg	3.72E-9	1	3.16	Range for RER refineries
	Phenol	-	-	kg	3.54E-8	1	5.77	Range for RER refineries
	Phosphorus	-	-	kg	8.96E-8	1	3.87	Range for RER refineries
	Potassium, ion	-	-	kg	2.31E-6	1	1.65	(3,5,4,3,1,4); Literature
	Selenium	-	-	kg	3.47E-9	1	5.13	(3,5,4,3,1,4); Literature
	Sodium, ion	-	-	kg	6.94E-5	1	1.65	(3,5,4,3,1,4); Literature
	Strontium	-	-	kg	1.62E-7	1	5.13	(3,5,4,3,1,4); Literature
	Sulfate	-	-	kg	4.58E-5	1	1.65	(3,5,4,3,1,4); Literature
	Sulfide	-	-	kg	2.35E-8	1	10.00	Range for RER refineries

3.4.14 External electricity supply

A renewable electricity mix in 2020 is modelled for the supply of electricity for hydrogen production. The idea is to produce BTL-fuels with an external hydrogen supply

The future development has been assessed base on a European scenario analysis (Mantzos 2003). The possibilities for an increased production of hydropower are quite limited. Photovoltaics are still quite expensive and thus they do not seem to be a realistic option for the BTL-processes. If biomass were available, it would be quite unrealistic to assume first a transformation to electricity as the conversion losses would be quite high and biomass would be better suited as a direct input to the conversion process. Thus, the only remaining option with a large potential increase of production capacity in the next years seems to be wind power. It is expected that the installed capacity will increase from 12.8 GWe in 2000 to 103.5 GWe in 2020.

The use of wind power for hydrogen production is modelled in scenario 1. The electricity demand of the different processes in scenario 1 is in the range of 135 MW to 560 MW. With an installed capacity of 1.5 MW per wind power plant, this would mean that a wind park with 100 to 400 wind power plants would be necessary for one conversion plant. The production of biofuels would be quite dependent on the actual supply situation.

It is quite unrealistic that such capacities for a clean source of electricity would be available at many locations. But, the idea is that such a scenario might be possible in remote areas with a possibility for producing electricity from renewable resources. Thus, scenario 1 with external inputs of electricity does not model the general improvement options until the year 2020, but a scenario for the rare possibility of using surplus renewable electricity.

Tab. 3.26 Life cycle inventory analysis and unit process raw data of the electricity supply with wind energy

	Name	Location	Infrastructure	Unit	electricity, medium voltage, RENEW, at grid	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kWh			
technosphere	electricity, at wind power plant 800kW	RER	0	kWh	1.00	1	1.05	(1,1,1,1,1,1); assumption for sensitivity analysis

Tab. 3.27 Documentation of the inventory data of the electricity supply

ReferenceFunction	401	Name	electricity, medium voltage, RENEW, at grid
Geography	662	Location	RER
ReferenceFun	493	InfrastructureProcess	0
ReferenceFun	403	Unit	kWh
	402	IncludedProcesses	Electricity mix used for scenario 1 in this study.
	491	Synonyms	
	492	GeneralComment	Sensitivity analysis. The base case is the use of wind power. The average European electricity mix is used in a sensitivity analysis. It is quite unrealistic that the amount of electricity necessary, can actually be provided in many cases by a renewable energy source. Thus, this scenario has only illustrative character. It cannot be regarded as a general option for BTL-production in the year 2020.
	495	Category	electricity
	496	SubCategory	supply mix
	499	Formula	
	501	StatisticalClassification	
	502	CASNumber	
TimePeriod	601	StartDate	2000
	602	EndDate	2000
	611	OtherPeriodText	
Geography	663	Text	Europe
Technology	692	Text	Mix
	724	ProductionVolume	unknown
	725	SamplingProcedure	sensitivity analysis
	726	Extrapolations	none
	727	UncertaintyAdjustments	none
	762	PageNumbers	electricity
ProofReading	5616	Validator	41
	5615	Details	automatic validation
	5619	OtherDetails	none

The electricity supply for hydrogen production is modelled with the European electricity mix in a sensitivity analysis.

Tab. 3.28 Life cycle inventory analysis and unit process raw data of the electricity supply

	Name	Location	Infrastructure	Unit	electricity, medium voltage, RENEW, at grid	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kWh			
technosphere	electricity, medium voltage, production UCTE, at grid	UCTE	0	kWh	1.00	1	1.05	(1,1,1,1,1,1); assumption for sensitivity analysis

3.4.15 Waste management services

Elaboration of LCI: Niels Jungbluth, ESU-services Ltd., Uster
Data provider UET, Literature

The waste management processes are based on the model developed by (Doka 2003). Data for the composition of slag, filter dust and effluents, have been provided by one plant owner (UET). These data have been complemented with information about the biomass composition and the content of trace elements in the ash. It is assumed that dust and ash are treated in a residual material landfill. Sludge is disposed of in a municipal waste incineration plant.

Waste water can erase from different process stages in the conversion plant, e.g. from water quench of raw syngas (for those process which uses it), waste water from syngas cleaning and conditioning and from FT and/or MeOH/DME synthesis. There might be significant levels of organic acids, alcohol, ketones, etc. Finding reliable data on waste water from biomass gasification/syngas conditioning and from FT /DME/MeOh is not easy. It has to be delivered from practical experience (industrial unit or pilot/demo realistically representative of industrial unit) and can hardly been obtained from a process simulation.[19]

All effluents have to be pre-treated within the conversion plant. These values have to meet the legal requirements. The necessary processes for achieving these limits are included in the modelling data for the conversion plants (SP5-Partners 2007).

Data for the composition of effluents were only available for one type of process. Thus, differences in the possible concentrations of pollutants could not be investigated.

3.4.16 Transport devices

Transport devices for the starting point calculation are modelled with literature data for the today average transport fleet (Spielmann et al. 2004).

The unit process data of future transport devices are based on the Euro 5 standards. The estimation for future reduction of emissions is based on (Keller et al. 2006; Spielmann et al. 2004). Other parts of the life cycle inventory as e.g. diesel use, the used infrastructure for roads are considered the same.

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[19] Personal communication with Véronique Hervouet, Total, 1.2007.

Tab. 3.29 Documentation of the inventory data of the operation of future transport devices

ReferenceFunction	Name	operation, lorry 32t, Euro 5, diesel
Geography	Location	RER
ReferenceFunctio	InfrastructureProcess	0
ReferenceFunctio	Unit	km
	IncludedProcesses	The inventory includes consumption of fuel. Direct airborne emissions of gaseous substances, particulate matters and heavy metals are accounted for. Also heavy metal emissions to soil and water are estimated. R134a emissions due to losses of air condition systems are estimated.
	Synonyms	
	GeneralComment	Average data for the operation of 50% loaded heavy duty vehicles (>16t) in Europe (EU 15)
	Category	transport systems
	SubCategory	road
	Formula	
	StatisticalClassification	
	CASNumber	
TimePeriod	StartDate	2008
	EndDate	2008
	OtherPeriodText	Time for emission standard
Geography	Text	Data refers to average transport conditions in Europe (EU 15: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden and the UK).
Technology	Text	Emission data of gaseous substances account for Euro 5 emission control standards.
	ProductionVolume	1.35E11 vkm in 2000.
	SamplingProcedure	European statistics, literature studies and official publications of the European Environmental Agency (EEA)
	Extrapolations	none
	UncertaintyAdjustments	none
	PageNumbers	background data

Tab. 3.30 Life cycle inventory analysis and unit process raw data of the operation of future transport devices

	Name	Location	Infrastruct	Unit	operation, lorry 32t, Euro 5, diesel	Uncertaint	StandardDeviation95	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				km			
Technosphere	diesel, low-sulphur, at regional storage	RER	0	kg	2.69E-1	1	1.33	(2,3,1,1,1,5); literature, INFRAS
	Ammonia	-	-	kg	3.00E-6	1	1.33	(3,1,1,1,1,1); environmental agency
	Benzene	-	-	kg	4.33E-6	1	1.64	(2,3,1,1,1,5); literature, INFRAS
	Cadmium	-	-	kg	6.23E-9	1	5.17	(4,5,1,2,1,1); expert estimate & own calculations
air, unspecified	Carbon dioxide, fossil	-	-	kg	8.53E-1	1	1.33	(2,3,1,1,1,5); literature, INFRAS
	Carbon monoxide, fossil	-	-	kg	1.70E-3	1	5.12	(2,3,1,1,1,5); literature, INFRAS
	Chromium	-	-	kg	4.80E-8	1	5.17	(4,5,1,2,1,1); expert estimate & own calculations
	Chromium VI	-	-	kg	9.59E-11	1	5.17	(2,3,1,1,3,5); Value is based on the assumption that 0.2% of the total Chromium is emitted as CrVI
	Copper	-	-	kg	4.07E-7	1	5.17	(4,5,1,2,1,1); expert estimate & own calculations
	Dinitrogen monoxide	-	-	kg	8.62E-6	1	1.64	(2,3,1,1,1,5); literature, INFRAS
	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	-	-	kg	6.69E-7	1	1.69	(2,3,1,1,3,5); literature study and own assumptions: initial input cooling agent: 2kg/vehicle. Yearly loss 8%. Yearly kilometric performance: 70000vkm
	Lead	-	-	kg	2.11E-8	1	5.17	(4,5,1,2,1,1); expert estimate & own calculations
	Mercury	-	-	kg	4.04E-12	1	5.17	(4,5,1,2,1,1); expert estimate & own calculations
	Methane, fossil	-	-	kg	7.16E-6	1	1.64	(2,3,1,1,1,5); literature, INFRAS
	Nickel	-	-	kg	4.78E-8	1	5.17	(4,5,1,2,1,1); expert estimate & own calculations
	Nitrogen oxides	-	-	kg	2.47E-3	1	1.64	(2,3,1,1,1,5); literature, INFRAS
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	2.91E-4	1	1.64	(2,3,1,1,1,5); literature, INFRAS
	PAH, polycyclic aromatic hydrocarbons	-	-	kg	4.00E-9	1	3.11	(2,3,1,1,1,5); literature, INFRAS
	Particulates, < 2.5 um	-	-	kg	3.69E-8	1	3.11	(2,3,1,1,1,5); literature, INFRAS
	Particulates, > 10 um	-	-	kg	4.43E-4	1	1.64	(3,5,1,2,1,1); environmental agency & literature and own calculations
	Particulates, > 2.5 um, and < 10um	-	-	kg	3.70E-6	1	2.12	(3,5,1,2,1,1); literature, INFRAS
	Selenium	-	-	kg	2.02E-9	1	5.17	(4,5,1,2,1,1); expert estimate & own calculations
	Sulfur dioxide	-	-	kg	5.39E-6	1	1.33	(2,3,1,1,1,5); literature, INFRAS
	Toluene	-	-	kg	2.51E-6	1	1.64	(3,5,1,2,1,1); environmental agency
	Xylene	-	-	kg	2.51E-6	1	1.64	(3,5,1,2,1,1); environmental agency
	Zinc	-	-	kg	7.83E-7	1	5.17	(4,5,1,2,1,1); expert estimate & own calculations
	Heat, waste	-	-	MJ	1.22E+1	1	1.40	(2,3,1,1,3,5); standard heat, waste
water, unspecified	Zinc, ion	-	-	kg	1.29E-8	1	6.52	(5,5,5,5,5,5); expert estimate & own calculations
	Copper, ion	-	-	kg	1.16E-7	1	4.31	(5,5,5,5,5,5); expert estimate & own calculations
	Cadmium, ion	-	-	kg	1.93E-7	1	4.31	(5,5,5,5,5,5); expert estimate & own calculations
	Chromium, ion	-	-	kg	6.45E-8	1	4.31	(5,5,5,5,5,5); expert estimate & own calculations
	Nickel, ion	-	-	kg	1.03E-7	1	6.52	(5,5,5,5,5,5); expert estimate & own calculations
	Lead	-	-	kg	1.04E-5	1	6.52	(5,5,5,5,5,5); expert estimate & own calculations
soil, unspecified	Zinc	-	-	kg	1.29E-8	1	2.84	(5,5,5,5,5,5); expert estimate & own calculations
	Copper	-	-	kg	1.16E-7	1	2.84	(5,5,5,5,5,5); expert estimate & own calculations
	Cadmium	-	-	kg	1.93E-7	1	2.84	(5,5,5,5,5,5); expert estimate & own calculations
	Chromium	-	-	kg	6.45E-8	1	2.84	(5,5,5,5,5,5); expert estimate & own calculations
	Nickel	-	-	kg	1.03E-7	1	2.84	(5,5,5,5,5,5); expert estimate & own calculations
	Lead	-	-	kg	1.04E-5	1	2.84	(5,5,5,5,5,5); expert estimate & own calculations

Tab. 3.31 Life cycle inventory analysis and unit process raw data of future transport processes

	Name	Location	Infrastructur	Unit	transport, lorry 32t, Euro 5, diesel	Uncertainty Tvpe	StandardDeviation95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				tkm			
Technosphere	operation, lorry 32t, Euro 5, diesel	RER	0	km	1.42E-1	1	2.78	(3,1,1,1,3,na); ecoinvent
Technosphere	disposal, lorry 40t	CH	1	unit	1.91E-7	1	3.79	(3,1,1,1,3,na); ecoinvent
	disposal, road	RER	1	ma	1.30E-3	1	3.79	(3,1,1,1,3,na); ecoinvent
	lorry 40t	RER	1	unit	1.91E-7	1	3.79	(3,1,1,1,3,na); ecoinvent
	maintenance, lorry 40t	CH	1	unit	1.91E-7	1	3.79	(3,1,1,1,3,na); ecoinvent
	operation, maintenance, road	CH	1	ma	1.61E-4	1	3.79	(3,1,1,1,3,na); ecoinvent
	road	CH	1	ma	1.30E-3	1	3.79	(3,1,1,1,3,na); ecoinvent

Tab. 3.32 Documentation of the inventory data of future transport devices

ReferenceFunction	401	Name	transport, lorry 32t, Euro 5, diesel
Geography	662	Location	RER
ReferenceFunctio	493	InfrastructureProcess	0
ReferenceFunctio	403	Unit	tkm
	402	IncludedProcesses	operation of vehicle; production, maintenance and disposal of vehicles; construction and maintenance and disposal of road.
	491	Synonyms	
	492	GeneralComment	Inventory refers to the entire transport life cycle. For road infrastructure, expenditures and environmental interventions due to construction, renewal and disposal of roads have been allocated based on the Gross tonne kilometre performance. Expenditures due to operation of the road infrastructure, as well as land use have been allocated based on the yearly vehicle kilometre performance. For the attribution of vehicle share to the transport performance a vehicle life time performance of 5.23E06 tkm/vehicle have been assumed.
	495	Category	transport systems
	496	SubCategory	road
	499	Formula	
	501	StatisticalClassification	
	502	CASNumber	
TimePeriod	601	StartDate	2008
	602	EndDate	2008
	611	OtherPeriodText	Time for emission standard
Geography	663	Text	Data refers to average transport conditions in Europe (EU 15: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden and the UK).The data for road infrastructure reflect Swiss conditions. Data for vehicle manufacturing and maintenance represents generic European data. Data for the vehicle disposal reflect Swiss situation.
Technology	692	Text	For vehicle operation all technologies are included in the average data. Road construction comprises bitumen and concrete roads. For the manufacturing of vehicles, the data reflects current modern technologies
	724	ProductionVolume	
	725	SamplingProcedure	National statistics, literature studies
	726	Extrapolations	see Technology and Geography
	727	UncertaintyAdjustments	none
	762	PageNumbers	background data

3.5 Centralized Entrained Flow Gasification, cEF-D (SP1-UET)

Elaboration of LCI: Niels Jungbluth, ESU-services Ltd., Uster
Data provider Matthias Rudloff (Choren), Dietmar Rüger, UET Freiberg GmbH

3.5.1 Carbo-V process

Fig. 3.3 shows the flow chart of this process. The Carbo-V process[20] can be divided into 3 steps:

- autothermal pyrolytic decomposition (so called "LTV reactor" by Choren/UET);
- oxidation of the low temperature carbonization gas (in the combustion chamber of the entrained flow reactor);
- gasification of char (with the gas from combustion chamber outlet) in the entrained flow reactor (chemical quench).

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[20] Description partly from www.choren.de.

The process allows to produce a raw gas with a non detectable tar content, and a very low methane content - without any catalytic after treatment. The fuel ash is converted into solid-bonded vitrified slag.

In the first stage, the dried biomass (water content 15 % - 25 % mass) is carbonized in a specially developed low temperature gasifier (LTV). By adopting the example of charcoal kiln technology, the biomass is broken down by partial oxidation (low-temperature carbonization) with oxygen at temperatures ranging between 400 and 600 °C to form biocoke and low temperature carbonization gas.

In the second stage, the low temperature carbonization gas containing tar is hypostoichiometrically burnt with air and/or oxygen in the combustion chamber of the Carbo-V gasifier at temperatures ranging between 1,300 °C and 1,500 °C, i.e. above the melting-point of ash. At these temperatures both the tar and all the long-chain hydrocarbons including methane are converted into CO, H_2, and CO_2 and steam.

In the third stage, the biocoke from the low temperature gasifier is blown into the Carbo-V reactor below the combustion chamber and there it reacts with the gas from the combustion chamber. During this process, the temperature drops from more than 1,300 °C to 800 °C in a matter of seconds because of endothermic reactions.

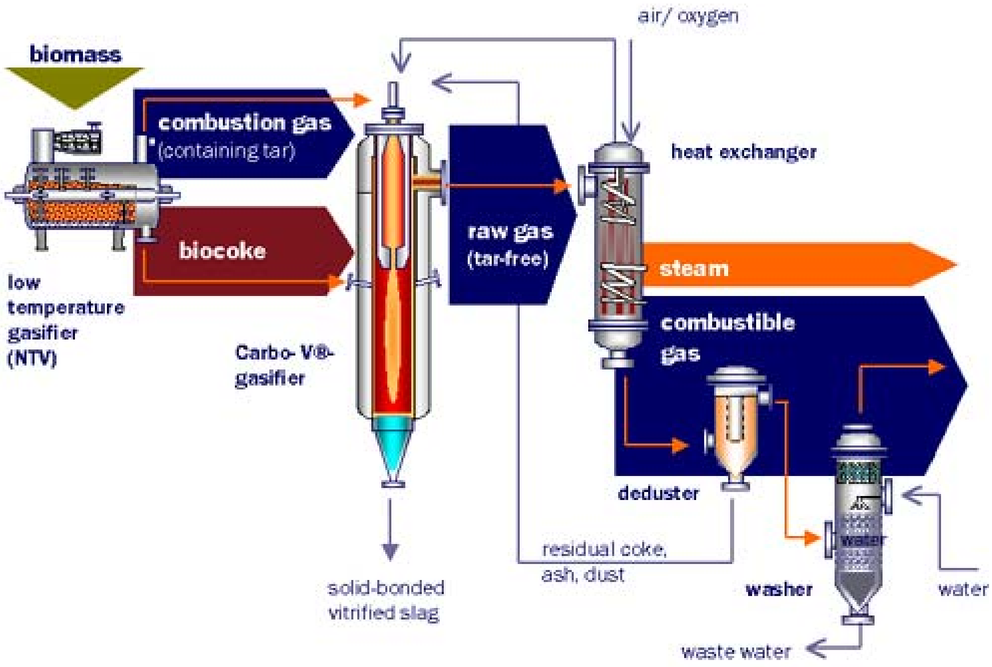

Fig. 3.3 Flow chart of the Carbo-V® process

3.5.2 Inventory

The life cycle inventory analysis and further information about the modelling are shown in the next tables.

Starting point

Tab. 3.33 Documentation of the inventory data of the UET process, starting point calculation, wood

ReferenceFunction	Name	biomass, incl. storage and preparation, wood	Carbo-V-gasifier, wood	gas cleaning, wood	gas conditioning, wood	BTL-fuel synthesis, wood	BTL-fuel, wood, at fuel synthesis
Geography	Location	UET	UET	UET	UET	UET	UET
ReferenceFunct	InfrastructureProcess	0	0	0	0	0	0
ReferenceFunct	Unit	h	h	h	h	h	kg
	IncludedProcesses	Transport from the 1st gathering point. Handling emissions. Storage and preparation of biomass for the conversion process.	Gasification of biomass	Cleaning of synthesis gas	Conditioning of clean gas	Fischer-Tropsch synthesis of BTL-fuel	Production of BTL-fuel including all sub-stages. The FT-naphtha is send for final treatment and fuel production to a refinery.
	Synonyms						
	GeneralComment	Starting point scenario. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by the respective technology partner.	Starting point scenario. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by the respective technology partner.	Starting point scenario. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by the respective technology partner.	Starting point scenario. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by the respective technology partner.	Starting point scenario. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by the respective technology partner.	Starting point scenario. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by the respective technology partner.
	Category	biomass	biomass	biomass	biomass	biomass	biomass
	SubCategory	fuels	fuels	fuels	fuels	fuels	fuels
	Formula						
	StatisticalClassification						
	CASNumber						
TimePeriod	StartDate	2005	2005	2005	2005	2005	2005
	EndDate	2006	2006	2006	2006	2006	2006
	OtherPeriodText	Starting point scenario	Starting point scenario	Starting point scenario	Starting point scenario	Starting point scenario	Starting point scenario
Geography	Text	Europe	Europe	Europe	Europe	Europe	Europe
Technology	Text	actual development state for biofuel conversion	actual development state for biofuel conversion	actual development state for biofuel conversion	actual development state for biofuel conversion	actual development state for biofuel conversion	actual development state for biofuel conversion
	ProductionVolume	500MW	500MW	500MW	500MW	500MW	500MW
	SamplingProcedure	questionnaire	questionnaire	questionnaire	questionnaire	questionnaire	questionnaire
	Extrapolations	none	none	none	none	none	none
	UncertaintyAdjustments	none	none	none	none	none	none
	PageNumbers	SP1-UET	SP1-UET	SP1-UET	SP1-UET	SP1-UET	SP1-UET

Tab. 3.34 Life cycle inventory analysis and unit process raw data of the UET process, starting point calculation, wood input

