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Deliverable 1total

Identification and mapping of existing fuel producing industrial complexes in Europe

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Fons Maes BVBA

Dissemination level

PU	Public	**X**
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the Consortium (including the Commission Services)	

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Summary

This report presents the results of the work carried out within the work package 1 of the BIOREF-INTEG project. The objective of the first work package is to identify and map the existing (fuel producing) complexes in Europe, that allow for integration of biorefinery processes.

The following market sectors have been considered:
- bioethanol sector;
- biodiesel sector;
- pulp & paper sector;
- conventional oil refinery sector;
- power production sector;
- food industry sector;
- agrosector.

A questionnaire has been developed to harmonise the data collection for work package 1 by the project partners, and to take into account the requirements within work package 4 and work package 5.

For each considered biomass processing sector, the existing industrial (fuel producing) complexes have been identified for the six partner-related countries (Belgium, Finland, Spain, Sweden, United Kingdom, and the Netherlands). Based on the performed survey, at least one reference case per sector has been defined as a realistic representative of that sector. The reference cases include different feedstocks: cereals, oilseed crops, sugar beet, micro-algae, grass, wood, milk and slaughter byproducts. The cases use different conversion technologies: fermentation, transesterification, anaerobic digestion, combustion, gasification, fluid catalytic cracking and hydrotreating. The reference cases are briefly described, including a block diagram with main overall mass and energy balances. The reference cases will be evaluated in WP4, where they will also be upgraded to high efficiency advanced biorefinery schemes, co-producing added value products and fuels.

1. Introduction

1.1 Work package 1

The objective of Bioref-Integ's first work package is to identify and map the existing fuel producing complexes in Europe, that allow for integration of biorefinery processes.

Work package 1 consists of two tasks, as described below.

1.1.1 Task 1: Identification and mapping existing (fuel producing) complexes

Within task 1 the existing industrial (fuel producing) complexes will be identified and mapped. These activities will be performed only for the partner-related countries (Figure 1.1: countries in green), giving a sufficient overview of the conventional (fuel producing) complexes over the whole Europe. The following market sectors will be considered:

- bioethanol sector;
- biodiesel sector;
- pulp & paper sector;
- conventional oil refinery sector;
- power production sector;
- food industry sector;
- agrosector.

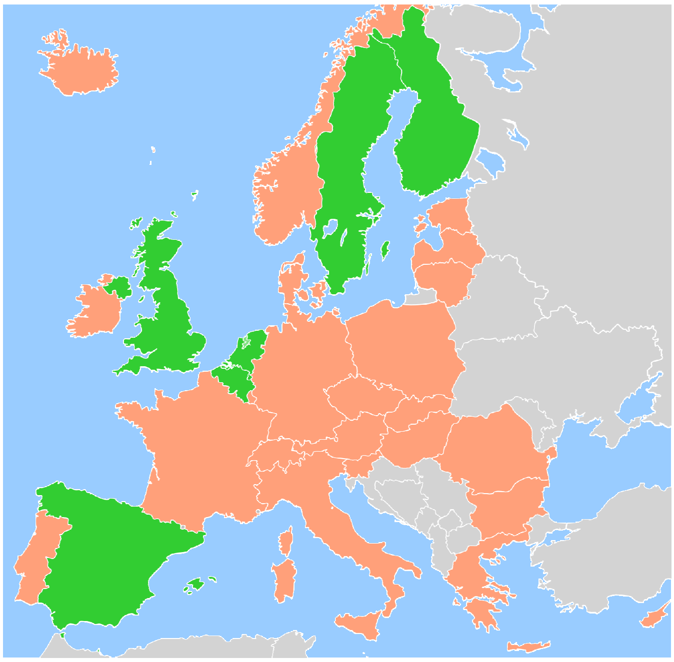

Figure 1-1 *Map of Europe with the partner-related countries in green*

1.1.2 Task 2: Definition of reference cases

Within task 2, based on the information gathered in task 1 at least one reference case will be defined for each sector, as a realistic representative of the sector[1]. Preferably, a reference case will be chosen owned by one of the industrial partners in the project, so that realistic data gathering will be guaranteed, and the market deployment of the identified biorefinery sub-technologies, later on in WP5, could potentially be easier. The reference cases will shortly be described, including a block diagram with main overall mass and energy balances, as presented in Figure 1.2.

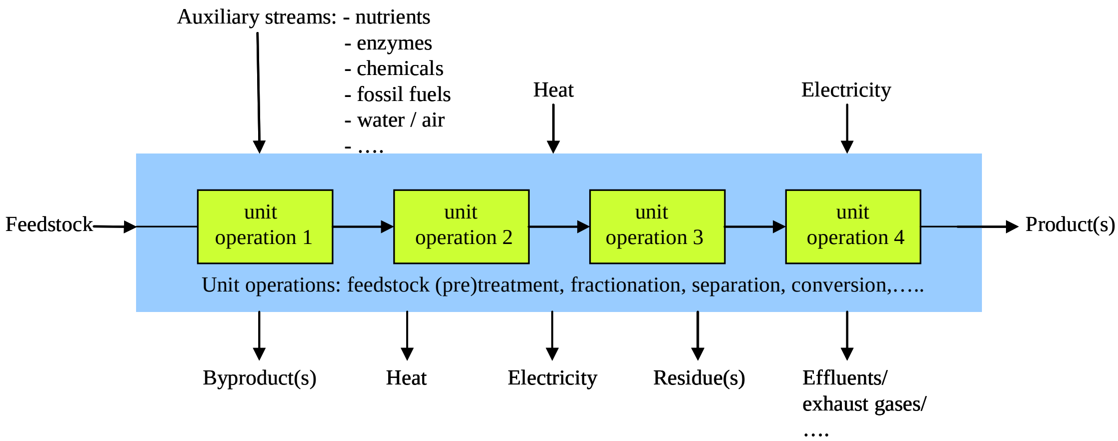

Figure 1-2 *General block diagram for the reference cases defined within work package 1*

The reference cases will be analysed in WP4, followed by upgrading to high efficiency advanced biorefinery schemes, co-producing added-value products and fuels.

1.1.3 The questionnaire

The activities within work package 1 have been based on desk study, analysis and assessment of the available national / international industry-based databases, conference proceedings, and information from different technology platforms.

A questionnaire has been developed to harmonise the data collection for work package 1 by the project partners, and to take into account the requirements within work package 4 and work package 5. The questionnaire, presented in appendix A, consists of two parts guaranteeing efficient and optimal data collection. In the first part of the questionnaire general questions are proposed, that could enable the selection of reference cases in each market sector. In the second part of the questionnaire some detailed questions are proposed, that relate only to the limited number of selected reference cases. The latter questions are aimed at making the block digrams, including mass and energy balances feasible.

1.1.4 The structure of the report

In Chapter 2 the results of sector-specific existing industrial (fuel producing) complexes in partner-related countries are presented. The reference cases for different sector-specific industrial (fuel producing) complexes in partner-related countries are described in chapter 3. Task 1 and task 2-related questionnaires are presented in Appendix A. The results of the sector-related data collection for task 1 are presented in Appendix B.

[1] The reference cases should, as far as possible, represent the countries covered by the project. However, in case of either lack of data, or lack of a realistic representative reference for a sector, other countries would be an option too.

2. Results of the sector-specific existing industrial (fuel producing) complexes in partner-related countries

2.1 Bioethanol sector

Figures 2.1 and 2.2 present the production capacities of bioethanol in EU27 in 2006/2007. Table 2.1 summarises the bioethanol production capacities in the partner-related countries in 2007.

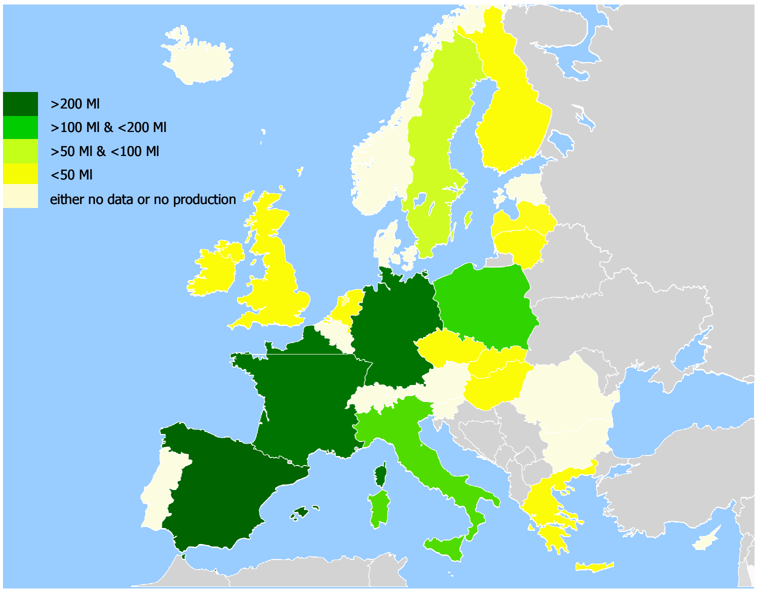

Figure 2-1 *Production of bioethanol in EU27(data for 2006/2007, EurObservÉR Biofuels barometer, 2008)*

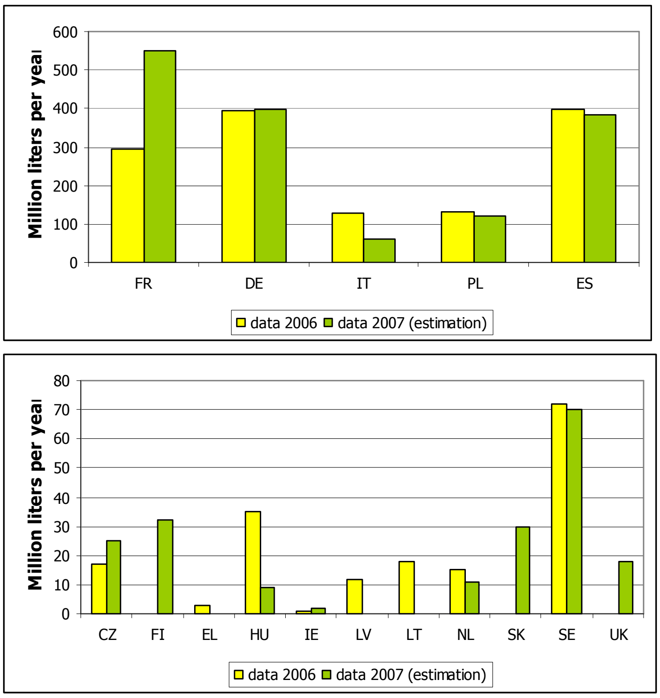

Figure 2-2 *Production of bioethanol in EU27 (data for 2006/2007, EurObservÉR Biofuels barometer, 2008)*

Table 2.1 *Bioethanol production in partner-related countries, 2007 (EurObservÉR, 2008)*

Country	Bioethanol (million litres)
Belgium	?
Finland	32
Netherlands	11
Spain	383
Sweden	70
United Kingdom	18
Total	514
Total EU27	1708

According to data in Table 2.1, 514 million litres from the total 1708 million litres of bioethanol produced in EU27 in 2007 were produced in the partner-related countries. The contribution of Spain was 22% of the total EU27 production, followed by Sweden (4%), Finland (2%), and the UK and the Netherlands each for 1%. Altogether, the partner-related countries had a considerable contribution of 30% to the total EU27 bioethanol production capacity in 2007.

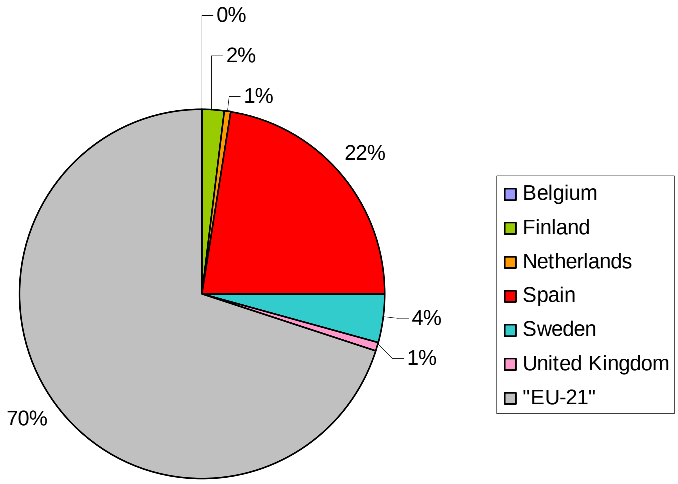

Figure 2-3 *Contribution of bioethanol production of partner-related countries in EU-27, 2007(EurObservÉR, 2008)*

The detailed data regarding existing and planned bioethanol plants in the partner-related countries are presented in Table B.1. Table 2.2 summarises the number of bioethanol plants and the main feedstock(s) used. As can be seen, data for 32 bioethanol plants are collected, with grain as the major feedstock.

Table 2.2 *Results survey bioethanol sector*

Country	Number of plants	Main feedstock(s)
Belgium	3	wheat, corn, sugar beet
Finland	1	waste
Netherlands	10	grain, potato, oil residue
Spain	8	grain, (sugar beet)
Sweden	2	grain
United Kingdom	8	wheat, sugar beet
Total	32	

According to the collected data (Table B.1), the average size of existing plants is within the range 100-300 million litres per year, increasing up to 600 million litres bioethanol in 2011. Main byproducts are DDGS (Distillers Dried Grains with Solubles) and CO_2, with current applications as animal feed, respectively in carbonated beverages.

2.2 Biodiesel sector

Figures 2.4 and 2.5 present the production capacities of biodiesel in EU27 in 2006/2007. Table 2.3 summarises the biodiesel production capacities in the partner-related countries, including France, in 2007.

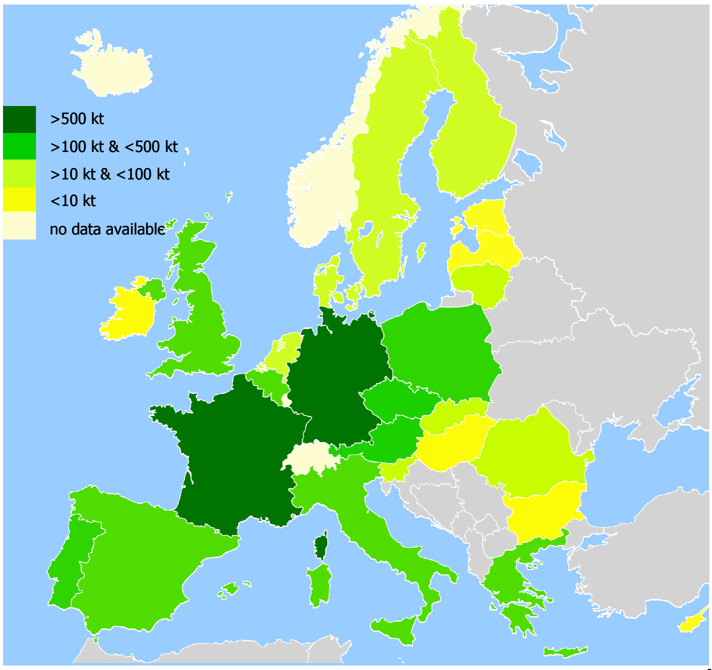

Figure 2-4 *Production of biodiesel in EU27 (data for 2006/2007, EurObservÉR Biofuels barometer, 2008)*

According to data in Table 2.3, 671 ktonnes from the total 5713 ktonnes of biodiesel produced in EU27 in 2007 were produced in the partner-related countries. The contribution of Belgium, Spain, and the UK was each 3%, followed by the Netherlands, Finland, and Sweden each for 1%. Altogether, the partner-related countries had a contribution of 12% to the total EU27 biodiesel production capacity in 2007. This contribution is not large enough to be representative for the whole Europe. Therefore, it was decided to include France to the survey. From Table 2.3, and Figure 2.6 it can be seen, that the seven countries together have produced 27% of the total EU27 biodiesel production capacity in 2007.

The detailed data regarding existing and planned biodiesel plants in the partner-related countries, including France, are presented in Table B.2. Table 2.4 summarises the number of biodiesel plants and the main feedstock(s) used. As can be seen, data for 108 biodiesel plants are collected, with rapeseed as the major feedstock.

According to the collected data (Table B.2), the average size of existing rapeseed-based plants is within the range 150-250 ktonnes biodiesel per year. For used oil/animal fat-based plants the average size is between 50 and 100 ktonnes biodiesel per year. Main byproducts are glycerine, rapeseed cake, and potassium sulphate, with current applications as chemicals, pharmaceuticals, lubricant, cosmetic, feed, fuel, and in fatty acid extraction and the food sector.

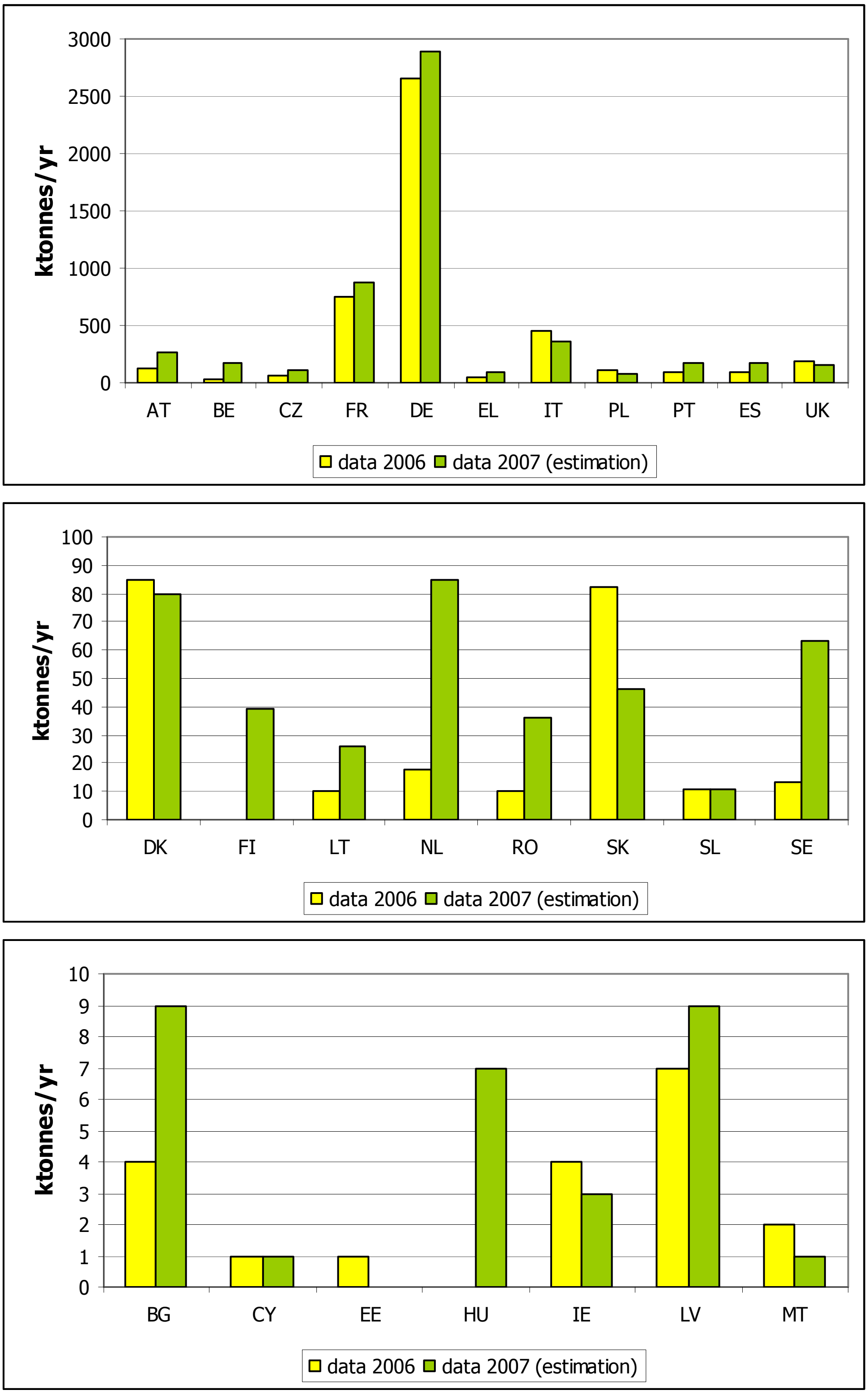

Figure 2-5 *Production of biodiesel in EU27(data for 2006/2007, EurObservÉR Biofuels barometer, 2008)*

Table 2.3 *Biodiesel production (estimation) in partner-related countries, 2007(EurObservÉR, 2008)*

Country	Biodiesel (ktonnes)
Belgium	166
Finland	39
Netherlands	85
Spain	168
Sweden	63
United Kingdom	150
France	872
Total	1543
Total EU-27	5713

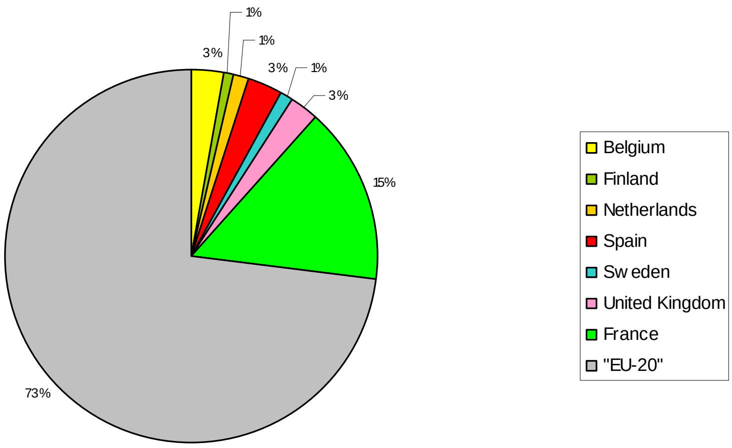

Figure 2-6 *Contribution of biodiesel production of partner-related countriesincluding France in EU-27, 2007(EurObservÉR, 2008)*

Table 2.4 *Survey biodiesel sector*

Country	Number of plants	Main feedstock(s)
Belgium	4	rapeseed soybean
Finland	2	palm oil
Netherlands	20	rapeseed oil residue animal fat palm oil
Spain	30	rapeseed soybean sunflower used oil
Sweden	12	rapeseed tall oil jatropha
United Kingdom	18	rapeseed cooking oil
France	22	rapeseed sunflower animal fat
Total	***108***	

2.3 Pulp & paper sector

Figure 2.7 presents the production capacities of pulp for paper in EU27 including Norway, Switzerland, and Iceland in 2006. Finland and Sweden are by far the largest producers of pulp for paper in Europe, followed by Spain, Germany, France, and Norway.