	Name	Location	InfrastructureProcess	Unit	biomass, incl. storage and preparation, wood	Carbo-V-gasifier, wood	gas cleaning, wood	gas conditioning, wood	BTL-fuel synthesis, wood	BTL-fuel, wood, at fuel synthesis	UncertaintyType	StandardDeviation95%	GeneralComment	Total	Total
	Location				UET	UET	UET	UET	UET	UET				UET	UET
	InfrastructureProcess				0	0	0	0	0	0					
	Unit				h	h	h	h	h	kg				h	kg
input	bundles, short-rotation wood, at intermediate storage	RER	0	kg	1.14E+5	0	0	0	0	0	1	1.05	(1,1,1,1,1,1); as dry matter	1.14E+5	5.20E+0
technosphere	natural gas, high pressure, at consumer	RER	0	MJ	0	8.03E+2	0	0	0	0	1	1.05	(1,1,1,1,1,1); Questionnaire	8.03E+2	3.68E-2
	heat, biomass, at power station	UET	0	MJ	0	4.25E+4	8.42E+3	3.37E+4	0	0	1	1.05	(1,1,1,1,1,1); rough calculation for steam use	8.46E+4	3.88E+0
	electricity, biomass, at power station	UET	0	kWh	2.40E+3	1.91E+4	1.00E+2	5.20E+3	3.10E+3	0	1	1.05	(1,1,1,1,1,1); Questionnaire	2.99E+4	1.37E+0
	sodium hydroxide, 50% in H2O, production mix, at plant	RER	0	kg	0	0	2.00E+0	0	0	0	1	1.05	(1,1,1,1,1,1); Questionnaire	2.00E+0	9.16E-5
	hydrogen, liquid, at plant	RER	0	kg	0	0	0	0	1.39E+2	0	1	1.05	(1,1,1,1,1,1); Questionnaire	1.39E+2	6.37E-3
	oxygen, liquid, at plant	RER	0	kg	0	0	0	0	0	0	1	1.24	(2,4,1,1,1,5); not included because on site production	0	0
	zinc for coating, at regional storage	RER	0	kg	0	0	0	0	0	0	1	1.32	(3,5,na,1,3,na); no catalytic after treatment	0	0
	catalyst, Fischer-Tropsch synthesis	RER	1	kg	0	0	0	0	2.18E+0	0	1	1.22	(2,5,1,1,1,na); general assumption catalyst use for Fischer-Tropsch synthesis	2.18E+0	1.00E-4
	portafer, at plant	RER	0	kg	0	0	1.84E+2	0	0	0	1	1.31	(2,3,1,1,3,5); approximation for Fe(OH)2 use	1.84E+2	8.43E-3
	transport, lorry 32t	RER	0	tkm	2.21E+4	0	1.12E+2	0	8.47E+1	0	1	2.09	(4,5,na,na,na,na); Standard distances	2.23E+4	1.02E+0
	transport, freight, rail	RER	0	tkm	0	0	1.86E+1	0	1.41E+1	0	1	2.09	(4,5,na,na,na,na); Standard distances	3.27E+1	1.50E-3
	tap water, at user	RER	0	kg	0	1.25E+5	0	0	0	0	1	1.31	(2,3,1,1,3,5); Questionnaire, for deionised water production	1.25E+5	5.71E+0
	treatment, inorganic production effluent, wood, to wastewater treatment, class 3	CH	0	m3	0	0	1.22E+1	0	0	0	1	1.31	(2,3,1,1,3,5); Questionnaire	1.22E+1	5.58E-4
	disposal, inert waste, 5% water, to inert material landfill	CH	0	kg	0	2.07E+3	0	0	0	0	1	1.31	(2,3,1,1,3,5); slag	2.07E+3	9.49E-2
	disposal, filter dust, wood, to residual material landfill	CH	0	kg	0	2.70E+2	0	0	0	0	1	1.31	(2,3,1,1,3,5); ash, filter dust	2.70E+2	1.24E-2
	disposal, sludge, gas washing water, wood, to municipal incineration	CH	0	kg	0	0	1.65E+1	0	0	0	1	1.31	(2,3,1,1,3,5); questionnaire, sludge	1.65E+1	7.56E-4
	disposal, catalyst base CH2O production, 0% water, to residual material landfill	CH	0	kg	0	0	0	0	0	0	1	1.22	(2,5,1,1,1,na); general assumption, catalyst for gas conditioning	0	0
	off-gas, per kg CO2 emission	RER	0	kg	0	0	0	8.66E+4	6.18E+3	0	1	1.31	(2,3,1,1,3,5); Questionnaire	9.28E+4	4.25E+0
	refinery gas, burned in flare	GLO	0	MJ	0	0	0	0	0	1.50E-1	1	1.32	(3,5,na,1,3,na); general assumption, 2.5 kg/t refinery input	3.27E+3	1.50E-1
	process specific emissions, conversion plant	RER	0	kg	0	0	0	0	0	2.68E-4	1	1.22	(2,na,na,1,3,na); general assumption per kg of fuel, process specific emissions	5.85E+0	2.68E-4
	refinery treatment, FT-raw liquid	RER	0	kg	0	0	0	0	0	0	1	1.24	(3,na,2,1,3,na); general assumption per kg of FT-raw liquid treated in a refinery	0	0
	biomass, incl. storage and preparation, wood	UET	0	h	0	0	0	0	0	4.58E-5	1	1.31	(2,3,1,1,3,5); Questionnaire	1.00E+0	4.58E-5
	Carbo-V-gasifier, wood	UET	0	h	0	0	0	0	0	4.58E-5	1	1.31	(2,3,1,1,3,5); Questionnaire	1.00E+0	4.58E-5
	gas cleaning, wood	UET	0	h	0	0	0	0	0	4.58E-5	1	1.31	(2,3,1,1,3,5); Questionnaire	1.00E+0	4.58E-5
	gas conditioning, wood	UET	0	h	0	0	0	0	0	4.58E-5	1	1.31	(2,3,1,1,3,5); Questionnaire	1.00E+0	4.58E-5
	BTL-fuel synthesis, wood	UET	0	h	0	0	0	0	0	4.58E-5	1	1.31	(2,3,1,1,3,5); Questionnaire	1.00E+0	4.58E-5
	fuel synthesis plant	RER	1	unit	0	0	0	0		2.47E-10	1	1.31	(2,3,1,1,3,5); Questionnaire	1.00E+0	2.47E-10
emission air	Heat, waste	-	-	MJ	8.64E+3	6.88E+4	3.60E+2	1.87E+4	1.12E+4	0	1	1.31	(2,3,1,1,3,5); Calculation from electricity use	1.08E+5	4.93E+0
	Particulates, > 10 um	-	-	kg	5.00E+0	0	0	0	0	0	1	3.01	(3,na,1,1,1,na); general assumption emissions from biomass handling per hour	5.00E+0	2.29E-4
	Carbon dioxide, fossil	-	-	kg	0	4.50E+1	0	0	0	0	1	1.31	(2,3,1,1,3,5); Calculation for natural gas use	4.50E+1	2.06E-3
													conversion rate (biomass to all liquids)		
Input	mass			kg	1.48E+5	1.22E+5	conf	conf	conf	6.77E+0			15%		
Output	mass, after preparation			kg	1.22E+5	conf	conf	conf	2.18E+4	1.00E+0			18%		
Output	energy			MJ	1.80E+6	conf	conf	conf	9.59E+5	43.9			53%		

conf Figures are not provided here because they are confidential

Tab. 3.35 Life cycle inventory analysis and unit process raw data of the UET process, starting point calculation, straw input

	Name	Location	InfrastructureProcess	Unit	biomass, incl. storage and preparation, straw	Carbo-V-gasifier, straw	gas cleaning, straw	gas conditioning, straw	BTL-fuel synthesis, straw	BTL-fuel, straw, at fuel synthesis	StandardDeviation95%	GeneralComment	Total	Total
	Location				UET	UET	UET	UET	UET	UET			UET	UET
	InfrastructureProcess				0	0	0	0	0	0				
	Unit				h	h	h	h	h	kg			h	kg
input technosphere	wheat straw, bales, at intermediate storage	RER	0	kg	1.10E+5	0	0	0	0	0	1.05	(1,1,1,1,1,1); as dry matter	1.10E+5	5.11E+0
	natural gas, high pressure, at consumer	RER	0	MJ	0	8.03E+2	0	0	0	0	1.05	(1,1,1,1,1,1); Questionnaire	8.03E+2	3.72E-2
	heat, biomass, at power station	UET	0	MJ	0	4.37E+4	8.42E+3	7.20E+4	0	0	1.05	(1,1,1,1,1,1); rough calculation for steam use	1.24E+5	5.75E+0
	electricity, biomass, at power station	UET	0	kWh	4.10E+3	1.97E+4	1.00E+2	6.20E+3	2.20E+3	0	1.05	(1,1,1,1,1,1); Questionnaire	3.23E+4	1.49E+0
	sodium hydroxide, 50% in H2O, production mix, at plant	RER	0	kg	0	0	8.48E+2	0	0	0	1.05	(1,1,1,1,1,1); Questionnaire	8.48E+2	3.93E-2
	hydrogen, liquid, at plant	RER	0	kg	0	0	0	0	1.39E+2	0	1.05	(1,1,1,1,1,1); Questionnaire	1.39E+2	6.43E-3
	oxygen, liquid, at plant	RER	0	kg	0	0	0	0	0	0	1.24	(2,4,1,1,1,5); not included because on site production	0	0
	zinc for coating, at regional storage	RER	0	kg	0	0	0	0	0	0	1.32	(3,5,na,1,3,na); no catalytic after treatment	0	0
	catalyst, Fischer-Tropsch synthesis	RER	1	kg	0	0	0	0	2.16E+0	0	1.22	(2,5,1,1,1,na); general assumption catalyst use for Fischer-Tropsch synthesis	2.16E+0	1.00E-4
	portafer, at plant	RER	0	kg	0	0	9.09E+2	0	0	0	1.31	(2,3,1,1,3,5); approximation for Fe(OH)2 use	9.09E+2	4.21E-2
	transport, lorry 32t	RER	0	tkm	1.91E+4	0	1.05E+3	0	8.47E+1	0	2.09	(4,5,na,na,na,na); Standard distances	2.02E+4	9.35E-1
	transport, freight, rail	RER	0	tkm	0	0	1.76E+2	0	1.41E+1	0	2.09	(4,5,na,na,na,na); Standard distances	1.90E+2	8.79E-3
	tap water, at user	RER	0	kg	0	1.25E+5	0	0	0	0	1.31	(2,3,1,1,3,5); Questionnaire, for deionised water production	1.25E+5	5.77E+0
	treatment, inorganic effluent, straw, to wastewater treatment, class 3	CH	0	m3	0	0	1.38E+1	0	0	0	1.31	(2,3,1,1,3,5); Questionnaire	1.38E+1	6.37E-4
	disposal, inert waste, 5% water, to inert material landfill	CH	0	kg	0	7.07E+3	0	0	0	0	1.31	(2,3,1,1,3,5); slag	7.07E+3	3.27E-1
	disposal, filter dust, straw, to residual material landfill	CH	0	kg	0	2.70E+2	0	0	0	0	1.31	(2,3,1,1,3,5); ash, filter dust	2.70E+2	1.25E-2
	disposal, sludge, gas washing water, straw, to municipal incineration	CH	0	kg	0	0	5.81E+2	0	0	0	1.31	(2,3,1,1,3,5); questionnaire, sludge	5.81E+2	2.69E-2
	disposal, catalyst base CH2O production, 0% water, to residual material landfill	CH	0	kg	0	0	0	0	0	0	1.22	(2,5,1,1,1,na); general assumption, catalyst for gas conditioning	0	0
	off-gas, per kg CO2 emission	RER	0	kg	0	0	0	8.69E+4	6.17E+3	0	1.31	(2,3,1,1,3,5); Questionnaire	9.30E+4	4.31E+0
	refinery treatment, FT-raw liquid	RER	0	kg	0	0	0	0	0	0	1.24	(3,na,2,1,3,na); general assumption per kg of FT-raw liquid treated in a refinery	0	0
	refinery gas, burned in flare	GLO	0	MJ	0	0	0	0	0	1.50E-1	1.32	(3,5,na,1,3,na); general assumption, 2.5 kg/t refinery input	3.23E+3	1.50E-1
	process specific emissions, conversion plant	RER	0	kg	0	0	0	0	0	2.68E-4	1.22	(2,na,na,1,3,na); general assumption per kg of fuel, process specific emissions	5.79E+0	2.68E-4
	biomass, incl. storage and preparation, straw	UET	0	h	0	0	0	0	0	4.63E-5	1.31	(2,3,1,1,3,5); Questionnaire	1.00E+0	4.63E-5
	Carbo-V-gasifier, straw	UET	0	h	0	0	0	0	0	4.63E-5	1.31	(2,3,1,1,3,5); Questionnaire	1.00E+0	4.63E-5
	gas cleaning, straw	UET	0	h	0	0	0	0	0	4.63E-5	1.31	(2,3,1,1,3,5); Questionnaire	1.00E+0	4.63E-5
	gas conditioning, straw	UET	0	h	0	0	0	0	0	4.63E-5	1.31	(2,3,1,1,3,5); Questionnaire	1.00E+0	4.63E-5
	BTL-fuel synthesis, straw	UET	0	h	0	0	0	0	0	4.63E-5	1.31	(2,3,1,1,3,5); Questionnaire	1.00E+0	4.63E-5
	fuel synthesis plant	RER	1	unit	0	0	0	0		2.47E-10	1.31	(2,3,1,1,3,5); Questionnaire	1.00E+0	2.47E-10
emission air, high population density	Heat, waste	-	-	MJ	1.48E+4	7.09E+4	3.60E+2	2.23E+4	7.92E+3	0	1.31	(2,3,1,1,3,5); Calculation from electricity use	1.16E+5	5.38E+0
	Particulates, > 10 um	-	-	kg	5.00E+0	0	0	0	0	0	3.01	(3,na,1,1,1,na); general assumption emissions from biomass handling per hour	5.00E+0	2.31E-4
	Carbon dioxide, fossil	-	-	kg	0	4.50E+1	0	0	0	0	1.31	(2,3,1,1,3,5); Calculation for natural gas use	4.50E+1	2.08E-3
												conversion rate (biomass to all liquids)		
Input	mass			kg	1.27E+5	1.27E+5	conf	conf	conf	5.88E+0		17%		
Output	mass, after preparation			kg	1.27E+5	conf	conf	conf	2.16E+4	1.00E+0		17%		
Output	energy			MJ	1.66E+6	conf	conf	conf	9.50E+5	43.9		57%		

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Scenario 1

Tab. 3.36 Life cycle inventory analysis and unit process raw data of the UET process, scenario 1, wood input

	Name	Location	InfrastructureProcess	Unit	biomass, incl. storage and preparation, wood	Carbo-V-gasifier, wood	gas cleaning, wood	gas conditioning, wood	BTL-fuel synthesis, wood	BTL-fuel, wood, at fuel synthesis	UncertaintyType	StandardDeviation95%	GeneralComment	Total	Total
	Location				UET	UET	UET	UET	UET	UET				UET	UET
	InfrastructureProcess				0	0	0	0	0	0					
	Unit				h	h	h	h	h	kg				h	kg
input	bundles, short-rotation wood, scenario 1, at intermediate storage	RER	0	kg	1.14E+5	0	0	0	0	0	1	1.05	(1,1,1,1,1,1); as dry matter	1.14E+5	2.57E+0
technosphere	natural gas, high pressure, at consumer	RER	0	MJ	0	8.03E+2	0	0	0	0	1	1.05	(1,1,1,1,1,1); Questionnaire	8.03E+2	1.82E-2
	heat, biomass, at power station	UET	0	MJ	0	4.25E+4	0	0	0	0	1	1.05	(1,1,1,1,1,1); rough calculation for steam use	4.25E+4	9.62E-1
	electricity, biomass, at power station	UET	0	kWh	2.40E+3	1.30E+3	1.00E+2	4.83E+4	4.20E+3	0	1	1.05	(1,1,1,1,1,1); Questionnaire	5.63E+4	1.27E+0
	electricity, medium voltage, RENEW, at grid	RER	0	kWh	0	0	0	4.89E+5	0	0	1	1.05	(1,1,1,1,1,1); Surplus electricity use for H2 minus credit for O2	4.89E+5	1.11E+1
	hydrogen, liquid, from water electrolysis, at plant	RER	0	kg	0	0	0	1.05E+4	0	0	1	1.31	(2,3,1,1,3,5); Production of H2 with internal and external electricity.	1.05E+4	2.37E-1
	sodium hydroxide, 50% in H2O, production mix, at plant	RER	0	kg	0	0	2.00E+0	0	0	0	1	1.05	(1,1,1,1,1,1); Questionnaire	2.00E+0	4.52E-5
	oxygen, liquid, at plant	RER	0	kg	0	0	0	0	0	0	1	1.24	(2,4,1,1,1,5); credit for by-product of water electrolysis	0	0
	zinc for coating, at regional storage	RER	0	kg	0	0	0	0	0	0	1	1.32	(3,5,na,1,3,na); no catalytic after treatment	0	0
	catalyst, Fischer-Tropsch synthesis	RER	1	kg	0	0	0	0	4.42E+0	0	1	1.22	(2,5,1,1,1,na); general assumption catalyst use for Fischer-Tropsch synthesis	4.42E+0	1.00E-4
	portafer, at plant	RER	0	kg	0	0	1.84E+2	0	0	0	1	1.31	(2,3,1,1,3,5); approximation for Fe(OH)2 use	1.84E+2	4.16E-3
	transport, lorry 32t, Euro 5, diesel	RER	0	tkm	1.85E+4	0	1.12E+2	0	2.65E+0	0	1	2.09	(4,5,na,na,na,na); Standard distances	1.86E+4	4.20E-1
	transport, freight, rail	RER	0	tkm	0	0	1.86E+1	0	4.42E-1	0	1	2.09	(4,5,na,na,na,na); Standard distances	1.90E+1	4.31E-4
	tap water, at user	RER	0	kg	0	1.25E+5	0	0	0	0	1	1.31	(2,3,1,1,3,5); Questionnaire, for deionised water production	1.25E+5	2.82E+0
	treatment, inorganic production effluent, wood, to wastewater treatment, class 3	CH	0	m3	0	0	1.22E+1	0	0	0	1	1.31	(2,3,1,1,3,5); Questionnaire	1.22E+1	2.76E-4
	disposal, inert waste, 5% water, to inert material landfill	CH	0	kg	0	2.07E+3	0	0	0	0	1	1.31	(2,3,1,1,3,5); slag	2.07E+3	4.69E-2
	disposal, filter dust, wood, to residual material landfill	CH	0	kg	0	2.70E+2	0	0	0	0	1	1.31	(2,3,1,1,3,5); ash, filter dust	2.70E+2	6.11E-3
	disposal, sludge, gas washing water, wood, to municipal incineration	CH	0	kg	0	0	1.65E+1	0	0	0	1	1.31	(2,3,1,1,3,5); questionnaire, sludge	1.65E+1	3.73E-4
	disposal, catalyst base CH2O production, 0% water, to residual material landfill	CH	0	kg	0	0	0	0	0	0	1	1.22	(2,5,1,1,1,na); general assumption, catalyst for gas conditioning	0	0
	off-gas, per kg CO2 emission	RER	0	kg	0	0	0	1.48E+4	1.17E+4	0	1	1.31	(2,3,1,1,3,5); Questionnaire	2.65E+4	5.99E-1
	refinery gas, burned in flare	GLO	0	MJ	0	0	0	0	0	1.50E-1	1	1.32	(3,5,na,1,3,na); general assumption, 2.5 kg/t refinery input	6.62E+3	1.50E-1
	process specific emissions, conversion plant	RER	0	kg	0	0	0	0	0	2.68E-4	1	1.22	(2,na,na,1,3,na); general assumption per kg of fuel, process specific emissions	1.18E+1	2.68E-4
	biomass, incl. storage and preparation, wood	UET	0	h	0	0	0	0	0	2.26E-5	1	1.31	(2,3,1,1,3,5); Questionnaire	1.00E+0	2.26E-5
	Carbo-V-gasifier, wood	UET	0	h	0	0	0	0	0	2.26E-5	1	1.31	(2,3,1,1,3,5); Questionnaire	1.00E+0	2.26E-5
	gas cleaning, wood	UET	0	h	0	0	0	0	0	2.26E-5	1	1.31	(2,3,1,1,3,5); Questionnaire	1.00E+0	2.26E-5
	gas conditioning, wood	UET	0	h	0	0	0	0	0	2.26E-5	1	1.31	(2,3,1,1,3,5); Questionnaire	1.00E+0	2.26E-5
	BTL-fuel synthesis, wood	UET	0	h	0	0	0	0	0	2.26E-5	1	1.31	(2,3,1,1,3,5); Questionnaire	1.00E+0	2.26E-5
	fuel synthesis plant	RER	1	unit	0	0	0	0		2.31E-10	1	1.31	(2,3,1,1,3,5); Questionnaire	1.00E+0	2.31E-10
	refinery treatment, FT-raw liquid	RER	0	kg	0	0	0	0	0	0	1	1.24	(3,na,2,1,3,na); general assumption per kg of FT-raw liquid treated in a refinery	0	0
emission air	Heat, waste	-	-	MJ	8.64E+3	4.68E+3	3.60E+2	1.93E+6	1.51E+4	0	1	1.31	(2,3,1,1,3,5); Calculation from electricity use	1.96E+6	4.44E+1
	Particulates, > 10 um	-	-	kg	5.00E+0	0	0	0	0	0	1	3.01	(3,na,1,1,1,na); general assumption emissions from biomass handling per hour	5.00E+0	1.13E-4
	Carbon dioxide, fossil	-	-	kg	0	4.50E+1	0	0	0	0	1	1.31	(2,3,1,1,3,5); Calculation for natural gas use	4.50E+1	1.02E-3
													conversion rate (biomass to all liquids)		
Input	mass			kg	1.48E+5	1.22E+5	conf	conf	conf	3.34E+0			30%		
Output	mass			kg	1.22E+5	conf	conf	conf	4.42E+4	1.00E+0			36%		
Output	energy			MJ	1.80E+6	conf	conf	conf	1.94E+6	43.9			108%		

conf confidential

Wastes

The following list shows the disposal routes considered for different types of wastes, e.g. sludge, ashes and filter dusts and the treatment options for effluents:

- treatment, inorganic effluent, straw, to wastewater treatment, class 3
- treatment, inorganic production effluent, wood, to wastewater treatment, class 3
- disposal, sludge, gas washing water, straw, to municipal incineration
- disposal, sludge, gas washing water, wood, to municipal incineration
- disposal, ash, 0% water, to residual material landfill
- disposal, filter dust, straw, to residual material landfill

- disposal, filter dust, wood, to residual material landfill
- disposal, slag, to inert material landfill

The content of elements is based on model calculations. For confidentiality reasons, this information is not shown in this report. Parts of the ashes that could not be specified in detail have been neglected in the calculation. The life cycle inventory of the waste treatment has been calculated with the model of Doka (2003). Although developed based on Swiss facilities, the model is also applicable on European landfill sites.

Tab. 3.37 Documentation of the inventory data of the waste treatment in landfills or municipal incineration (example)

ReferenceFunction	Name	disposal, slag, wood, to residual material landfill	disposal, slag, wood, to municipal incineration
Geography	Location	CH	CH
ReferenceFunction	InfrastructureProcess	0	0
ReferenceFunction	Unit	kg	kg
ReferenceFunction	IncludedProcesses	Waste-specific short-term emissions to water from leachate. Long-term emissions from landfill to ground water.	waste-specific air and water emisions from incineration, auxiliary material consumption for flue gas cleaning. Short-term emissions to river water and long-term emisisons to ground water from slag compartment (from bottom slag) and residual material landfill (from solidified fly ashes and scrubber slugde). Process energy demands for MSWI.
ReferenceFunction	Synonyms		
ReferenceFunction	GeneralComment	Inventoried waste contains 100% slag, wood; . waste composition (wet, in ppm): H2O n.a.; O n.a.; H n.a.; C n.a.; S n.a.; N n.a.; P 38970; B n.a.; Cl n.a.; Br n.a.; F n.a.; I n.a.; Ag n.a.; As 4; Ba n.a.; Cd 69; Co n.a.; Cr 49; Cu 145; Hg 0.75; Mn 4707; Mo n.a.; Ni 24; Pb 4; Sb n.a.; Se n.a.; Sn n.a.; V n.a.; Zn 3072; Be n.a.; Sc n.a.; Sr n.a.; Ti 500; Tl n.a.; W n.a.; Si 522700; Fe 4871; Ca 243560; Al 7464.7; K 142470; Mg 24356; Na 6974.2; Share of carbon in waste that is biogenic 60.4%. Additional solidification with 0.0866 kg of cement.	Inventoried waste contains 100% slag, wood; . waste composition (wet, in ppm): H2O n.a.; O n.a.; H n.a.; C n.a.; S n.a.; N n.a.; P 38970; B n.a.; Cl n.a.; Br n.a.; F n.a.; I n.a.; Ag n.a.; As 4; Ba n.a.; Cd 69; Co n.a.; Cr 49; Cu 145; Hg 0.75; Mn 4707; Mo n.a.; Ni 24; Pb 4; Sb n.a.; Se n.a.; Sn n.a.; V n.a.; Zn 3072; Be n.a.; Sc n.a.; Sr n.a.; Ti 500; Tl n.a.; W n.a.; Si 522700; Fe 4871; Ca 243560; Al 7464.7; K 142470; Mg 24356; Na 6974.2; Share of carbon in waste that is biogenic 60.4%. Share of iron in waste that is metallic/recyclable 0%. Net energy produced in MSWI: 0MJ/kg waste electric energy and 0MJ/kg waste thermal energy Allocation of energy production: no substitution or expansion. Total burden allocated to waste disposal function of MSWI. One kg of this waste produces 1.58 kg of slag and 0.2165 kg of residues, which are landfilled. Additional solidification with 0.0866 kg of cement.
ReferenceFunction	Category	waste management	waste management
ReferenceFunction	SubCategory	residual material landfill	municipal incineration
ReferenceFunction	Formula		
ReferenceFunction	StatisticalClassification		
ReferenceFunction	CASNumber		
TimePeriod	StartDate	1994-01	1994-01
TimePeriod	EndDate	2000-12	2000-12
TimePeriod	OtherPeriodText	Waste composition as given in literature reference, theoretical data or other source. Transfer coefficients from prospective model.	Waste composition as given in literature reference, theoretical data or other source. Transfer coefficients for modern Swiss MSWI. Emission speciation based on early 90ies data.
Geography	Text	Technology encountered in Switzerland in 2000. Landfill includes base seal and leachate collection system.	Specific to the technology mix encountered in Switzerland in 2000. Well applicable to modern incineration practices in Europe, North America or Japan.
Technology	Text	Swiss residual material landfill for polluted, inorganic waste. With base seal and leachate collection system. Recultivation after closure.	average Swiss MSWI plants in 2000 (grate incinerators) with electrostatic precipitator for fly ash (ESP), wet flue gas scrubber and 0% SNCR , 0% SCR-high dust , 100% SCR-low dust -DeNOx facilities and 0% without Denox (by burnt waste, according to Swiss average). Share of waste incinerated in plants with magnetic scrap separation from slag : 100%. Gross electric efficiency technology mix 12.997% and Gross thermal efficiency technology mix 25.57%
Representativeness	ProductionVolume		
Representativeness	SamplingProcedure	Landfill model based on observed leachate concentrations in literature. Extrapolated to 60'000 years heeding chemical characteristics. Initial waste composition from various literature sources.	waste-specific calculation based on literature data
Representativeness	Extrapolations		Typical elemental transfer coefficients from current studies for modern MSWI, completed with data from coal power plants and estimates, adapted for inert/burnable waste.
Representativeness	UncertaintyAdjustments	uncertainty of waste input composition data derived from generic formula GSD(c) = N*ln(c)+1. Minimal long-term emissions are the emissions until the carbonate buffer in the landfill is used up. Mean long-term emissions are the emissions until the next ice age.	uncertainty of waste input composition data derived from generic formula GSD(c) = N*ln(c)+1
DataGeneratorAndPul	PageNumbers	SP1-UET	SP1-UET

Effluents

Data on the effluent composition are based on model calculations. The life cycle inventory of the effluent treatment has been calculated with the model of Doka (2003).

3.6 Centralized Autothermal Circulating Fluidized Bed Gasification, CFB-D (SP2-CUTEC)

Elaboration of LCI: Niels Jungbluth, ESU-services Ltd., Uster
Data provider Hans-Joachim Gehrmann, Michael Schindler, Stefan Vodegel, Maly, CUTEC, DE

3.6.1 Circulating fluidised bed steam gasification with steam and O_2

CUTEC is developing a process with a circulating fluidised bed (CFB) gasifier (Fig. 3.4, Carlowitz et al. 2004). The applied gasification technology at CUTEC can be classified and explained as follows:

Tab. 3.38 Gasification technology at CUTEC

Reactor-Type:	CFBR (Circulating-Fluidized-Bed-Reactor)
Bed-Material:	Sand
Feed:	Biomass (Wood, Straw, Miscanthus)
Gasification-Agent:	Steam/Oxygen or Air
Heat-Transfer:	autothermal, via part. Oxidation
Pressure:	atmospheric
Temperature:	950°C max.
Product-Gas-Application:	Fischer-Tropsch-Synthesis
Scale:	Pilot (400kW)

A typical attribute of any gasification-process is its endothermic behaviour, which means, that in any case a gasification-reactor has to be supplied with heat. At CUTEC this is done by internal partial oxidation, also known as the autothermal operation-mode. As gasification-agent either air, oxygen-enriched air or a mixture of steam and oxygen can be used.

The autothermal operation-mode gives the advantage that the heat can directly be provided in the fluidized-bed, without internals or fouling-vulnerable heat-transfer-surfaces. The compromise, which has to be tolerated, is the loss in LHV (lower heating value) by inert-gas-components, produced as a result of the partial oxidation. To reduce the loss in LHV, at CUTEC the gasification-agent can be preheated up to 500°C before entering the reactor. Thereby the requirement of gasification-heat can be met partially and in addition oxygen can be saved.

A 100kW steam-generator designed as a package-unit supplies the CFBR with low-pressure-steam. Oxygen is provided outside the pilot-plant-station through a 6m^3-cryogenic-tank with adapted evaporator-unit. For pressurizing the air-feed a roots-blower is used. The biomass is stored in an 8m^3-bunker and fed by screws and cell-locks into the gasifier. Subsequently the feed together with the gasification-agent is physically and chemically converted into a hydrogen- and carbon monoxide-rich synthesis-gas. The operation of a CFBR is featured by several advantages:

- reliable technology, without moving parts
- safeness, availability and stability
- wide range of particle-sizes can be used
- low tar-concentration in the product-gas
- constant gas-composition, because of homogenous fluidized bed

To compensate heat losses and speeding up the starting-procedure, the reactor-hull is equipped with an electrical heating system. Because of safety-reasons, the biomass-feed is started at a minimum-temperature of 700°C.

The gasification-agent as a reaction-partner for fluidizing and circulating the bed-material. After passing the riser-part of the CFBR, the solids are separated in an adapted cyclone and re-feed by the downer-part back into the reaction-system. At the outlet of the cyclone a pre-dedusted raw-synthesis-gas is available for further treatment.

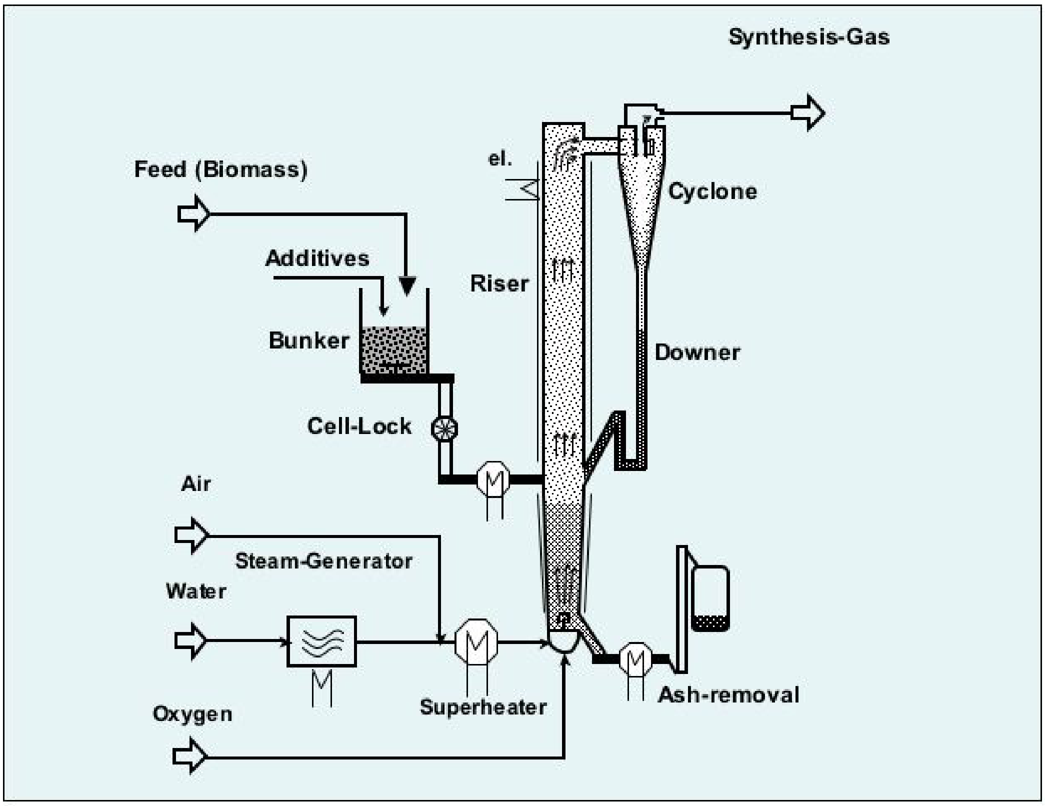

Fig. 3.4 Process-Flow-Diagram - CUTEC-Gasifier

3.6.2 Inventory

Unit process raw data are investigated for the conversion of wood and straw. In principle, it would be possible to use also miscanthus, but data have not been provided for this input. The conversion rate would be similar as for straw. Main changes are for the higher ash content and a more complicated biomass preparation.

The life cycle inventory analysis and further information about the modelling are shown in the next tables.

Starting point

Tab. 3.39 Documentation of the inventory data of the CUTEC process, starting point calculation, wood

ReferenceFunction	Name	biomass, incl. storage and preparation, wood	gasification, circulating fluidized bed reactor, wood	gas cleaning, wood	gas conditioning and compression, wood	Fischer-Tropsch synthesis, wood	BTL-fuel, wood, at refinery
Geography	Location	CUTEC	CUTEC	CUTEC	CUTEC	CUTEC	CUTEC
ReferenceFunct	InfrastructureProcess	0	0	0	0	0	0
ReferenceFunct	Unit	h	h	h	h	h	kg
	IncludedProcesses	Transport from the 1st gathering point. Handling emissions. Biomass preparation (hacking, milling, drying, palletizing, feeding).	Low temperature Steam-Oxygen-Gasification (800°C), partial catalytic tar cracking directly inside the gasification reactor; low tar content in raw gas, fluidized bed gasification of biomass with critical ash melting behaviour (e.g. straw), in-bed alkali and chlorine absorption. Electricity use for oxygen production in air separation unit included.	Cleaning of synthesis gas. Hot gas filtration, CO-Shift, Heat recovery, Quench, Water scrubber, FAME Scrubber, Compression. RME is discharged to the CFB gasification unit for combustion. Ceramic filters are used for hot gas filtration. They are exchanged during normal plant revision. The amount is not known. Electricity use of following sub stages included: Waste water treatment system, Tower water system, (30°C), Chilled water system (6°C), Refrigerant system (-30°C)	Gas conditioning and clean up (COS Hydrolysis, Sulphur removal, CO2 removal, Guard bed). Compression to synthesis pressure (ca. 25 bar)	Fischer-Tropsch synthesis of BTL-fuel. synthesis, product separation and distillation. Fixed bed with cobalt-catalyst. FT-Product separation. The following products of the Fischer-Tropsch synthesis are used internally e.g. in the power plant: tail gas, CH4, C2-C4. Only fractions C5-C22+ are considered as throughput for upgrade and distillation in a refinery.	Includes external upgrade and distillation of Fischer-Tropsch raw product in a refinery.
	Synonyms		CFBR				
	GeneralComment	Starting point scenario. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use	Starting point scenario. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by the respective technology partner.	Starting point scenario. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by the respective technology partner.	Starting point scenario. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use	The fixed-process needs no further separation steps of fine catalyst particles and product hydrocarbons. The catalyst bed itself is a sulphur trap. Deactivation due to sulphur poisoning concerns at the beginning only a small layer of catalyst. Time dependent deactivation can be compensated by increasing the bed temperature and cooling temperature, respectively. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data	Starting point scenario. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by
	Category	biomass	biomass	biomass	biomass	biomass	biomass
	SubCategory	fuels	fuels	fuels	fuels	fuels	fuels
	Formula						
	StatisticalClassification						
	CASNumber						
TimePeriod	StartDate	2005	2005	2005	2005	2005	2005
	EndDate	2006	2006	2006	2006	2006	2006
	OtherPeriodText	Starting point scenario	Starting point scenario	Starting point scenario	Starting point scenario	Starting point scenario	Starting point scenario
Geography	Text	Europe	Europe	Europe	Europe	Europe	Europe
Technology	Text	Mathcad/Matlab process simulation supported by experimental data, generated in a pilot plant. It covers a whole 500MW-BTL-complex, up to FT-product separation.	Mathcad/Matlab process simulation supported by experimental data, generated in a pilot plant. It covers a whole 500MW-BTL-complex, up to FT-product separation.	Mathcad/Matlab process simulation supported by experimental data, generated in a pilot plant. It covers a whole 500MW-BTL-complex, up to FT-product separation.	Mathcad/Matlab process simulation supported by experimental data, generated in a pilot plant. It covers a whole 500MW-BTL-complex, up to FT-product separation.	Mathcad/Matlab process simulation supported by experimental data, generated in a pilot plant. It covers a whole 500MW-BTL-complex, up to FT-product separation.	Mathcad/Matlab process simulation supported by experimental data, generated in a pilot plant. It covers a whole 500MW-BTL-complex, up to FT-product separation.
	ProductionVolume	500MW	500MW	500MW	500MW	500MW	500MW
	SamplingProcedure	questionnaire	questionnaire	questionnaire	questionnaire	questionnaire	questionnaire
	Extrapolations	none	none	none	none	none	none
	UncertaintyAdjustments	none	none	none	none	none	none
	PageNumbers	SP2-CUTEC	SP2-CUTEC	SP2-CUTEC	SP2-CUTEC	SP2-CUTEC	SP2-CUTEC

Tab. 3.40 Life cycle inventory analysis and unit process raw data of the CUTEC process, starting point calculation, wood

	Name	Location	Unit	biomass, incl. storage and preparation, wood	gasification, circulating fluidized bed reactor, wood	gas cleaning, wood	gas conditioning and compression, wood	Fischer-Tropsch synthesis, wood	BTL-fuel, wood, at refinery	UncertaintyType	StandardDeviation 95%	GeneralComment	Total	Total
	Location			CUTEC	CUTEC	CUTEC	CUTEC	CUTEC	CUTEC				CUTEC	CUTEC
	InfrastructureProcess			0	0	0	0	0	0				0	0
	Unit			h	h	h	h	h	kg				h	kg
input	bundles, short-rotation wood, at intermediate storage	RER	kg	1.10E+5	0	0	0	0	0	1	1.05	(1,1,1,1,1,1); Questionnaire	1.10E+5	6.87E+0
ressource	Water, cooling, unspecified natural origin	-	m3	0	1.50E+1	0	0	0	0	1	3.00	(1,1,1,1,1,1); Questionnaire	1.50E+1	9.34E-4
technosphere	heat, biomass, at gas and steam turbine	CUTEC	MJ	0	1.80E+5	1.16E+5	4.42E+4	0	0	1	1.05	(1,1,1,1,1,1); Questionnaire	3.41E+5	2.12E+1
	electricity, biomass, at gas and steam turbine	CUTEC	kWh	2.12E+3	1.94E+4	3.60E+4	7.31E+3	2.70E+1	0	1	1.05	(1,1,1,1,1,1); Questionnaire, unspecified uses added at gas cleaning	6.50E+4	4.04E+0
	ceramic tiles, at regional storage	CH	kg	0	0	0	1.00E-3	0	0	1	1.05	(1,1,1,1,1,1); Filter ceramic for the hot gas filtration. Amount not known.	1.00E-3	6.22E-8
	soya oil, at plant	RER	kg	0	0	2.70E+2	0	0	0	1	1.05	(1,1,1,1,1,1); assumption for RME, burned in gasifier	2.70E+2	1.68E-2
	zinc for coating, at regional storage	RER	kg	0	0	0	9.64E+1	0	0	1	1.32	(3,5,na,1,3,na); general assumption, catalyst for gas conditioning	9.64E+1	6.00E-3
	catalyst, Fischer-Tropsch synthesis	RER	kg	0	0	0	0	1.61E+0	0	1	1.22	(2,5,1,1,1,na); general assumption catalyst use for Fischer-Tropsch synthesis	1.61E+0	1.00E-4
	silica sand, at plant	DE	kg	0	1.00E-3	0	0	0	0	1	1.05	(1,1,1,1,1,1); only used in small amounts	1.00E-3	6.22E-8
	quicklime, milled, loose, at plant	CH	kg	0	2.01E+3	0	0	0	0	1	1.05	(1,1,1,1,1,1); used as catalyst	2.01E+3	1.25E-1
	iron (III) chloride, 40% in H2O, at plant	CH	kg	0	0	0	1.00E-3	0	0	1	1.05	(1,1,1,1,1,1); iron chelate, amount not known	1.00E-3	6.22E-8
	transport, lorry 32t	RER	tkm	2.15E+4	1.01E+2	1.62E+2	5.78E+1	9.64E-1	0	1	2.09	(4,5,na,na,na,na); Standard distances	2.19E+4	1.36E+0
	transport, freight, rail	RER	tkm	0	2.01E+2	2.70E+1	9.64E+0	1.61E-1	0	1	2.09	(4,5,na,na,na,na); Standard distances	2.38E+2	1.48E-2
	treatment, inorganic production effluent, wood, to wastewater treatment, class 3	CH	m3	0	0	1.96E+1	0	0	0	1	1.05	(1,1,1,1,1,1); waste water treated and disposed off to a river	1.96E+1	1.22E-3
	disposal, slag, wood, to residual material landfill	CH	kg	0	1.65E+3	0	0	0	0	1	1.05	(1,1,1,1,1,1); bed ash (coarse)	1.65E+3	1.03E-1
	disposal, filter dust, wood, to residual material landfill	CH	kg	0	1.19E+3	0	0	0	0	1	1.05	(1,1,1,1,1,1); filter ash, fine	1.19E+3	7.41E-2
	disposal, catalyst base CH2O production, 0% water, to residual material landfill	CH	kg	0	0	0	9.64E+1	0	0	1	1.22	(2,5,1,1,1,na); general assumption, catalyst for gas conditioning	9.64E+1	6.00E-3
	refinery gas, burned in flare	GLO	MJ	0	0	0	0	0	1.50E-1	1	1.32	(3,5,na,1,3,na); general assumption, 2.5 kg/t refinery input	2.40E+3	1.50E-1
	process specific emissions, conversion plant	RER	kg	0	0	0	0	0	2.68E-4	1	1.22	(2,na,na,1,3,na); general assumption per kg of fuel, process specific emissions	4.31E+0	2.68E-4
	biomass, incl. storage and preparation, wood	CUTEC	h	0	0	0	0	0	6.22E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	6.22E-5
	gasification, circulating fluidized bed reactor, wood	CUTEC	h	0	0	0	0	0	6.22E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	6.22E-5
	gas cleaning, wood	CUTEC	h	0	0	0	0	0	6.22E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	6.22E-5
	gas conditioning and compression, wood	CUTEC	h	0	0	0	0	0	6.22E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	6.22E-5
	Fischer-Tropsch synthesis, wood	CUTEC	h	0	0	0	0	0	6.22E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	6.22E-5
	fuel synthesis plant	RER	unit	0	0	0	0	0	2.47E-10	1	1.31	(2,3,1,1,3,5); Calculation	3.97E-6	2.47E-10
	refinery treatment, FT-raw liquid	RER	kg	0	0	0	0	0	1.05E+0	1	1.24	(3,na,2,1,3,na); FT-fraction C5-C22+ are treated in a refinery, other fractions are used internally	1.69E+4	1.05E+0
emission air	Heat, waste	-	MJ	7.64E+3	7.00E+4	1.30E+5	2.63E+4	9.72E+1	0	1	1.31	(2,3,1,1,3,5); Calculation from electricity use	2.34E+5	1.46E+1
	Particulates, > 10 um	-	kg	5.00E+0	0	0	0	0	0	1	3.01	(3,na,1,1,1,na); general assumption emissions from biomass handling per hour	5.00E+0	3.11E-4
												conversion rate (biomass to all liquids)		
Input	mass		kg	143573	111668	216210	152813	57960	8.9			11%		8.94E+0
Output	mass, after preparation		kg	111668	216210	152813	57960	16066	1.0			14%		
Output	energy		MJ	1'746'452	1'182'669	1'433'386	1'527'023	705'648	43.9			40%		

Tab. 3.41 Life cycle inventory analysis and unit process raw data of the CUTEC process, starting point calculation, straw

	Name	Location	Unit	biomass, incl. storage and preparation, straw	gasification, circulating fluidized bed reactor, straw	gas cleaning, straw	gas conditioning and compression, straw	Fischer-Tropsch synthesis, straw	BTL-fuel, straw, at refinery	UncertaintyType	StandardDeviation 95%	GeneralComment	Total	Total
	Location			CUTEC	CUTEC	CUTEC	CUTEC	CUTEC	CUTEC				CUTEC	CUTEC
	InfrastructureProcess			0	0	0	0	0	0				0	0
	Unit			h	h	h	h	h	kg				h	kg
input	wheat straw, bales, at intermediate storage	RER	kg	1.11E+5	0	0	0	0	0	1	1.05	(1,1,1,1,1,1); Questionnaire	1.11E+5	7.63E+0
ressource	Water, cooling, unspecified natural origin	-	m3	0	1.50E+1	0	0	0	0	1	3.00	(1,1,1,1,1,1); Questionnaire	1.50E+1	1.03E-3
technosphere	heat, biomass, at gas and steam turbine	CUTEC	MJ	0	2.21E+5	1.08E+5	4.14E+4	0	0	1	1.05	(1,1,1,1,1,1); Questionnaire	3.71E+5	2.55E+1
	electricity, biomass, at gas and steam turbine	CUTEC	kWh	1.87E+4	8.15E+3	1.02E+4	3.26E+4	2.50E+1	0	1	1.05	(1,1,1,1,1,1); Questionnaire, unspecified uses added at gas cleaning	6.97E+4	4.80E+0
	electricity, medium voltage, RENEW, at grid	RER	kWh	0	1.51E+4	0	0	0	0	1	1.05	(1,1,1,1,1,1); external electricity supply	1.51E+4	1.04E+0
	ceramic tiles, at regional storage	CH	kg	0	0	0	1.00E-3	0	0	1	1.05	(1,1,1,1,1,1); Filter ceramic for the hot gas filtration. Amount not known.	1.00E-3	6.89E-8
	soya oil, at plant	RER	kg	0	0	2.70E+2	0	0	0	1	1.05	(1,1,1,1,1,1); assumption for RME, burned in gasifier	2.70E+2	1.86E-2
	zinc for coating, at regional storage	RER	kg	0	0	0	8.71E+1	0	0	1	1.32	(3,5,na,1,3,na); general assumption, catalyst for gas conditioning	8.71E+1	6.00E-3
	catalyst, Fischer-Tropsch synthesis	RER	kg	0	0	0	0	1.45E+0	0	1	1.22	(2,5,1,1,1,na); general assumption catalyst use for Fischer-Tropsch synthesis	1.45E+0	1.00E-4
	silica sand, at plant	DE	kg	0	1.00E-3	0	0	0	0	1	1.05	(1,1,1,1,1,1); only used in small amounts	1.00E-3	6.89E-8
	iron (III) chloride, 40% in H2O, at plant	CH	kg	0	0	0	1.00E-3	0	0	1	1.05	(1,1,1,1,1,1); iron chelate, amount not known	1.00E-3	6.89E-8
	quicklime, milled, loose, at plant	CH	kg	0	8.39E+3	0	0	0	0	1	1.05	(1,1,1,1,1,1); used as catalyst	8.39E+3	5.78E-1
	transport, lorry 32t	RER	tkm	1.91E+4	4.20E+2	1.62E+2	5.23E+1	8.71E-1	0	1	2.09	(4,5,na,na,na,na); Standard distances	1.97E+4	1.36E+0
	transport, freight, rail	RER	tkm	0	8.39E+2	2.70E+1	8.71E+0	1.45E-1	0	1	2.09	(4,5,na,na,na,na); Standard distances	8.75E+2	6.03E-2
	treatment, inorganic effluent, straw, to wastewater treatment, class 3	CH	m3	0	0	1.75E+1	0	0	0	1	1.05	(1,1,1,1,1,1); waste water treated and disposed off to a river	1.75E+1	1.21E-3
	disposal, slag, straw, to residual material landfill	CH	kg	0	1.42E+4	0	0	0	0	1	1.05	(1,1,1,1,1,1); bed ash (coarse)	1.42E+4	9.76E-1
	disposal, filter dust, straw, to residual material landfill	CH	kg	0	1.31E+3	0	0	0	0	1	1.05	(1,1,1,1,1,1); filter ash, fine	1.31E+3	9.03E-2
	disposal, catalyst base CH2O production, 0% water, to residual material landfill	CH	kg	0	0	0	8.71E+1	0	0	1	1.22	(2,5,1,1,1,na); general assumption, catalyst for gas conditioning	8.71E+1	6.00E-3
	refinery gas, burned in flare	GLO	MJ	0	0	0	0	0	1.50E-1	1	1.32	(3,5,na,1,3,na); general assumption, 2.5 kg/t refinery input	2.17E+3	1.50E-1
	process specific emissions, conversion plant	RER	kg	0	0	0	0	0	2.68E-4	1	1.22	(2,na,na,1,3,na); general assumption per kg of fuel, process specific emissions	3.89E+0	2.68E-4
	biomass, incl. storage and preparation, straw	CUTEC	h	0	0	0	0	0	6.89E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	6.89E-5
	gasification, circulating fluidized bed reactor, straw	CUTEC	h	0	0	0	0	0	6.89E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	6.89E-5
	gas cleaning, straw	CUTEC	h	0	0	0	0	0	6.89E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	6.89E-5
	gas conditioning and compression, straw	CUTEC	h	0	0	0	0	0	6.89E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	6.89E-5
	Fischer-Tropsch synthesis, straw	CUTEC	h	0	0	0	0	0	6.89E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	6.89E-5
	fuel synthesis plant	RER	unit	0	0	0	0	0	2.47E-10	1	1.31	(2,3,1,1,3,5); Calculation	3.59E-6	2.47E-10
	refinery treatment, FT-raw liquid	RER	kg	0	0	0	0	0	1.05E+0	1	1.24	(3,na,2,1,3,na); FT-fraction C5-C22+ are treated in a refinery, other fractions are used internally	1.53E+4	1.05E+0
emission air	Heat, waste	-	MJ	6.75E+4	8.37E+4	3.66E+4	1.17E+5	9.00E+1	0	1	1.31	(2,3,1,1,3,5); Calculation from electricity use	3.05E+5	2.10E+1
	Particulates, > 10 um	-	kg	5.00E+0	0	0	0	0	0	1	3.01	(3,na,1,1,1,na); general assumption emissions from biomass handling per hour	5.00E+0	3.44E-4
												conversion rate (biomass to all liquids)		
Input	mass		kg	127307	120234	242634	163947	55336	8.8			11%		8.77E+0
Output	mass, after preparation		kg	120234	242634	163947	55336	14514	1.0			12%		
Output	energy		MJ	1'667'716	1'327'208	1'537'823	1'457'891	637'487	43.9			38%		

Scenario 1

Hydrogen replaces the shift stage in the conversion plant. Other inventory data of the conversion process in Tab. 3.42 are similar as for the starting point scenario.