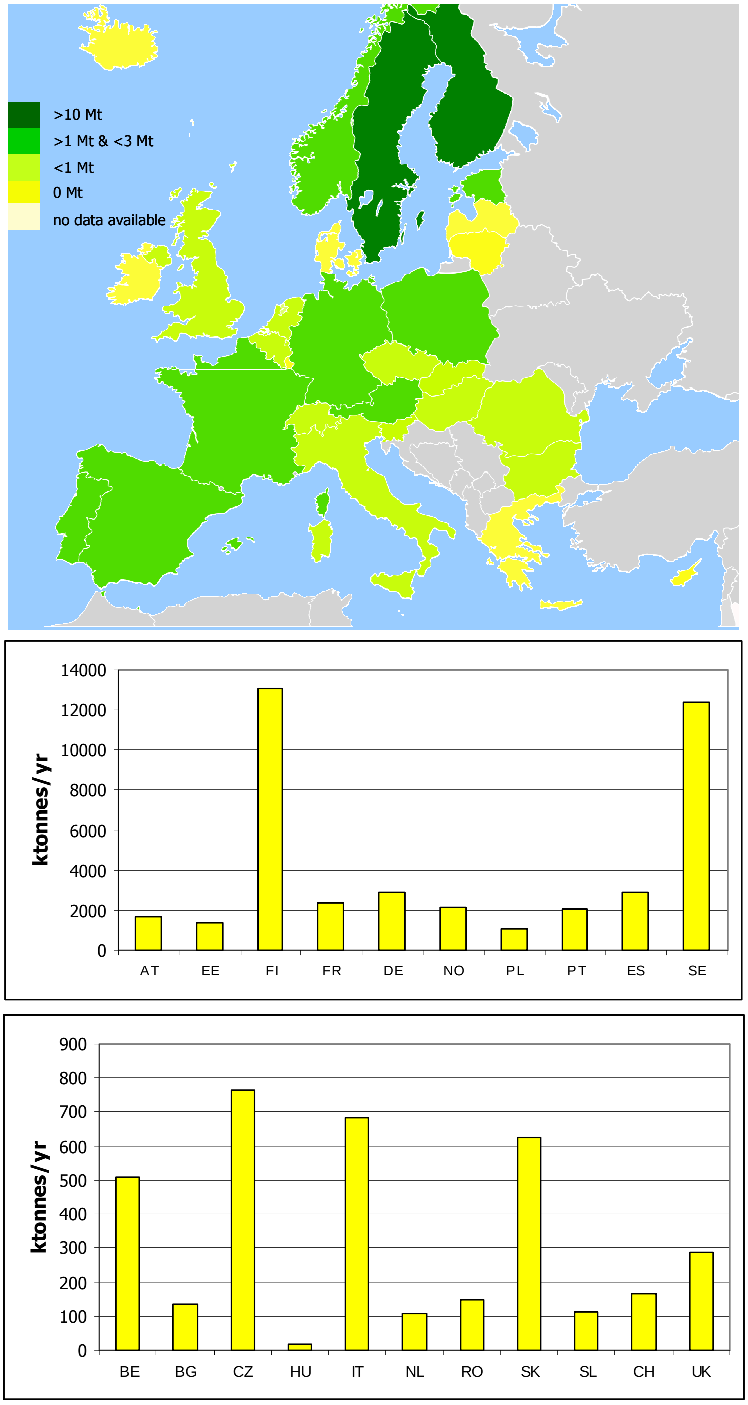

Figure 2-7 *Production of pulp for paper in EU27 including NO, CH, and IC (data for 2006, FAO statistics)*

The detailed data regarding existing pulp mills in the partner-related countries are presented in Table B.3. Table 2.5 summarises the number of pulp mills and the main feedstock used. As can be seen, data for 43 pulp mills are collected, with wood (both soft and hardwood) as the major feedstock.

Table 2.5 *Survey pulp & paper sector*

Country	Number of plants	Main feedstock
Belgium	1	wood
Finland	13	wood
Netherlands	-	-
Spain	4	wood
Sweden	25	wood
United Kingdom	-	-
Total	43	

Byproducts of pulp production are electricity, bark, and turpentine for both types of wood as feedstock. In case of softwood as feedstock an additional byproduct is tall oil.

2.4 Conventional oil refinery sector

The detailed data regarding existing oil refineries in the partner-related countries are presented in Table B.4. Table 2.6 summarises the number of oil refineries and the main feedstock used. As can be seen, data for 33 refineries are collected, with crude oil as feedstock.

Table 2.6 *Survey oil refinery sector*

Country	Number of plants	Main feedstock
Belgium	4	crude oil
Finland	2	crude oil
Netherlands	5	crude oil
Spain	9	crude oil
Sweden	4	crude oil
United Kingdom	9	crude oil
Total	33	

Byproducts of oil refineries are petrochemicals, asphalts, coke, and lubes.

2.5 Power production sector

Table 2.7 presents the gross electricity production (TWh) by partner-related countries per fuel type in 2006. Figure 2.8 shows the contribution of fuel types to electricity production in each country. Finland has the highest contribution of combustible renewables and waste to the gross electricity production, followed by Sweden, the Netherlands, Belgium, United Kingdom, and Spain.

Table 2.7 *Gross electricity production (TWh), by country, per fue typel, 2006 (IEA statistics (a), 2008)*

Country	Nuclear	Hydro	Solar/wind	Fossil fuels	Comb. renew & waste	Total
Belgium	46.65	1.63	0.62	33.62	3.11	85.62
Finland	22.91	11.49	0.59	36.41	10.91	82.30
Netherlands	3.47	0.11	2.92	85.27	6.64	98.39
Spain	60.13	29.50	27.99	182.38	3.05	303.05
Sweden	66.98	61.74	0.99	4.24	9.36	143.30
United Kingdom	75.45	8.46	4.23	298.28	11.91	398.33

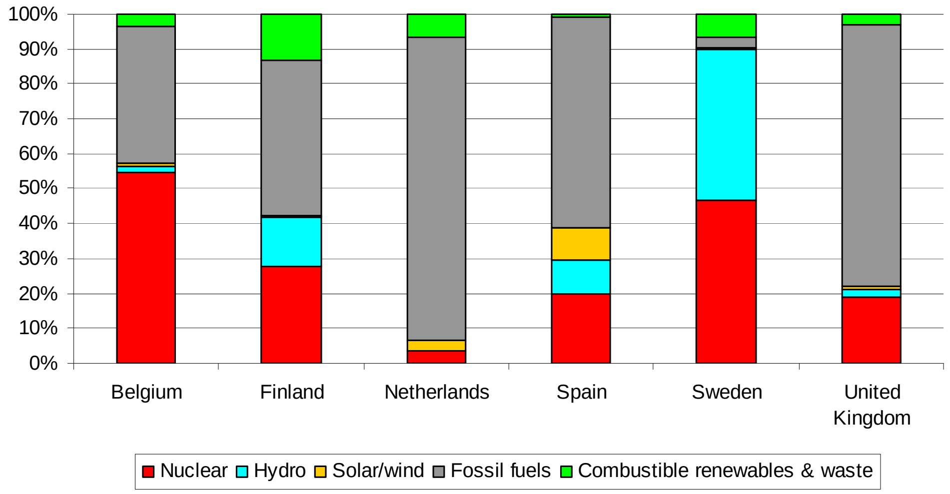

Figure 2-8 *Gross electricity production, by country, per fuel type (%), 2006 (IEA statistics (a), 2008)*

Table 2.8 gives the gross electricity production (TWh) from combustible fuels by country in 2006. The contribution of combustible fuel types for each country is presented in Figure 2.9. Sweden has the highes contribution of wood, industrial / municipal wastes, and biogas / liquid fuels to the gross electricity production from combustible fuels, followed by Finland, Belgium, the Netherlands, United Kingdom, and Spain.

Table 2.8 *Gross electricity production (TWh) from combustible fuels, by country, 2006 (IEA statistics (a), 2008)*

Country	Coal	Oil	Gas	Wood	Industrial waste	Municipal waste	Biogas/ liq. biof.	Total
Belgium	9.22	1.38	23.02	1.41	0.11	1.09	0.50	36.73
Finland	23.61	0.48	12.32	10.54	0.05	0.30	0.03	47.33
Netherlands	26.51	2.10	56.66	1.84		2.78	2.02	91.91
Spain	68.26	23.83	90.28	1.57		0.81	0.67	185.42
Sweden	1.99	1.67	0.58	7.50	0.15	1.42	0.29	13.6
United Kingdom	151.93	5.00	141.34	3.32	1.96	1.74	4.89	310.18

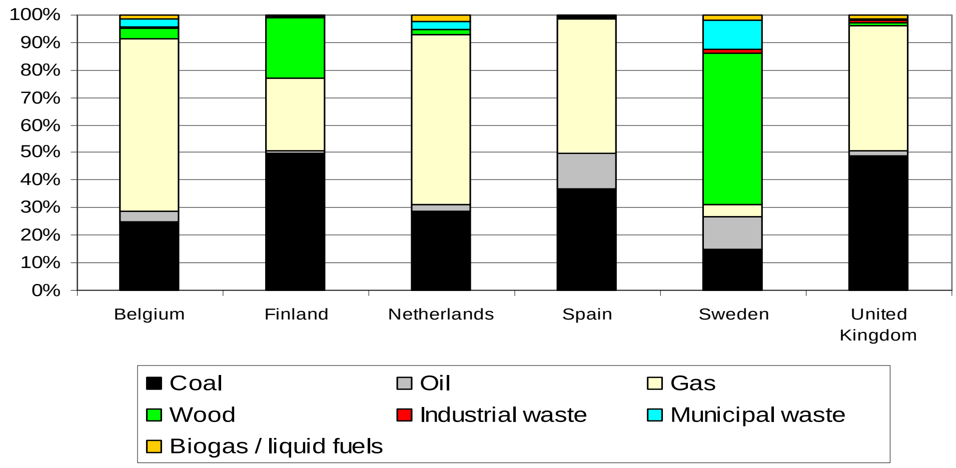

Figure 2-9 *Gross electricity production from combustible fuels (%), by country, 2006 (IEA statistics (a), 2008)*

2.5.1 Biomass-based power generation in partner-related countries

Tables 2.9 and 2.10 present the primary energy production (PJ) and gross electricity production (TWh) from solid biomass, respectively renewable municipal solid waste, by country in 2006. Tables 2.11 and 2.12 present the primary energy production (PJ) and gross electricity production (TWh) from biogas by country in 2006. Solid biomass has the highest contribution to the gross biomass-based electricity production for partner-related countries, followed by biogas, and renewable municipal solid wastes.

Table 2.9 *Primary energy production (PJ) and gross electricity production (TWh) from solid biomass, by country, 2006 (EurObserv'ER, 2008c)*

Country	Primary energy production (PJ)	Electricity plants only (TWh)	CHP plants (TWh)	Total electricity (TWh)
Belgium	19	1.079	0.327	1.406
Finland	313	1.532	9.007	10.539
Netherlands	23	0.699	1.141	1.840
Spain	176	0.275	1.298	1.573
Sweden	349	-	7.503	7.503
United Kingdom	33	3.324	-	3.324
Total	913	6.909	19.276	26.185

Table 2.10 *Primary energy production (PJ) and gross electricity production (TWh) from renewable municipal solid waste, by country, 2006 (EurObserv'ER, 2008b)*

Country	Primary energy production (PJ)	Electricity plants only (TWh)	CHP plants (TWh)	Total electricity (TWh)
Belgium	7.7	0.189	0.104	0.293
Finland	3.8	0.056	0.148	0.204
Netherlands	26.6	0.371	0.962	1.333
Spain	9.4	0.538	-	0.538
Sweden	12.8	-	0.568	0.568
United Kingdom	16.9	0.990	0.093	1.083
Total	77.2	2.144	1.875	4.019

Table 2.11 *Primary energy production (PJ) from biogas, by country, 2006 (EurObserv'ER, 2008b)*

Country	Landfill gas (PJ)	Sewage gas (PJ)	Other biogases (PJ)	Total (PJ)
Belgium	2.14	0.74	0.38	3.26
Finland	1.09	0.44	-	1.53
Netherlands	1.93	2.01	1.97	5.91
Spain	10.52	2.03	0.83	13.38
Sweden	0.39	0.72	0.33	1.14
United Kingdom	55.20	7.54	-	62.74
Total	71.27	13.48	3.51	88.26

Table 2.12 *Gross electricity production (TWh) from biogas, by country, 2006 (EurObserv'ER, 2008b)*

Country	Electricity plants only (TWh)	CHP plants (TWh)	Total electricity (TWh)
Belgium	0.158	0.121	0.279
Finland	0.001	0.021	0.022
Netherlands	0.146	0.215	0.361
Spain	0.610	0.056	0.666
Sweden	-	0.046	0.046
United Kingdom	4.424	0.463	4.887
Total	5.339	0.922	6.261

<u>*Electricity production from co-firing of biomass*</u>

Basically one can distinguish three different concepts for co-firing of biomass in pulverised coal-fired power plants or boilers, all of which have already been implemented either on a demonstration scale or on a fully commercial basis:

- *Direct co-firing* is the most straightforward application, which most common and low-cost. Biomass fuel and coal are combusted together in the same boiler, using combined or separate mills and burners depending on the biomass fuel characteristics.
- In the concept of *indirect co-firing*, a biomass gasifier can be used to convert solid biomass raw materials into a clean fuel gas, which can be burned in the same boiler as coal. This concept offers the advantages that a wider range of biomass fuels can be used (e.g. difficult to grind) and that the fuel gas can eventually be cleaned and filtered to remove impurities before it is burned.
- Finally, it is possible to install a *completely separate biomass boiler* (parallel) and increase the steam parameters in the coal-fired power plant steam system.

Based on a global database prepared by the IEA, a list of the European coal-based cofiring projects is presented in Table B.5. Table 2.13 summarises the number of direct and indirect co-firing plants in partner-related countries and the main feedstock used.

Table 2.13 *Survey direct and indirect co-firing of biomass in coal-based power plants*

Country	Number of direct co-firing plants	Main feedstock(s)	Number of indirect co-firing plants	*Main feedstock(s)*
Belgium	-		1	*wood chips, bark, hard and soft board residues*
Finland	17	waste wood, peat, oil, bark, sawdust, paper waste, fibre wastes	1	
Netherlands	5	kernels, paper sludge, shells, fibres, compost residue, pulverised wood	1	*waste wood*
Spain	1	wood waste		
Sweden	15	peat, wood, bark, wood waste, wood pellets, oil		
United Kingdom	16	wood, oil, cereal residues		
Total	*54*		*3*	

Due to different technology / fuel combinations for biomass-based electricity production options, and the size dependency of these combinations, it is recommended to define different reference cases for the power sector, taking these combinations and dependencies into account.

2.6 Food industry sector

Data regarding some important existing food complexes in the partner-related countries are presented in Table B.6. Table 2.14 summarises the number of the plants and the main feedstocks used. As can be seen, data for 42 plants have been collected, with milk, meat, sugar beet, slaughter byproducts, and barley as the major feedstocks.

Table 2.14 *Survey food industry sector*

Country	Number of plants	*Main feedstock(s)*
Belgium	10	*meat. sugar beet, fats & oils, maize, wheat, chicory roots*
Finland	8	*barley, grains, meat, milk, fruit*
Netherlands	10	*slaughter byproducts, grains, oilseeds, potatos, milk*
Spain	5	*milk, oilseeds, grape*
Sweden	4	*meat, milk, fish, fruit*
United Kingdom	5	*sugar beet, coffee, milk, sodium chloride*
Total	*42*	

Figures 2.10 and 2.11 present the milk and meat production capacities (ktonnes/yr) in the EU27 (Eurostat 2005/2006). As can be seen, United Kingdom, the Netherlands, and Spain are among the largest producers of milk and meat in Europe.

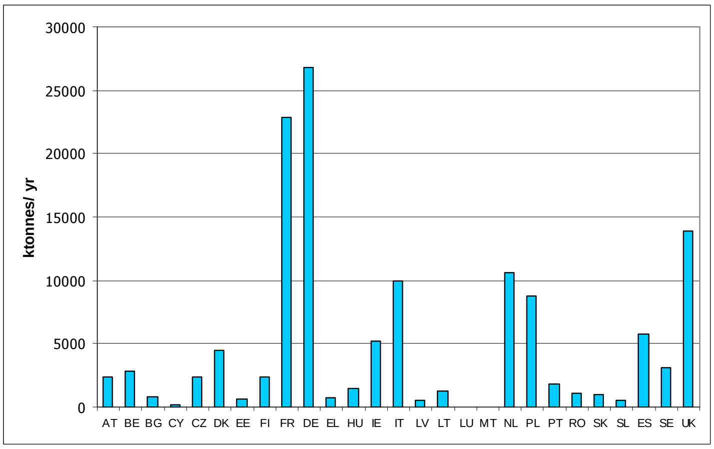

Figure 2-10 *Milk production in EU27 (Eurostat 2005/2006)*

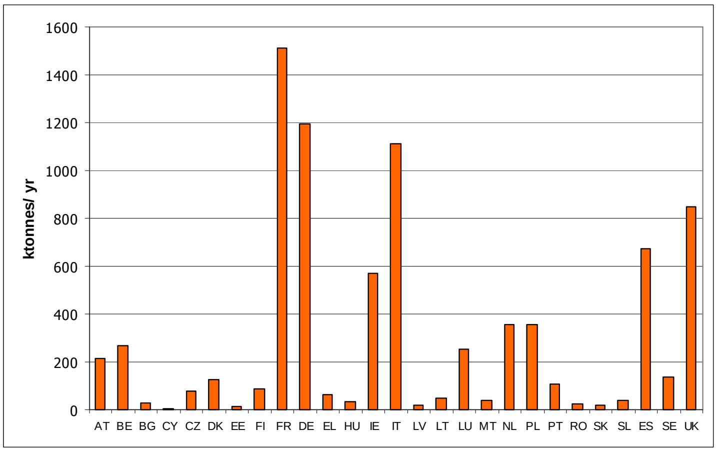

Figure 2-11 *Meat production in EU27 (Eurostat 2005/2006)*

2.7 Agrosector

Data regarding existing complexes within agrosector in the partner-related countries are presented in Table B.7. According to Table 2.15 data have been collected for 51 plants in this sector. The main feedstocks used in these plants, the byproducts and their current applications are summarised in Table 2.16.