Tab. 3.42 Life cycle inventory analysis and unit process raw data of the CUTEC process, scenario 1, wood

	Name	Location	Unit	biomass, incl. storage and preparation, wood	gasification, circulating fluidized bed reactor, wood	gas cleaning, wood	gas conditioning and compression, wood	Fischer-Tropsch synthesis, wood	BTL-fuel, wood, at refinery	UncertaintyType	StandardDeviation 95%	GeneralComment	Total	Total
	Location			CUTEC	CUTEC	CUTEC	CUTEC	CUTEC	CUTEC				CUTEC	CUTEC
	InfrastructureProcess			0	0	0	0	0	0				0	0
	Unit			h	h	h	h	h	kg				h	kg
input	bundles, short-rotation wood, scenario 1, at intermediate storage	RER	kg	1.10E+5	0	0	0	0	0	1	1.05	(1,1,1,1,1,1); Questionnaire	1.10E+5	4.88E+0
ressource	Water, cooling, unspecified natural origin	-	m3	0	1.50E+1	0	0	0	0	1	3.00	(1,1,1,1,1,1); Questionnaire	1.50E+1	6.63E-4
technosphere	heat, biomass, at gas and steam turbine	CUTEC	MJ	6.84E+4	1.27E+5	4.65E+4	5.83E+4	0	0	1	1.05	(1,1,1,1,1,1); Questionnaire	3.00E+5	1.32E+1
	electricity, biomass, at gas and steam turbine	CUTEC	kWh	2.12E+3	1.09E+4	9.85E+3	3.11E+4	2.63E+4	0	1	1.05	(1,1,1,1,1,1); unspecified uses added at gas cleaning, remaining added at FT-synthesis for H2 electrolysis	8.02E+4	3.55E+0
	electricity, medium voltage, RENEW, at grid	RER	kWh	0	0	0	0	1.35E+5	0	1	1.05	(1,1,1,1,1,1); Surplus electricity use for H2 minus credit for O2	1.35E+5	5.96E+0
	hydrogen, liquid, from water electrolysis, at plant	RER	kg	0	0	0	0	3.02E+3	0	1	1.05	(1,1,1,1,1,1); Questionnaire	3.02E+3	1.34E-1
	ceramic tiles, at regional storage	CH	kg	0	0	0	1.00E-3	0	0	1	1.05	(1,1,1,1,1,1); Filter ceramic for the hot gas filtration. Amount not known.	1.00E-3	4.42E-8
	soya oil, at plant	RER	kg	0	0	2.60E+2	0	0	0	1	1.05	(1,1,1,1,1,1); assumption for RME, burned in process	2.60E+2	1.15E-2
	zinc for coating, at regional storage	RER	kg	0	0	0	1.36E+2	0	0	1	1.32	(3,5,na,1,3,na); general assumption, catalyst for gas conditioning	1.36E+2	6.00E-3
	catalyst, Fischer-Tropsch synthesis	RER	kg	0	0	0	0	2.26E+0	0	1	1.22	(2,5,1,1,1,na); general assumption catalyst use for Fischer-Tropsch synthesis	2.26E+0	1.00E-4
	silica sand, at plant	DE	kg	0	1.00E-3	0	0	0	0	1	1.05	(1,1,1,1,1,1); only used in small amounts	1.00E-3	4.42E-8
	quicklime, milled, loose, at plant	CH	kg	0	2.01E+3	0	0	0	0	1	1.05	(1,1,1,1,1,1); used as catalyst	2.01E+3	8.87E-2
	iron (III) chloride, 40% in H2O, at plant	CH	kg	0	0	0	1.00E-3	0	0	1	1.05	(1,1,1,1,1,1); iron chelate, amount not known	1.00E-3	4.42E-8
	transport, lorry 32t, Euro 5, diesel	RER	tkm	1.79E+4	1.00E+2	1.56E+2	8.14E+1	8.28E+4	0	1	2.09	(4,5,na,na,na,na); Standard distances	1.01E+5	4.47E+0
	transport, freight, rail	RER	tkm	0	2.01E+2	2.60E+1	1.36E+1	1.38E+4	0	1	2.09	(4,5,na,na,na,na); Standard distances	1.40E+4	6.20E-1
	treatment, sewage, unpolluted, to wastewater treatment, class 3	CH	m3	0	4.55E+0	6.81E+1	0	0	0	1	1.05	(1,1,1,1,1,1); Questionnaire, amount of waste water reused in the plant after treatment, no emission to rivers	7.26E+1	3.21E-3
	treatment, inorganic production effluent, wood, to wastewater treatment, class 3	CH	m3	0	0	1.06E+1	0	1.61E+1	0	1	1.05	(1,1,1,1,1,1); waste water treated and disposed off to a river	2.67E+1	1.18E-3
	disposal, slag, wood, to residual material landfill	CH	kg	0	2.06E+3	0	0	0	0	1	1.05	(1,1,1,1,1,1); bed ash (coarse)	2.06E+3	9.11E-2
	disposal, filter dust, wood, to residual material landfill	CH	kg	0	9.80E+2	0	0	0	0	1	1.05	(1,1,1,1,1,1); filter ash, fine	9.80E+2	4.33E-2
	disposal, catalyst base CH2O production, 0% water, to residual material landfill	CH	kg	0	0	0	1.36E+2	0	0	1	1.22	(2,5,1,1,1,na); general assumption, catalyst for gas conditioning	1.36E+2	6.00E-3
	refinery gas, burned in flare	GLO	MJ	0	0	0	0	0	1.50E-1	1	1.32	(3,5,na,1,3,na); general assumption, 2.5 kg/t refinery input	3.38E+3	1.50E-1
	process specific emissions, conversion plant	RER	kg	0	0	0	0	0	2.68E-4	1	1.22	(2,na,na,1,3,na); general assumption per kg of fuel, process specific emissions	6.06E+0	2.68E-4
	biomass, incl. storage and preparation, wood	CUTEC	h	0	0	0	0	0	4.42E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	4.42E-5
	gasification, circulating fluidized bed reactor, wood	CUTEC	h	0	0	0	0	0	4.42E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	4.42E-5
	gas cleaning, wood	CUTEC	h	0	0	0	0	0	4.42E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	4.42E-5
	gas conditioning and compression, wood	CUTEC	h	0	0	0	0	0	4.42E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	4.42E-5
	Fischer-Tropsch synthesis, wood	CUTEC	h	0	0	0	0	0	4.42E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	4.42E-5
	fuel synthesis plant	RER	unit	0	0	0	0	0	2.31E-10	1	1.31	(2,3,1,1,3,5); Calculation	5.22E-6	2.31E-10
	refinery treatment, FT-raw liquid	RER	kg	0	0	0	0	0	1.05E+0	1	1.24	(3,na,2,1,3,na); general assumption per kg of FT-raw liquid treated in a refinery	2.38E+4	1.05E+0
emission air	Heat, waste	-	MJ	7.63E+3	3.94E+4	3.54E+4	1.12E+5	5.80E+5	0	1	1.31	(2,3,1,1,3,5); Calculation from electricity use	7.75E+5	3.42E+1
	Particulates, > 10 um	-	kg	5.00E+0	0	0	0	0	0	1	3.01	(3,na,1,1,1,na); general assumption emissions from biomass handling per hour	5.00E+0	2.21E-4
												conversion rate (biomass to all liquids)		
Input	mass		kg	143388	143388	178715	141966	74986	6.3			16%		6.34E+0
Output	mass		kg	111524	178715	141966	71965	22621	1.0			20%		
Output	energy		MJ	1'744'200	977'571	1'487'804	1'828'188	993'546	43.9			57%		

Tab. 3.43 Life cycle inventory analysis and unit process raw data of the CUTEC process, scenario 1, straw

	Name	Location	Unit	biomass, incl. storage and preparation, straw	gasification, circulating fluidized bed reactor, straw	gas cleaning, straw	gas conditioning and compression, straw	Fischer-Tropsch synthesis, straw	BTL-fuel, straw, at refinery	UncertaintyType	StandardDeviation 95%	GeneralComment	Total	Total
	Location			CUTEC	CUTEC	CUTEC	CUTEC	CUTEC	CUTEC				CUTEC	CUTEC
	InfrastructureProcess			0	0	0	0	0	0				0	0
	Unit			h	h	h	h	h	kg				h	kg
input	wheat straw, bales, scenario 1, at intermediate storage	RER	kg	1.11E+5	0	0	0	0	0	1	1.05	(1,1,1,1,1,1); Questionnaire	1.11E+5	5.21E+0
ressource	Water, cooling, unspecified natural origin	-	m3	0	1.50E+1	0	0	0	0	1	3.00	(1,1,1,1,1,1); Questionnaire	1.50E+1	7.06E-4
technosphere	heat, biomass, at gas and steam turbine	CUTEC	MJ	6.84E+4	1.56E+5	4.87E+4	5.56E+4	0	0	1	1.05	(1,1,1,1,1,1); Questionnaire	3.28E+5	1.54E+1
	electricity, biomass, at gas and steam turbine	CUTEC	kWh	1.87E+4	1.49E+4	9.35E+3	3.14E+4	4.33E+3	0	1	1.05	(1,1,1,1,1,1); unspecified uses added at gas cleaning, remaining added at FT-synthesis for H2 electrolysis	7.87E+4	3.70E+0
	electricity, medium voltage, RENEW, at grid	RER	kWh	0	0	0	0	1.49E+5	0	1	1.05	(1,1,1,1,1,1); Surplus electricity use for H2 minus credit for O2	1.49E+5	6.99E+0
	hydrogen, liquid, from water electrolysis, at plant	RER	kg	0	0	0	0	2.87E+3	0	1	1.05	(1,1,1,1,1,1); not used	2.87E+3	1.35E-1
	ceramic tiles, at regional storage	CH	kg	0	0	0	1.00E-3	0	0	1	1.05	(1,1,1,1,1,1); Filter ceramic for the hot gas filtration. Amount not known.	1.00E-3	4.71E-8
	soya oil, at plant	RER	kg	0	0	2.60E+2	0	0	0	1	1.05	(1,1,1,1,1,1); assumption for RME, burned in process	2.60E+2	1.22E-2
	zinc for coating, at regional storage	RER	kg	0	0	0	1.28E+2	0	0	1	1.32	(3,5,na,1,3,na); general assumption, catalyst for gas conditioning	1.28E+2	6.00E-3
	catalyst, Fischer-Tropsch synthesis	RER	kg	0	0	0	0	2.13E+0	0	1	1.22	(2,5,1,1,1,na); general assumption catalyst use for Fischer-Tropsch synthesis	2.13E+0	1.00E-4
	silica sand, at plant	DE	kg	0	1.00E-3	0	0	0	0	1	1.05	(1,1,1,1,1,1); only used in small amounts	1.00E-3	4.71E-8
	quicklime, milled, loose, at plant	CH	kg	0	8.39E+3	0	0	0	0	1	1.05	(1,1,1,1,1,1); used as catalyst	8.39E+3	3.95E-1
	iron (III) chloride, 40% in H2O, at plant	CH	kg	0	0	1.00E-3	0	0	0	1	1.05	(1,1,1,1,1,1); iron chelate, amount not known	1.00E-3	4.71E-8
	transport, lorry 32t, Euro 5, diesel	RER	tkm	1.59E+4	4.20E+2	1.56E+2	7.65E+1	9.09E+4	0	1	2.09	(4,5,na,na,na,na); Standard distances	1.07E+5	5.06E+0
	transport, freight, rail	RER	tkm	0	8.39E+2	2.60E+1	1.28E+1	1.51E+4	0	1	2.09	(4,5,na,na,na,na); Standard distances	1.60E+4	7.54E-1
	treatment, inorganic effluent, straw, to wastewater treatment, class 3	CH	m3	0	0	1.38E+1	0	0	0	1	1.05	(1,1,1,1,1,1); waste water treated and disposed off to a river	1.38E+1	6.48E-4
	disposal, slag, straw, to residual material landfill	CH	kg	0	1.47E+4	0	0	0	0	1	1.05	(1,1,1,1,1,1); bed ash (coarse)	1.47E+4	6.90E-1
	disposal, filter dust, straw, to residual material landfill	CH	kg	0	1.06E+3	0	0	0	0	1	1.05	(1,1,1,1,1,1); filter ash, fine	1.06E+3	4.99E-2
	disposal, catalyst base CH2O production, 0% water, to residual material landfill	CH	kg	0	0	0	1.28E+2	0	0	1	1.22	(2,5,1,1,1,na); general assumption, catalyst for gas conditioning	1.28E+2	6.00E-3
	refinery gas, burned in flare	GLO	MJ	0	0	0	0	0	1.50E-1	1	1.32	(3,5,na,1,3,na); general assumption, 2.5 kg/t refinery input	3.18E+3	1.50E-1
	process specific emissions, conversion plant	RER	kg	0	0	0	0	0	2.68E-4	1	1.22	(2,na,na,1,3,na); general assumption per kg of fuel, process specific emissions	5.70E+0	2.68E-4
	biomass, incl. storage and preparation, straw	CUTEC	h	0	0	0	0	0	4.71E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	4.71E-5
	gasification, circulating fluidized bed reactor, straw	CUTEC	h	0	0	0	0	0	4.71E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	4.71E-5
	gas cleaning, straw	CUTEC	h	0	0	0	0	0	4.71E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	4.71E-5
	gas conditioning and compression, straw	CUTEC	h	0	0	0	0	0	4.71E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	4.71E-5
	Fischer-Tropsch synthesis, straw	CUTEC	h	0	0	0	0	0	4.71E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	4.71E-5
	fuel synthesis plant	RER	unit	0	0	0	0	0	2.31E-10	1	1.31	(2,3,1,1,3,5); Calculation	4.90E-6	2.31E-10
	refinery treatment, FT-raw liquid	RER	kg	0	0	0	0	0	1.05E+0	1	1.24	(3,na,2,1,3,na); FT-fraction C5-C22+ are treated in a refinery, other fractions are used internally	2.24E+4	1.05E+0
emission air	Heat, waste	-	MJ	6.75E+4	5.36E+4	3.36E+4	1.13E+5	5.50E+5	0	1	1.31	(2,3,1,1,3,5); Calculation from electricity use	8.18E+5	3.85E+1
	Particulates, > 10 um	-	kg	5.00E+0	0	0	0	0	0	1	3.01	(3,na,1,1,1,na); general assumption emissions from biomass handling per hour	5.00E+0	2.35E-4
												conversion rate (biomass to all liquids)		
Input	mass		kg	127415	120336	197370	153135	72428	6.0			17%		6.00E+0
Output	mass		kg	120336	197370	153135	72428	21250	1.0			18%		5.66E+0
Output	energy		MJ	1'669'131	1'079'614	1'436'406	1'849'700	933'332	43.92			56%		

3.7 Decentralized Entrained Flow Gasification, dEF-D (SP2-FZK)

Elaboration of LCI: Niels Jungbluth, ESU-services Ltd., Uster
Data provider Edmund Henrich, Ralph Stahl, FZK

3.7.1 Pressurised entrained flow gasifier

The concept for biomass gasification and syngas utilisation as it is developed by FZK is shown in Fig. 3.5.[21] The first process step is a fast pyrolysis at atmospheric pressure, which produces much condensate and only little char and gas. Pyrolysis condensate and pulverised pyrolysis char are then mixed to

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[21] Description taken from www.fzk.de/stellent/groups/itc-cpv/documents/published_pages/itccpv__20_90__publ_ia401545fb.pdf.

a slurry, containing up to 90% of the initial biomass energy. In contrast to the loose-packed original biomass the dense slurries are easily pumped and stored in tanks. From a number of regional pyrolysis plants, the slurries might be transported by rail to a large central gasification facility. Thus, the economy of scale facilitates an efficient but more complex gasification and syngas utilisation technology to produce valuable products.

The slurries are pumped into a slagging entrained flow gasifier and are atomised and converted to syngas at high operating temperatures and pressures, above the operating pressure of a downstream synthesis plant. High gasification temperatures and pressures help to produce a tar-free syngas, simplify downstream gas cleaning steps and obviate intermediate compression before synthesis. To achieve a high process conversion rate, the utilisation of chemical energy in synthesis products like methanol must be complemented and combined with a use of the sensible heat for electric power generation.

Fast pyrolysis of biomass will be achieved by mixing with an excess of hot sand in a special twin screw reactor.

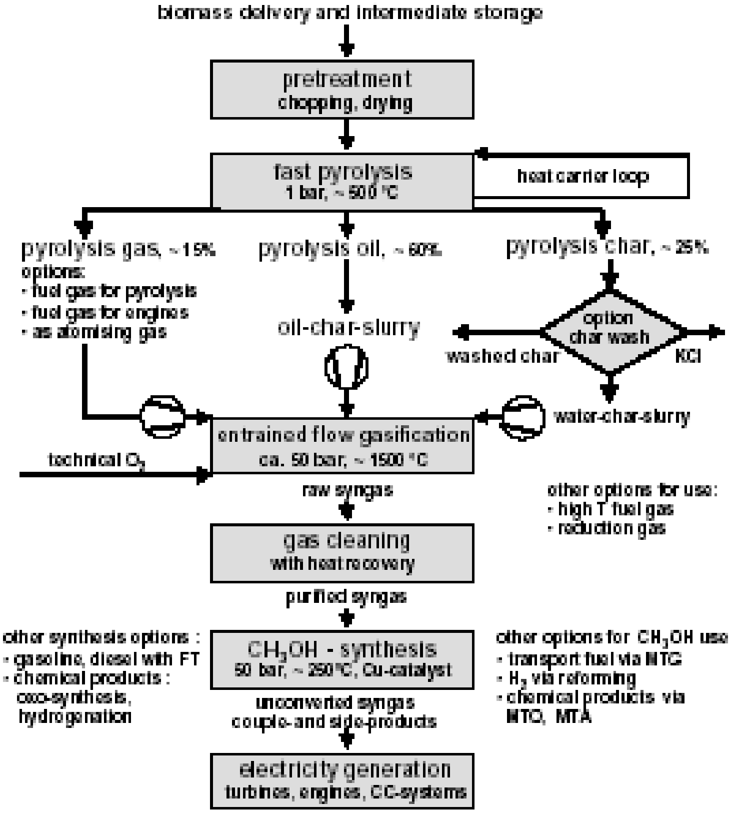

Fig. 3.5 Concept for biomass gasification and syngas utilisation

3.7.2 Inventory

All produced electricity and steam is used internally in the plant. The allocation to sub-processes is partly based on rough assumptions.

The life cycle inventory analysis and further information about the modelling are shown in the next tables.

Starting point

Tab. 3.44 Documentation of the inventory data of the FZK process, starting point calculation

ReferenceFunction	Name	biomass, incl. storage and preparation, straw	pyrolysis, straw	gasification, straw pyrolysis slurry, pressurized entrained flow, autothermal	gas cleaning, straw	gas conditioning, straw	Fischer-Tropsch synthesis, straw	BTL-fuel, straw, at refinery
Geography	Location	FZK	FZK	FZK	FZK	FZK	FZK	FZK
ReferenceFunct	InfrastructureProcess	0	0	0	0	0	0	0
ReferenceFunct	Unit	h	h	h	h	h	h	kg
	IncludedProcesses	Transport from the 1st gathering point. Handling emissions. Storage and preparation of biomass for the conversion process. A pre-drying of biomass is not considered necessary.	Pyrolysis of wheat straw and production of pyrolysis slurry.	Gasification of pyrolysis slurry with pressurized entrained flow gasification that operates autothermal. Includes feed slurry preparation, slurry gasification. Heavy metals are mainly found in the sludge of the gasification. This sludge is disposed off in an inert material landfill or it can be used as construction material. Only arsenic might be transferred to effluents, but this is not important in the case of straw.	Cleaning of synthesis gas	Conditioning of clean gas	Fischer-Tropsch synthesis of BTL-fuel.	Includes all process stages and the external treatment of FT-raw liquid in a refinery. It has to be noted that about 50% of the electricity production from the power plant is sold to the market. Supply of district heat is foreseen but not accounted for as a product.
	Synonyms	Decentralized Entrained Flow Gasification//dEF-D	Decentralized Entrained Flow Gasification//dEF-D	Decentralized Entrained Flow Gasification//dEF-D	Decentralized Entrained Flow Gasification//dEF-D	Decentralized Entrained Flow Gasification//dEF-D	Decentralized Entrained Flow Gasification//dEF-D	Decentralized Entrained Flow Gasification//dEF-D
	GeneralComment	Starting point scenario. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is	Starting point scenario. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may	Starting point scenario. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by the respective technology partner.	Starting point scenario. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology	Starting point scenario. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology	Starting point scenario. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may	Starting point scenario. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future
	Category	biomass	biomass	biomass	biomass	biomass	biomass	biomass
	SubCategory	fuels	fuels	fuels	fuels	fuels	fuels	fuels
	Formula							
	StatisticalClassification							
	CASNumber							
TimePeriod	StartDate	2005	2005	2005	2005	2005	2005	2005
	EndDate	2006	2006	2006	2006	2006	2006	2006
	OtherPeriodText	Starting point scenario	Starting point scenario	Starting point scenario	Starting point scenario	Starting point scenario	Starting point scenario	Starting point scenario
Geography	Text	Europe	Europe	Europe	Europe	Europe	Europe	Europe
Technology	Text	actual development state for biofuel conversion	actual development state for biofuel conversion	actual development state for biofuel conversion	actual development state for biofuel conversion	actual development state for biofuel conversion	actual development state for biofuel conversion	actual development state for biofuel conversion
	ProductionVolume	5*100MW	5*100MW	500MW	500MW	500MW	500MW	500MW
	SamplingProcedure	questionnaire	questionnaire	questionnaire	questionnaire	questionnaire	questionnaire	questionnaire
	Extrapolations	none	none	none	none	none	none	none
	UncertaintyAdjustments	none	none	none	none	none	none	none
	PageNumbers	SP2-FZK	SP2-FZK	SP2-FZK	SP2-FZK	SP2-FZK	SP2-FZK	SP2-FZK

Tab. 3.45 Life cycle inventory analysis and unit process raw data of the FZK process, starting point calculation

	Name	Location	Unit	biomass, incl. storage and preparation, straw	pyrolysis, straw	gasification, straw pyrolysis slurry, pressurized entrained flow, autothermal	gas cleaning, straw	gas conditioning, straw	Fischer-Tropsch synthesis, straw	BTL-fuel, straw, at refinery	UncertaintyType	StandardDeviation 95%	GeneralComment	Total	Total
	Location			FZK	FZK	FZK	FZK	FZK	FZK	FZK				FZK	FZK
	InfrastructureProcess			0	0	0	0	0	0	0					0
	Unit			h	h	h	h	h	h	kg				h	kg
input	wheat straw, bales, at intermediate storage	RER	kg	1.09E+5	0	0	0	0	0	0	1	1.05	(1,2,1,1,1,1); as dry matter	1.09E+5	6.43E+0
ressource	Water, cooling, unspecified natural origin	-	m3	0	2.70E+2	2.50E+3	0	0	0	0	1	3.00	(1,1,1,1,1,1); Questionnaire	2.77E+3	1.64E-1
technosphere	heat, biomass, at steam and power boiler	FZK	MJ	0	0	2.82E+5	0	0	0	0	1	2.24	(5,1,1,1,5,1); rough calculation for steam use	2.82E+5	1.66E+1
	electricity, biomass, at steam and power boiler	FZK	kWh	0	1.50E+3	2.15E+4	8.50E+3	1.00E+3	1.00E+3	0	1	1.05	(1,1,1,1,1,1); Questionnaire, full use of produced electricity.	3.35E+4	1.98E+0
	oxygen, liquid, at plant	RER	kg	0	0	0	0	0	0	0	1	1.24	(2,4,1,1,1,5); external plant at the fence, electricity use included in plant data	0	0
	nitrogen, liquid, at plant	RER	kg	0	0	9.40E+2	0	0	0	0	1	1.24	(2,4,1,1,1,5); Questionnaire	9.40E+2	5.56E-2
	silica sand, at plant	DE	kg	0	5.00E+2	0	0	0	0	0	1	1.24	(2,4,1,1,1,5); Questionnaire	5.00E+2	2.96E-2
	zinc for coating, at regional storage	RER	kg	0	0	1.01E+2	0	0	0	0	1	1.32	(3,5,na,1,3,na); general assumption, catalyst for gas conditioning	1.01E+2	6.00E-3
	catalyst, Fischer-Tropsch synthesis	RER	kg	0	0	0	0	0	1.69E+0	0	1	1.22	(2,5,1,1,1,na); general assumption catalyst use for Fischer-Tropsch synthesis	1.69E+0	1.00E-4
	transport, lorry 32t	RER	tkm	0	3.00E+2	1.08E+2	0	0	1.01E+0	0	1	2.09	(4,5,na,na,na,na); Standard distance	4.09E+2	2.42E-2
	transport, freight, rail	RER	tkm	0	5.00E+1	2.09E+4	0	0	1.69E-1	0	1	2.10	(2,3,1,1,3,5); Questionnaire, slurry transport 250km and standard distance	2.10E+4	1.24E+0
	transport, tractor and trailer	CH	tkm	3.75E+3	0	0	0	0	0	0	1	2.10	(2,3,1,1,3,5); Questionnaire, biomass transport 30km	3.75E+3	2.22E-1
	chemical plant, organics	RER	unit	0	3.33E-5	0	0	0	0	0	1	3.09	(4,5,na,na,na,na); Rough assumption	3.33E-5	1.97E-9
	treatment, inorganic effluent, straw, to wastewater treatment, class 3	CH	m3	0	0	1.25E+1	0	0	8.47E+0	0	1	1.31	(2,3,1,1,3,5); Personal communication by Fax	2.10E+1	1.24E-3
	disposal, catalyst base CH2O production, 0% water, to residual material landfill	CH	kg	0	0	1.01E+2	0	0	0	0	1	1.22	(2,5,1,1,1,na); general assumption, catalyst for gas conditioning	1.01E+2	6.00E-3
	disposal, inert waste, 5% water, to inert material landfill	CH	kg	0	0	8.06E+3	0	0	0	0	1	1.31	(2,3,1,1,3,5); questionnaire	8.06E+3	4.77E-1
	disposal, filter dust, straw, to residual material landfill	CH	kg	0	0	1.60E+3	0	0	0	0	1	1.31	(2,3,1,1,3,5); questionnaire, 1% filter dust	1.60E+3	9.46E-2
	off-gas, per kg CO2 emission	RER	kg	0	6.60E+3	4.60E+3	1.21E+4	0	7.00E+2	0	1	1.31	(2,3,1,1,3,5); Calculation from mass balance	2.40E+4	1.42E+0
	refinery gas, burned in flare	GLO	MJ	0	0	0	0	0	0	1.50E-1	1	1.32	(3,5,na,1,3,na); general assumption, 2.5 kg/t refinery input	1.11E+5	1.50E-1
	process specific emissions, conversion plant	RER	kg	0	0	0	0	0	0	2.68E-4	1	1.22	(2,na,na,1,3,na); general assumption per kg of fuel, process specific emissions	1.99E+2	2.68E-4
	biomass, incl. storage and preparation, straw	FZK	h	0	0	0	0	0	0	5.91E-5	1	1.24	(2,4,1,1,1,5); Production per hour	1.00E+0	5.91E-5
	pyrolysis, straw	FZK	h	0	0	0	0	0	0	5.91E-5	1	1.24	(2,4,1,1,1,5); Production per hour	1.00E+0	5.91E-5
	gasification, straw pyrolysis slurry, pressurized entrained flow, autothermal	FZK	h	0	0	0	0	0	0	5.91E-5	1	1.24	(2,4,1,1,1,5); Production per hour	1.00E+0	5.91E-5
	gas cleaning, straw	FZK	h	0	0	0	0	0	0	5.91E-5	1	1.24	(2,4,1,1,1,5); Production per hour	1.00E+0	5.91E-5
	gas conditioning, straw	FZK	h	0	0	0	0	0	0	5.91E-5	1	1.24	(2,4,1,1,1,5); Production per hour	1.00E+0	5.91E-5
	Fischer-Tropsch synthesis, straw	FZK	h	0	0	0	0	0	0	5.91E-5	1	1.24	(2,4,1,1,1,5); Production per hour	1.00E+0	5.91E-5
	fuel synthesis plant	RER	unit	0	0	0	0	0	0	2.47E-10	1	1.31	(2,3,1,1,3,5); Calculation	4.18E-6	2.47E-10
	refinery treatment, FT-raw liquid	RER	kg	0	0	0	0	0	0	1.05E+0	1	1.24	(3,na,2,1,3,na); general assumption per kg of FT-raw liquid treated in a refinery	1.78E+4	1.05E+0
emission air	Heat, waste	-	MJ	0	5.40E+3	7.74E+4	3.06E+4	3.60E+3	3.60E+3	0	1	1.31	(2,3,1,1,3,5); Calculation from electricity use	1.21E+5	7.13E+0
	Particulates, > 10 um	-	kg	5.00E+0	0	0	0	0	0	0	1	3.01	(3,na,1,1,1,na); general assumption emissions from biomass handling per hour	5.00E+0	2.96E-4
													conversion rate (biomass to all liquids)		
Input	mass		kg	1.25E+5	1.16E+5	8.33E+4	1.22E+5	7.39E+4	5.50E+4	7.4			14%		
Output	mass, after preparation		kg	1.16E+5	8.33E+4	1.22E+5	7.39E+4	5.50E+4	1.69E+4	1.0			15%		
Output	energy		MJ	1.64E+6	1.31E+6	1.08E+6	1.08E+6	1.08E+6	7.43E+5	43.9			45%		