Table 2.15 *Survey agrosector*

Country	***Number of plants***
Belgium	*11*
Finland	*5*
Netherlands	*10*
Spain	*5*
Sweden	*4*
United Kingdom	*10*
France	*6*
Total	*51*

Table 2.16 *Byproducts from agrosector and their current applications*

Feedstock	**Byproduct(s)**	**Country**	**Current application(s) byproduct(s)**
Sugar beet	Molasses	BE, FI, NL, ES, SE, UK, FR	Fermentation, animal feed, soil improvement
Sugar beet	Beet pulp	BE, FI, NL, ES, SE, UK, FR	Fermentation, animal feed, soil improvement
Sugar beet	Vinasse	NL	Animal feed
Algae biomass	Proteins	BE, NL, ES, UK	Animal feed
Vegetable oils	Glycerol	BE, NL, SE, UK	Chemicals, pharmaceuticals, cosmetic, lubricant
Rapeseed	Rapeseed cake	FI, SE	Animal feed
Linseed	Linseed cake	BE, FI,	Animal feed, food
Maize	Corn gluten feed & meal, corn steep liquor	NL, ES	Animal feed
Wheat	Wheat bran	BE, NL, UK, FR	Animal feed
Chicory root	Chicory pulp	BE,	Food
Chicory root	Inuline pulp	NL	Animal feed
Pea	Pea fibres	BE, FR	Food, animal feed

Glycerine, rapeseed and linseed cakes are all byproducts of biodiesel production and would be considered within the biodiesel sector. Also starch-based crops would be the feedstocks for bioethanol production and would be considered within that sector. Therefore, it was dicided to focus on sugar beet and algae biomass as two reference feedstocks within the agrosector.

Figure 2.12 presents the sugar beet production capacities in the EU27 including Switzerland (FAO statistics 2006/2007). As can be seen, the United Kingdom, Spain, Belgium, and the Netherlands are among the largest producers of sugar beet in Europe.

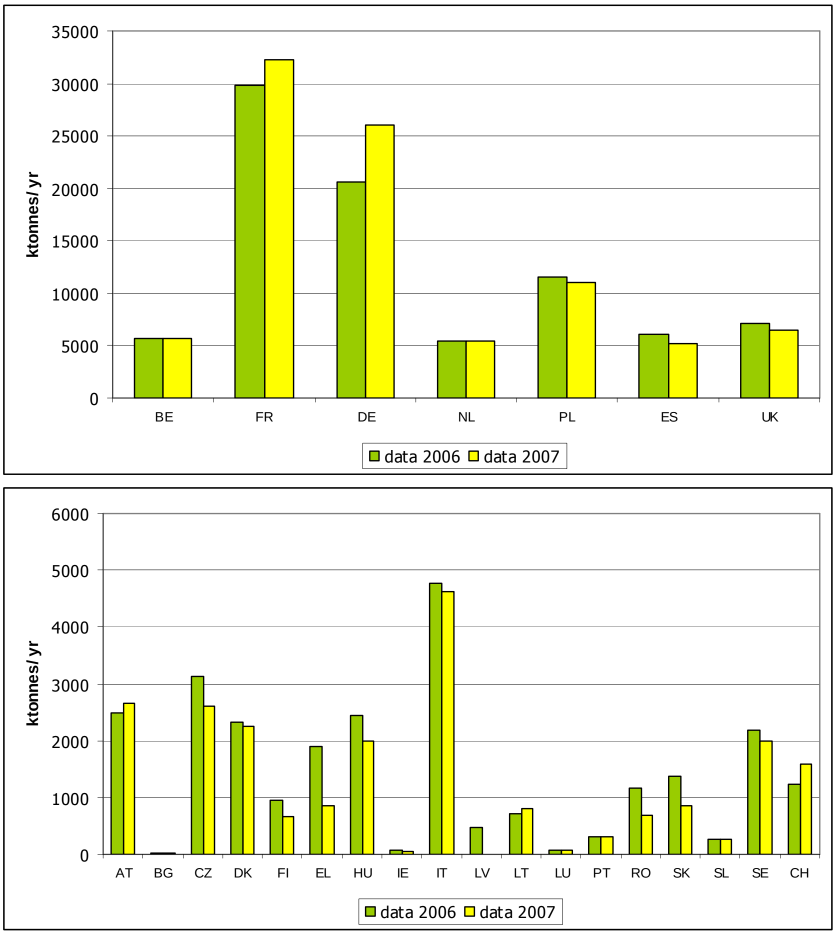

Figure 2-12 *Production of sugar beet in EU27 including CH (FAO statistics 2006/2007)*

3. Selection and definition of reference case industrial (fuel producing) complexes

3.1 Bioethanol sector

A conventional grain-to-ethanol plant has been chosen as reference case to represent the Bioethanol sector. The size of the industrial plants already existing, as well as the raw materials that they employ and the main product they produce make any of them suitable for representing the Bioethanol sector.

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Process description

First of all, grain is milled until flour with determined particle distribution is obtained and afterwards mixed with process water to obtain slurry.

The slurry is heated and sent to the cooking step, where the mixture is held for a determined time. During the cooking process, the starch in the flour starts to become physically and chemically prepared for fermentation, since the hydration of the starch granules facilitates the penetration of enzymes for hydrolysis of starch in subsequent steps. After cooking, the mixture is cooled and liquefaction then takes place. The resulting mixture is cooled down before saccharification, where enzymes break down the starch into short chain. Finally, the mixture is pumped into the fermentation tanks.

Once inside the fermentation tanks, transformation of glucose into ethanol is carried out through alcoholic fermentation by the yeast *Saccharomyces cerevisiae*:

$$\underset{\text{Glucose}}{C_6H_{12}O_6} + S.\ cerevisiae \longrightarrow \underset{\text{Ethanol}}{2C_2H_5OH} + 2CO_2$$

As a result of the fermentation process, a mixture containing ethanol, not fermented solids from grain and yeast is obtained. Purification of ethanol takes place by means of distillation and dehydration. As a result, 99% pure ethanol is obtained. Outsourced wine alcohol is purified on-site by this process. During ethanol recovery a solid by-product is obtained, which is dried and pelletized to form DDGS.

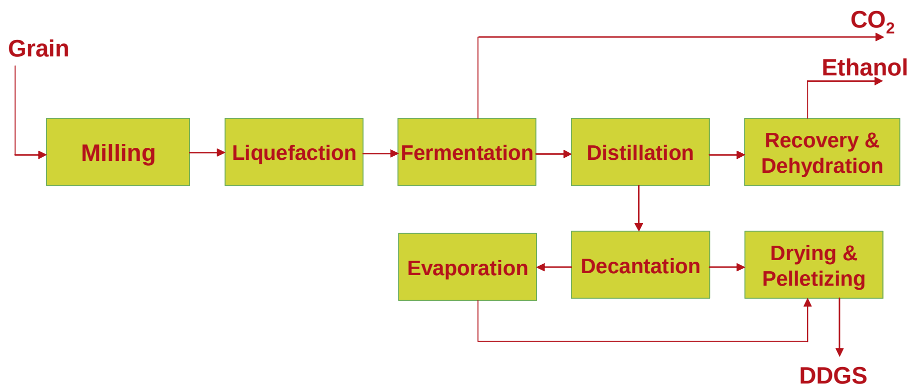

Figure 3-1 *Block diagram reference case bioethanol sector*

Mass and energy balance

The overall mass balance for the Base Case is summarized in Table 3.1. It must be taken into account that also 50 Ml ethanol is produced from wine alcohol as well. However, these are not included in the presented mass balance.

Table 3.1 *Mass balance of the base case bioethanol plant*

Parameter	**Grain meal**	**Ethanol**	**CO_2**	**DDGS**
	Input	Output	Output	Output
Total mass flow (t/h)	47	14	13	20

With regard to the energy requirement, about 45-50 MW natural gas are required for the whole process. Regarding the electricity requirement, no external electricity is needed. A cogeneration plant provides about 5-6 MW_e to the starch-to-ethanol process and about 14-16 MW_e is exported.

3.2 Biodiesel sector

The reference case for the biodiesel sector is representative for the majority of biodiesel plants in Europe, producing biodiesel out of rapeseed oil. An extension to this reference case can be made by including the pressing of the rapeseed into rapeseed oil and rapeseed cake, offering additional opportunities for valorisation.

Process decription
A block diagram of the complete process is represented in Figure 3.2.

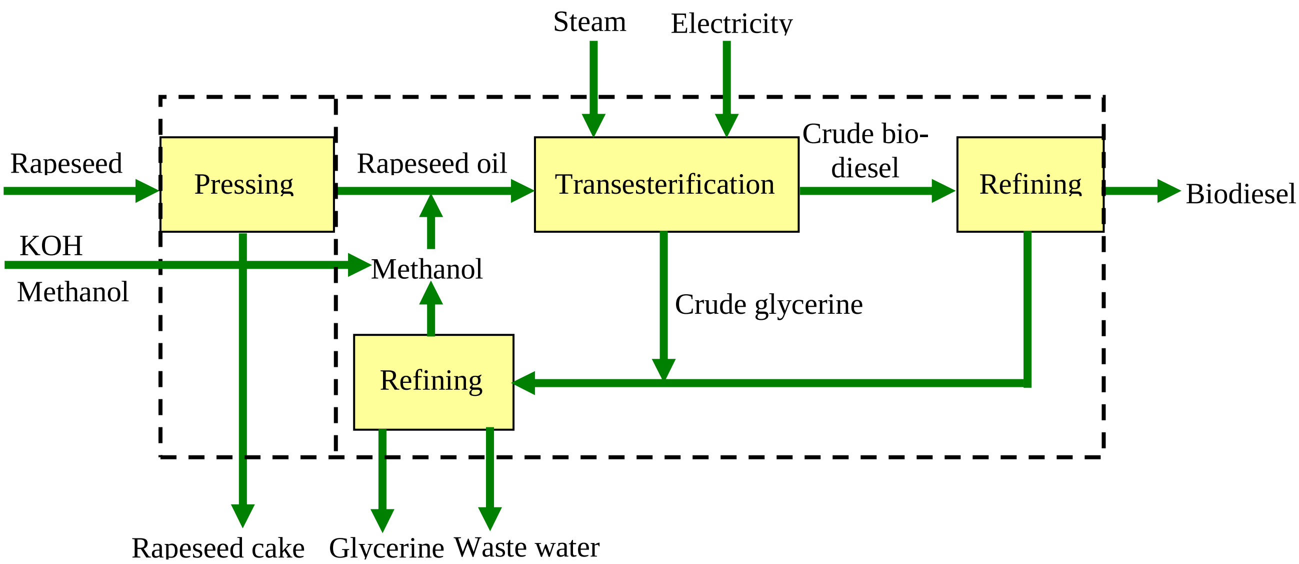

Figure 3-2 *Block diagram of the complete process for biodiesel production from rapeseed; the reference case for biodiesel sector is based on rapeseed oil*

Pressing of the rapeseed

Prior to delivery to the extraction plant, the rapeseed is cleaned to remove dust, small particles and large refuse material which are normally part of harvested seeds. This is usually obtained by a combination of sieves and aspiration. The cleaning is followed by an extra drying of 1 to 2% and a resting period of 24 hours in order to be prepared for further processing.

The following step is the preconditioning of the seeds, consisting of preheating of the whole seed (to about 30-40°C) prior to processing by indirect heating or direct hot air contact. This process improves flaking, screw pressing capacity, cake formation and extractability.

The preheated rapeseed is then flaked between two rolling surfaces. This results in a rupture of the cell walls, allowing the lipid particles to migrate to the surface of the flakes. The flaked seeds are transferred directly to the cookers where they are heated to about 75-85°C.

The cooked flakes are transferred to the expellers where 60–70% of the oil is removed by pressing the flakes, leaving a more dense and durable cake with improved solvent extractability and percolation properties. The removed oil is further purified/dewatered by decantation, resulting in crude rapeseed oil.

The cake undergoes additional extraction with hexane to remove the remaining oil. The hexane is recovered from the crude rapeseed oil by distillation. Further toasting and drying/cooling is

done to remove the hexane solvent from the extracted cake to produce rapeseed meal (Figure 3.3).

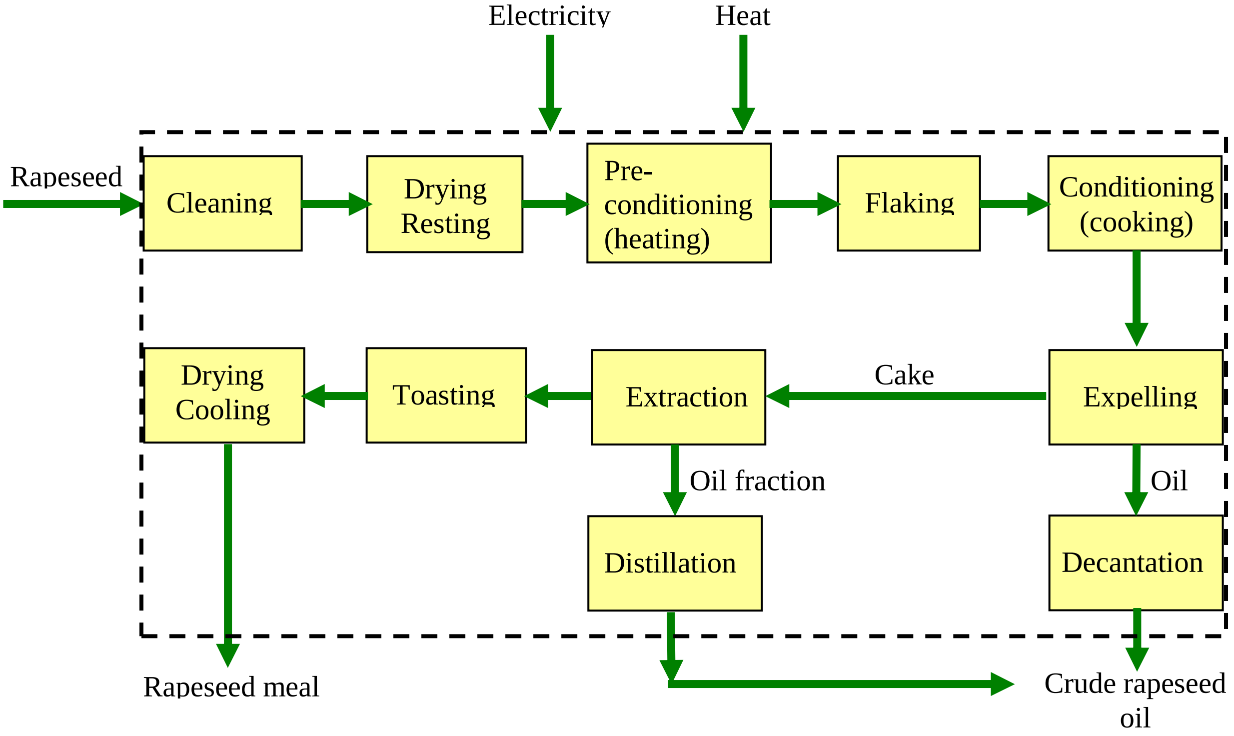

Figure 3-3 *Block diagram of rapeseed processing to crude rapeseed oil and rapeseed meal*

Biodiesel production

The vegetable oil is filtered and preprocessed to remove water, free fatty acids and contaminants and fed to the transesterification process. The catalyst, potassium hydroxide, is dissolved in methanol and then mixed with the pretreated oil. The mixture is heated (typically 50°C) for several hours (4 to 8 typically) to allow the transesterification to proceed. Figure 2.4 shows the reaction taking place during the transesterification.

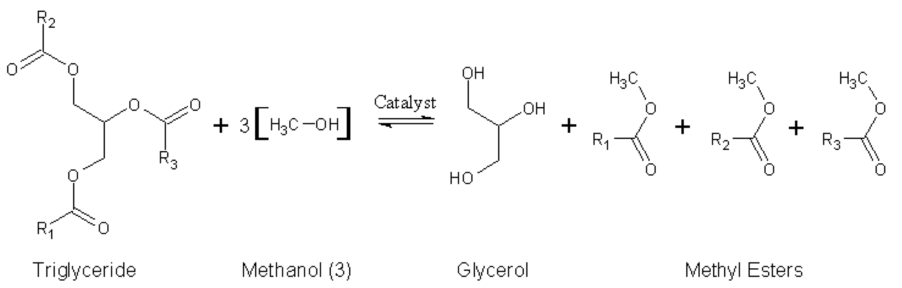

Figure 3-4 *Transesterification reaction* (Source: Wikipedia, http://en.wikipedia.org/wiki/Biodiesel_production)

Once the reaction is complete, the major co-products, biodiesel and glycerine, are separated into two layers. The lower layer of the process is composed primarily of glycerinee and other waste products (methanol, sodium methoxide, soaps). The top layer, the ester phase containing biodiesel, unreacted oil, methanol and soaps, is decanted. Once separated from the glycerine, the biodiesel goes through a clean-up or purification process to remove excess alcohol, residual

catalyst and soaps. This consists of one or more washings with clean water after which the remaining aqueous phase is separated from the biodiesel in settler tanks. The biodiesel is then dried to remove any trace amounts of moisture and sent to storage.

The resulting waste stream is collected for methanol recovery. It is combined with the glycerine stream and heated to the normal boiling point of methanol (65°C), followed by stripping of the methanol and distillation to recover pure methanol that is recycled back to the beginning of the process.

Bottoms of the distillation columns contain the glycerine and other impurities such as unreacted catalyst and soaps that are neutralized with an acid (HCl). The impurities are separated from the glycerine using a decanter, producing 50%-80% crude glycerine. The remaining contaminants include unreacted fats and oils. In large biodiesel plants, the glycerine can be further purified, to 99% or higher purity, for sale to the pharmaceutical and cosmetic industries.

Some of the main parameters for the biodiesel production are listed in Tables 3.2 and 3.3. The heat requirement for biodiesel production is 320 kg saturated steam 3 barg/tonne biodiesel. The power requirement for biodiesel production is 12 kWh/tonne biodiesel.

Table 3.2 *Process flows biodiesel production*

Stream	Value (tonnes/day)
Rapeseed oil	300
Potassium hydroxide	5
Methanol	28
Biodiesel	300
Crude glycerine	35 (85%)
Waste water	0.5

Table 3.3 *Energy content different streams*

Stream	Value
Rapeseed oil	34,11 MJ/l
Rapeseed cake	19,32 MJ/kg
Biodiesel	37.7 MJ/kg (35.9 MJ/l)
Pure glycerine	19.0 MJ/kg
Crude glycerine	> 19.0 MJ/kg
Rape straw	14500 MJ/tonne

3.3 Pulp & paper sector

There are two reference cases, one for softwood as feedstock (Figure 3.5) and one for hardwood as feedstock (Figure 3.6). The process configuration is identical but the capacities and by-products are slightly different, as presented in Table 3.4. A schematic of the reference case is presented in Figure 3.7.

Process description

The reference cases are based on chemical pulp mills producing pulp through the Kraft process. The reference mill is a hypothetical pulp mill representing existing best available commercially proven Nordic technology in 2004.

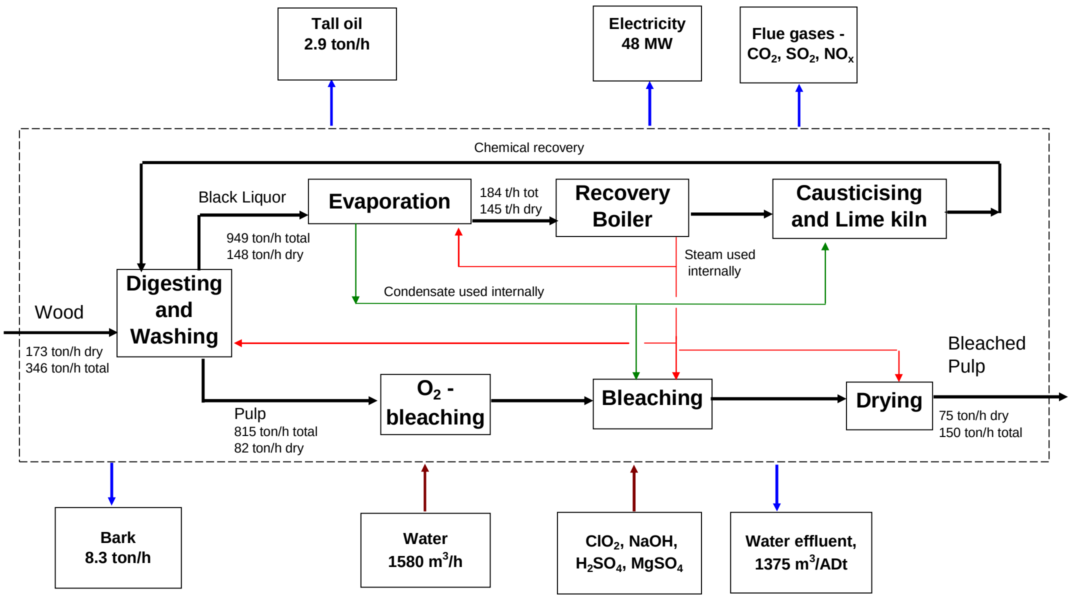

Figure 3-5 *Block diagram reference case (softwood) for pulp & paper sector*

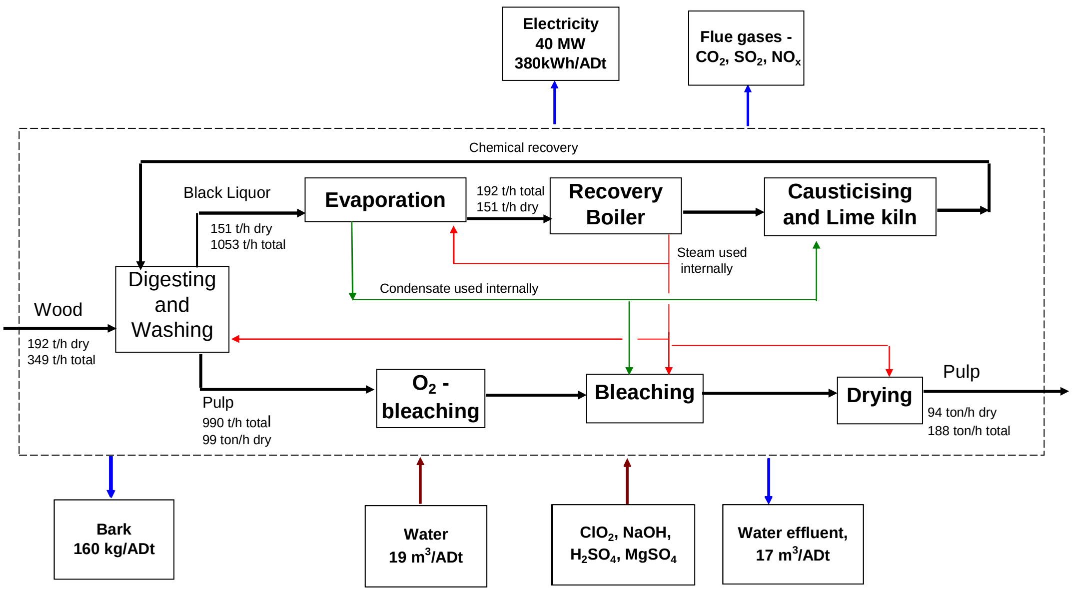

Figure 3-6 *Block diagram reference case (hardwood) for pulp & paper sector*

Table 3.4 *Major characteristics of the reference cases*

Characteristic	Unit	Softwood	Hardwood
Mill capacity	Dry tonne/d	1800	2250
	Dry tonne/h	75	94
Composition	%	50% pine and 50% spruce	minimum 90% birch, 10% other
By-product sold	-	Electricity, bark, tall oil	Electricity, bark
Equipped with	-	Back-pressure turbine condensing turbine	Back-pressure turbine condensing turbine
Black liquor processed by recovery boiler	tDS/d	3400	3400

The process starts in the *wood yard* where logs are debarked and cut into wood chips a few centimetres in length. It is also common for mills to use a fraction of purchased sawmill chips. The wood chips are impregnated with cooking liquor and then fed to the *digester,* commonly of the continuous type, although there are many mills that use batch digesters as well. The residence time in the digester is several hours, during which the chips are cooked at a temperature of 150-170°C under strongly alkaline conditions and in the presence of sulphide. The main objective is to dissolve as much of the lignin as possible while minimising the simultaneous dissolution of the carbohydrates.

The pulp produced in the digester is washed to recover the cooking liquor and reduce the carry-over of dissolved organic material to the *oxygen delignification* stage (O_2-bleaching). This stage is more selective than cooking, i.e. the yield loss is smaller per unit of lignin removed. After further washing, the pulp goes to the *bleach plant*. Final bleaching is still more selective than oxygen delignification and is usually done in a sequence of acidic and alkaline stages with washing in between the stages. The most common bleaching chemicals used today are chlorine dioxide and hydrogen peroxide. After final bleaching the lignin content is very low, giving the pulp high brightness stability.

In the reference case, the bleached pulp is dried with hot air in a *pulp dryer* before it is baled and shipped to the customers (paper mills).

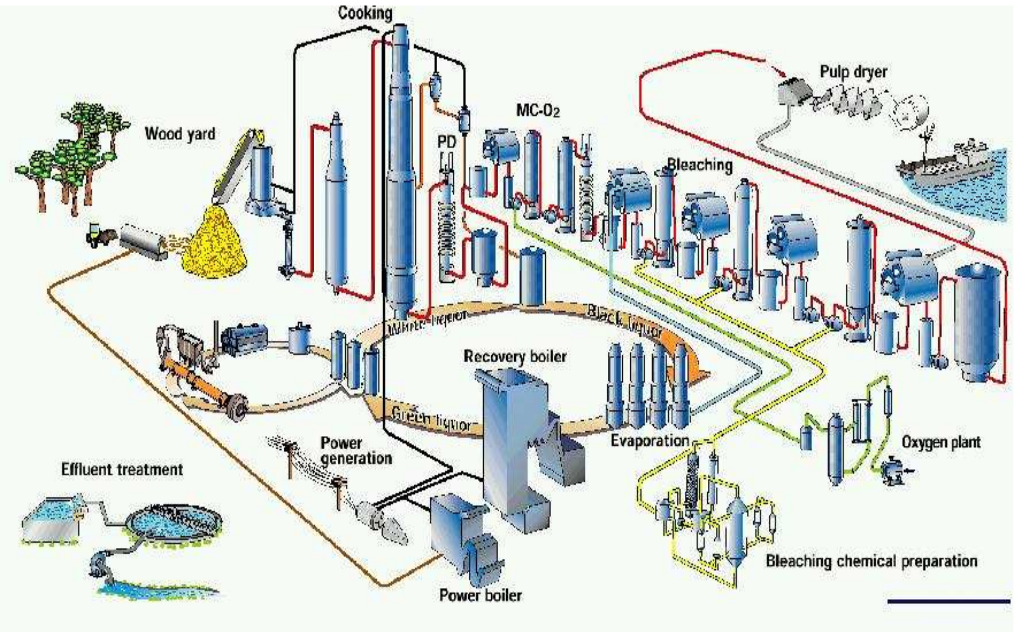

Figure 3-7 *Schematic of the reference case with its process units. In a black liquor gasification system, only the recovery boiler has to be replaced.*

An extremely important part of the pulp mill is the *recovery cycle*, which is shown as the circle in the centre of Figure 3.7. In this cycle, energy is recovered from the dissolved organic material and the cooking chemicals are regenerated. Without the recovery cycle, the process would be both economically and environmentally impossible.

The raw material for the recovery cycle is the cooking liquor that has been displaced during the washing of the pulp. Due to its colour, it is called *black liquor*. It contains approximately half of the organic material (mainly lignin) that was originally in the wood and almost all of the inorganic chemicals that were used for delignification. The solids content of the black liquor is relatively low when it is withdrawn from the digester, and to produce a combustible material the black liquor is evaporated to high dryness in a multi-stage *evaporation plant*.

After evaporation, the black liquor is burned in the *recovery boiler*. By employing a staged combustion process, the conditions in the furnace can be reducing at the bottom and oxidising at the top. In this way, the sodium and sulphur can be recovered as molten sodium sulphide and sodium carbonate – called *smelt* – that is tapped from the bottom of the boiler. Meanwhile, the organic material is completely oxidised in the upper parts of the furnace to provide heat for high pressure steam generation.

After the smelt has been dissolved in *weak wash* it is known as *green liquor*. Before it can be reused in the cooking process, the carbonate ions in the liquor need to be replaced by hydroxide ions. This is done through a process called *causticising* where the green liquor reacts with quick lime to produce calcium carbonate and sodium hydroxide. The result is called *white liquor*, which is the cooking liquor needed to start the delignification process again.

The calcium carbonate formed in the causticising vessels is washed and then burned in the *lime kiln* to regenerate the quick lime. The reference mill is thus nearly self-sufficient in the production of the major chemicals used for cooking. Small amounts of sodium and sulphur must sometimes be added to compensate for losses. The most common make-up chemical is sodium sulphate, which has given the process its alternative name (Sulphate process). The reference mill is self sufficient in both steam and power, and excess electricity can be sold.

Black liquor

As it exits the digester, the black liquor contains 15–17% solids, consisting of dissolved organics from the wood and spent pulping chemicals. The reference case uses several hundred tonnes of inorganic chemicals per day. For both environmental and economic reasons, it is desirable to recover and recycle these chemicals. Black liquor has a high organic content from the dissolved lignin and carbohydrates, and in concentrated form (>60% solids) it burns in a manner similar to heavy oil. In a modern pulp mill, the black liquor is usually concentrated to 70–80% dry solids. A typical black liquor composition is shown in Table 3.5. The inorganic content is high – about 45% of the black liquor exits the recovery boiler as smelt. The heating value per tonne of black liquor solids is thus relatively low, despite the fact that black liquor is rich in lignin, which has a higher heating value than the other major components of the wood. Some data for the black liquor in the reference cases are presented in Table 3.6.

Table 3.5 *Typical black liquor elementary composition*

Element	Composition
C	34.9%
H	3.4%
S	5.0%
O	35.1%
Na	19.4%
K	2.1%
Cl	0.1%
Inerts	0.0%

Table 3.6 *Data for black liquor to recovery boiler*

Parameter	Unit	Softwood	Hardwood
Estimated higher heating value of virgin DS	MJ/kg	14.41	14.24
Black liquor flow to recovery boiler	tDS/h	142	142
Net useful heat from black liquor, virgin solids	MJ/kg DS	10.41	10.15
Net useful heat from black liquor	MW	412	421

Integration options within the pulp & paper industry

Three new technologies entering the pulp and paper industry will be investigated and integrated with the reference cases. These three are:

- Black liquor gasification with following DME or methanol production;
- Lignin extraction;
- Ethanol production.

Black liquor gasification

In a *black liquor gasification* (*BLG*) system, the recovery boiler is replaced with a gasification plant. The evaporated black liquor is gasified in a pressurised reactor under reducing conditions. The generated gas is separated from the inorganic smelt and ash. The gas and smelt are cooled and separated in the quench zone below the gasifier. The smelt falls into the quench bath where it dissolves to form green liquor in a manner similar to the dissolving tank of a recovery boiler.

The raw fuel gas exits the quench and is further cooled in a counter-current condenser. Water vapour in the fuel gas is condensed, and this heat release is used to generate steam. Hydrogen sulphide is removed from the cool, dry fuel gas in a pressurised absorption stage. The resulting gas is a nearly sulphur-free synthesis gas (*syngas*) consisting of mostly carbon monoxide, hydrogen and carbon dioxide.

Some of the main parameters for the black liquor gasification and the following biofuel production for the reference case are listed in Table 3.7 and Table 3.8.

Table 3.7 *Gasifier data*

Parameter	Value
Gasifier temperature	950°C
Gasifier pressure	32 bar(a)
Fraction of black liquor to gasification	100%
HP Steam Pressure	140 bar(a)
HP Steam temperature	545°C

Table 3.8 *Overall plant data*

Parameter	Value
Black liquor feed (dry)	3420 dry ton/day
Black liquor feed (total)	4400 ton/day (79% dry)
Oxygen consumption	1172 t/d (as 100% O_2)
DME-production	824 t/d (as 100% DME)
Methanol production	1183 t/d (as 100% methanol)

If the black liquor gasification is implemented, additional biofuel will be needed to cover up the lack in energy (see Table 3.9). This will be combusted in a separate power boiler.

Table 3.9 *Biofuel import*

Case	MW or t/h bark
Methanol	129 MW or 23.9 t/h as dry bark (19.4 MJ/kg bark)
DME	125 MW or 23.2 t/h as dry bark (19.4 MJ/kg bark)

Lignin extraction

Lignin can be extracted from the black liquor in the evaporation plant. The lignin is separated by lowering the pH by injecting CO_2. The lignin then precipitates and is separated from the black liquor in a filter press. The separated lignin is washed under acidic conditions. It is possible to extract 155 kg lignin/tonne dry produced pulp. The heat value in the black liquor will decrease, and the recovery boiler will generates less steam if lignin is separated from it. If the recovery boiler is the bottleneck of the pulp mill, which is quite common, there is a potential of an approximately 25% increase in pulp production since the load on the recovery boiler is decreased when lignin is extracted from the black liquor. The production increase is of course only possible if all other equipment can handle the increase.

Many pulp mills use oil or natural gas in the lime kiln, which is the last big consumer of fossil fuel in the industry, but with lignin extraction it is possible to replace the fossil fuel with lignin.

Ethanol production

Since the worldwide capacity of pulp is larger than the demand today, it may be beneficial to convert a pulp mill to produce ethanol instead of pulp. Some mills also have several pulp production lines and one option is to convert one of these lines to ethanol production. The chemical recovery line is intact, but the fibre line is replaced with new units, for example a pH-adjuster and a fermentation stage. The produced ethanol is distilled.

3.4 Conventional oil refinery sector

The reference case for conventional oil refinery sector is the Coruña refinery, located in the north-west region of Spain. It is one of the five refineries belonging to Repsol in Spain. The region's climate is suitable for biomass production. Figure 3.8 presents a general scheme of the Coruña refinery.

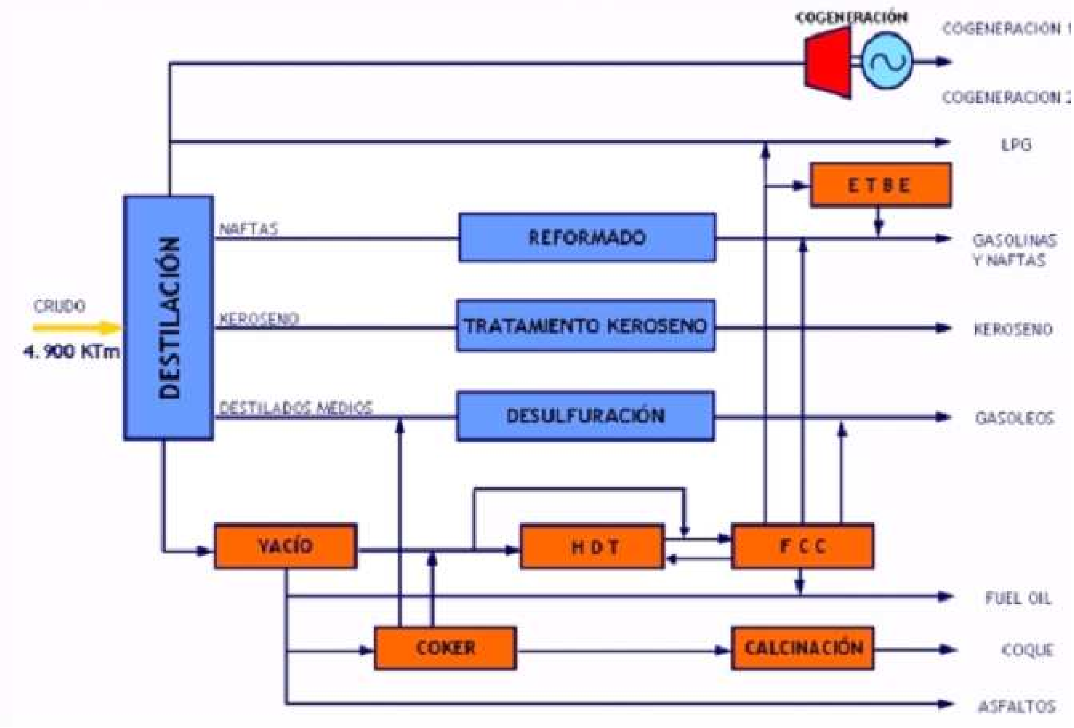

Figure 3-8 *General scheme of Coruña refinery*

There are several options to integrate biofuels within Coruña refinery, as presented in Figure 3.9.

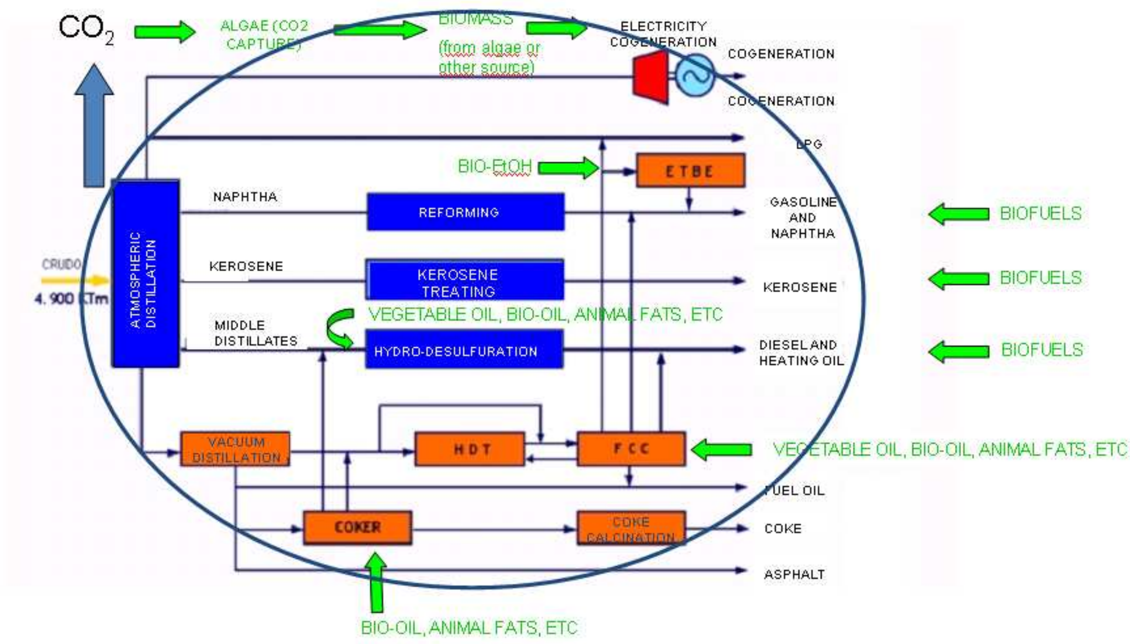

Figure 3-9 *Integration options of biofules in Coruña refinery*

One of the integration options could be direct blending of externally produced biofuels to gasoline, kerosene, and diesel fuel. Biofuels that might be blended to gasoline are: bio-MeOH, bio-EtOH, bio-dimethylether (DME), bio-MTBE, bio-ETBE, other bio-ethers, synthetic biofuel (BTL gasoline), etc. Kerosene could be blended with hydrogenated vegetable oil, and disel could be blended with FAME, FAEE, synthetic biofuel (BTL diesel), hydrogenated vegetal oil, bio-BuOH, etc. However, this route is not considered as an advanced biorefinery route.

Another integration option could be algae cultivation, by capturing the CO_2 emissions inside the refinery. Current problems to be overcome for this route are the separation/drying steps, and the high production costs.

Biomass may also be used within the refinery as feedstock for cogeneration, but this is not a biorefinery route.

Integration of biofuels or renewable-based feedstocks in existing refining processes is therefore the option selected for this sector. A main option is the integration of bioethanol as feedstock in the etherification unit (ETBE). This is an easy integration without any technological problems to be overcome. Another integration option is the co-processing of vegetal oil, animal fat, or bio-oil in a middle distillates hydrotreating unit that is used for desulphurisation of diesel. Vegetal oil, animal fat, or bio-oil may also be co-processed in a Fluid Catalytic Cracker unit (FCC) or a coker.

Concerning co-processing of vegetal oil (palm, rapeseed, soy, etc., or non-conventional vegetal oil like jatropha) in a hydro-desulphurisation unit data are available from previous R&D studies carried out by Repsol with palm oil at pilot scale, and the technical feasibility has been demonstrated. Also some commercial trials has been carried out by other oil companies. Co-processing of animal fats in a hydro-desulphurisation unit is feasible from a technical point of view. Also in this case data are available from previous R&D studies carried out by Repsol at pilot scale.

Regarding co-processing of animal fats in an FCC unit data are available from previous R&D studies carried out by Repsol at pilot scale, and technical feasibility has been demostrated at commercial scale.

A coker unit allows processing more residual feedstocks. However, there are no data available from previous R&D studies carried out by any company, or R&D centre, or any demo at comercial scale. The technical feasibility has not been demostrated so far. Besides, it is expected, that this option would be less attractive from an economical point of view. For these reasons, it is recommend to discard this option.

Among the different options discussed above, it is therefore recommended to select the following two options as the reference cases for oil refinery sector:

- Co-processing of vegetal oils or animal fats in a middle distillates hydrotreater (hydro-desulphurisation unit);
- Co-processing of animal fats in a Fluid Catalytic Cracking unit.

These options have been deeply investigated by Repsol at laboratory and pilot scale, and previous techno-economical feasibility studies based on existing units are available.

The block diagrams of the hydro-desulphurisation and FCC units, including mass & energy flows are shown in Figures 3.10 and 3.11.