Scenario 1

Tab. 3.46 Life cycle inventory analysis and unit process raw data of the FZK process, scenario 1

	Name	Location	Unit	biomass, incl. storage and preparation, straw	pyrolysis, straw	gasification, straw pyrolysis slurry, pressurized entrained flow, autothermal	gas cleaning, straw	gas conditioning, straw	Fischer-Tropsch synthesis, straw	BTL-fuel, straw, at refinery	UncertaintyType	StandardDeviation95%	GeneralComment	Total	Total
	Location			FZK	FZK	FZK	FZK	FZK	FZK	FZK				FZK	FZK
	InfrastructureProcess			0	0	0	0	0	0	0					0
	Unit			h	h	h	h	h	h	kg				h	kg
input	wheat straw, bales, scenario 1, at intermediate storage	RER	kg	1.09E+5	0	0	0	0	0	0	1	1.05	(1,2,1,1,1,1); as dry matter	1.09E+5	3.21E+0
ressource	Water, cooling, unspecified natural origin	-	m3	0	7.38E+1	3.00E+2	0	0	0	0	1	3.00	(1,1,1,1,1,1); Questionnaire	3.74E+2	1.11E-2
technosphere	heat, biomass, at steam and power boiler	FZK	MJ	0	0	5.63E+5	0	0	0	0	1	2.24	(5,1,1,1,5,1); rough calculation for steam use	5.63E+5	1.66E+1
	electricity, biomass, at steam and power boiler	FZK	kWh	0	1.50E+3	2.15E+4	8.50E+3	1.00E+3	6.75E+4	0	1	1.05	(1,1,1,1,1,1); Questionnaire, full use of produced electricity.	1.00E+5	2.96E+0
	electricity, medium voltage, RENEW, at grid	RER	kWh	0	0	0	0	0	5.15E+5	0	1	1.05	(1,1,1,1,1,1); Surplus electricity use for H2 minus credit for O2	5.15E+5	1.52E+1
	hydrogen, liquid, from water electrolysis, at plant	RER	kg	0	0	0	0	0	1.14E+4	0	1	1.31	(2,3,1,1,3,5); Questionnaire	1.14E+4	3.38E-1
	oxygen, liquid, at plant	RER	kg	0	0	0	0	0	0	0	1	1.24	(2,4,1,1,1,5); 60% of oxygen from electrolysis is used. The rest is sold.	0	0
	nitrogen, liquid, at plant	RER	kg	0	0	9.40E+2	0	0	0	0	1	1.24	(2,4,1,1,1,5); Questionnaire	9.40E+2	2.78E-2
	silica sand, at plant	DE	kg	0	5.00E+2	0	0	0	0	0	1	1.24	(2,4,1,1,1,5); Questionnaire	5.00E+2	1.48E-2
	zinc for coating, at regional storage	RER	kg	0	0	2.03E+2	0	0	0	0	1	1.32	(3,5,na,1,3,na); general assumption, catalyst for gas conditioning	2.03E+2	6.00E-3
	catalyst, Fischer-Tropsch synthesis	RER	kg	0	0	0	0	0	3.38E+0	0	1	1.22	(2,5,1,1,1,na); general assumption catalyst use for Fischer-Tropsch synthesis	3.38E+0	1.00E-4
	transport, lorry 32t, Euro 5, diesel	RER	tkm	0	3.00E+2	1.69E+2	0	0	6.87E+3	0	1	2.09	(4,5,na,na,na,na); Standard distance	7.33E+3	2.17E-1
	transport, freight, rail	RER	tkm	0	5.00E+1	2.09E+4	0	0	1.14E+3	0	1	2.10	(2,3,1,1,3,5); Questionnaire, slurry transport 250km and standard distance	2.21E+4	6.54E-1
	transport, tractor and trailer	CH	tkm	3.75E+3	0	0	0	0	0	0	1	2.10	(2,3,1,1,3,5); Questionnaire, biomass transport 30km	3.75E+3	1.11E-1
	chemical plant, organics	RER	unit	0	3.33E-5	0	0	0	0	0	1	3.09	(4,5,na,na,na,na); Rough assumption	3.33E-5	9.85E-10
	treatment, inorganic effluent, straw, to wastewater treatment, class 3	CH	m3	0	0	1.25E+1	0	0	0	0	1	1.31	(2,3,1,1,3,5); Personal communication by Fax	1.25E+1	3.70E-4
	disposal, catalyst base CH2O production, 0% water, to residual material landfill	CH	kg	0	0	2.03E+2	0	0	0	0	1	1.22	(2,5,1,1,1,na); general assumption, catalyst for gas conditioning	2.03E+2	6.00E-3
	disposal, inert waste, 5% water, to inert material landfill	CH	kg	0	0	8.06E+3	0	0	0	0	1	1.31	(2,3,1,1,3,5); questionnaire	8.06E+3	2.38E-1
	disposal, filter dust, straw, to residual material landfill	CH	kg	0	0	1.60E+3	0	0	0	0	1	1.31	(2,3,1,1,3,5); questionnaire, 1% filter dust	1.60E+3	4.73E-2
	off-gas, per kg CO2 emission	RER	kg	0	6.96E+4	0	0	0	0	0	1	1.31	(2,3,1,1,3,5); Calculation from mass balance	6.96E+4	2.06E+0
	refinery gas, burned in flare	GLO	MJ	0	0	0	0	0	0	1.50E-1	1	1.32	(3,5,na,1,3,na); general assumption, 2.5 kg/t refinery input	2.22E+5	1.50E-1
	process specific emissions, conversion plant	RER	kg	0	0	0	0	0	0	2.68E-4	1	1.22	(2,na,na,1,3,na); general assumption per kg of fuel, process specific emissions	3.98E+2	2.68E-4
	biomass, incl. storage and preparation, straw	FZK	h	0	0	0	0	0	0	2.96E-5	1	1.24	(2,4,1,1,1,5); Production per hour	1.00E+0	2.96E-5
	pyrolysis, straw	FZK	h	0	0	0	0	0	0	2.96E-5	1	1.24	(2,4,1,1,1,5); Production per hour	1.00E+0	2.96E-5
	gasification, straw pyrolysis slurry, pressurized entrained flow, autothermal	FZK	h	0	0	0	0	0	0	2.96E-5	1	1.24	(2,4,1,1,1,5); Production per hour	1.00E+0	2.96E-5
	gas cleaning, straw	FZK	h	0	0	0	0	0	0	2.96E-5	1	1.24	(2,4,1,1,1,5); Production per hour	1.00E+0	2.96E-5
	gas conditioning, straw	FZK	h	0	0	0	0	0	0	2.96E-5	1	1.24	(2,4,1,1,1,5); Production per hour	1.00E+0	2.96E-5
	Fischer-Tropsch synthesis, straw	FZK	h	0	0	0	0	0	0	2.96E-5	1	1.24	(2,4,1,1,1,5); Production per hour	1.00E+0	2.96E-5
	fuel synthesis plant	RER	unit	0	0	0	0	0	0	2.31E-10	1	1.31	(2,3,1,1,3,5); Calculation	3.43E-4	2.31E-10
	refinery treatment, FT-raw liquid	RER	kg	0	0	0	0	0	0	1.05E+0	1	1.24	(3,na,2,1,3,na); general assumption per kg of FT-raw liquid treated in a refinery	3.56E+4	1.05E+0
emission air	Heat, waste	-	MJ	0	5.40E+3	7.74E+4	3.06E+4	3.60E+3	2.10E+6	0	1	1.31	(2,3,1,1,3,5); Calculation from electricity use	2.22E+6	6.55E+1
	Particulates, > 10 um	-	kg	5.00E+0	0	0	0	0	0	0	1	3.01	(3,na,1,1,1,na); general assumption emissions from biomass handling per hour	5.00E+0	1.48E-4
													conversion rate (biomass to all liquids)		
Input	mass		kg	1.25E+5	1.16E+5	8.33E+4	1.22E+5	7.39E+4	5.50E+4	3.70			27%		
Output	mass		kg	1.16E+5	8.33E+4	1.22E+5	7.39E+4	5.50E+4	3.38E+4	1.00			29%		
Output	energy		MJ	1.64E+6	1.31E+6	1.08E+6	1.08E+6	1.08E+6	1.49E+6	43.9			91%		

3.8 Allothermal Circulating Fluidized Bed Gasification, ICFB-D (SP2-TUV)

Elaboration of LCI: Niels Jungbluth, ESU-services Ltd., Uster
Data provider Reinhard Rauch, Stefan Fürnsinn, TU Vienna, AT

3.8.1 Allothermal gasification with FICFB (Fast internal circulating fluidized bed)

This system is equipped with fluidized bed steam gasification technology. The subsequent operation of gas cooling and purification enables the wood gas product to be used in a gas engine. With a fuel thermal performance of 8 MW, a district heating output of approximately 4.5 MWth, and an electrical output of approximately 2 MWth should be produced, initially in the 2 year old demonstration operation, and later in regular operation

The fundamental idea of this gasification system is to physically separate the gasification reaction and the combustion reaction in order to gain a largely nitrogen-free product gas. The endothermic gasification of the fuel takes place in a stationary fluidized bed. This is connected via a diagonal chute to the combustion section, which is operated as a circulating fluidized bed. Here, transported along with the bed material, any non-gasified fuel particles are fully combusted. The heated bed material delivered there is then separated and brought back into the gasification section.

The heat required for the gasification reaction is produced by burning carbon, brought along with the bed material into the combustion section. The gasification section is fluidised with steam. The combustion section with air and the gas flows are separately streamed off. Thus, a nearly nitrogen-free product gas with heating values of more than 12 MJ/Nm^3 (dry) is produced. A further advantage of this method of production are its compact construction by using steam as the gasification medium, there is a smaller tar content in the product than when using air.

Another advantage of this system is that an equilibrium between combustion and gasification reactions takes place automatically, thus one can keep the operation running stably without excessive regulation and adjustment. The gasification reaction is endothermic. If the temperature in the gasification section drops, less fuel is fully decomposed and this leads to an increasing proportion of carbon or non oxidised fuel in the combustion section. Due to the increased combustion, one transfers more energy to the bed material and this supplies in turn more energy back to the gasification section. Thus a renewed temperature rise in the gasification section is brought about. In this way a stable equilibrium is maintained between the gasification and combustion chambers. Additionally, the temperature in the combustion section can be regulated by controlling the flow of product gas.

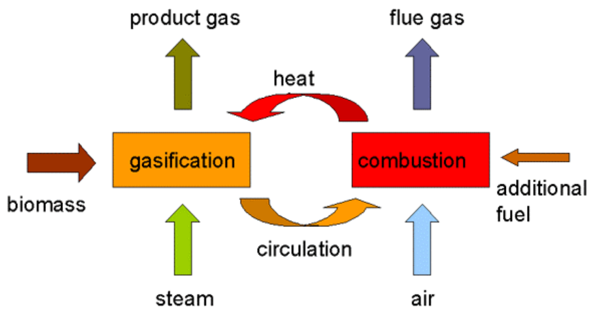

Fig. 3.6 Flow chart of fluidized bed gasification system

The fuel entering into the reactor is heated up, dried and devolatilised. The following main by-products are produced CO; CO_2; CH_4; H2; H_2Og; C. The strongly endothermic gasification reactions (reactions with water vapour) are taking place at the same time in the gasification section of the reactor.

The remaining non-gasified carbon (non volatile part) crosses into the combustion section, where it is burned. The energy liberated there is used for the reaction in the gasification section. Fig. 3.7 shows a flow chart of this process (Aichernig et al. 2004). The system consists of the following main components:

- biomass feeding system
- gasifier (gasification and combustion zone)
- product gas cooler
- product gas filter
- product gas scrubber

- product gas blower
- gas engine
- water boiler
- flue gas cooler
- flue gas filter
- flue gas (gas engine) cooler

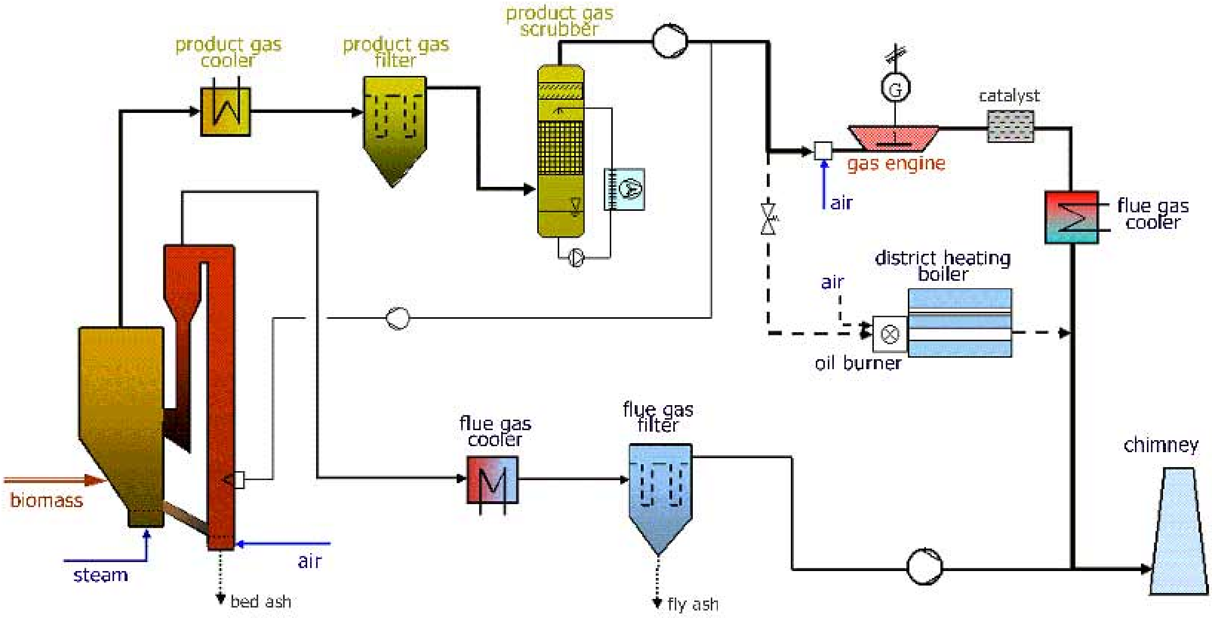

Fig. 3.7 Schematic layout of the Biomass Power Station, Güssing (Aichernig et al. 2004)

Some technical data of the biomass power station are shown in Tab. 3.47.

Tab. 3.47 Technical data of the Biomass Power Station, Güssing

wood consumption	1760 kg/h
fuel input	8 MW
electrical output	2 MW
Heat output	4.5 MW

The following Fig. 3.8 shows an overview of the TUV starting point conversion process (50MW). The process includes steam gasification, FT-synthesis and power & district heat production.

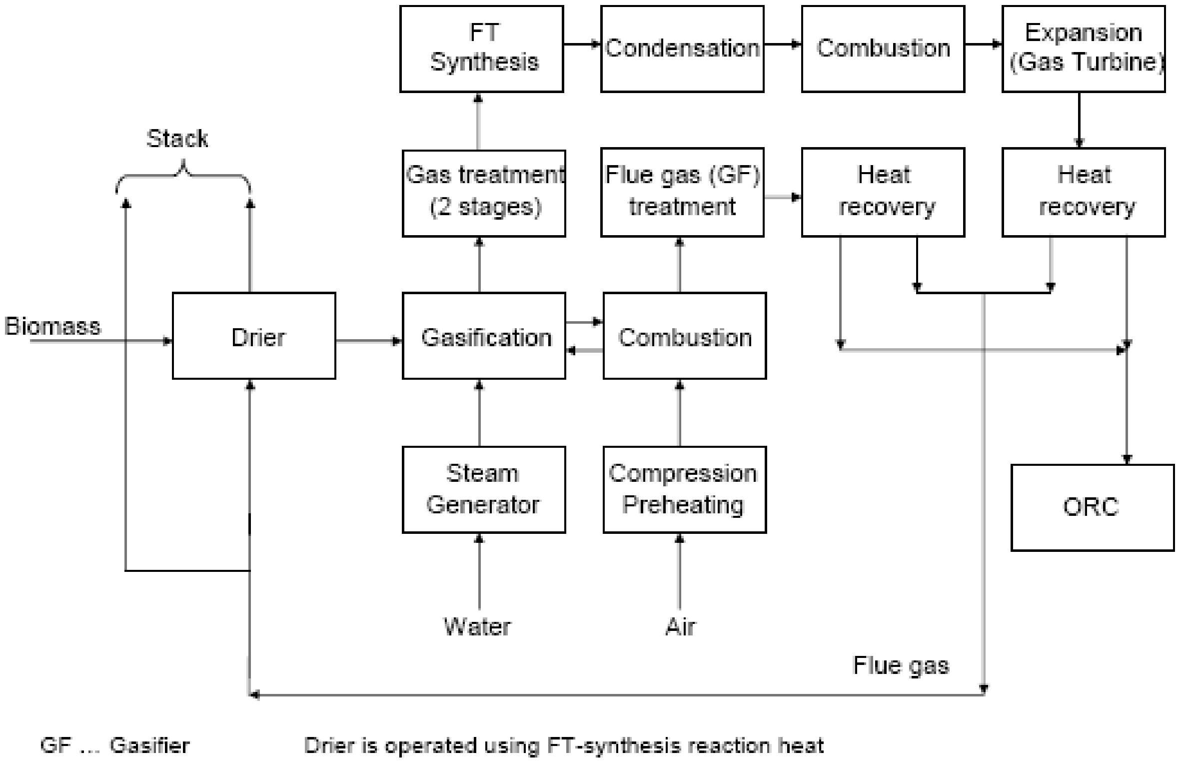

Fig. 3.8 Flow chart TUV starting point (50MW). steam gasification – FT-synthesis – power& district heat production

The constant gas volume flow and composition of the gas provide good conditions for operating the gas engine. The gas composition of the 100kWth unit at the institute is shown in Tab. 3.48.

Tab. 3.48 Composition of gas

Hydrogen	30-45 Vol%
Carbon monoxide	20-30 Vol%
Carbon dioxide	15-25 Vol%
Methane	8-12 Vol%
Nitrogen	3-5 Vol%

3.8.2 Inventory

The life cycle inventory analysis and further information are shown in the following tables.

Data have been provided for the use of short-rotation wood and miscanthus.

Starting point

The conversion rate of the fuel production is comparably low, but therefore electricity production in this process is quite higher than for other process routes. A part of the heat should be used as district heat. According to the boundary conditions for all process developers, this part of the energy output is not accounted for.

Tab. 3.49 Documentation of the inventory data of the TUV process, starting point calculation

ReferenceFunction	Name	biomass, incl. storage and preparation, wood	allothermal steam gasification, dual fluidized bed, wood	gas cleaning, wood	gas conditioning and compression, wood	Fischer-Tropsch synthesis, wood	BTL-fuel, wood, at refinery
Geography	Location	TUV	TUV	TUV	TUV	TUV	TUV
ReferenceFunct	InfrastructureProcess	0	0	0	0	0	0
ReferenceFunct	Unit	h	h	h	h	h	kg
	IncludedProcesses	Transport from the 1st gathering point. Handling emissions. Storage and preparation of biomass for the conversion process. Drying with heat.	Gasification of biomass with a 50MW atmospheric steam gasification. Condensate water is used here.	Cleaning of synthesis gas. All air emissions are released with the stack gases from the power plant.	Conditioning of clean gas	Fischer-Tropsch synthesis of FT-raw liquid	Includes all process stages and the external treatment of FT-raw liquid in a refinery. It has to be noted that about 50% of the electricity production from the power plant is sold to the market. Supply of district heat is foreseen but not accounted for as a product.
	Synonyms	Allothermal CFB-Gasification//ICFB-D	Allothermal CFB-Gasification//ICFB-D	Allothermal CFB-Gasification//ICFB-D	Allothermal CFB-Gasification//ICFB-D	Allothermal CFB-Gasification//ICFB-D	Allothermal CFB-Gasification//ICFB-D
	GeneralComment	Starting point scenario. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by the respective technology partner.	Starting point scenario. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by the respective technology partner.	Starting point scenario. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by the respective technology partner.	Starting point scenario. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by the respective technology partner.	Starting point scenario. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by the respective technology partner.	Starting point scenario. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by the respective technology partner.
	Category	biomass	biomass	biomass	biomass	biomass	biomass
	SubCategory	fuels	fuels	fuels	fuels	fuels	fuels
	Formula						
	StatisticalClassification						
	CASNumber						
TimePeriod	StartDate	2005	2005	2005	2005	2005	2005
	EndDate	2006	2006	2006	2006	2006	2006
	OtherPeriodText	Starting point scenario	Starting point scenario	Starting point scenario	Starting point scenario	Starting point scenario	Starting point scenario
Geography	Text	Europe	Europe	Europe	Europe	Europe	Europe
Technology	Text	Simulation with IPSEpro by plant developers for a 50MW plant.	Simulation with IPSEpro by plant developers for a 50MW plant.	Simulation with IPSEpro by plant developers for a 50MW plant.	Simulation with IPSEpro by plant developers for a 50MW plant.	Simulation with IPSEpro by plant developers for a 50MW plant.	Simulation with IPSEpro by plant developers for a 50MW plant.
	ProductionVolume	50MW	50MW	50MW	50MW	50MW	50MW
	SamplingProcedure	questionnaire	questionnaire	questionnaire	questionnaire	questionnaire	questionnaire
	Extrapolations	none	none	none	none	none	none
	UncertaintyAdjustments	none	none	none	none	none	none
	PageNumbers	SP2-TUV	SP2-TUV	SP2-TUV	SP2-TUV	SP2-TUV	SP2-TUV

Tab. 3.50 Life cycle inventory analysis and unit process raw data of the TUV process, starting point calculation, short-rotation wood