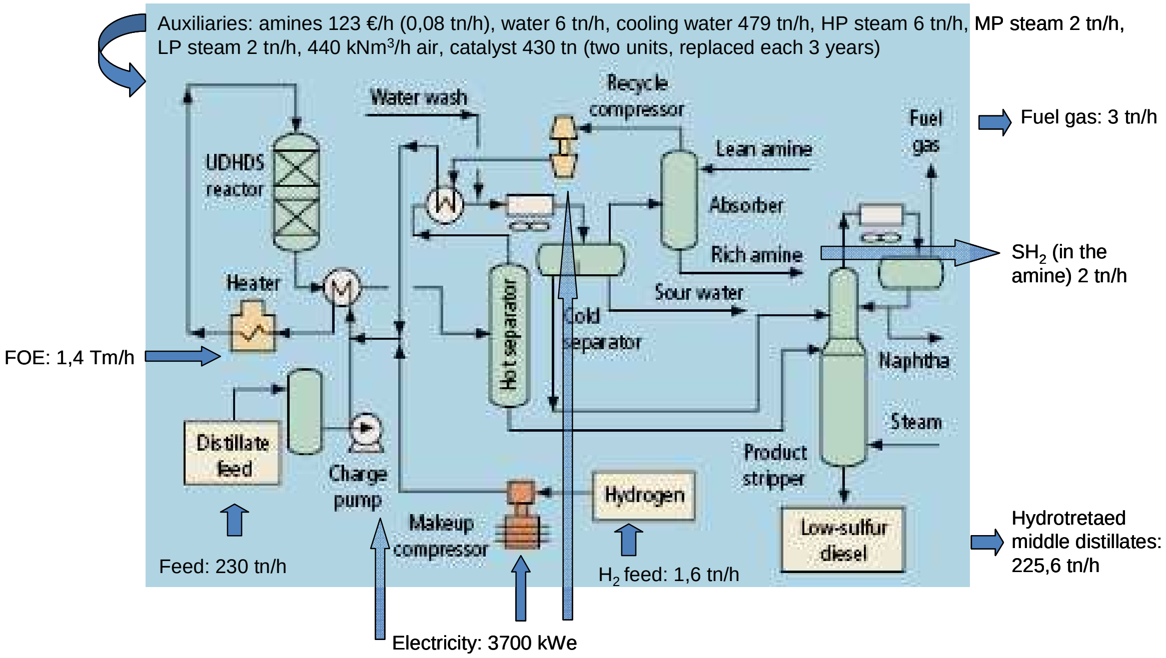

Figure 3-10 *Block diagram reference case conventional oil refinery: hydro-desulphurisation unit including mass & energy flows*

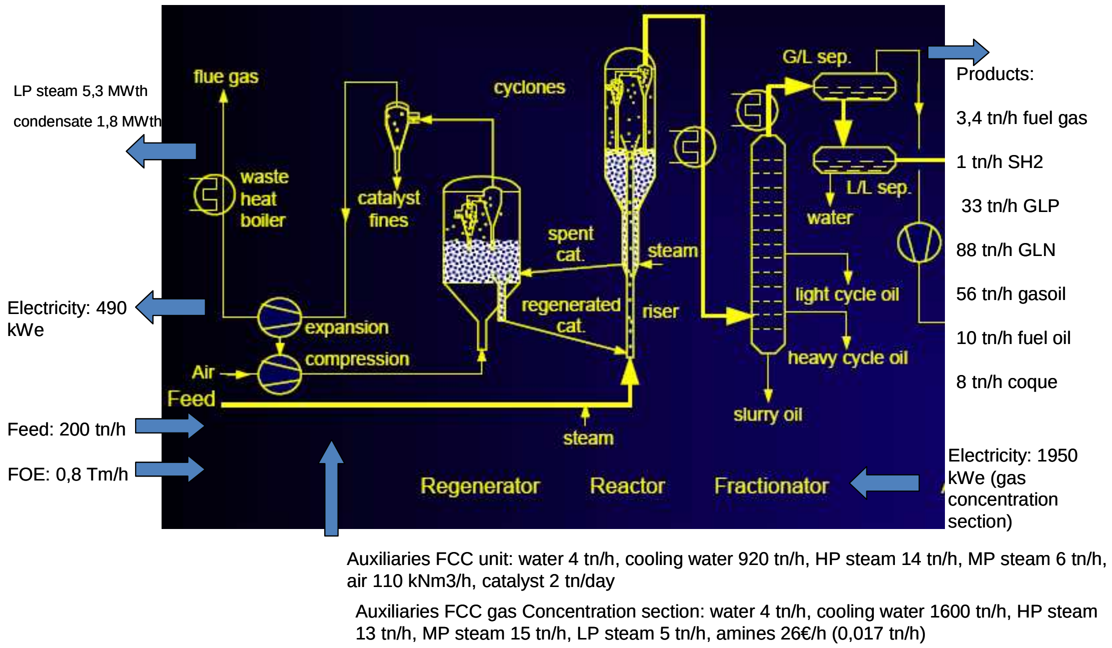

Figure 3-11 *Block diagram reference case conventional oil refinery: FCC unit including mass & energy flows*

3.5 Power production sector

Within the power sector three reference cases are described for respectively small-scale, medium-scale, and large-scale power production. Also possibilities for integration of biorefineries with the power industry are proposed.

3.5.1 Small-scale power production and an integrated grass-based biorefinery

Reference case

Anaerobic digestion is the reference case for energy production from grass. Grass is among other lignocellulosic feedstocks a suitable candidate for anaerobic digestion, due to the high moisture content (50-70 wt.%), and high sugar polymers content (40-60 wt.% on dry matter basis). These properties are beneficial as the process water input required is low (dry anaerobic digestion can be performed), and sugar polymers are converted mainly into biogas (CH_4 and CO_2) and a solid digestate.

Anaerobic digestion can be applied to any residual stream with fermentable organic matter content. The conditions of anaerobic digestion are very simple: avoid the presence of an electron acceptor (e.g. oxygen, nitrate or sulphate) or an external energy source (e.g. light). In the absence of an external electron acceptor organic matter can be only fermented with final products CH_4, CO_2 and NH_4^+ (Kleerebezem and van Loosdrecht, 2007). The conversion of fermentable organic carbon into biogas is a stepwise conversion by bacteria, as shown in Figure 3.12.

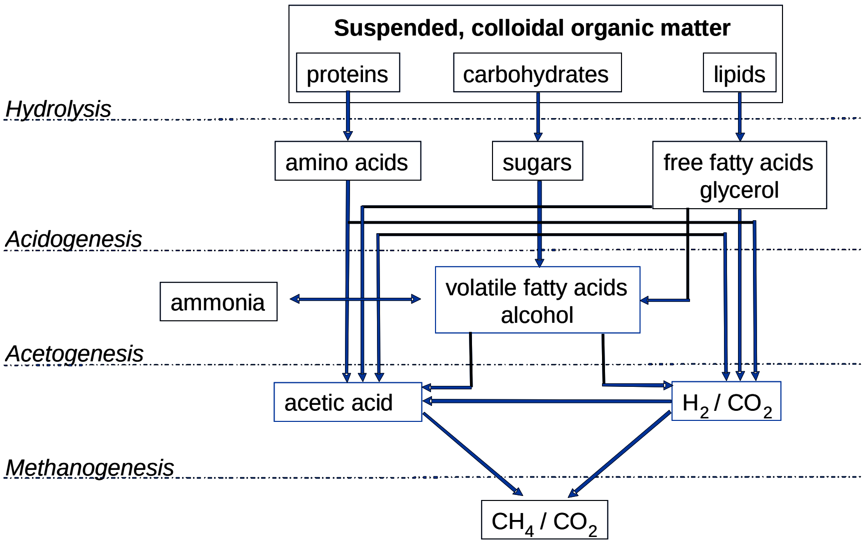

Figure 3-12 *General scheme for anaerobic digestion (De Mes, 2003)*

In dry systems, the solid content of the reactor is kept in the range of 20-40% dry matter. Due to the high viscosity, the fermenting feedstock can be moved via plug flow inside the reactors, which offers the advantage of technical simplicity as no mechanical devices need to be installed within the reactor (Lissens, 2001). These processes can be run under mesophilic or thermophilic temperatures.

Dry fermentation processes have been applied for many years for the treatment of source separated municipal solid wastes. Most of these processes are operated continuously with both completely mix or plug-flow reactor systems. However, in the agricultural sector, dry fermentation processes have been seldom applied, but recently, several new concepts have been developed specially for the treatment of energy crops. Mainly batch systems without mixing are used in agriculture (Weiland, 2003).

Digestion systems can be classified based on the number of phases in the digestion process. The two-phase systems physically separates the phases that occur during anaerobic digestion. The first reactor is a liquefaction-acidification compartment and the second is the acetogenic and methanogenic compartment. The main advantage of two phase systems is that they are very stable for highly degradable wastes (Pavan, 2000). Two stage digestion have shown to improve methane yields possibly due to the pH conditions favourable for hydrolysis (Lehtomaki, Bjornsson, 2006). However, one phase systems can be as reliable as two phase systems if the operational parameters are carefully adjusted.

Process description
A block diagram of the process is represented in Figure 3.13. Grass is fed to the reactor where the anaerobic digestion takes place. The produced solid digestate is collected and dewatered for further use as a fertilizer, a liquid fraction and part of the digestate are returned to the process for inoculation and nutrients recovery. Biogas (mixture of CH_4 and CO_2) is continuously produced and collected for heat and power generation using a gas engine CHP unit.

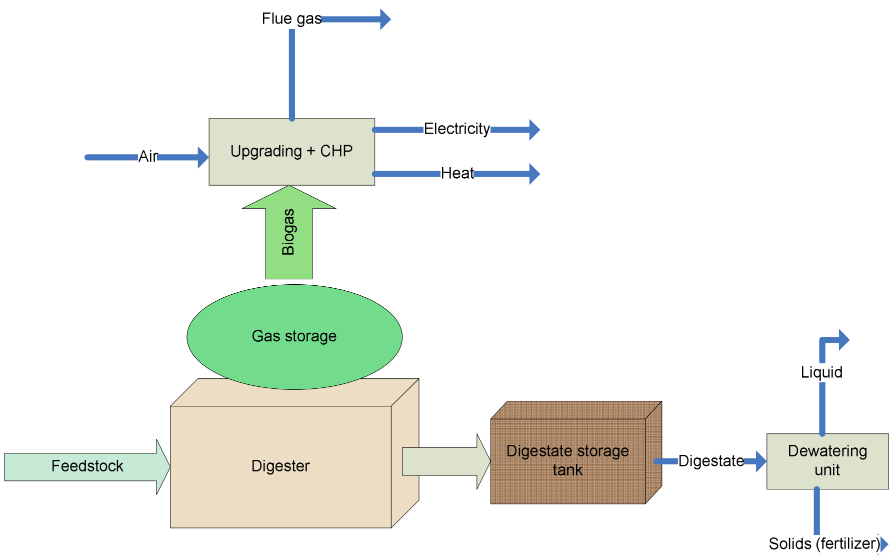

Figure 3-13 *Process block diagram anaerobic digestion (reference case)*

The main equipment required is:
- Feedstock storage tank;
- Digester with gas holder;
- Storage tank for digestate;
- Dewatering unit for digestate;
- Pumps;
- Gas cleaning unit;
- Combined Heat and Power unit (CHP).

Batch systems are technically simple; the investment costs are significantly (ca. 40%) less than those of continuous-fed systems. The land area required by batch processes is however considerable larger than for continuously-fed "dry systems". Operational cost, on the other hand, seem comparable to those of other systems (Vandevivere, 2001).

Anaerobic digestion is a net energy producing process and the electricity production potential is about 150 to 390 kWh per tonne of grass, depending on the grass composition (20 to 50 wt.% dry matter content). The residues treatment of anaerobic digestion of grass is simpler than other systems such as sewage sludge digestion, due to the feedstock nature which determines gas,

solid and liquid effluents. Grass composition is homogeneous and the solid digestate can be used directly as a fertilizer as no pathogens are present.

Mass & energy balance

The mass and energy balances are given based on a grass flow of 1.4 tonnes/hr. The feedstock composition is 30 wt.% dry matter with 54 wt.% (d.m. basis) fermentable sugars with a COD load of 248 kg COD/m^3. The mass balance overall results are shown in Table 3.10.

Table 3.10 *Mass balance for anaerobic digestion of grass*

Component	Formula	Input (kg/hr)	Output (kg/hr)
Grass (Dry matter)	-	420	
Ammonia	NH_4^+	10	
Moisture	H_2O	980	
Air	-	627	
Solids			
Digestate	$CH_{1,8}O_{0,5}N_{0,2}$		70
Lignin	$C_{10}H_{11}O_2$		68
Ashes	-		126
Water	H_2O		1003
CHP Flue gases			
Carbon dioxide	CO_2		216
Water	H_2O		82
Nitrogen	N_2		472
Total		**2037**	**2037**

For the energy balance, the lower heating value (LHV) of grass is assumed to be 17 MJ/kg dry matter, and the conversions efficiencies for a gas engine are about 35% to electricity and 57% to heat. The residual digestate LHV is considered to be 26 MJ/kg, while for lignin the LHV is 23 MJ/kg. Energy efficiency is calculated as [Energy output]/ [LHV input]. The overall energy balance results are shown in Table 3.11.

Table 3.11 *Energy balance for anaerobic digestion of grass*

Parameter	Units	Value
Input		
Feedstock input	[MWth]	1.98
Energy output		
Electricity	[Mwe]	0.20
Heat	[MWth]	0.33
Energy efficiency	[%]	27
Residues output		
Digestate	[MWth]	0.52
Lignin	[MWth]	0.43

The energy efficiency of the reference case is 27%, being 10% from electricity and 17% from heat. If considering all outputs (energy and LHV of residues) the total energy efficiency would be 73%; 27% from energy, and 47% from residues.

Capital and operating costs
Cost data of capital investment for anaerobic digestion of VFG (vegetable, fruit and garden) waste have been reported elsewhere (Van Tilburg, 2008b) being about 7800 €/Nm^3/h biogas for a plant capacity of 225 Nm^3/h biogas (= 500 kW$_e$). The total capital cost including the CHP unit for the system has been estimated as 3900 €/kW$_e$ (Van Tilburg, 2008a)

For detailed equipment design and capital cost estimation several aspects have to be considered such as: Feedstock composition, mass flow rate, the organic matter load (kg COD/m^3) and biogas production (CH_4/day). The combined heat power (CHP) unit size and cost is dependent on the biogas production rate; for small scale applications (0.1 MW$_e$–5 MW$_e$) gas engines are applicable and the installed cost range between €350 and €1500/kW$_e$ depending on the size, the operating and maintenance cost range between 1.3–2 €ct/kWh.

The overall investment cost as a function of grass flow (30 wt.% d.m.) is shown in Figure 3.14. The specific investment cost (€/kW$_e$) as function of electricity output (CHP efficiency to electricity= 35%) is presented in Figure 3.15. The reference case economic parameters are presented in Table 3.12.

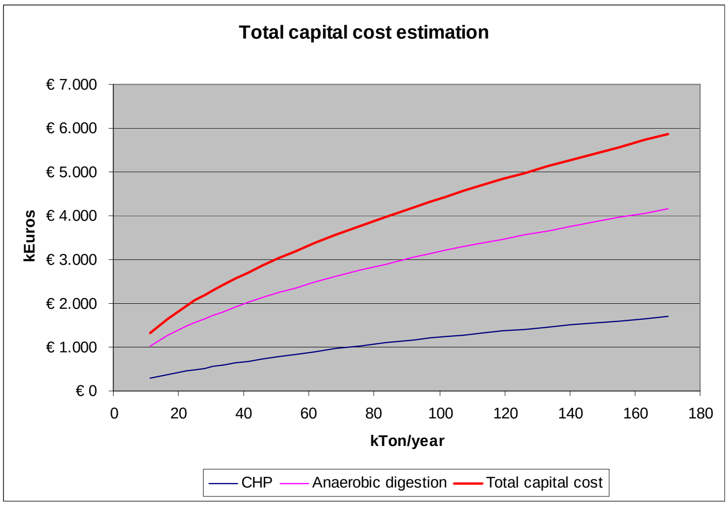

Figure 3-14 *Overall investment cost as function of feedstock flow*

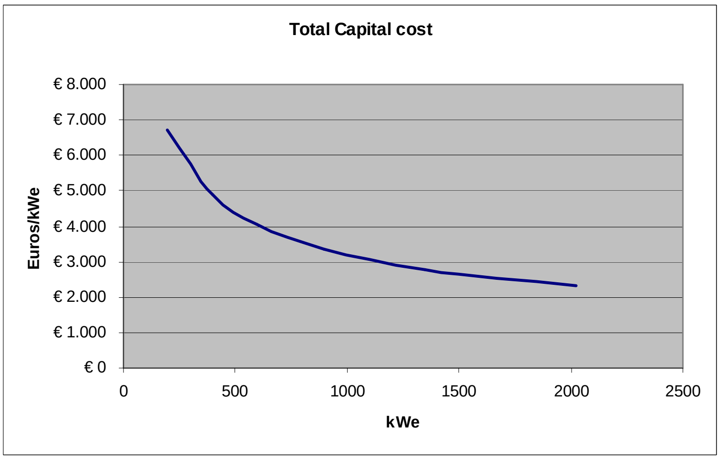

Figure 3-15 *Specific investment cost as function of electricity output*

Table 3.12 *Reference case economic parameters*

Parameter	Units	Value
Feedstock flow	[ktonne/year]	11.2
Operating hours	[hours/year]	8000
Electricity output	[kW_e]	200
Heat output	[kW_{th}]	330
Investment cost	[€/tonne]	120
Investment cost	[€/kW_e]	6705
Maintenance	[€/kW_e]	250
Grass cost (30 wt.% d.m.)	[[€/tonne]	7

Integration option

In the small-scale grass-based biorefinery the feedstock is split in different valuable products by a series of relatively simple separation processes. Different concepts for these kinds of biorefineries, also called "Green biorefineries", are reported in literature.

In all these concepts green biomass, like grass, is used as feedstock. To account for fluctuations in feedstock supply, the feedstock can be ensiled. Ensiling of the feedstock can also help to increase yields of individual products. In all concepts, the first process step is mechanical fractionation of the feedstock by pressing or extrusion producing a fibre-rich press cake and a press juice. Downstream processing of the two major product streams from mechanical fractionation differs from case to case dependent on the products to be recovered.

In the Austrian Green Biorefinery, presented in Figure 3.16, fibres are recovered from the press-cake by processes known from pulping industry, like alkali cooking and steam explosion. The fibres can be used in fibre boards, insulation materials and biocomposites.

Proteins can be recovered from the press juice by heating, coagulation and filtration. The proteins can be used for nutrition of animals. Combinations of membrane technology (ultra and nano filtration and electrodialysis) and chromatography have been suggested as methods for recovery of the lactic acid. Lactic acid has multiple applications, e.g. the production of the biopolymer poly lactic acid.

Residual press juice (after recovery of proteins and lactic acid) and residues from the production of fibres from the press cake can be used for biogas production that is converted to heat and power in a gas engine.

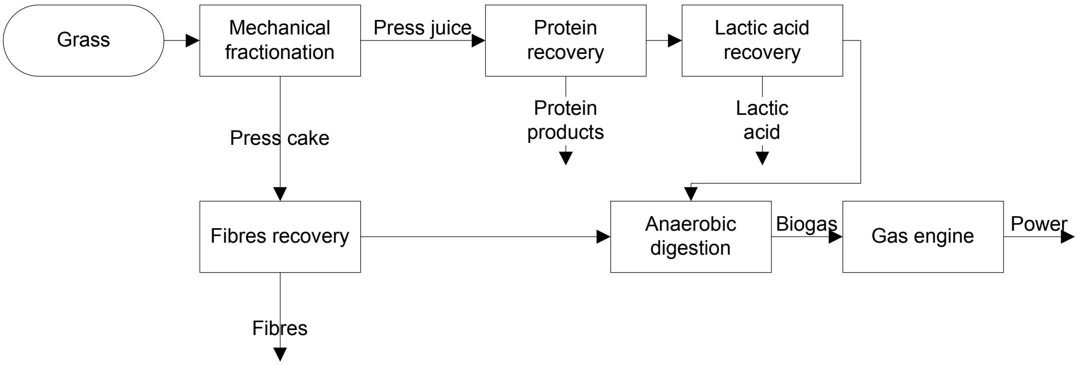

Figure 3-16 *Flow diagram for Green biorefinery*

3.5.2 Medium-scale pyrolysis-based biorefinery

Reference case

Combined heat and power (CHP) production that utilizes circulating fluidized bed (CFB) boiler is the reference case (Figure 3.17) for medium-scale pyrolysis-based biorefinery. In conventional power production by combustion, the combustible material (coal, peat, wood, forest residue etc.) burns inside the boiler. The released heat is transferred to water that boils into steam. The steam flows into a steam turbine, where it expands and spins the turbine which drives an electric generator. After the turbine the steam still has a lot of heat energy. In order to complete the thermal cycle, this extra heat is being disposed of with a cooling tower or other heat sink.

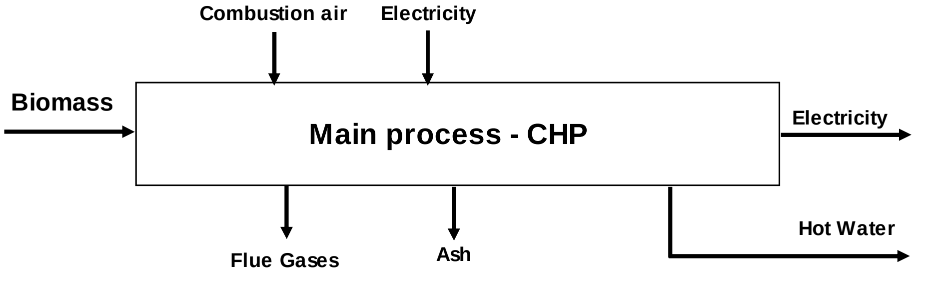

Figure 3-17 *Block flow chart for reference case medium-scale power production*

In combined heat and power production the steam that leaves the turbine is condensated back to water by cooling it with water from district heating. This way the wasted heat energy is minimized and total plant efficiencies around 90% can be achieved.

In this case the CHP plant uses peat as fuel, but also wood, forest residue and other biomasses could be used. On these alternative fuels the respective mass and energy balances would be very similar to this case.

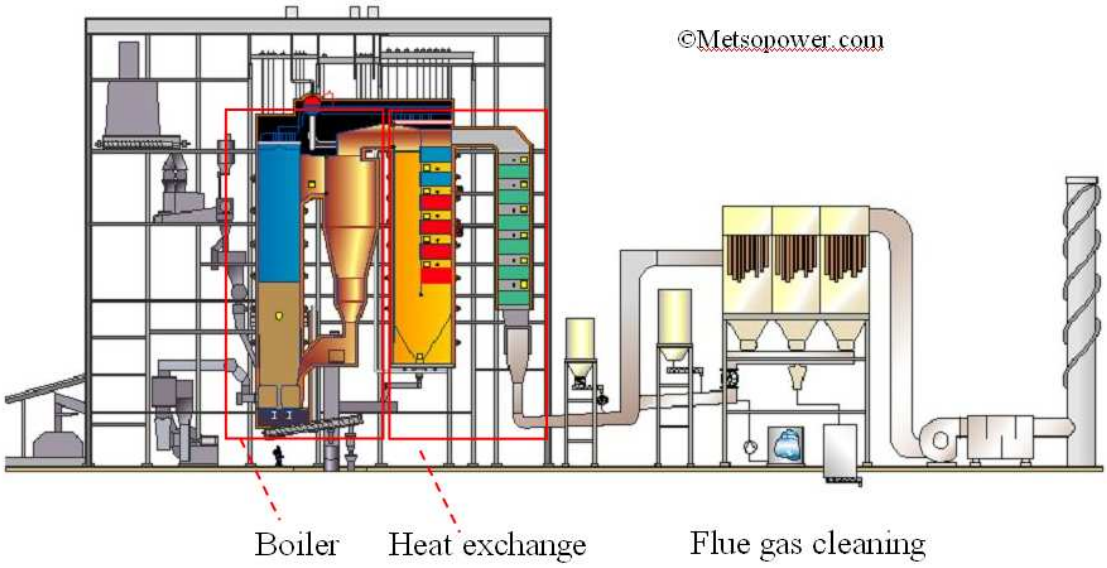

Figure 3-18 *General scheme for CHP plant*

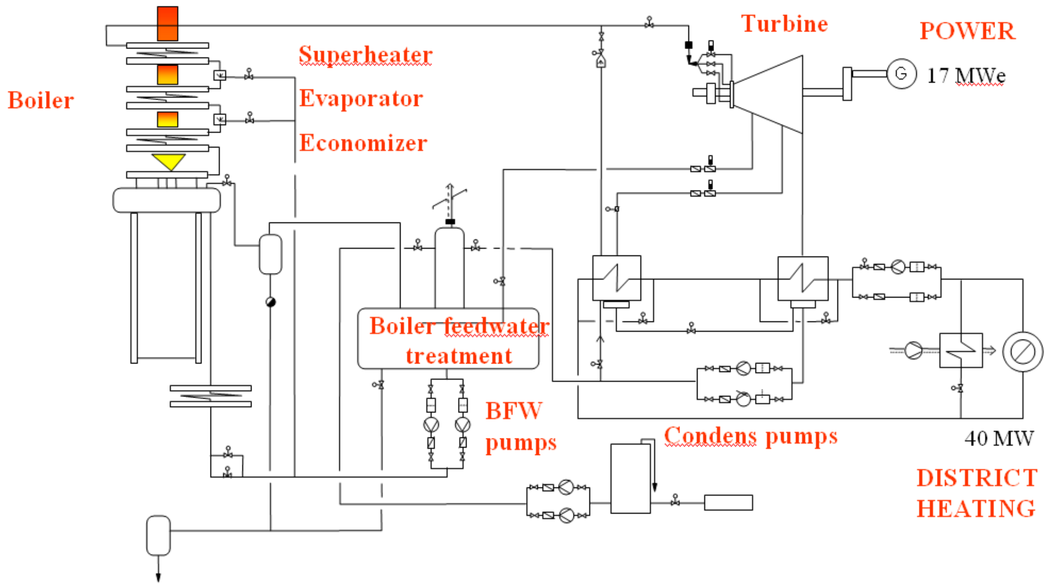

Figure 3-19 *Scheme for the steam cycle of a 60 MWth CHP power plant.*

Mass & energy balance
The higher heating value (HHV) of milled peat is estimated to be 21 MJ/kg, and the lower heating value (LHV) is 9 MJ/kg. Peat has natural moisture of 50%. The mass & energy balances of the reference case 60 MW_{th} CHP plant (Figure 3.19) are presented in Tables 3.13 and 3.14.

Table 3.13 *Energy balance for 60 MWth CHP plant using peat as fuel*

Parameter	**Units**	**Value**
Input		
Feedstock	[MW_{th}]	67
Output		
Electricity	[MW_e]	17
Heat	[MW_{th}]	40
Energy efficiency	[%]	85

Table 3.14 *Mass balance for 60 MWth CHP plant using peat as fuel*

Component	**Formula**	**Input (t/hr)**	**Output (t/hr)**
Peat (Dry matter)	-	26,7	
Moisture (Natural)	H_2O	26,7	
Air	-	274,0	
Solids			
Ashes	-		13
CHP Flue gases			
Oxygen	O_2		14,7
Nitrogen	N_2		210,1
Carbon dioxide	CO_2		47,9
Water	H_2O		41,3
Total		**327,4**	**327,4**

Integration option
VTT (Finland) has been developing an integrated concept, in which fast pyrolysis is integrated to a fluidized-bed boiler (Figure 3.20). Extra biofuels (compared to existing heat loads) are often available at sites, where combined-heat-and-power is produced (district heating plants, forest industry sites). The alternative for using the extra biofuel for the CHP plant is to generate more power with a partly condensing turbine. However, condensing head of a steam turbine has only a total efficiency of about 25-30%, whereas bio-oil may be exported from the site to high value users.

The integration is considered to bring in some technical and economic advantages:

- A high overall efficiency compared to stand-alone pyrolysis concepts;
- Lower investment costs due to no need for a specific char combustor (effects to the cost of the main boiler are considered marginal);
- Lower operating costs than stand-alone pyrolysis due to reduced man-power;
- Operating flexibility due to full exploitation of by-product in the main boiler;
- Operation is easier, because there is no need to combust by-product char in a small sub-optimal boiler, which often would be needed to generate plant energy requirements.

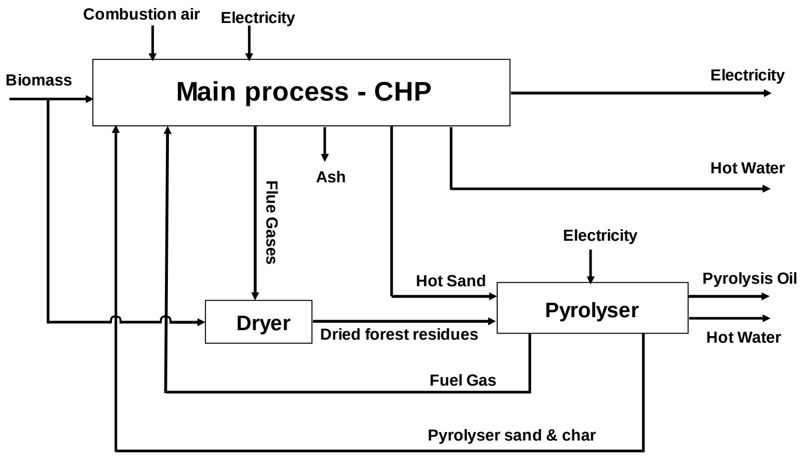

Figure 3-20 *Block flow chart for biorefinery case based on fast pyrolysis*

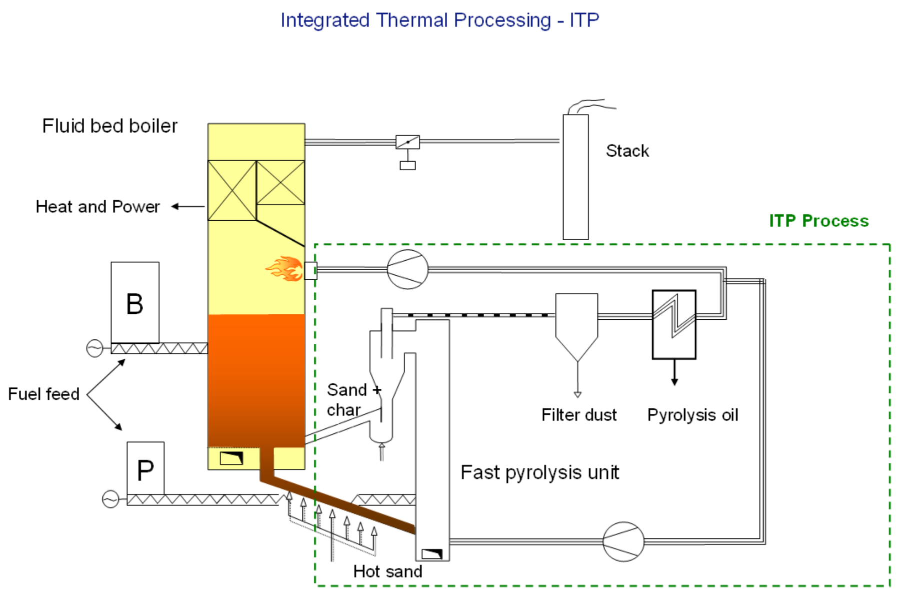

Figure 3-21 *Scheme for biorefinery case based on fast pyrolysis*

3.5.3 Large-scale wood-based biorefinery

3.5.4 Large-scale power production and wood-based biorefinery

For the large-scale biorefinery, the Biomass Integrated Gasification Combined Cycle (BIGCC) plant using woody biomass is the reference case. The technology is not yet commercially available at large scale. A few biomass gasification demonstration plants have been built at small scale, some of them for power generation and some of them for Combined Heat and Power production. A few other gasification plants have been built for co-firing biomass in existing coal-fired power plants.

Process description

The process of biomass integrated gasification combined cycle technology (BIGCC) is depicted as a block diagram in Figure 3.22. Biomass may need to be pre-treated before gasification. Drying may be needed to reduce the moisture content of the biomass if it exceeds the level prescribed by the gasifier. After that, the biomass is gasified with preheated air in an atmospheric gasifier. This is depicted as the gasification section of the BIGCC in Figure 3.22.

The gas exiting the gasifier is cleaned before it is fed to the combined cycle section. The (cleaned) gas is fired in the gas turbine and expanded for electricity generation. Heat present in the fuel gas from the gasifier and the flue gas from the gas turbine is recovered in the Heat Recovery Steam Generator (HRSG) and steam produced by heat recovery is fed into the steam turbine (gas turbine and steam turbine together are denoted as the combined cycle). It has been noted that the reference BIGCC power plant is not yet commercially available at large scale. Biomass gasifiers have been built on a commercial scale for power or CHP plants on a smaller scale or for integration in existing (coal-fired) power plants.

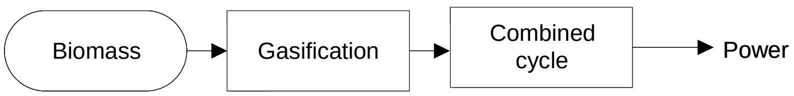

Figure 3-22 *Reference case large-scale power generation*

Mass & energy balance

The mass and energy balances of a large-scale biomass integrated gasification combined cycle (BIGCC) power plant depends on the scale and type of the gasifier and the gas turbine (combined cycle) applied. In Table 3.15 the mass and energy flows are given for a 155 MW_e system with a pressurised air-blown gasifier. The data given in Table 3.15 are based on detailed modelling of the integrated system (Faaij *et al.*, 1998).

Table 3.15 *Mass and energy balance for biomass integrated gasification combined cycle system*

Component	**Mass flow (ton/hr)**	**Energy flow (MW)**
Input		
- Woody biomass	160	344
- Air	1181	
- Total in	1341	344
Output		
- Flue gas	1341	
- Ash	0.055	
- Electricity		155
- Total out	1341	155
Net electrical efficiency		45%

The feedstock for the plant is woody biomass with a moisture content of 50 wt.% and a lower heating value of 7.74 MJ/kg a.r. The feedstock is dried with flue gas to a moisture content of 15 wt.% before gasification. The dried wood is gasified with air at a temperature of 850°C, with a cold gas effiency of 75%. The fuel gas produced by gasification is cleaned and fired in a gas turbine with an efficiency of 45%. Heat present in the different gas streams, fuel gas after gasification and the fuel gas from the gas turbine, is recovered and used to generate steam that is converted into electricity in a steam turbine. The efficiency of the whole steam cycle is 33%. After subtraction of internal electricity consumption the net electrical efficiency of the integrated system is 45%.

Capital costs

The currently operating biomass gasification plants have been built as demonstration plants for power generation or CHP. Furthermore, they have a relatively low capacity, i.e. <10 MW_e. Investent costs for existing plants are given in Table 3.16. The specific investment costs of biomass gasification with power generation based on a gas turbine (the upper four examples) are ranging from 2700-5500 €/kW_e. These plants show capacities ranging from 0.5 MW_e (Neustad, Austria) up to 5.4 MW_e (Skive, Denmark). The generating efficiencies are between 25 and 28%. The fifth example pertains to a somewhat larger gasifier than that demonstrated in Kokemäki (Finland). However, also this plant would not be based on a combined cycle. Therefore, the specific investment costs reported (averaging approximately €4,000/kW_e) are not representative of those of a biomass integrated combined cycle plant.

The lower half of Table 3.16 shows examples of co-gasification of biomass in a coal-fired power plant. In these cases, investment in the power plant section was not necessary. The specific investment costs for the gasification section range from €570/kW_e (Lahti, Finland) to €1,400/kW_e (Amergas, the Netherlands). While coal-fired power plants may have an average net efficiency of 40%, biomass co-gasification attains a level of 34-35% (Atwood, 2004).

Table 3.16 *Features of biomass gasification combined with power/CHP or co-gasification*

Plant	Country	Year of commissioning	Fuel	Capacity [MW_e]	[MW_{th}]	Efficiency [%]	Investment cost [$M€_{2007}$]	Specific investment cost [$€_{2007}/kW_e$]
Güssing	Austria	2003	Wood	2.0	4.5	25	11.0	5,520
Neustadt	Austria	2003	Wood	0.52	0.72	28	N/A	N/A
Skive	Denmark	2007	Wood	5.4	11.5	28	26.2	4,861
Kokemäki (NOVEL)	Finland	2005	Wood	1.836	4.3	28	5.0	2,720
NOVEL medium-scale	N/A		Wood	6.4		32	17.0	2,656
Co-gasification [1]	Europe		Biomass	100		36		1,300
Lahti co-gasification	Finland	1997	Biomass	~ 25			14.2	567
Amergas co-gasification	Netherlands	2002	Demolition wood	29.0		34	40.7	1,402

1 Based on (NETBIOCOF, 2006). In case of co-gasification, the fuel gas is co-fired in the coal boiler.

Sources: OPET, 2004; Kurkela, 2006; Spindler, 2008; Ikka et al, 2007; Helinen, 2006; Atwood, 2004; Oravainen, 2008; Girard et al, 2007; Babu, 2006; Patel, 2004; REW, 2008; NETBIOCOF, 2006.

In different system assessment studies capital costs of large-scale Biomass Integrated Gasification Combined Cycle systems have been estimated. Costs estimated depend on system lay out and assumptions made. The costs from the different studies have been converted to costs in 2009 and are given in Table 3.17 and Figure 3.23. The costs given in Figure 3.23 show that capital costs for a 150 MW_e system will be ~220 M€ or 1467 €/kW_e. These costs are for commercial systems at large scale, i.e. 150 MW_e. The short-term demonstration plants and first-of-a-kind plants may be considerably more expensive.

Table 3.17 *Capital cost for Biomass Gasification Combined Cycle systems*

Reference	**Size (MW_e)**	**Capital costs ($M€_{2009}$)**	**Specific investment ($€_{2009}/kW_e$)**
Caputo et. al (2005)	10	49	4881
	30	101	3370
Faaij, et. al (1997)	30	80	2677
	64	134	2093
	151	236	1562
Solantausta et. al. (1995)	30	101	3380
	60	152	2535
	33	101	3072
	62	158	2544
Bain et.al. (2003)	75	159	2126
	150	210	1401
Craig and Mann (1996)	56	106	1887
	132	216	1637
	122	162	1329
	105	170	1624

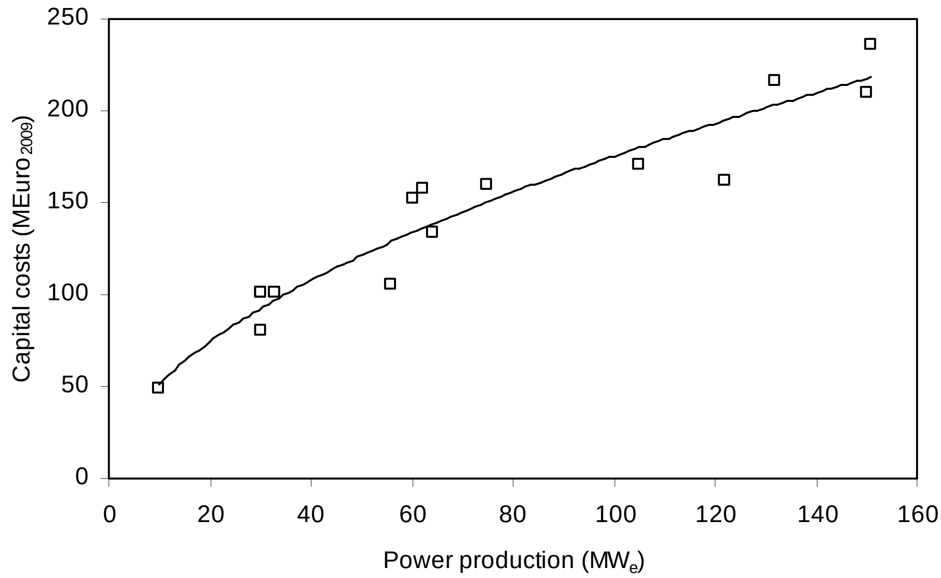

Figure 3-23 *Capital costs for Biomass Integrated Gasification Combined Cycle system as a function of size*

Integration option

In the large-scale wood-based biorefinery wood is gasified to produce fuel gas for production of fuels by catalytic synthesis and power production in a combined cycle. For wood gasification basically two options exits:

- Gasification at low temperatures (<900°C) to produce a fuel gas containing syngas components (H_2 and CO) and hydrocarbons (CH_4, C_2H_4, BTX and tars).
- Gasification at high temperatures (>1300°C) to produce a synthesis gas (H_2 and CO).

In the former option, at low temperatures, the hydrocarbon fraction contains valuable products, like ethylene, BTX and tars. Separation of the valuable hydrocarbons (ethylene and aromatics) can result in significant income.