	Name	Location	InfrastructureProcess	Unit	biomass, incl. storage and preparation, wood	allothermal steam gasification, dual fluidized bed, wood	gas cleaning, wood	gas conditioning and compression, wood	Fischer-Tropsch synthesis, wood	BTL-fuel, wood, at refinery	UncertaintyType	StandardDeviation95%	GeneralComment	Total	Total
	Location				TUV	TUV	TUV	TUV	TUV	TUV				TUV	TUV
	InfrastructureProcess				0	0	0	0	0	0				0	0
	Unit				h	h	h	h	h	kg				h	kg
input	bundles, short-rotation wood, at intermediate storage	RER	0	kg	1.18E+4	0	0	0	0	0	1	1.05	(1,1,1,1,1,1); as dry matter	1.18E+4	1.06E+1
ressource	Water, river	-	-	m3	0	0	0	0	0	0	1	3.00	(1,1,1,1,1,1); not used	0	0
	heat, biomass, at gas turbine and ORC cycle	TUV	0	MJ	3.60E+2	7.20E+3	0	0	0	0	1	1.05	(1,1,1,1,1,1); Questionnaire	7.56E+3	6.79E+0
	electricity, biomass, at gas turbine and ORC cycle	TUV	0	kWh	2.94E+2	2.80E+2	2.11E+3	6.10E+1	5.50E+1	0	1	1.05	(1,1,1,1,1,1); Questionnaire	2.80E+3	2.51E+0
	oxygen, liquid, at plant	RER	0	kg	0	0	0	0	0	0	1	1.24	(2,4,1,1,1,5); not included because on site production	0	0
	nitrogen, liquid, at plant	RER	0	kg	0	2.50E+2	0	0	0	0	1	1.24	(2,4,1,1,1,5); Questionnaire	2.50E+2	2.25E-1
	zinc for coating, at regional storage	RER	0	kg	0	0	0	7.07E+0	0	0	1	1.24	(2,4,1,1,1,5); ZnO catalyst, information in questionnaire	7.07E+0	6.35E-3
	catalyst, Fischer-Tropsch synthesis	RER	1	kg	0	0	0	0	1.11E-1	0	1	1.22	(2,5,1,1,1,na); general assumption catalyst use for Fischer-Tropsch synthesis	1.11E-1	1.00E-4
	soya oil, at plant	RER	0	kg	0	0	1.00E+2	0	0	0	1	1.31	(2,3,1,1,3,5); assumption for RME, burned in gasifier	1.00E+2	8.98E-2
	quicklime, milled, loose, at plant	CH	0	kg	0	5.00E+1	0	0	0	0	1	1.31	(2,3,1,1,3,5); limestone	5.00E+1	4.49E-2
	silica sand, at plant	DE	0	kg	0	2.50E+2	0	0	0	0	1	1.31	(2,3,1,1,3,5); bed material	2.50E+2	2.25E-1
	transport, lorry 32t	RER	0	tkm	2.30E+3	1.63E+2	6.00E+1	4.24E+0	6.68E-2	0	1	2.09	(4,5,na,na,na,na); Standard distances	2.53E+3	2.27E+0
	transport, freight, rail	RER	0	tkm	0	2.50E+1	1.00E+1	7.07E-1	1.11E-2	0	1	2.09	(4,5,na,na,na,na); Standard distances	3.57E+1	3.21E-2
	tap water, at user	RER	0	kg	0	1.00E+3	0	0	0	0	1	1.31	(2,3,1,1,3,5); Questionnaire, used for gasifier	1.00E+3	8.98E-1
	treatment, inorganic production effluent, wood, to wastewater treatment, class 3	CH	0	m3	0	0	0	0	0	0	1	1.31	(2,3,1,1,3,5); no data	0	0
	disposal, slag, wood, to residual material landfill	CH	0	kg	0	0	0	0	0	0	1	1.31	(2,3,1,1,3,5); slag	0	0
	disposal, filter dust, wood, to residual material landfill	CH	0	kg	0	4.02E+2	0	0	0	0	1	1.31	(2,3,1,1,3,5); ash, filter dust	4.02E+2	3.61E-1
	disposal, catalyst base CH2O production, 0% water, to residual material landfill	CH	0	kg	0	0	0	7.07E+0	0	0	1	1.31	(2,3,1,1,3,5); disposal catalyst	7.07E+0	6.35E-3
	off-gas, per kg CO2 emission	RER	0	kg	0	0	0	0	0	0	1	1.31	(2,3,1,1,3,5); All emissions are allocated to the electricity production	0	0
	refinery gas, burned in flare	GLO	0	MJ	0	0	0	0	0	1.50E-1	1	1.32	(3,5,na,1,3,na); general assumption, 2.5 kg/t refinery input	1.67E+2	1.50E-1
	process specific emissions, conversion plant	RER	0	kg	0	0	0	0	0	2.68E-4	1	1.22	(2,na,na,1,3,na); general assumption per kg of fuel, process specific emissions	2.98E-1	2.68E-4
	biomass, incl. storage and preparation, wood	TUV	0	h	0	0	0	0	0	8.98E-4	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	8.98E-4
	allothermal steam gasification, dual fluidized bed, wood	TUV	0	h	0	0	0	0	0	8.98E-4	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	8.98E-4
	gas cleaning, wood	TUV	0	h	0	0	0	0	0	8.98E-4	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	8.98E-4
	gas conditioning and compression, wood	TUV	0	h	0	0	0	0	0	8.98E-4	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	8.98E-4
	Fischer-Tropsch synthesis, wood	TUV	0	h	0	0	0	0	0	8.98E-4	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	8.98E-4
	fuel synthesis plant	RER	1	unit	0	0	0	0	0	2.47E-10	1	1.31	(2,3,1,1,3,5); Calculation	2.75E-7	2.47E-10
	refinery treatment, FT-raw liquid	RER	0	kg	0	0	0	0	0	1.05E+0	1	1.24	(3,na,2,1,3,na); FT raw wax to refinery	1.17E+3	1.05E+0
emission air, high population density	Heat, waste	-	-	MJ	1.06E+3	1.01E+3	7.58E+3	2.20E+2	1.98E+2	0	1	1.31	(2,3,1,1,3,5); Calculation from electricity use	1.01E+4	9.04E+0
	Particulates, > 10 um	-	-	kg	5.00E+0	0	0	0	0	0	1	3.01	(3,na,1,1,1,na); general assumption emissions from biomass handling per hour	5.00E+0	4.49E-3
													conversion rate (biomass to all liquids)		
Input	mass			kg	15331	12626	14530	10610	9586	13.8			7%		
Output	mass, after preparation			kg	12626	14530	10610	9586	1113	1.0			9%		
Output	energy			MJ	186489	131497	134323	129312	48902	43.9			26%		

Tab. 3.51 Life cycle inventory analysis and unit process raw data of the TUV process, starting point calculation, miscanthus

	Name	Location	InfrastructureProcess	Unit	biomass, incl. storage and preparation, miscanthus	allothermal steam gasification, dual fluidized bed, miscanthus	gas cleaning, miscanthus	gas conditioning and compression, miscanthus	Fischer-Tropsch synthesis, miscanthus	BTL-fuel, miscanthus, at refinery	UncertaintyType	StandardDeviation95%	GeneralComment	Total	Total
	Location				TUV	TUV	TUV	TUV	TUV	TUV				TUV	TUV
	InfrastructureProcess				0	0	0	0	0	0				0	0
	Unit				h	h	h	h	h	kg				h	kg
input	miscanthus-bales, at intermediate storage	RER	0	kg	1.10E+4	0	0	0	0	0	1	1.05	(1,1,1,1,1,1); as dry matter	1.10E+4	1.04E+1
	heat, biomass, at gas turbine and ORC cycle	TUV	0	MJ	1.80E+2	7.92E+3	0	0	0	0	1	1.05	(1,1,1,1,1,1); Questionnaire	8.10E+3	7.67E+0
	electricity, biomass, at gas turbine and ORC cycle	TUV	0	kWh	3.27E+2	2.74E+2	1.99E+3	5.80E+1	5.30E+1	0	1	1.05	(1,1,1,1,1,1); Questionnaire	2.70E+3	2.56E+0
	oxygen, liquid, at plant	RER	0	kg	0	0	0	0	0	0	1	1.24	(2,4,1,1,1,5); not included because on site production	0	0
	nitrogen, liquid, at plant	RER	0	kg	0	2.50E+2	0	0	0	0	1	1.24	(2,4,1,1,1,5); Questionnaire	2.50E+2	2.37E-1
	zinc for coating, at regional storage	RER	0	kg	0	0	0	7.07E+0	0	0	1	1.24	(2,4,1,1,1,5); ZnO catalyst, information in questionnaire	7.07E+0	6.69E-3
	catalyst, Fischer-Tropsch synthesis	RER	1	kg	0	0	0	0	1.06E-1	0	1	1.22	(2,5,1,1,1,na); general assumption catalyst use for Fischer-Tropsch synthesis	1.06E-1	1.00E-4
	soya oil, at plant	RER	0	kg	0	0	1.00E+2	0	0	0	1	1.31	(2,3,1,1,3,5); assumption for RME, burned in gasifier	1.00E+2	9.47E-2
	quicklime, milled, loose, at plant	CH	0	kg	0	5.00E+1	0	0	0	0	1	1.31	(2,3,1,1,3,5); lime stone	5.00E+1	4.73E-2
	silica sand, at plant	DE	0	kg	0	2.50E+2	0	0	0	0	1	1.31	(2,3,1,1,3,5); bed material	2.50E+2	2.37E-1
	transport, lorry 32t	RER	0	tkm	1.97E+3	1.63E+2	6.00E+1	4.24E+0	6.34E-2	0	1	2.09	(4,5,na,na,na,na); Standard distances	2.20E+3	2.08E+0
	transport, freight, rail	RER	0	tkm	0	2.50E+1	1.00E+1	7.07E-1	1.06E-2	0	1	2.09	(4,5,na,na,na,na); Standard distances	3.57E+1	3.38E-2
	tap water, at user	RER	0	kg	0	1.00E+3	0	0	0	0	1	1.31	(2,3,1,1,3,5); Questionnaire, used for gasifier	1.00E+3	9.47E-1
	treatment, inorganic effluent, straw, to wastewater treatment, class 3	CH	0	m3	0	0	0	0	0	0	1	1.31	(2,3,1,1,3,5); not used	0	0
	disposal, slag, straw, to residual material landfill	CH	0	kg	0	0	0	0	0	0	1	1.31	(2,3,1,1,3,5); slag	0	0
	disposal, filter dust, straw, to residual material landfill	CH	0	kg	0	4.02E+2	0	0	0	0	1	1.31	(2,3,1,1,3,5); ash, filter dust	4.02E+2	3.81E-1
	disposal, catalyst base CH2O production, 0% water, to residual material landfill	CH	0	kg	0	0	0	7.07E+0	0	0	1	1.31	(2,3,1,1,3,5); disposal catalyst	7.07E+0	6.69E-3
	off-gas, per kg CO2 emission	RER	0	kg	0	0	0	0	0	0	1	1.31	(2,3,1,1,3,5); All emissions are allocated to the electricity production	0	0
	refinery gas, burned in flare	GLO	0	MJ	0	0	0	0	0	1.50E-1	1	1.32	(3,5,na,1,3,na); general assumption, 2.5 kg/t refinery input	1.58E+2	1.50E-1
	process specific emissions, conversion plant	RER	0	kg	0	0	0	0	0	2.68E-4	1	1.22	(2,na,na,1,3,na); general assumption per kg of fuel, process specific emissions	2.83E-1	2.68E-4
	biomass, incl. storage and preparation, miscanthus	TUV	0	h	0	0	0	0	0	9.47E-4	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	9.47E-4
	allothermal steam gasification, dual fluidized bed, miscanthus	TUV	0	h	0	0	0	0	0	9.47E-4	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	9.47E-4
	gas cleaning, miscanthus	TUV	0	h	0	0	0	0	0	9.47E-4	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	9.47E-4
	gas conditioning and compression, miscanthus	TUV	0	h	0	0	0	0	0	9.47E-4	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	9.47E-4
	Fischer-Tropsch synthesis, miscanthus	TUV	0	h	0	0	0	0	0	9.47E-4	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	9.47E-4
	fuel synthesis plant	RER	1	unit	0	0	0	0	0	2.47E-10	1	1.31	(2,3,1,1,3,5); Calculation	2.61E-7	2.47E-10
	refinery treatment, FT-raw liquid	RER	0	kg	0	0	0	0		1.05E+0	1	1.24	(3,na,2,1,3,na); FT raw wax to refinery	1.11E+3	1.05E+0
emission air, high population density	Heat, waste	-	-	MJ	1.18E+3	9.86E+2	7.17E+3	2.09E+2	1.91E+2	0	1	1.31	(2,3,1,1,3,5); Calculation from electricity use	9.73E+3	9.22E+0
	Particulates, > 10 um	-	-	kg	5.00E+0	0	0	0	0	0	1	3.01	(3,na,1,1,1,na); general assumption emissions from biomass handling per hour	5.00E+0	4.73E-3
													conversion rate (biomass to all liquids)		
Input	mass			kg	13149	12376	14060	10189	9155	12.4			8%		
Output	mass, after preparation			kg	12376	14060	10189	9155	1056	1.0			9%		
Output	energy			MJ	179389	126259	128687	123318	46390	43.9			26%		

Sensitivity analysis

The biomass to fuel conversion rate of the TUV process in the starting point scenario is quite low because the process layout foresees an important share of electricity production. With the allocation approach in the base case, were all biomass input is allocated to the fuel production, this is a major disadvantage of the process.

With the data in Tab. 3.51 we perform a sensitivity analysis that considers that also a part of the wood input should be allocated to the electricity production and thus the environmental impacts allocated to the fuel production should be lower.

The exergy of the fuel output is about 50 GJ. If the electricity sold to the outside is included as a product, the total exergy output would be 67 GJ. In the sensitivity analysis, only 73% (=50/67) of the biomass input is allocated to the conversion process and the rest is allocated to the electricity used outside the plant. With this assumption the overall conversion rate exergy input to output would be about 38% in comparison to only 26% calculated for the biomass to fuel conversion rate.

Tab. 3.52 **Key factors for a sensitivity analysis considering the exergy output of the process**

	Exergy Faktor	Unit	Sensitivity analysis	Base case
Fuel	1.02	MJ	49880	49880
Electricity	1.00	MJ	34945	10062
Heat	0.28	MJ	2091	2091
Total output		MJ	74763	49880
Input wood	1.05	MJ	195814	195814
Share considered		%		67%
Conversion rate		%	38.2%	25.5%
Wood input		kg	7868	11793

Scenario 1

Tab. 3.53 Documentation of the inventory data of the TUV process, scenario 1

ReferenceFunction	Name	biomass, incl. storage and preparation, wood	allothermal steam gasification, dual fluidized bed, wood	gas cleaning, wood	gas conditioning and compression, wood	Fischer-Tropsch synthesis, wood	BTL-fuel, wood, at refinery
Geography	Location	TUV	TUV	TUV	TUV	TUV	TUV
ReferenceFunction	InfrastructureProcess	0	0	0	0	0	0
ReferenceFunction	Unit	h	h	h	h	h	kg
	IncludedProcesses	Storage and preparation of biomass for the conversion process. Drying with heat.	Gasification of biomass with a 500MW pressurized steam gasification.	Cleaning of synthesis gas	Conditioning of clean gas	Fischer-Tropsch synthesis of FT-raw liquid. No H2 throughput because O2 from electrolysis cannot be used.	Includes all process stages and the external treatment of FT-raw liquid in a refinery. The plant produces electricity for the grid. Allocation is based on the electricity delivered to different users.
	Synonyms	Allothermal CFB-Gasification//ICFB-D	Allothermal CFB-Gasification//ICFB-D	Allothermal CFB-Gasification//ICFB-D	Allothermal CFB-Gasification//ICFB-D	Allothermal CFB-Gasification//ICFB-D	Allothermal CFB-Gasification//ICFB-D
	GeneralComment	Scenario 1 for maximized fuel production. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by the respective technology partner.	Scenario 1 for maximized fuel production. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by the respective technology partner.	Scenario 1 for maximized fuel production. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by the respective technology partner.	Scenario 1 for maximized fuel production. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by the respective technology partner.	Scenario 1 for maximized fuel production. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by the respective technology partner.	Scenario 1 for maximized fuel production. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by the respective technology partner.
	Category	biomass	biomass	biomass	biomass	biomass	biomass
	SubCategory	fuels	fuels	fuels	fuels	fuels	fuels
	Formula						
	StatisticalClassification						
	CASNumber						
TimePeriod	StartDate	2005	2005	2005	2005	2005	2005
	EndDate	2020	2020	2020	2020	2020	2020
	OtherPeriodText	Scenario 1	Scenario 1	Scenario 1	Scenario 1	Scenario 1	Scenario 1
Geography	Text	Europe	Europe	Europe	Europe	Europe	Europe
Technology	Text	Future technology for maximized biofuel production. 500MW plant.	Future technology for maximized biofuel production. 500MW plant.	Future technology for maximized biofuel production. 500MW plant.	Future technology for maximized biofuel production. 500MW plant.	Future technology for maximized biofuel production. 500MW plant.	Future technology for maximized biofuel production. 500MW plant.
	ProductionVolume	500MW	500MW	500MW	500MW	500MW	500MW
	SamplingProcedure	Optimistic simulation with IPSEpro by plant developers.	Optimistic simulation with IPSEpro by plant developers.	Optimistic simulation with IPSEpro by plant developers.	Optimistic simulation with IPSEpro by plant developers.	Optimistic simulation with IPSEpro by plant developers.	Optimistic simulation with IPSEpro by plant developers.
	Extrapolations	none	none	none	none	none	none
	UncertaintyAdjustments	none	none	none	none	none	none
	PageNumbers	SP2-TUV	SP2-TUV	SP2-TUV	SP2-TUV	SP2-TUV	SP2-TUV

Tab. 3.54 Life cycle inventory analysis and unit process raw data of the TUV process, scenario 1, short-rotation wood

	Name	Location	InfrastructureProcess	Unit	biomass, incl. storage and preparation, wood	allothermal steam gasification, dual fluidized bed, wood	gas cleaning, wood	gas conditioning and compression, wood	Fischer-Tropsch synthesis, wood	BTL-fuel, wood, at refinery	UncertaintyType	StandardDeviation95%	GeneralComment	Total	Total
	Location				TUV	TUV	TUV	TUV	TUV	TUV				TUV	TUV
	InfrastructureProcess				0	0	0	0	0	0				0	0
	Unit				h	h	h	h	h	kg				h	kg
input	bundles, short-rotation wood, scenario 1, at intermediate storage	RER	0	kg	1.18E+5	0	0	0	0	0	1	1.05	(1,1,1,1,1,1); as dry matter	1.18E+5	5.04E+0
ressource	Water, river	-	-	m3	0	0	0	0	0	0	1	3.00	(1,1,1,1,1,1); not used	0	0
technosphere	heat, biomass, at gas turbine and ORC cycle	TUV	0	MJ	6.88E+3	0	0	0	0	0	1	1.05	(1,1,1,1,1,1); Questionnaire	6.88E+3	2.94E-1
	electricity, biomass, at gas turbine and ORC cycle	TUV	0	kWh	7.10E+1	3.32E+4	0	6.89E+2	2.50E+1	0	1	1.05	(1,1,1,1,1,1); Questionnaire	3.40E+4	1.45E+0
	electricity, medium voltage, RENEW, at grid	RER	0	kWh	0	0	0	0	0	0	1	1.05	(1,1,1,1,1,1); Surplus electricity use for H2 minus credit for O2	0	0
	hydrogen, liquid, from water electrolysis, at plant	RER	0	kg	0	0	0	0	0	0	1	1.05	(1,1,1,1,1,1); not used because no advantage for this process	0	0
	oxygen, liquid, at plant	RER	0	kg	0	0	0	0	0	0	1	1.24	(2,4,1,1,1,5); not used	0	0
	nitrogen, liquid, at plant	RER	0	kg	0	0	0	0	0	0	1	1.24	(2,4,1,1,1,5); not used	0	0
	zinc for coating, at regional storage	RER	0	kg	0	0	0	1.40E+2	0	0	1	1.24	(2,4,1,1,1,5); ZnO catalyst, information in questionnaire	1.40E+2	6.00E-3
	catalyst, Fischer-Tropsch synthesis	RER	1	kg	0	0	0	0	2.34E+0	0	1	1.22	(2,5,1,1,1,na); general assumption catalyst use for Fischer-Tropsch synthesis	2.34E+0	1.00E-4
	soya oil, at plant	RER	0	kg	0	0	0	0	0	0	1	1.31	(2,3,1,1,3,5); not used	0	0
	chemicals organic, at plant	GLO	0	kg	0	0	0	0	0	0	1	1.31	(2,3,1,1,3,5); not used	0	0
	silica sand, at plant	DE	0	kg	0	2.14E+3	0	0	0	0	1	1.31	(2,3,1,1,3,5); bed material	2.14E+3	9.17E-2
	transport, lorry 32t, Euro 5, diesel	RER	0	tkm	1.91E+4	1.07E+2	0	8.42E+1	1.40E+0	0	1	2.09	(4,5,na,na,na,na); Standard distances	1.93E+4	8.27E-1
	transport, freight, rail	RER	0	tkm	0	0	0	1.40E+1	2.34E-1	0	1	2.09	(4,5,na,na,na,na); Standard distances	1.43E+1	6.10E-4
	tap water, at user	RER	0	kg	0	0	0	0	0	0	1	1.31	(2,3,1,1,3,5); Questionnaire	0	0
	treatment, inorganic production effluent, wood, to wastewater treatment, class 3	CH	0	m3	0	3.14E+1	0	0	0	0	1	1.31	(2,3,1,1,3,5); waste water, Email	3.14E+1	1.34E-3
	disposal, slag, wood, to residual material landfill	CH	0	kg	0	0	0	0	0	0	1	1.31	(2,3,1,1,3,5); slag	0	0
	disposal, filter dust, wood, to residual material landfill	CH	0	kg	0	4.29E+3	0	0	0	0	1	1.31	(2,3,1,1,3,5); ash, filter dust	4.29E+3	1.83E-1
	disposal, catalyst base CH2O production, 0% water, to residual material landfill	CH	0	kg	0	0	0	1.40E+2	0	0	1	1.31	(2,3,1,1,3,5); disposal catalyst	1.40E+2	6.00E-3
	off-gas, per kg CO2 emission	RER	0	kg	0	0	0	0	0	0	1	1.31	(2,3,1,1,3,5); All emissions are allocated to the electricity production	0	0
	refinery gas, burned in flare	GLO	0	MJ	0	0	0	0	0	1.50E-1	1	1.32	(3,5,na,1,3,na); general assumption, 2.5 kg/t refinery input	3.50E+3	1.50E-1
	process specific emissions, conversion plant	RER	0	kg	0	0	0	0	0	2.68E-4	1	1.22	(2,na,na,1,3,na); general assumption per kg of fuel, process specific emissions	6.27E+0	2.68E-4
	biomass, incl. storage and preparation, wood	TUV	0	h	0	0	0	0	0	4.28E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	4.28E-5
	allothermal steam gasification, dual fluidized bed, wood	TUV	0	h	0	0	0	0	0	4.28E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	4.28E-5
	gas cleaning, wood	TUV	0	h	0	0	0	0	0	4.28E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	4.28E-5
	gas conditioning and compression, wood	TUV	0	h	0	0	0	0	0	4.28E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	4.28E-5
	Fischer-Tropsch synthesis, wood	TUV	0	h	0	0	0	0	0	4.28E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	4.28E-5
	fuel synthesis plant	RER	1	unit	0	0	0	0	0	2.31E-10	1	1.31	(2,3,1,1,3,5); Calculation	5.40E-6	2.31E-10
	refinery treatment, FT-raw liquid	RER	0	kg	0	0	0	0	0	1.05E+0	1	1.24	(3,na,2,1,3,na); general assumption per kg of FT-raw liquid treated in a refinery	2.46E+4	1.05E+0
emission air, high population density	Heat, waste	-	-	MJ	2.56E+2	1.20E+5	0	2.48E+3	9.00E+1	0	1	1.31	(2,3,1,1,3,5); Calculation from electricity use	1.22E+5	5.23E+0
	Particulates, > 10 um	-	-	kg	5.00E+0	0	0	0	0	0	1	3.01	(3,na,1,1,1,na); general assumption emissions from biomass handling per hour	5.00E+0	2.14E-4
	Carbon dioxide, fossil	-	-	kg	0	0	0	0	0	0	1	1.31	(2,3,1,1,3,5); Calculation for fossil based chemicals	0	0
													conversion rate (biomass to all liquids)		
Input	mass			kg	153166	126137	142897	162826	163143	6.6			15%		
Output	mass			kg	126137	142897	162826	163143	23384	1.0			19%		
Output	energy			MJ	1863142	1881943	1910225	1839053	1033578	43.9			55%		

Tab. 3.55 Life cycle inventory analysis and unit process raw data of the TUV process, scenario 1, miscanthus