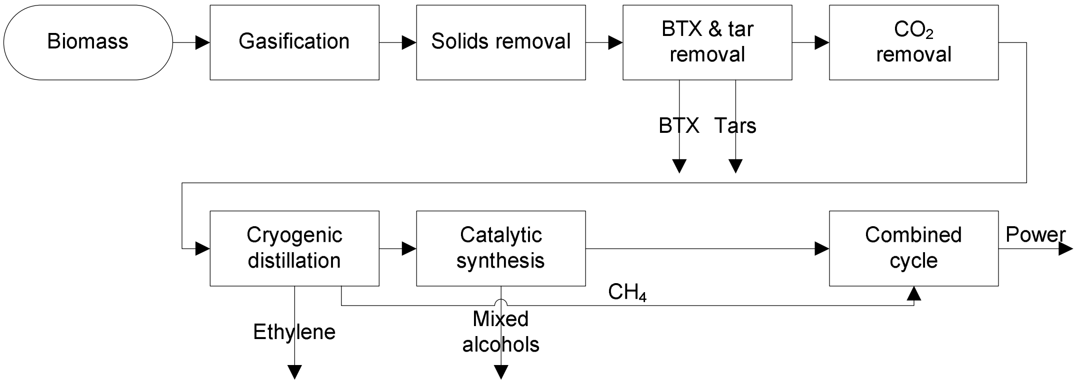

Figure 3-24 *Large-scale gasification-based biorefinery*

A simplified flowsheet of the process is given in Figure 3.24. The biomass is gasified in an indirectly heated gasifier to produce a fuel gas low in N_2 content. After dust removal, BTX and tars are removed as products by a scrubbing process. CO_2 is removed from the fuel gas by scrubbing to enable cryogenic separation. In the cryogenic separation the fuel gas is split in ethylene, CH_4 and synthesis gas. The synthesis gas is converted catalytically into mixed alcohols. The CH_4 together with off-gas from the mixed alcohol synthesis is used for power production in a combined cycle.

3.6 Food industry sector

Two cases are considered within the food industry sector: production of cheese, and the Ten Kate process with slaughter byproducts as feedstock. The first case will be used later on in work package 4 as a reference case, and will be extended to an integrated biorefinery plant. The second case is described only in this work package, together with its integrated biorefinery scheme. Due to confidentiality aspects, It was unfortunately not possible to collect mass, energy, and economic data of this case for techno-economic and environmental assessment within WP4.

3.6.1 Cheese production

Process description

A block diagram of the cheese production process is shown in Figure 3.25. Milk is pumped into storage tanks where the temperature is kept constant at 4°C. Milk then undergoes cream separation process to provide for the uniform fat content. Most of the cream goes back to the process and the reminder is sold for butter production. Next step is pasteurisation process, where milk is heated until 72°C for about half a minute, and then it is rapidly cooled down to 30°C. Milk is then sent to the vats where fermentation takes place. Rennet and the starting culture are added in the small proportions to the cheese vats, and the curd is formed. The curd is solidified in the cheddar tower, and the aqueous stream of whey is separated. The whey is composed of unconsumed proteins, fat, lactose, mineral salts, and water. After the cheddar tower curd blocks are shredded and mixed with salt in the mixer/tumbler. Blocks are formed by pressing the solids. After blocks forming cheese is sealed, cooled, and stored to mature. Cheese yield is about 10 wt.% based on the milk basis.

Whey removed during the curd forming is stored in the tank from where it flows to the multistage evaporator to concentrate the solids and remove part of the water. After the first concentration step, resulting slurry is spray-dried to remove almost all the water. Resulting whey powder that contains around 5 wt.% water is sent for packaging. Amount of whey powder produced is about 7 wt.% on the milk basis.

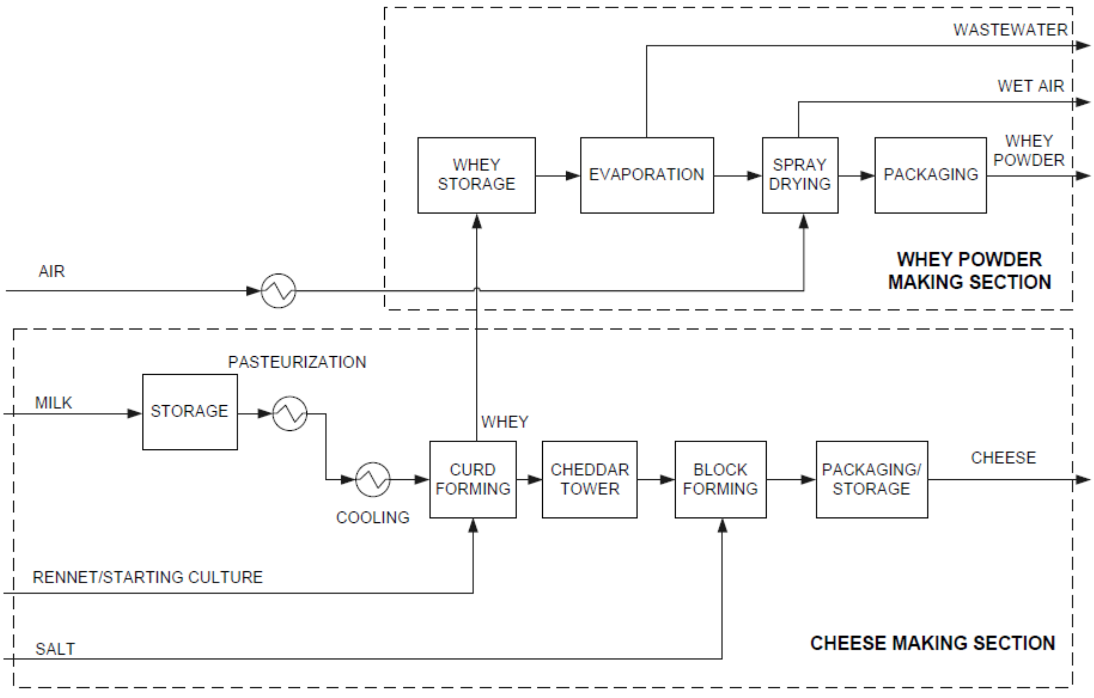

Figure 3-25 *Block diagram of a typical cheese production process*

Table 3.18 shows overall mass balance of the process. About 80% of the total amount of material is water that is evaporated during the whey power concentration. As a result there is a large stream of waste water produced that has to be treated before releasing it to the environment. Table 3.19 gives an overview of the process utilities. All the glycerine, about half of the chilled water and 21% of electricity are attributed to the cheese section, while almost all the steam, nearly 80% of electricity and half of chilled water are used in the whey powder section, mainly for whey drying (water evaporation).

Table 3.18 *Overall mass balance*

	IN, ktonnes/yr	OUT, ktonnes/yr
Milk	279.6	
Rennet	0.25	
Starting Culture	0.25	
Salt	0.02	
Air	135.6	
Cheese		28.8
Whey powder		19.2
Cream		1.8
Wastewater		220.0
Wet Air		145.9
Total	**415.7**	**415.7**

Table 3.19 *Utilities breakdown per utility type*

	ktonnes/yr	kWh/yr	Attributed to Cheese Section
LP Steam	303.6		6.1%
Chilled Water	1 231.7		49.2%
Glycerine	1 029.8		100%
Electricity		10 008 400	21%

Integration Options

Whey powder section could be potential integration point with biorefinery. Liquid whey is already proven potential medium for various fermentations. It is relatively rich in sugars (lactose) and it also contains proteins and minerals, which are useful nutrients. Table 3.20 shows approximate composition of liquid whey used in the modelling.

Table 3.20 C*omposition of liquid whey*

	tonnes/yr	wt.%	g/l
Anions	1060.9	0.43	4.25
Casein	451.1	0.18	1.81
Cations	795.7	0.32	3.19
Fats	1127.7	0.45	4.52
Lactose	12995.8	5.21	52.07
Rennet	13.7	0.01	0.06
Water	231537.7	92.77	927.69
Whey	1603.9	0.64	6.43

Anions and cations represent all the mineral salts present in the whey. Casein, fats and lactose are given separately, while all other solid compounds are given as whey. Most of the material is still water (~92%), but concentration of lactose (52 g/l) and mineral salts (~7 g/l) are very close to corresponding concentrations of sugars and minerals used in e.g. ethanol or butanol fermentations. Therefore, this stream could be used as medium either directly or in the combination with some other source of fermentable sugars for fermentation in the potential integration concept with biorefinery to increase the output of useful, added-value products.

Another integration option with biorefinery is separation of lactoferrin from whey. Lactoferrin is multifunctional protein with antimicrobial activity. It is present in the human milk and in lower extent in the cow milk. Due to a wide spectrum of functions ascribed to lactoferrin, its market value is rather high and in integrated biorefinery setup lactoferrin could be an important added-value product. Liquid chromatography could be a separation option compatible with the large-scale process, such as cheese manufacturing.

3.6.2 Slaughter byproducts

The production activity of Ten Kate Vetten was in 1998 based on a standard rendering process, processing pig slaughter fats into pig fat and byproducts such as proteins and protein water, as presented in Figure 3.26. Since 2002, a sustainable cooperation has been built between Ten Kate and three neighboring companies Gelita, AFB, and AVEBE. Figure 3.27 presents a schematic overview of this industrial eco-cluster. Compared to the previous standard process, this industrial eco-cluster could be considered as an improved biorefinery.

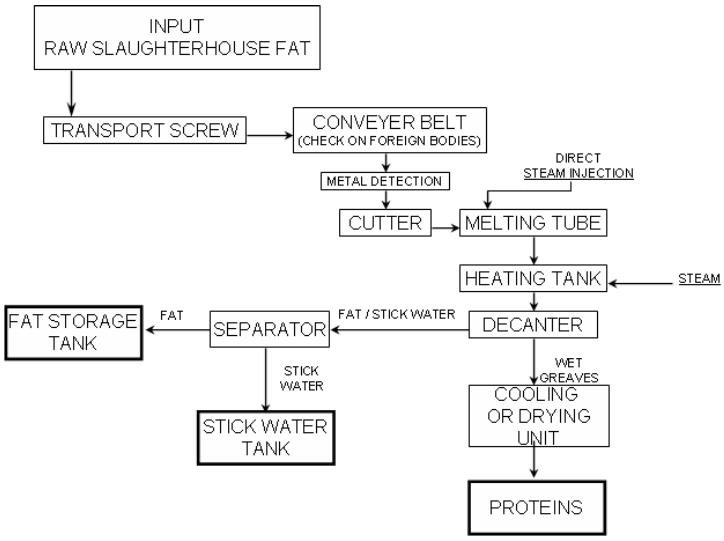

Figure 3-26 *Ten Kate process (1998-2002): reference case standard rendering process*

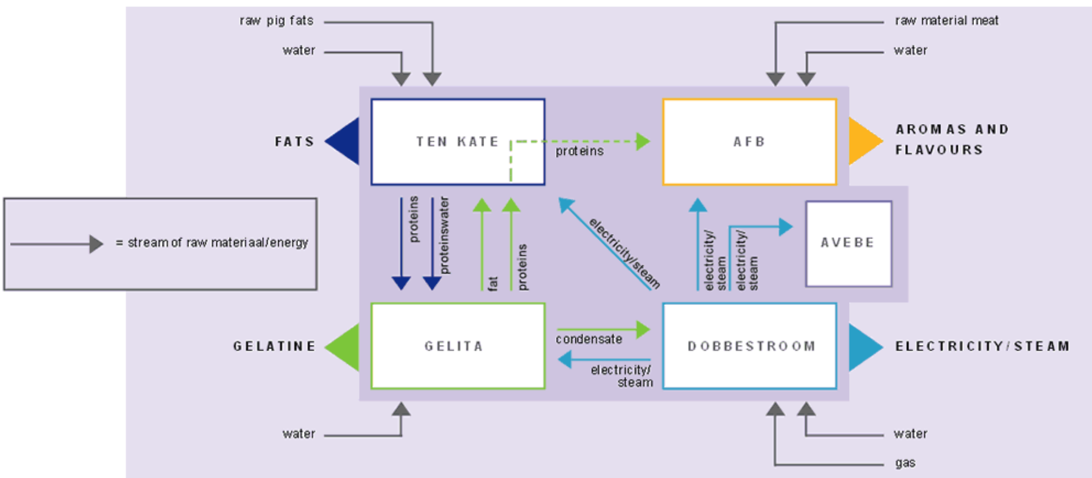

Figure 3-27 *Schematic overview of the industrial eco-cluster*

The byproducts proteins and protein water are now integrated as raw materials for Gelita, a gelatin producing company. They are delivered at high temperatures to the neighbor Gelita, so no additional cooling and heating is necessary. Moreover the byproducts are upgraded to more

valuable products, an important driving force for designing sustainable clusters. The pork proteins and fats, byproducts of Gelita, are delivered back to Ten Kate for further processing into products. The transport of the materials between Ten Kate and Gelita is achieved by a short pipeline without any involvement of trucks. AFB produces aromas and flavours from proteins from Ten Kate. The industrial cluster Ten Kate, Gelita, and AFB receive their electricity and steam from the Dobbestroom CHP plant of the potato starch company AVEBE. The effluent from Gelita is treated at the AVEBE waste water treatment installation.

The produced lard oil at Ten Kate is used as a biofuel (comparable to rapeseed and sunflower oils), while the produced fats are sold to biodiesel producers who use it as a raw material.

Based on the above-mentioned cooperation, Ten Kate could save 52% in steam consumption in 2002, compared to 1998. The electricity consumption decreased by 36%, and the CO_2 emissions decreased by 55% (more than 4000 tonnes).

Figure 3.28 shows an aerial photograph of the Ten Kate company in Ter Apelkanaal, the Netherlands. Figure 3.29 shows the pipeline between Ten Kate and Gelita companies.

Figure 3-28 *Aerial photograph of the Ten Kate company in Ter Aperkanaal, the Netherlands*

Figure 3-29 *Pipeline between Ten Kate and Gelita companies*

3.7 Agrosector

Two cases are considered within the agrosector: production of sugar from sugar beet, and anaerobic digestion of wet biomass, upgraded to an integrated algae plant. The first case will be used later on in work package 4 as a reference case for the agrosector, and will be extended to an integrated biorefinery plant. The second case was also aimed to be used as another reference case within this sector. However, as the economic data on algae-related processes are lacking, after discussions within the project Consortium, is was decided to shift the algae case to activity 4.5 of work package 4 “Overview innovative biorefinery concepts”.

3.7.1 Sugar industry

Introduction
A sugar factory task consists of extracting sugar out of the beet with a chemical transformation. Sugar is obtained through photosynthesis, out of CO_2 of the atmosphere, the soil moisture and the effect of the sunlight, according to the equation below.

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

The sugars are stored in the root of the beet. The beet is a bi-annual plant. Its harvest for industrial use is carried out the first year, the second year it flowers and produces seeds. The leaves are cut off and the roots are harvested. The leaves are used for cattle feed or remain in the field as fertilizer, whereas the beets are transported to the factory for treatment.

Sugar beet composition
The beet contains:

- 14-17% sugar;
- 76-78% water;
- 4-5% insoluble dry ingredients;
- 2-3% soluble dry ingredients (nitrogenous and non-nitrogenous organic and inorganic components).

The insoluble dry ingredients (cellulose, lignin, pectin, pentosane) form the main components of the byproduct called pulp (fresh or dry pellets). The soluble dry ingredients are the main components of the molasses, together with sugar remains. Figure 3.30 presents the sugar beet process according to British Sugar. The related process data are presented in Table 3.21.

Yields and mass balances
Treatment of 1,000 tonnes of beets with a sugar content of 14.5% yields:

- 115 tonnes of sugar (11.5%);
- 50 tonnes of molasses (content in sucrose 47%);
- 35-40 tonnes of dry pulp (up to 90 tonnes of fresh pulp).

Process step by step (as from British Sugar)

Extracting sugar from beet
Annually some seven million tonnes of sugar beet are processed. Around 2,500 lorry loads of sugar beet are delivered daily to British Sugar's factories which take in around 350,000 tonnes of beet each week during the processing season (campaign), this is completed by the end of February.

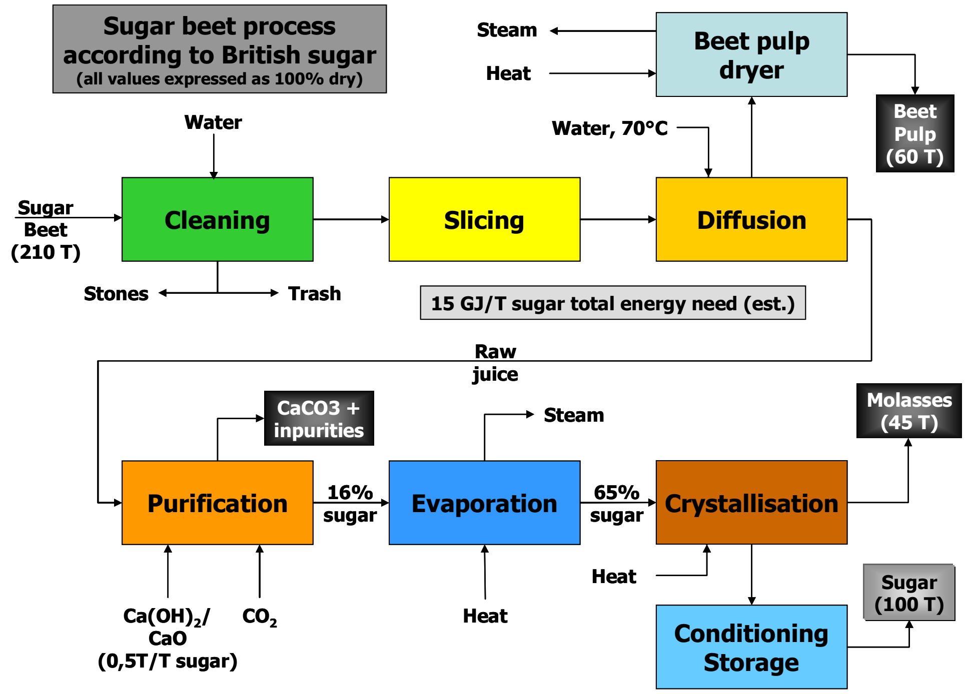

Figure 3-30 *Sugar beet process according to British Sugar*

Table 3.21 *Data sugar beet process according to British Sugar*

Parameter	Unit	Value
Production data		
cultivated area	ha	45,000
wet beets	tonne	2,800,000
dry sugar	tonne	319,000
wet molasses	tonne	140,000
dry pellets	tonne	100,000
wet pulp	tonne	250,000
Consumptions		
heavy oil (treated)	tonne	80,000
lime-stone	tonne	160,000
coke	tonne	12,500
heavy oil (dryer)	tonne	20,000

Sampling

On arrival, a sample of the sugar beet is taken from the load and tested to measure the sugar content and to determine the amount of soil, tops or leaves present in the load. These analyses, combined with the weight of the vehicle entering and leaving the factory, enables the calculation of the quantity of sugar delivered and hence the payment due.

Cleaning

Sugar beet floats in water and in the cleaning stage of the process it is moved around in large quantities of water, allowing the beet to pass through machinery which 'catches' stones but allows the beet to float over the top. Weeds and other trash are also removed before the beet enters the factory, where it is sliced into thin slices called 'cossettes'.

Slicing

The slicing machines work in a similar manner to a kitchen grater and the cossettes they produce have a 'V' cross section. This ensures the largest possible surface area is presented to maximise the sugar extraction stage.

Diffusion

Sugar is extracted from the beet by diffusion. This process takes place in a large vessel. The cossettes are mixed with hot water at around 70°C for a period of time and the sugar simply passes from the plant cells into the surrounding water by the diffusion process. The vegetable material left behind from this stage is mechanically pressed to extract as much remaining sugar and water as possible and, after the addition of molasses, is dried to produce animal feed products. It is this drying process which gives rise to the familiar plume of steam rising from the factory. The liquid resulting from the diffusion process is dark in colour and is called raw juice.

Purification

This juice is passed through an important purification stage called carbonatation. This involves mixing the juice with milk of lime and adding carbon dioxide gas. During this process, the carbon dioxide and the milk of lime re-combine to produce calcium carbonate which precipitates out, taking most of the impurities from the juice with it. This lime which contains important trace elements is sold as a soil improving agent under the LimeX brand.

Evaporation

The pale yellow juice which remains is called thin juice and while much purer, it is still relatively low in sugar content. It passes to the next stage of the process - evaporation - where the water is boiled off in a series of evaporator vessels to increase the solids content of the juice from the previous 16% in thin juice to 65% in the thick juice. The concentrated juice passes through filters, after which it is ready for the final stage of the process; or it can be stored and brought back into the factory during the summer to produce crystal sugar.

Crystallisation

The crystallisation process takes place in vacuum pans which boil the juice at lower temperatures under vacuum. When the juice reaches a predetermined concentration it is 'seeded' with tiny sugar crystals which provide the nucleus for larger crystals to form and grow. When the crystals reach the desired size the process is stopped and the resultant mixture of crystal sugar and syrup - known as massecuite - is spun in centrifuges to separate the sugar from the 'mother liquor'. The sugar crystals are washed and after drying and cooling, are conveyed to storage silos. Some sugar remains in the separated liquid so it is boiled again in a further set of vacuum pans to produce raw sugar. This process is repeated a third time resulting in final product sugar and molasses. Raw and final product sugars are redissolved into the thick juice.

Co-product composition

The 2 main co-products of the beet sugar process are beet pulp and molasses.