	Name	Location	InfrastructureProcess	Unit	biomass, incl. storage and preparation, miscanthus	allothermal steam gasification, dual fluidized bed, miscanthus	gas cleaning, miscanthus	gas conditioning and compression, miscanthus	Fischer-Tropsch synthesis, miscanthus	BTL-fuel, miscanthus, at refinery	UncertaintyType	StandardDeviation95%	GeneralComment	Total	Total
	Location				TUV	TUV	TUV	TUV	TUV	TUV				TUV	TUV
	InfrastructureProcess				0	0	0	0	0	0				0	0
	Unit				h	h	h	h	h	kg				h	kg
input	miscanthus-bales, scenario 1, at intermediate storage	RER	0	kg	1.10E+5	0	0	0	0	0	1	1.05	(1,1,1,1,1,1); as dry matter	1.10E+5	4.71E+0
ressource	Water, river	-	-	m3	0	0	0	0	0	0	1	3.00	(1,1,1,1,1,1); not used	0	0
technosphere	heat, biomass, at gas turbine and ORC cycle	TUV	0	MJ	3.81E+3	0	0	0	0	0	1	1.05	(1,1,1,1,1,1); Questionnaire, steam	3.81E+3	1.64E-1
	electricity, biomass, at gas turbine and ORC cycle	TUV	0	kWh	7.30E+1	3.10E+4	0	5.63E+2	2.90E+1	0	1	1.05	(1,1,1,1,1,1); Questionnaire	3.16E+4	1.36E+0
	electricity, medium voltage, RENEW, at grid	RER	0	kWh	0	0	0	0	0	0	1	1.05	(1,1,1,1,1,1); Surplus electricity use for H2 minus credit for O2	0	0
	hydrogen, liquid, from water electrolysis, at plant	RER	0	kg	0	0	0	0	0	0	1	1.05	(1,1,1,1,1,1); not used because no advantage for this process	0	0
	oxygen, liquid, at plant	RER	0	kg	0	0	0	0	0	0	1	1.24	(2,4,1,1,1,5); not used	0	0
	nitrogen, liquid, at plant	RER	0	kg	0	0	0	0	0	0	1	1.24	(2,4,1,1,1,5); not used	0	0
	zinc for coating, at regional storage	RER	0	kg	0	0	0	1.40E+2	0	0	1	1.24	(2,4,1,1,1,5); ZnO catalyst, information in questionnaire	1.40E+2	6.00E-3
	catalyst, Fischer-Tropsch synthesis	RER	1	kg	0	0	0	0	2.33E+0	0	1	1.22	(2,5,1,1,1,na); general assumption catalyst use for Fischer-Tropsch synthesis	2.33E+0	1.00E-4
	soya oil, at plant	RER	0	kg	0	0	0	0	0	0	1	1.31	(2,3,1,1,3,5); not used	0	0
	chemicals organic, at plant	GLO	0	kg	0	0	0	0	0	0	1	1.31	(2,3,1,1,3,5); not used	0	0
	silica sand, at plant	DE	0	kg	0	4.21E+3	0	0	0	0	1	1.31	(2,3,1,1,3,5); bed material	4.21E+3	1.81E-1
	transport, lorry 32t, Euro 5, diesel	RER	0	tkm	1.64E+4	2.10E+2	0	8.37E+1	1.40E+0	0	1	2.09	(4,5,na,na,na,na); Standard distances	1.67E+4	7.19E-1
	transport, freight, rail	RER	0	tkm	0	0	0	1.40E+1	2.33E-1	0	1	2.09	(4,5,na,na,na,na); Standard distances	1.42E+1	6.10E-4
	tap water, at user	RER	0	kg	0	0	0	0	0	0	1	1.31	(2,3,1,1,3,5); Questionnaire	0	0
	treatment, inorganic effluent, straw, to wastewater treatment, class 3	CH	0	m3	0	2.45E+1	0	0	0	0	1	1.31	(2,3,1,1,3,5); waste water, Email	2.45E+1	1.05E-3
	disposal, slag, straw, to residual material landfill	CH	0	kg	0	0	0	0	0	0	1	1.31	(2,3,1,1,3,5); slag	0	0
	disposal, filter dust, straw, to residual material landfill	CH	0	kg	0	8.41E+3	0	0	0	0	1	1.31	(2,3,1,1,3,5); ash, filter dust	8.41E+3	3.62E-1
	disposal, catalyst base CH2O production, 0% water, to residual material landfill	CH	0	kg	0	0	0	1.40E+2	0	0	1	1.31	(2,3,1,1,3,5); disposal catalyst	1.40E+2	6.00E-3
	off-gas, per kg CO2 emission	RER	0	kg	0	0	0	0	0	0	1	1.31	(2,3,1,1,3,5); All emissions are allocated to the electricity production	0	0
	refinery gas, burned in flare	GLO	0	MJ	0	0	0	0	0	1.50E-1	1	1.32	(3,5,na,1,3,na); general assumption, 2.5 kg/t refinery input	3.48E+3	1.50E-1
	process specific emissions, conversion plant	RER	0	kg	0	0	0	0	0	2.68E-4	1	1.22	(2,na,na,1,3,na); general assumption per kg of fuel, process specific emissions	6.23E+0	2.68E-4
	biomass, incl. storage and preparation, miscanthus	TUV	0	h	0	0	0	0	0	4.30E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	4.30E-5
	allothermal steam gasification, dual fluidized bed, miscanthus	TUV	0	h	0	0	0	0	0	4.30E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	4.30E-5
	gas cleaning, miscanthus	TUV	0	h	0	0	0	0	0	4.30E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	4.30E-5
	gas conditioning and compression, miscanthus	TUV	0	h	0	0	0	0	0	4.30E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	4.30E-5
	Fischer-Tropsch synthesis, miscanthus	TUV	0	h	0	0	0	0	0	4.30E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	4.30E-5
	fuel synthesis plant	RER	1	unit	0	0	0	0	0	2.31E-10	1	1.31	(2,3,1,1,3,5); Calculation	5.37E-6	2.31E-10
	refinery treatment, FT-raw liquid	RER	0	kg	0	0	0	0	0	1.05E+0	1	1.24	(3,na,2,1,3,na); general assumption per kg of FT-raw liquid treated in a refinery	2.45E+4	1.05E+0
emission air, high population density	Heat, waste	-	-	MJ	2.63E+2	1.11E+5	0	2.03E+3	1.04E+2	0	1	1.31	(2,3,1,1,3,5); Calculation from electricity use	1.14E+5	4.90E+0
	Carbon dioxide, fossil	-	-	kg	0	0	0	0	0	0	1	1.31	(2,3,1,1,3,5); Calculation for fossil based chemicals	0	0
	Particulates, > 10 um	-	-	kg	5.00E+0	0	0	0	0	0	1	3.01	(3,na,1,1,1,na); general assumption emissions from biomass handling per hour	5.00E+0	2.15E-4
													conversion rate (biomass to all liquids)		
Input	mass			kg	131406	116805	138323	161906	162053	5.7			18%		
Output	mass			kg	116805	138323	161906	162053	23252	1.0			20%		
Output	energy			MJ	1792746	1845126	1899961	1831871	1027747	43.9			57%		

3.9 Entrained Flow Gasification of Black Liquor for DME-production, BLEF-DME (SP3-CHEMREC)

Elaboration of LCI: Niels Jungbluth, ESU-services Ltd., Uster
Data provider Ingvar Landälv, Daniel Ingman, Chemrec

3.9.1 Pressurized gasification of black liquor with oxygen

Black liquor is an internal product in pulp and paper mills, currently incinerated in so-called recovery boilers for process steam generation. The integration of the gasification plant with the mill is shown in Fig. 3.9. Black liquor gasification (BLG) produces an energy-rich syngas, which instead may be used to synthesise automotive fuels. The use of black liquor for chemical syntheses implies that the withdrawn energy has to be replaced with imported biomass to comply with the pulp mill's need for steam and power. The use of black liquor as an intermediate product results in a positive leverage on the amount of biomass fuel used.

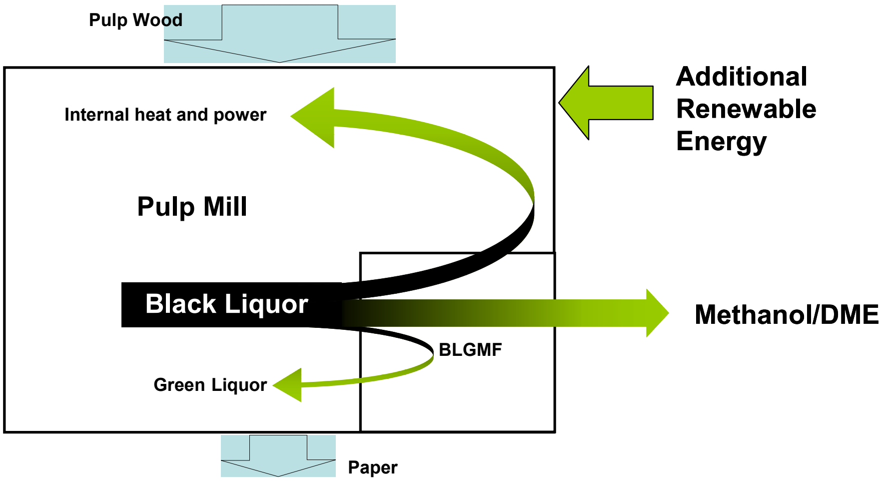

Fig. 3.9 Process integration of BLGMF plant with pulp and paper mill, size of streams not in scale (© Chemrec AB)

Fig. 3.10 shows the flow chart for pressurized gasification of black liquor with oxygen[22], that part of Fig. 3.9 which is named BLGMF i.e. black liquor gasification with motor fuel production. The core of the system is the gasifier unit, a refractory-lined entrained flow reactor where concentrated black liquor is gasified with oxygen at elevated pressure. Black liquor is converted in the reaction zone into smelt droplets consisting of inorganic compounds and an energy-rich syngas.

The smelt droplets and the raw syngas are separated in a quench dissolver where they are simultaneously brought into direct contact with condensate. The smelt droplets dissolve in the liquid to form a green liquor solution. The gas leaving the quench dissolver is scrubbed and cooled.

The BLG product gas is a well-suited raw gas for synthesis gas production. The cooled raw gas is purified in a liquid scrubber mainly for tar and hydrogen sulphide removal, but also for carbon dioxide removal. The purified syngas, now consisting of hydrogen, carbon monoxide and a small amount of carbon dioxide, is further conditioned in order to match the synthesis unit requirements in terms of H_2:CO stoichiometry for maximum DME/methanol output.

The gasifier is designed to achieve high carbon conversion and sulphur reduction. The quantity of unburned carbon and sulphate in the green liquor is consequently low.

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[22] Information based on description on www.chemrec.se.

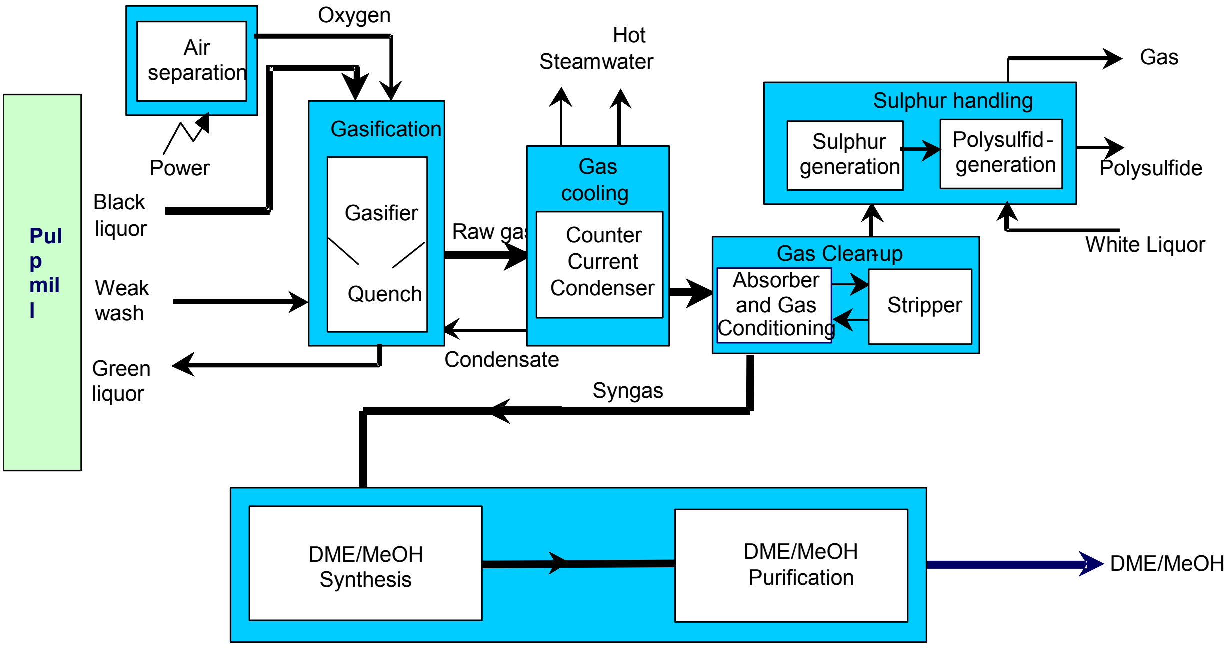

Fig. 3.10 Flow chart of pressurized gasification of black liquor with oxygen, the BLGMF process (© Chemrec AB)

Fig. 3.11 shows the system boundaries of this process for the data questionnaire. The delivery of biomass to the pulp mill compensates for black liquor withdrawn for use in the DME synthesis. This biomass will be used for: 1) Steam production to cover the mill's total needs; 2) Electric power generation to cover for the mill's needs and the internal consumption of the BLGMF plant as well as external deliveries of power to the grid (the same amount as a state-of-the-art recovery boiler would have produced).

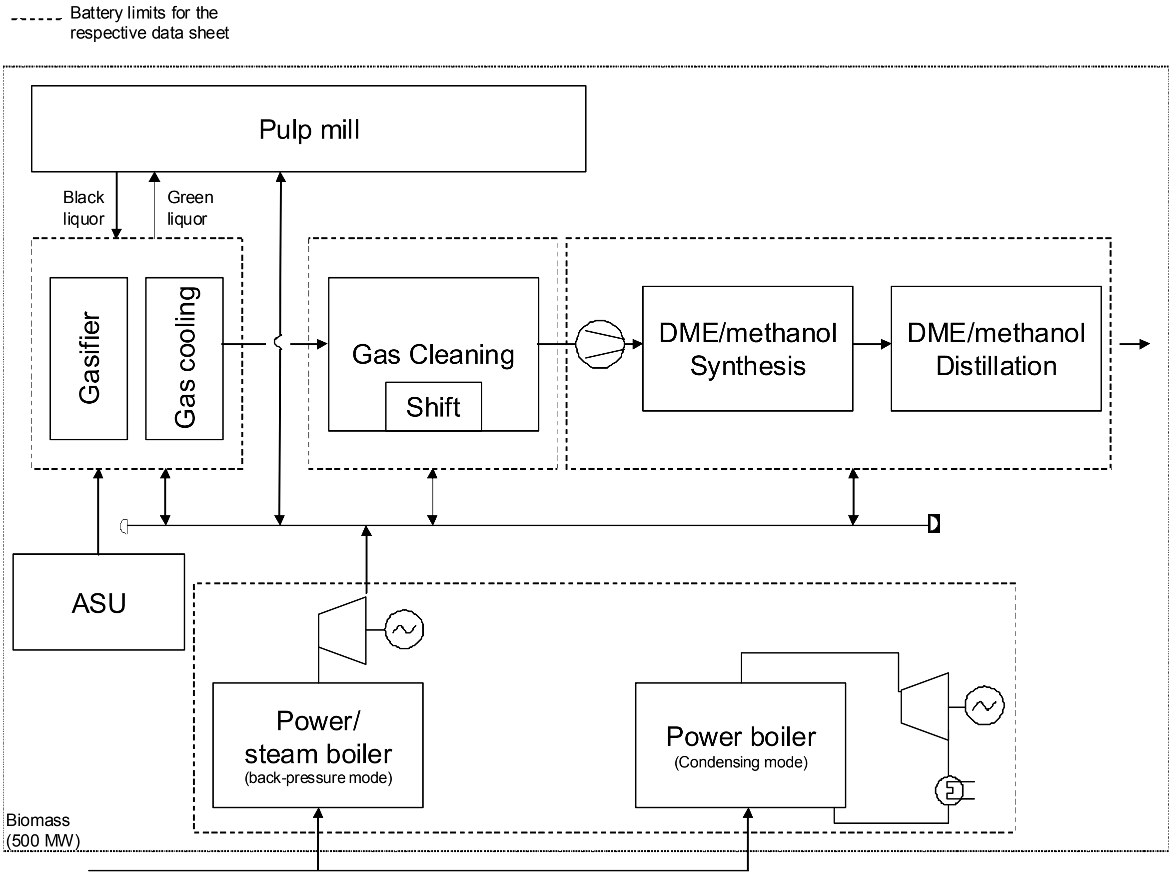

Fig. 3.11 System boundaries of pressurized gasification of black liquor with oxygen in the BLGMF process (© Chemrec AB); ASU – air separation unit

3.9.2 Inventory

The oxygen is produced on site in a cryogenic air separation unit. The power consumption of this, in the order of 23 MW, as well as all other internal consumers are included in the overall energy balance, which is covered by the 500 MW biomass import. There is no power demand that has to be covered by import from the national grid, rather the plant result in a net electricity surplus of approximately 66 MW.

The CO_2 emissions are calculated based on the change in mill plant concept before and after the inclusion of the gasification plant. The CO_2 emissions from burning the black liquor in the recovery boiler will disappear. The same amount will show up in two places namely the CO_2 emissions from the gas purification and in the product DME. Thus the CO_2 emissions from these to places shall not be included when calculating the CO_2 emissions from the BLGMF concept. New (additional) CO_2 emissions will come from the H&P boiler which supplies the steam and power required for the pulp mill process combined with the BLGMF plant. The total additional CO_2 emissions stem from this boiler plus a separate power boiler, which is needed to sustain the electric power balance. The amount correspond to the 500 MW imported biomass which is totally used in combustion processes in the two boilers. The BLGMF concept shall be credited the CO_2 emissions which will come from the use of the DME in the engines as this CO_2 emissions is originating from the black liquor which is already in the net balance.

The ASU (air separation unit) consumes 23 MW, synthesis 12 MW, AGR (Acid Gas Removal or gas cleaning used to take out the acidic gases CO2 and H2S) plant 4.3 MW and the boilers 8 MW for BFW (Boiler Feed Water and is de-ionized water of quality suitable to be added into a steam system) pumps etc. The internal consumption of the processes directly associated with the BLGMF plant is 44.6 MW. Additional and smaller consumers (steam compressors, gasifier etc) add up to approximately 5 MW. The 44 MW does not include the consumption of the boilers. They are covered in the overall scope, together with the power consumption of the mill.

The ash content of the biomass fuel is normally between 40-50% on an as received mass basis, depending on the moisture content and other parameters. The 500 MW of biomass imported is typical forest residues, with about 1% ash content. As described previously, this biomass is used as fuel for the stem and power boilers. The “ashes” of the black liquor is returned to the pulp mill in the form of so called green liquor for re-use as cooking chemical and there is thus no net ash formed from the gasifier e.g. to be put on landfill or spread on forestland. (The 500 MW biomass import will of course result in production of ash to be recycled to forestland.) The life cycle inventory analysis of this process takes into account only the incremental change of the original system for the production of paper. The amount of wood is calculated with the energy content that is necessary to replace the Black Liquor plus the amount of wood burned in the power plant for delivering heat and electricity to the conversion process. As wood is used for the power plant, also the emission profile of a wood power plant is used in this case. All emissions coming directly from the conversion and due to the supply of heat and electricity for the conversion process are accounted for. The life cycle inventory analysis and further information are shown in the following tables.

The additional power boiler supplies the steam required for the pulp mill process. The gross CO_2 emissions stem from this boiler, a separate power boiler to sustain the electric power balance (as well as some surplus for export) as well as the CO_2 separated from the syngas. The amount corresponds to the 500 MW biomass plus the CO_2 from the syngas, as the imported biomass is totally used in combustion processes (no part of the biomass is used for syngas generation – black liquor is the fuel for the gasifier). The net CO_2 emissions are the total emissions reduced with the total carbon amount contained in the black liquor, since this is used today in a combustion process. The only change in emissions is due to the incremental biomass import of 500 MW.

The life cycle inventory analysis of this process takes into account only the incremental change of the original system for the production of paper. The amount of wood is calculated with the energy content that is necessary to replace the Black Liquor plus the amount of wood burned in the power plant for delivering heat and electricity to the conversion process. As wood is used for the power plant, also the emission profile of a wood power plant is used in this case.

All emissions coming directly from the conversion and due to the supply of heat and electricity for the conversion process are accounted for.

The effluents have a total organic carbon content of 0.26 kg/m^3 and are discharged to a biologic treatment at the pulp mill site.

The life cycle inventory analysis and further information are shown in the following tables.

Starting point calculation

Tab. 3.56 Documentation of the inventory data of the Chemrec process, starting point calculation

ReferenceFunction	Name	biomass, incl. storage and preparation, wood	autothermal entrained flow gasification, black liquor	gas cleaning, black liquor	dimethylether synthesis, black liquor	dimethylether, black liquor, at synthesis plant
Geography	Location	Chemrec	Chemrec	Chemrec	Chemrec	Chemrec
ReferenceFunct	InfrastructureProcess	0	0	0	0	0
ReferenceFunct	Unit	h	h	h	h	kg
	IncludedProcesses	Transport from the 1st gathering point. Handling emissions. Storage and preparation of biomass for the conversion process. The biomass is actually used in the paper mill and replaces the amount of black liquor that is used for the conversion process.	Gasification of biomass. Includes electricity use for air separation unit (ASU).	Cleaning of synthesis gas in liquid scrubber mainly for tar and H2S removal.	Synthesis of dimethylether from synthesis gas and distillation for the product. Amount of copper - chromium catalyst not known.	All process stages for the production of dimethylether. Wood is included in the analysis as an replacement for Black Liquor in the energy regime of the paper mill
	Synonyms	Entrained Flow Gasification of Black Liquor for DME-production//BLEF-DME	Entrained Flow Gasification of Black Liquor for DME-production//BLEF-DME	Entrained Flow Gasification of Black Liquor for DME-production//BLEF-DME	Entrained Flow Gasification of Black Liquor for DME-production//BLEF-DME	Entrained Flow Gasification of Black Liquor for DME-production//BLEF-DME
	GeneralComment	Starting point scenario. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by the respective technology partner.	Starting point scenario. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by the respective technology partner.	Starting point scenario. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by the respective technology partner.	Starting point scenario. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by the respective technology partner.	Starting point scenario. All inventory data are based on information provided by plant developers and on own assumptions. The data given here represents the current status of BtL technology. Further technology progress may strongly influence the LCI data. Therefore it is recommended to use updated data for future studies or to approve this data by the respective technology partner.
	Category	biomass	biomass	biomass	biomass	biomass
	SubCategory	fuels	fuels	fuels	fuels	fuels
	Formula				C2H6O	C2H6O
	StatisticalClassification					
	CASNumber					
TimePeriod	StartDate	2005	2005	2005	2005	2005
	EndDate	2006	2006	2006	2006	2006
	OtherPeriodText	Starting point scenario	Starting point scenario	Starting point scenario	Starting point scenario	Starting point scenario
Geography	Text	Europe	Europe	Europe	Europe	Europe
Technology	Text	actual development state for biofuel conversion	actual development state for biofuel conversion	actual development state for biofuel conversion	actual development state for biofuel conversion	actual development state for biofuel conversion
	ProductionVolume	500MW	500MW	500MW	500MW	500MW
	SamplingProcedure	questionnaire	questionnaire	questionnaire	questionnaire	questionnaire
	Extrapolations	none	none	none	none	none
	UncertaintyAdjustments	none	none	none	none	none
	PageNumbers	SP3-CHEMREC	SP3-CHEMREC	SP3-CHEMREC	SP3-CHEMREC	SP3-CHEMREC

Tab. 3.57 Life cycle inventory analysis and unit process raw data of the Chemrec process, starting point calculation

	Name	Location	Unit	biomass, incl. storage and preparation, wood	autothermal entrained flow gasification, black liquor	gas cleaning, black liquor	dimethylether synthesis, black liquor	dimethylether, black liquor, at synthesis plant	UncertaintyType	StandardDeviation 95%	GeneralComment	Total	Total
	Location			Chemrec	Chemrec	Chemrec	Chemrec	Chemrec				Chemrec	Chemrec
	InfrastructureProcess			0	0	0	0	0					
	Unit			h	h	h	h	kg				h	kg
input	bundles, short-rotation wood, at intermediate storage	RER	kg	1.14E+5	0	0	0	0	1	1.05	(1,2,1,1,1,1); as dry matter	1.14E+5	2.65E+0
ressource	Water, river	-	m3	0	2.80E+2	0	0	0	1	3.00	(1,1,1,1,1,1); Questionnaire	2.80E+2	6.53E-3
	Carbon dioxide, in air	-	kg	2.06E+5	0	0	0	0	1	1.05	(1,1,1,1,1,1); Carbon bound in Black Liquor	2.06E+5	4.79E+0
technosphere	heat, biomass, at steam and power boiler	Chemrec	MJ	0	0	0	0	5.85E+0	1	1.05	(1,1,1,1,1,1); rough calculation for steam use	2.51E+5	5.85E+0
	electricity, biomass, at steam and power boiler	Chemrec	kWh	0	2.68E+4	4.30E+3	1.35E+4	0	1	1.05	(1,1,1,1,1,1); gasification, rest for ASU (air fractionation) also as input for gasification	4.46E+4	1.04E+0
	oxygen, liquid, at plant	RER	kg	0	0	0	0	0	1	1.24	(2,4,1,1,1,5); not included because on site production in ASU	0	0
	catalyst, Fischer-Tropsch synthesis	RER	kg	0	0	0	4.29E+0	0	2	1.22	(2,5,1,1,1,na); rough assumption, catalysts used are made of copper and chromium	4.29E+0	1.00E-4
	zinc for coating, at regional storage	RER	kg	0	2.57E+2	0	0	0	1	1.32	(3,5,na,1,3,na); general assumption, catalyst for gas conditioning	2.57E+2	6.00E-3
	transport, lorry 32t	RER	tkm	2.22E+4	1.54E+2	0	2.57E+0	0	1	2.09	(4,5,na,na,na,na); Standard distance	2.24E+4	5.21E-1
	transport, freight, rail	RER	tkm	0	2.57E+1	0	4.29E-1	0	1	2.09	(4,5,na,na,na,na); Standard distance	2.62E+1	6.10E-4
	treatment, inorganic effluent, straw, to wastewater treatment, class 3	CH	m3	0	0	0	0	0	1	1.31	(2,3,1,1,3,5); not used	0	0
	treatment, organic effluent, wood, to wastewater treatment, class 3	CH	m3	0	0	0	1.89E+1	0	1	1.31	(2,3,1,1,3,5); Questionnaire	1.89E+1	4.41E-4
	disposal, slag, wood, to residual material landfill	CH	kg	0	0	0	0	0	1	1.31	(2,3,1,1,3,5); not used	0	0
	disposal, filter dust, wood, to residual material landfill	CH	kg	0	0	0	0	0	1	1.31	(2,3,1,1,3,5); ash 40000 kg/h from gasification is fully re-used as cooking chemical.	0	0
	disposal, catalyst base CH2O production, 0% water, to residual material landfill	CH	kg	0	2.57E+2	0	0	0	1	1.22	(2,5,1,1,1,na); general assumption, catalyst for gas conditioning	2.57E+2	6.00E-3
	off-gas, per kg CO2 emission	RER	kg	0	0	1.27E+5	0	0	1	1.31	(2,3,1,1,3,5); Questionnaire	1.27E+5	2.96E+0
	refinery gas, burned in flare	GLO	MJ	0	0	0	0	1.50E-1	1	1.32	(3,5,na,1,3,na); general assumption, 2.5 kg/t refinery input	6.42E+3	1.50E-1
	process specific emissions, conversion plant	RER	kg	0	0	0	0	2.68E-4	1	1.22	(2,na,na,1,3,na); general assumption per kg of fuel, process specific emissions	1.15E+1	2.68E-4
	biomass, incl. storage and preparation, wood	Chemrec	h	0	0	0	0	2.33E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	2.33E-5
	autothermal entrained flow gasification, black liquor	Chemrec	h	0	0	0	0	2.33E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	2.33E-5
	gas cleaning, black liquor	Chemrec	h	0	0	0	0	2.33E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	2.33E-5
	dimethylether synthesis, black liquor	Chemrec	h	0	0	0	0	2.33E-5	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	2.33E-5
	fuel synthesis plant	RER	unit	0	0	0	0	2.47E-10	1	1.31	(2,3,1,1,3,5); Calculation	1.00E+0	2.33E-5
emission air, high population density	Heat, waste	-	MJ	0	9.65E+4	1.55E+4	4.86E+4	0	1	1.31	(2,3,1,1,3,5); Calculation from electricity use	1.61E+5	3.74E+0
	Particulates, > 10 um	-	kg	5.00E+0	0	0	0	0	1	3.01	(3,na,1,1,1,na); general assumption emissions from biomass handling per hour	5.00E+0	1.17E-4
											conversion rate (biomass to all liquids)		
Input	mass		kg	1.48E+5	2.20E+5	1.62E+5	6.70E+4	3.45E+0			29%		
Output	mass, after preparation		kg	1.48E+5	1.62E+5	6.70E+4	4.29E+4	1.00E+0			29%		
Input	energy		MJ	1.80E+6	2.16E+6	1.21E+6	1.64E+6	-			69%		

Scenario 1

CHEMREC has not provided data for Scenario 1. Thus, no evaluation is made.

3.10 Circulating Fluidized Bed Ethanol, CFB-E (SP4-ABENGOA)

Author:	Niels Jungbluth, ESU-services Ltd., Uster
Data provider	No data

3.10.1 Optimization of bioethanol production

SP4 focuses on research and development for the optimization of the ethanol production from ligno-cellulosic biomass in two different ways: the enzymatic pathway and the thermochemical pathway. The project work plan includes six work packages having individual research and technical objectives and deliverables.

An assessment of the enzyme pathway will be undertaken to integrate the information generated by current R&D projects being developed by Abengoa Bioenergía. They are analysing each stage of the complete enzymatic process.

AICIA will investigate the catalytic conversion of syngas to ethanol, at lab scale, using a catalyst available from Abengoa Bioenergía. Furthermore, a complete simulation model of the global thermo-chemical pathway will be developed.

Enzyme-based bioethanol process

Fig. 3.12 shows the schematic flow chart of an enzyme based bioethanol production process.[23] Cereal grain (wheat, barley, corn, etc.) harvesting generates biomass residues, which are comprised of stalks, leaves, and cobs (in the case of corn). These agricultural residues are normally left in the field and used as an organic source for the soil. A substantial amount of these residues could be collected and used as raw material for bioethanol production. The major unit operations include: feedstock storage and preparation, pre-treatment, hydrolysis, fermentation, ethanol recovery and solid liquid separation.

<u>Feedstock Storage and Preparation:</u> The plant will process approximately 70 tonnes of wheat or barley straw per day. BCL and Abengoa will work closely with the feedstock suppliers and farmers to ensure appropriate harvest, baling and storing techniques are used to meet the requirements of the ethanol plant. Upon delivery at the plant, the straw bales will be stored in stacks under cover. The straw is reduced in particle size to facilitate feeding into the pre-treatment reactor. Dust collection equipment will be incorporated with the milling system to minimize release of dust inside the plant or to the environment. The milled straw will then be conveyed to a surge bin in the pre-treatment area.

<u>Pre-treatment:</u> Ligno-cellulosic biomass such as straw requires thermo chemical pre-treatment to significantly increase the accessibility of cellulose to enzyme attack. Pre-treatment breaks down the carbohydrate lignin matrix that shields the cellulosic fibres. The BCL plant adopts one of the most effective pre-treatment methods, which use direct steam for breaking down of the carbohydrate lignin complex. The main goals of the pre-treatment step are: (1) to increase the cellulose enzymatic digestibility, (2) solubilise the hemicellulose, and (3) minimize formation of degradation products that are inhibitory to yeast. Milled straw is fed into the pre-treatment reactor. High pressures team is then injected to rapidly heat up the straw particles. After a short heating period, the pre-treated material is discharged from the pre-treatment reactor into a flask tank, where flash vapour is either used for preheating incoming feed, or condensed and used in other processing steps. A measured amount of alkali solution is added to the flash tank to adjust the pH of the pre-treated slurry (or pre-hydrolysate) to a desirable value. The slurry is cooled down further using a heat exchanger, and then forwarded to the hydrolysis and fermentation area.

<u>Hydrolysis and Fermentation:</u> Enzymatic cellulose hydrolysis and ethanol fermentation are carried out simultaneously. This method is referred to as simultaneous saccharification and fermentation (SSF). SSF is carried out in 4 fermentors operating in batch mode. Commercially available cellulase enzyme will be purchased and stored on site. A propagation fermentation system will be used to activate dry yeast from commercial sources. A fraction of the pre-hydrolysate is added to the yeast propagation fermentors to adapt the yeast to potential inhibitors. As the pH-adjusted pre-hydrolysate is pumped into a fermentor, measured amounts of enzyme and yeast cream (from the propagation fermentors) are added to start the SSF process while the fermentor is being filled. The SSF cycle for each fermentor is about 72-96 hours. At the end of the cycle, the beer is sent to the distillation area. Carbon dioxide from the fermentors is routed through a vent scrubber to recovered ethanol vapour, then to the main carbon dioxide collection system of the grain ethanol plant.

<u>Distillation</u>: The beer streams from the fermentors are sent to a beer well, and from there forwarded to a conventional distillation system similar to that used in the grain ethanol plant. Ethanol is stripped

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[23] Description based on www.abengoabioenergy.com.

from the beer, distilled to 92% (w/w), and then sent to the dehydration system of the grain ethanol plant.

Solid Liquid Separation: The whole stillage (about 7% w/w total solids) from the distillation system is sent to a centrifuge feed tank, and from there fed into a decanter centrifuge. The centrate or thin stillage is mixed with the thin stillage from the grain ethanol plant. The combined thin stillage is then concentrated to 35% w/w syrup in the evaporator of the grain ethanol plant. The cake can either be blended with the distiller's grain from the grain ethanol plant or collected separately for further processing and evaluation. As the amount of biomass SSF residual solids is less than about 5% of the distiller's grain, mixing the two streams is expected to result in a small impact on the characteristics of the distiller's grain product.

The production of bioethanol from agricultural residues, specifically, corn stalks and wheat straw, requires extensive processing to release the polymeric sugars in cellulose and hemicellulose that account for 35 to 40% and 20 to 25% of plant material, respectively. Abengoa is developing a novel biomass-to-ethanol process, with emphasis on thermochemical fractionation and enzymatic hydrolysis to release these sugars for ethanol fermentation. The development of the process technology has the following goals:

- Potential for further improvement to be competitive with starch-based bioethanol production;
- Compatibility with grain bioethanol production process to achieve synergistic gains when integrating the stover-to-bioethanol plant with the grain bioethanol production facility (for example, the two processes could share utilities and even certain process equipment).

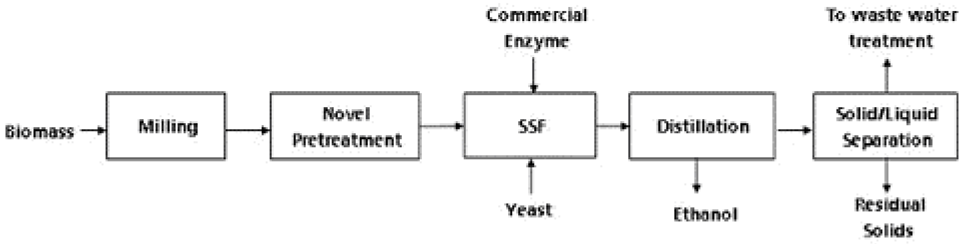

Fig. 3.12 Flow chart of a typical enzyme-based bioethanol process

Thermochemical conversion of biomass to ethanol[24]

Fig. 3.13 shows the thermochemical conversion process of biomass to ethanol. Agricultural residues like corn stalks and straw can be used for the production of fuels. The thermochemical pathway to produce ethanol from biomass consists in two main parts, biomass gasification and syngas catalytic conversion. Both parts are being studied by AICIA for the Renew project.

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[24] Description based on AICIA information.

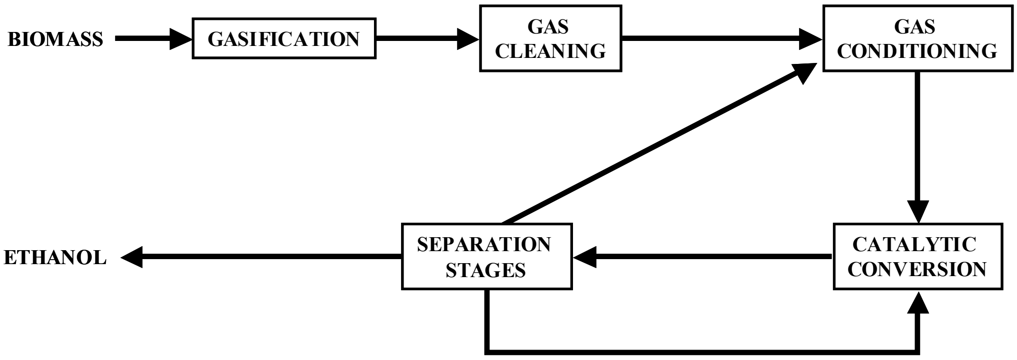

Fig. 3.13 Thermochemical conversion process of biomass to ethanol

The gasification process is going to be studied in a 150 kW_{th} pilot gasifier, using steam and enriched air as gasifier agent, in order to get data. Gas cleaning processes will be studied too.

After the gas cleaning, gas conditioning processes are being studied. AICIA is considering and comparing, steam and autothermal reforming, and CO_2 removal processes, like MEA and Rectisol. CO_2 could be reintroduced partly in the reforming reactor in order to shift the reactions equilibrium. After these processes the gas is at the desired conditions for the catalytic synthesis.

Catalytic synthesis will be carried out in a tubular fixed-bed reactor, with temperatures between 250-350ºC. This reactor could work at high pressure (up to 100 bar). The catalysts that are going to be tested in an experimental facility are combinations of metal (Rh, Fe, Mo, Co, Cu) and alkalises. Effluent gases are recycled to the reactor inlet or to the steam reforming, in order to be reintroduced in the process. Liquids products are a mixture of alcohols and other oxygenated hydrocarbons. Liquids products are separated with distillation techniques from the ethanol and then can be recycled as well to the reforming reactor or to the gasifier.

3.10.2 Inventory (no data)

No data were available until the deadline. Thus, this process has been excluded from all further analyses.

3.11 Data quality

Many data for the conversion processes have been directly provided by the RENEW partners. The data were cross-checked by technology experts from WP 5.4. Other data describing the investigated technology in this study were not available for verification. According to the project partners in WP5.4 a quantitative assessment of the data uncertainties is not possible. Further details for the data quality check can be found in the WP5.4-reports (Vogel 2007; Vogel et al. 2007).

The data have been checked during the life cycle impact assessment and interpretation of this study. Single data points important for the results have been confirmed with the plant developers. Thus, several mistakes could be corrected. Furthermore, the correctness of the carbon balances has been checked.

All conversion concepts are investigated on a scale of 500 MW biomass input. Some conversion concepts could be improved by increasing the plant size to up to 5 GW. This has not been considered in this study.

Tab. 3.58 shows an overview about the data provided by the conversion plant developers and generic assumptions used to supplement the life cycle inventory data.

All background data, e.g. on fertilizer production or agricultural machinery are based on the ecoinvent database. This has been investigated following the same methodological rules as used in this study.

The quality of background data and foreground data is on a comparable and consistent level and all data are fully transparent.

Tab. 3.58 Overview on data provided by different conversion plant developers

Concept	Centralized Entrained Flow Gasification	Centralized Autothermal Circulating Fluidized Bed Gasification	Decentralized Entrained Flow Gasification	Allothermal Circulating Fluidized Bed Gasification	Entrained Flow Gasification of Black Liquor for DME-production
Abbreviation	cEF-D	CFB-D	dEF-D	ICFB-D	BLEF-DME
Developer	UET	CUTEC	FZK	TUV	CHEMREC
Biomass input	Amount and type	Amount and type	Amount and type	Amount and type	Amount and type
Biomass type	Wood, straw	Wood, straw	Straw	Wood, miscanthus	Wood, black liquor
Heat and electricity use	Provided	Provided	Provided and own assumptions	Provided	Provided
Auxiliary materials	Hydrogen, Fe(OH)2	Filter ceramic, RME, silica sand, quicklime, iron chelate	Nitrogen, silica sand	Nitrogen, RME, quicklime, silica sand	No auxiliaries reported
Catalysts	Literature	Literature	Literature	Amount of zinc catalyst	Literature
Emission profile	Literature for gas firing and plant data for CO	Literature for gas firing	Literature for gas firing, plant data for H_2S and own calculations	Literature for gas firing and plant data for CO, CH_4, NMVOC	Literature for wood firing and plant data for CO, H_2S, CH_4
Amount of air emissions	Calculated with emission profile and CO_2 emissions	Calculated with emission profile and CO_2 emissions	Calculated with emission profile and own assumptions on CO_2.	Calculated with emission profile and CO_2 emissions	Calculated with emission profile and CO_2 emissions
Effluents	Amount and concentrations	Only amount. Rough assumption on pollutants	Only amount. Rough assumption on pollutants	Only amount. Rough assumption on pollutants	Amount and TOC concentration. Rough assumption on pollutants
Wastes	Amount and composition	Only amount	Only amount	Only amount	Only amount
Fuel upgrading	Included in process data	Standard RENEW model for upgrading	Standard RENEW model for upgrading	Standard RENEW model for upgrading	Included in process data
Products	BTL-FT, electricity	FT-raw product, electricity	FT-raw product, electricity	FT-raw product, electricity	BTL-DME

4 Life cycle inventory of fuel distribution

Elaboration of LCI: Niels Jungbluth, ESU-services Ltd., Uster
Data provider ESU-services Ltd., Oliver Busch, BP

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. 4.1 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. 4.1 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	-

Inventory data of the regional storage of liquid biofuels are consistent with the inventory data of petrol and diesel fuels (Jungbluth 2004:174). This unit process includes all transports from the processing to the filling station, the infrastructure of intermediate tanks and the filling station, fugitive emissions to air during refilling and storage operations, water emissions from run-off water at the filling station.

The following standard assumptions are used, if data are not available:

- 0.119 g/kg diesel and 0.38 g/kg DME are assumed as losses to air (Winkler 2004: assumption for DME based on figure for petrol). The fugitive emission profile to air has to be adapted to the fuel properties.
- Transport of fuel to the filling station is 150 km with lorry 28 t and 150 km with freight train.
- Data on electricity use, infrastructure, water use and emissions are based on the inventory of petrol (see Tab. 4.3)
- The reference flow (MJ) is based on the lower heating contents estimated by the conversion plant developers (see Tab. 4.4).

Due to lack of data, the energy use, infrastructure and losses for the distribution of DME are considered to be the same as petrol, even thought they have different heating values and losses might be not the same.[25] Thus, no difference between BTL-FT and BTL-DME is made for the inventory analysis except the fugitive emissions.

Tab. 4.2 Documentation of the inventory data of fuel distribution, starting point calculation (extract)

ReferenceFunction	Name	BTL-fuel, wood, at service station	BTL-fuel, straw, at service station	BTL-fuel, wood, at service station
Geography	Location	UET	UET	CUTEC
ReferenceFunctio	InfrastructureProcess	0	0	0
ReferenceFunctio	Unit	kg	kg	kg
	IncludedProcesses	Transportation of product from the production plant to the end user. Operation of storage tanks and filling stations. Emissions from evaporation and treatment of effluents. Excluding emissions from car-washing at filling stations.	Transportation of product from the production plant to the end user. Operation of storage tanks and filling stations. Emissions from evaporation and treatment of effluents. Excluding emissions from car-washing at filling stations.	Transportation of product from the production plant to the end user. Operation of storage tanks and filling stations. Emissions from evaporation and treatment of effluents. Excluding emissions from car-washing at filling stations.
	Synonyms	Centralized Entrained Flow Gasification//cEF-D	Centralized Entrained Flow Gasification//cEF-D	CFBR//Centralized Autothermal CFB-Gasification//CFB-D
	GeneralComment	Inventory for the distribution of the fuel product to the final consumer (household, car, power plant, etc.) including all necessary transports.	Inventory for the distribution of the fuel product to the final consumer (household, car, power plant, etc.) including all necessary transports.	Inventory for the distribution of the fuel product to the final consumer (household, car, power plant, etc.) including all necessary transports.
	InfrastructureIncluded	1	1	1
	Category	biomass	biomass	biomass
	SubCategory	fuels	fuels	fuels
	Formula			
	StatisticalClassification			
	CASNumber			
TimePeriod	StartDate	2000	2000	2000
	EndDate	2005	2005	2005
	OtherPeriodText	Most information for the year 2000. Split up of NMVOC emissions published 1989. Amount of NMVOC estimated in 2004.	Most information for the year 2000. Split up of NMVOC emissions published 1989.	Most information for the year 2000. Split up of NMVOC emissions published 1989.
Geography	Text	Surveys mainly for DE and CH.	Surveys mainly for DE and CH.	Surveys mainly for DE and CH.
Technology	Text	Distribution of petroleum fuel products.	Distribution of petroleum fuel products.	Distribution of petroleum fuel products.
	ProductionVolume			
	SamplingProcedure	Environmental reports and literature.	Environmental reports and literature.	Environmental reports and literature.
	Extrapolations	From single companies to average data. Data for petrol are used for other fuels.	From single companies to average data. Data for petrol are used for other fuels.	From single companies to average data. Data for petrol are used for other fuels.
	UncertaintyAdjustments	none	none	none
	PageNumbers	distribution	distribution	distribution

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[25] Email communication with Robert Svensson, Patrick Klintbom, Volvo Technology Corporation, 19.7.2006.

Tab. 4.3 Life cycle inventory data of fuel distribution (dimethylether and one example for BTL-fuel)

	Name	Location	InfrastructureP	Unit	BTL-fuel, wood, at service station	dimethylether, black liquor, at service station	StandardDeviation95%	GeneralComment
	Location				UET	Chemrec		
	InfrastructureProcess				0	0		
	Unit				kg	kg		
technosphere	BTL-fuel, wood, at fuel synthesis	UET	0	kg	1.0001E+0	-	1.05	(1,1,1,1,1,1); Product plus losses
	BTL-fuel, straw, at fuel synthesis	UET	0	kg	-	-	1.05	(1,1,1,1,1,1); Product plus losses
	BTL-fuel, wood, at refinery	CUTEC	0	kg	-	-	1.05	(1,1,1,1,1,1); Product plus losses
	BTL-fuel, straw, at refinery	CUTEC	0	kg	-	-	1.05	(1,1,1,1,1,1); Product plus losses
	BTL-fuel, straw, at refinery	FZK	0	kg	-	-	1.05	(1,1,1,1,1,1); Product plus losses
	BTL-fuel, wood, at refinery	TUV	0	kg	-	-	1.05	(1,1,1,1,1,1); Product plus losses
	BTL-fuel, miscanthus, at refinery	TUV	0	kg	-	-	1.05	(1,1,1,1,1,1); Product plus losses
	dimethylether, black liquor, at synthesis plant	Chemrec	0	kg	-	1.0004E+0	1.05	(1,1,1,1,1,1); Product plus losses
	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh	6.70E-3	6.70E-3	1.25	(2,4,1,3,3,3); Data for fuel distribution (storage and filling station)
	light fuel oil, burned in boiler 100kW, non-modulating	CH	0	MJ	6.21E-4	6.21E-4	1.25	(2,4,1,3,3,3); Data for fuel distribution (storage)
	tap water, at user	RER	0	kg	6.89E-4	6.89E-4	1.25	(2,4,1,3,3,3); Data for petrol distribution
	transport, lorry 32t	RER	0	tkm	1.50E-1	1.50E-1	2.09	(4,5,na,na,na,na); Standard assumption 150km from plant to filling station
	transport, freight, rail	RER	0	tkm	1.50E-1	1.50E-1	2.09	(4,5,na,na,na,na); Standard assumption 150km from plant to filling station
	regional distribution, oil products	RER	1	unit	2.78E-10	2.78E-10	3.06	(3,na,1,3,3,na); Average data for petrol station
	treatment, sewage, to wastewater treatment, class 2	CH	0	m3	6.89E-7	6.89E-7	1.25	(2,4,1,3,3,3); Used water
	treatment, rainwater mineral oil storage, to wastewater treatment, class 2	CH	0	m3	7.50E-5	7.50E-5	1.40	(4,5,3,3,3,na); Treatment of rainwater with pollutants
	disposal, municipal solid waste, 22.9% water, to sanitary landfill	CH	0	kg	6.27E-6	6.27E-6	1.25	(2,4,1,3,3,3); Environmental report for wastes
	disposal, separator sludge, 90% water, to hazardous waste incineration	CH	0	kg	1.68E-4	1.68E-4	1.27	(2,4,3,3,3,3); Sludge from storage, environmental report and literature
emission air, high population density	Heat, waste	-	-	MJ	2.41E-2	2.41E-2	1.14	(2,4,1,3,1,3); Calculation with electricity use
	Hydrocarbons, aliphatic, alkanes, unspecified	-	-	kg	1.19E-4	-	1.50	(1,3,1,1,1,na); Losses according to literature
	Dimethyl ether	-	-	kg	-	3.80E-4	2.00	(1,3,1,1,1,na); Losses according to literature

The life cycle inventory per MJ energy content of the fuel is a simple recalculation of the data per kg fuel and the lower heating value of the different fuels.

Tab. 4.4 Life cycle inventory data of fuel distribution (per MJ of fuel)

	Name	Location	Infrastructu	Unit	BTL-fuel, wood, at service station	BTL-fuel, straw, at service station	BTL-fuel, wood, at service station	BTL-fuel, straw, at service station	BTL-fuel, straw, at service station	BTL-fuel, wood, at service station	BTL-fuel, miscanthus, at service station	dimethylether, black liquor, at service station	BTL-fuel, mix, at service station
	Location				UET	UET	CUTEC	CUTEC	FZK	TUV	TUV	Chemrec	RER
	InfrastructureProcess				0	0	0	0	0	0	0	0	0
	Unit				MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ	kg
technosphere	BTL-fuel, wood, at service station	UET	0	kg	2.27E-2	-	-	-	-	-	-	-	1.25E-1
	BTL-fuel, straw, at service station	UET	0	kg	-	2.27E-2	-	-	-	-	-	-	1.25E-1
	BTL-fuel, wood, at service station	CUTEC	0	kg	-	-	2.27E-2	-	-	-	-	-	1.25E-1
	BTL-fuel, straw, at service station	CUTEC	0	kg	-	-	-	2.27E-2	-	-	-	-	1.25E-1
	BTL-fuel, straw, at service station	FZK	0	kg	-	-	-	-	2.27E-2	-	-	-	1.25E-1
	BTL-fuel, wood, at service station	TUV	0	kg	-	-	-	-	-	2.27E-2	-	-	1.25E-1
	BTL-fuel, miscanthus, at service station	TUV	0	kg	-	-	-	-	-	-	2.27E-2	-	1.25E-1
	dimethylether, black liquor, at service station	Chemrec	0	kg	-	-	-	-	-	-	-	3.47E-2	1.91E-1
	lower heating value of fuel delivered to the tank			MJ/kg	44.0	44.0	44.0	44.0	44.0	44.0	44.0	28.8	44.0

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Annexe

The following three reports are provided on demand.

- Regional inventory data for biomass production: Northern Europe (Lantz 2005)
- Regional inventory data for biomass production: Eastern Europe (Ganko 2005)
- Regional inventory data for biomass production: Southern Europe (Nikolaou 2005)

Chapter “Short-rotation wood plantation”

Tab. 4.5 shows the factors that have been used for calculating the nitrogen emissions in the calculation model. The factors describe the monthly nitrogen uptake of plants per hectare. These factors are an own rough estimation. For further information about the use of these factors please refer to this publication.

Tab. 4.5 Factors used in the emission calculation model for nitrogen mineralization and nitrogen uptake of short rotation wood plantation

		N min, m	N upt m
Jan.	kg N/ha/month	0	0
Feb	kg N/ha/month	0	15
Mrz	kg N/ha/month	10	30
Apr	kg N/ha/month	15	40
Mai	kg N/ha/month	20	40
Jun	kg N/ha/month	25	40
Jul	kg N/ha/month	30	40
Aug	kg N/ha/month	35	40
Sep	kg N/ha/month	40	40
Okt	kg N/ha/month	20	30
Nov	kg N/ha/month	10	10
Dez	kg N/ha/month	0	5
Total	kg N/ha	205	330

Tab. 4.6 shows the factors that have been used for calculating the nitrogen emissions in the calculation model for miscanthus. The factors show for each month (m) how much nitrogen is mineralized (min) and how much nitrogen is taken up (upt) by the plants. These factors are based on information provided by (Wolfensberger & Dinkel 1997).

Tab. 4.6 Factors used in the emission calculation model for nitrogen mineralization and nitrogen uptake of miscanthus (kg/N/ha/month)

	N min, m	N upt m
Jan.	-	-
Feb	-	-
Mrz	9	-
Apr	14	9
Mai	20	18
Jun	25	27
Jul	30	41
Aug	35	41
Sep	40	42
Okt	19	26
Nov	9	8
Dez	-	-
Total	202	212

Critical Review

(next pages)

RENEW
Renewable fuels for advanced powertrains

Critical Review

According to ISO 14040

by

Walter Klöpffer (chair)

Richard van den Broek

and

Lars-Gunnar Lindfors

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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