Beet molasses are liquid, but contain up to 75-77% solids. Sugars account for about 50% of the dry weight of molasses. These sugars are predominantly sucrose, next to glucose and fructose. Other components are proteins (6%), minerals (9%, mainly potassium) and non-protein nitrogen. Beet molasses is also rich in vitamins, such as choline and to a lesser extent biotin, pantothenic acid and riboflavin (Curtin *et al.*).

Beet pulp contains the non-sugar carbohydrates such as cellulose, pectin, hemicellulose. Also lignin is present in beet pulp.

Beet molasses are primarily used in animal feed and fermentation. Beet pulp is mainly an animal feed. Research is going on to diversify the use of sugar byproducts, such as metal chelation (molasses), and paper making, pectin extraction from pulp (Finnsugar Bioproducts).

Integration options

- Molasses are good sugar sources for fermentation. Bioethanol and hydrogen might be possible.

- Beet pulp contains 18% crude fiber and 10% protein, the remaining part should be fermentable sugars and minerals. As such, it has low value, just good as forage or energy food (value: €50-150/tonne). By combined saccharification/fermentation -to ethanol- it is possible to increase the protein content to 40% (Süddeutsche Zucker AG). This is a protein enrichment feed compound (value €250-350/tonne).
- Co-products from the sugar industry, including DDGS from ethanol fermentation, can be used as feedstock for anaerobic digestion. Methane gas can be burned in a cogeneration plant and transformed in electricity and heat.

3.7.2 Integrated algae plant for the biogas industry

Introduction
In this paragraph an algae production facility is considered, integrated to an anaerobic digestion facility, such as the one described as reference case for the power production sector. Basically, algae need CO_2, NPK nutrients, water and light to grow. An effective high yield production will also require the temperature to be controlled within sharp limits. And the final valorisation of algae biomass will require a drying step. This will need heat. The algae will then use the three waste streams of an anaerobic fermentation/cogeneration plant: CO_2 emitted after combustion of biogas in a cogeneration plant, the NPK contained in the digestate and the heat produced in a cogeneration. This process basically turns waste streams into highly valuable components.

Background

What are microalgae?[2]
Microalgae are microscopic organisms, typically found in freshwater and marine systems. Microalgae are unicellular species which exist individually or in chains or groups. Depending on the species, their sizes can range from a few micrometers to a few hundreds of micrometers. Microalgae such as microphytes constitute the basic foodstuff for numerous aquaculture species, especially filtering bivalves. They provide them with vitamins and polyunsaturated fatty acids, necessary for the growth of the bivalves which are unable to synthesize it themselves. Because the cells grow in aqueous suspension, they have more efficient access to water, CO_2 and other nutrients than conventional land plants.

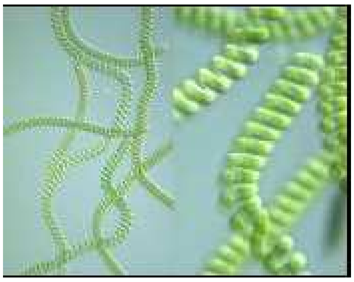

Figure 3-31 *Spirulina sp.*

Microalgae comprise a vast group of photosynthetic or heterotrophic organisms which have an extraordinary potential for cultivation as energy crops or source of renewable polymers. They can be cultivated under difficult agro-climatic conditions and are able to produce a wide range of commercially interesting products such as fats, oils, sugars and functional bioactive compounds. Certain microalgae are effective in the production of hydrogen and oxygen through the process of biophotolysis, while others naturally manufacture hydrocarbons which are suitable for direct use as high-energy liquid fuels.

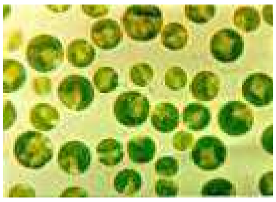

Figure 3-32 *Chlorella sp.*.

[2] Partially abstracted from Wikipedia and FAO report

Microalgae can be cultivated under aqueous conditions ranging from freshwater to situations of extreme salinity. They can live in moist, in the dessert sands, and in all the conditions in between. Microalgae have been found living in clouds and are long known to be essential components of coral reefs.

Composition of microalgae

Microalgae consist mainly of proteins, lipids and carbohydrate. Unlike land plants, there is no lignin in microalgae. This is a major advantage in scope of biorefinery concepts, as lignin is difficult to separate from the other components and has only a limited -energetic- value. Carbohydrates are mainly starch and cellulose (cell wall components), although it should be stated that very little is known about the exact composition of the carbohydrate fraction. Starch is a highly valuable component with functionality as thickener, binder or as glucose source for fermentation processes. The lipid fraction of algae consists mainly of unsaturated fatty acids (up to 90%) of which almost half is poly-unsaturated. Such a composition has added value in food and feed or as feedstock for oleochemistry, but is less optimal as biodiesel feedstock (tendency to polymerize due to high level of poly-unsaturated, to thicken when cooled due to 10%+ unsaturated…). Amino acid composition of proteins vary of course from algae strain to algae strain. Out of preliminary analysis, it looks well balanced regarding essential amino acids. Proteins can also have a high functional value (gelling, emulsifying, foaming properties; flame retarding properties…), but little is known on the functionality of algae proteins. As shown in Table 3.22, depending on the strain, the ratio between the major components can vary significantly.

Table 3.22 *(Becker, 1994)*

Strain	Protein	Carbohydrates	Lipids	Nucleic acid
Scenedesmus obliquus	50-56	10-17	12-14	3-6
Scenedesmus dimorphus	8-18	21-52	16-40	-
Chlamydomonas rheinhardi	48	17	21	-
Chlorella vulgaris	51-58	12-17	14-22	4-5
Spirogyra sp.	6-20	33-64	11-21	-
Dunaliella salina	57	32	6	-
Prymnesium parvum	28-45	25-33	22-38	1-2
Spirulina maxima	60-71	13-16	6-7	3-4.5
Synechoccus sp.	63	15	11	5

Growing microalgae

When cultivating algae several factors must be considered, and different algae have different requirements. The water must be in a temperature range that will support the specific algal species being grown, typically between 25-30°C; pH optimised according to algae species. Nutrients (mainly N and P) must be controlled so that algae will not be "starved" and so that nutrients will not be wasted. Light must not be too strong (photo inhibition) nor too weak (not enough energy for photosynthesis). In optimal conditions, algae can double its biomass in 5-6 hours. When biomass density increases, light penetration reduces. This is the right time for harvesting the biomass.

OPEN-PONDS (OP)

Raceway-type ponds and lakes are open to the elements and so sometimes called "open-pond" systems. They are much more vulnerable to contamination by other micro-organisms, such as invasive algal species or bacteria. Because of these factors, the number of species successfully cultivated in an "open-pond" system for a specific purpose (such as for food, for the production of oil, or for pigments) are relatively limited. In open systems one does not have full control over water temperature and lighting conditions. Because light does not penetrate well in water, open ponds are designed with a maximal depth of 30-40cm. A major benefit to this type of system is that it is one of the cheaper ones to construct, in the very least only a trench or pond needs to be dug. Yield: 0.5-0.8 g dry biomass/l/day; harvest rate: 10-20% (harvest rate=amount of biomass effectively collected; remainder serves as insemination for the next growing phase).

Figure 3-33 *Algae open pond*

PHOTOBIOREACTORS (PBR)

Algae can also be grown in a photobioreactor (PBR). A PBR is a closed vessel or container which incorporates some type of light source. Virtually any translucent container could be called a PBR. As an example, photobioreactors can vary from simple, externally-illuminated glass jars to highly engineered fermentors saturated with light transmitting fibre optic filaments to ensure even lighting to all cells and infused with specific gas mixtures to control metabolism and growth rates.

Figure 3-34 *Algae PBR*

Because these systems are closed, all essential nutrients must be introduced into the system to allow algae to grow and be cultivated. Essential nutrients include carbon dioxide, water, nutrients (mainly a N and P source) and light.

A PBR can be operated in "batch mode", but it is also possible to introduce a continuous stream of water containing nutrients and carbon dioxide. As the algae grows, excess culture overflows and is harvested. Different types of PBRs include:

- tanks provided with a light source;
- polyethylene or PVC sleeves or bags;
- glass or plastic tubes, horizontal or vertical;
- flat plate containers made of glass or plastic.

Figure 3-35 *Algae PBR*

Because of high cell densities that can be reached in photobioreactors, light penetrates less deep. Typically, photobioreactor tubes are 7.5-10.0 cm diameter or thick. Yield: up to 2-6g dry biomass/l/day; harvest rate: 20-35%.

Concept
The proposed concept below is just an example to illustrate the potential of growing algae in an integrated way. In this concept, the algae plant will use the wet digestate (thin fraction only), CO_2 (after cogeneration) and heat/electricity (after cogeneration) to grow biomass, with additional energy input from the sun. The proposed concept is balanced on a total consumption or the nitrogen (NPK) present in the digestate of a 25,000 tonnes wet biomass input in an anaerobic digester. There should be enough nutrients to produce 1,200 tonnes of algae (on solid base).

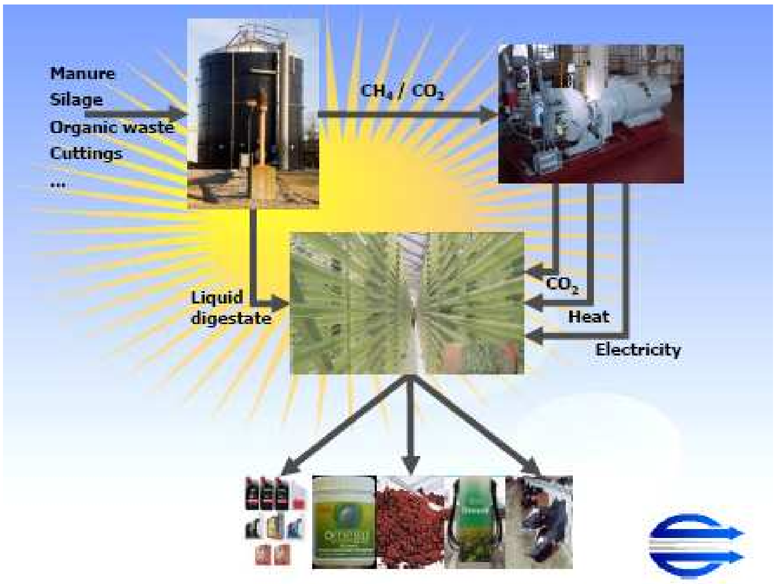

Figure 3-36 *Concept of integrated algae plant for the biogas industry*

The mass and energy flows for this plant is presented in Figure 3.37 (rounded figures, all expressed in 100% solid content except otherwise stated).

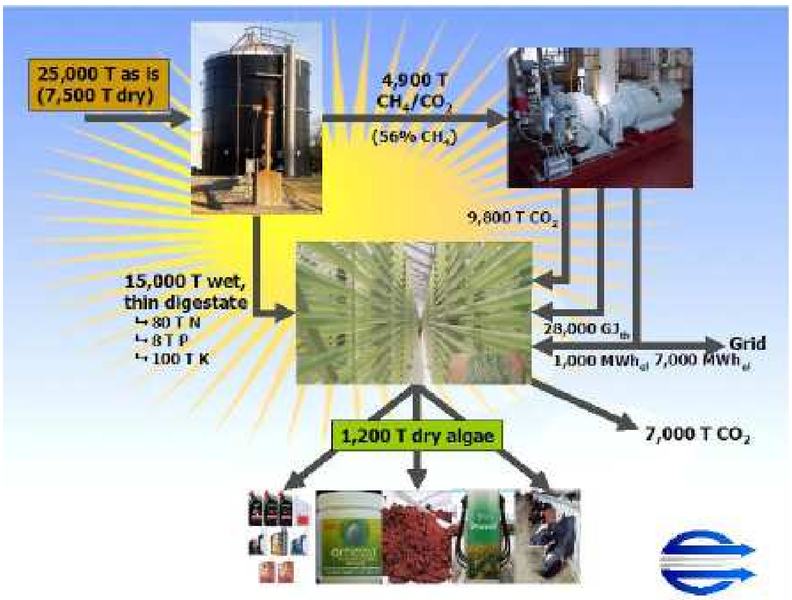

Figure 3-37 *Mass & energy flows of the concept: integrated algae plant for the biogas industry*

Electricity balance

After burning biogas in a cogeneration plant, there are 6.6 MWh_{el} /tonne dry algae available for operating the algae plant (pumps, centrifuges, downstream equipment…). According to different sources, the electricity need will be between 0.5-2.0 MWh/tonne dry algae produced. The surplus electricity can be sold on the grid or used for artificial light for algae production during the night. There is enough surplus electricity available to produce 200 tonnes extra algae during the night. We can consider as an option to use electricity surpluses produced during the night (low demand on the grid).

Heat balance

The net heat produced in the cogeneration can be used to keep the algae production unit at the right temperature and to dry the algae. Assuming a 20% algae solid content after filtration/centrifugation/decantation (whatever technique used). For drying 1,200 tonne algae, 4,700 tonnes water need to be evaporated. Raising the temperature of 1 tonne water from 25 to 100°C requires 1 tonne x 75°C x 4.18 MJ/tonne/°C = 315 MJ, or 1,480 GJ for 4,700 tonnes water. The cogeneration plant produces 28,000 GJ, more than enough for drying 1,200 tonnes algae. However, substantial heat will be needed to maintain the production volume at a temperature between 25-30°C. As an order of magnitude, a 1,200 T dry algae plant will need a photobioreactor volume of 5,000 m^3 (order of magnitude). Assuming 500 m^3 needs to be refilled daily and assuming an average fresh water temperature of 10°C, we need daily 500 m^3 x 15°C x 4.18 $MJ/m^3/°C$ = 31 GJ, or 10,540 GJ annually to keep the production volume at temperature (all order of magnitude figures). Total available heat (28,0000 GJ) still exceeds the demand.

CO_2 balance

To produce 1,200 tonnes dry algae, there is a need for 2,800 tonnes CO_2. The anaerobic digestion + burning of biogas generate 9,800 tonnes CO_2: we have a clear surplus in CO_2, even considering a possible 10-20% extra night production with artificial light.

Nutrient balance

As indicated in the beginning of this chapter, this concept is based on total consumption of the nitrogen. Experimental work to be performed during a pilot trial should indicate how well other nutrients are balanced. It is assumedthat a supplement of P will have to be added.

Algae biomass in the market

Algae biomass has various market opportunities, depending on the degree of sophistication of the downstream processing and the commodity-specialty character of the targeted markets.

Whole algae cells

The simplest downstream processing consists of drying the whole cells and selling them as such. Due to the well-balanced nutritional composition of algae (oil with 45% poly-unsaturated fatty acids, proteins with decent levels of essential amino acids, low level of non-digestible carbohydrates), the first target market for whole algae cells can be the animal feed. Algae can also be used in human nutrition, as it also contains many interesting micro-nutrients such as anti-oxidants, vitamins… In more bulky markets, whole algae cells can be sold for €750-1000/tonne; in specialty markets (such as feed for larval fishes), price can go up to €100-200/kg!

Fractionated algae biomass

There are different techniques available to separate algae biomass in its main constituents. This procedure makes only sense when a higher value can be obtained by selling separate fractions compared to whole algae cells.

Oil fraction

Algae oil contains approx. 11-12% saturated, 40-45% mono-unsaturated and 45-50% poly-unsaturated fatty acids, next to some phospholipids. Although this oil is not ideal for biodiesel (too much saturated and poly-unsaturated fatty acids), most attention goes to this application. Of

higher value is the substitution of fish oil in feed by algae oil, the use of algae oil as source of omega-3 fatty acids or the development of biomaterials from algae oil. Price level for algae oil should range from €600-1000/tonne.

Protein fraction
Most vegetable and animal proteins are used for their nutritional value. There is no reason why algae proteins can't play a role in this market. Proteins are used in large quantities as supplement in animal feed and in specialty quantities as protein supplement for athletes. Next to the nutritional properties, proteins can also have attractive functional properties: emulsifying, gelling, foaming… Functional proteins tend to be sold with a premium over the strictly nutritional value. Typical price levels: €700 (bulk, nutritional) – 2,500 (functional proteins).

Carbohydrate fraction
Algae carbohydrates can be starch-like, hydrocolloid-like or other polysaccharides. Unless well identified, it is difficult to estimate the precise value of this fraction. At the lower end, it can be used as feedstock for fermentation, but it can also be transformed into bioplastics or used as high value hydrocolloids (thickeners, gelling agents, structure modifiers, water binders…). Price will range from €200 (fermentation) to 4,000 (hydrocolloids).

Other components
Next to these major components, algae are also rich in colorants (used in food and feed), antioxidants, vitamins, minerals…, all present in small percentages, but with potentially high value: up to €2,000/kg

Facts and figures

Selected scenario
Based on the input above, Value for Technology (VFT) made a first attempt to calculate the profitability of an algae plant, integrated in anaerobic digestion complex. The concept above has been taken as template.

This exercise is only considering the algae plant, not the anaerobic digestion and cogeneration plant. Profits from 'Green certificates' for electricity are not included, as already taken into account in the economical models of biogas plants. Credits for 'green heat' (CHP certificates) however are considered, as the algae project allows for a commercial use of the heat generated by the biogas / cogeneration installation.

An average and realistic scenario consists in fractionating the algae and selling the main components separately on the semi-bulk market. Specialties are not extracted and valorised in this scenario. The input assumptions are described in Table 3.23. All values refer to dry metric tonnes.

Table 3.23 *Input assumptions for the semi-bulk scenario*

Parameter	**Assumption**
Biomass volume	1,200 tonnes at €1,800 / tonne
Oil	110 tonnes at €1,500 / tonne
Functional protein	550 tonnes at €2,500 / tonne
Carbohydrate	270 tonnes at €1,300 / tonne
Minerals	110 tonnes at €1000 / tonne
CO_2	(€15) / tonne
Nutrients	€0 / tonne
Electricity	800 kWh / tonne at €0.05 / kWh
Heat	327 kWh / tonne at (€100) / kWh
Labour	4 FTE at €65,000 / year
Pilot cost	€500,000 (one time)

This input has been combined to standard elements of financial analysis (maintenance cost, insurance, tax rate, linear depreciation over 10 years…) to evaluate the attractiveness of this concept.

Key economical indicators

The most important cost parameter in an algae project is the capex. Unfortunately, currently it is very difficult to have reliable data on this, as no algae technology providers have yet experience in large-scale installations.

Therefore, a reversed approach has been used: based on the above assumptions, what would be the maximal capex to have an IRR of 15 or 20%? This figure can be considered as a target for algae technology providers.

Table 3.24 *Maximal capex / tonne as function of IRR (corresponding to the maximal capex / tonne annual installed capacity, expressed in dry solids)*

IRR	Maximal capex / tonne	Maximal total capex
15%	€3,900	€4,680,000
20%	€3,500	€4,200,000

The capex calculated here includes downstream processing and land acquisition.

According to the indications obtained from the algae technology providers, this target for a maximal capex/tonne installed capacity should be reached easily. Depending on the source, the values are ranging between €1,500-2,500/tonne installed capacity.

Conclusions

Anaerobic digestion is a very attractive way to transform agrowaste into valuable energy (electricity). The heat however is mainly used to dry the digestate (very low value product) or –even worse- is discarded. Integrating an algae plant offers the possibility to use this heat to dry a high value product (algae biomass) and can also use the non-treated wet digestate as nutrient source. Basically, an integrated biogas-algae plant is a machine to recycle part of the carbon of agro-waste, recover its energy content and upgrade the whole to nutritional and functional products by capturing solar energy.

A basic feasibility analysis indicated that a standard-sized biogas plant (25,000 tonnes wet feedstock ≈ 7,500 tonnes dry feedstock), can feed an economically attractive algae plant with a capacity of 1,200 tonnes dry biomass/year.

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http://www.danishcrown.com/ (Sweden)

http://www.dsm.com/en_US/html/home/dsm_home.cgi. Active in nutritional and pharma ingredients (the Netherlands)

http://www.duvel.be/pages/home.aspx?culture=nl&pageid=home (Belgium)

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Agro sector

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Appendix A The Questionnaire

Table A.1 *Task 1-related questions*

No	Question
1	What is the number of industrial fuel producing complexes per market sector (per country)?
2	Where is the fuel producing complex located?
3	What is the size of the enterprise as function of the number of employees: micro (1-9), small (10-49), medium (50-249), large (250+)?
4	Which feedstock(s) is/are applied in the process?
5	What is/are the main product(s) per complex?
6	What is/are the byproduct(s) per complex?
7	What are the auxiliary input streams (nutrients, enzymes, chemicals, fossil fuels, water, air,...) per complex?
8	What are the residues, effluents, exhaust gases, and other outputs not mentioned yet per complex?
9	Does the process require heat? If yes, what is the heat source (internal or external source)?
10	Does the process require electricity? If yes, what is the power source (internal or external)?
11	Does the process generate heat? If yes, does it have an application?
12	Does the process generate power? If yes, is it only used internally, or also (partly) exported?
13	What is/are the current application(s) of the main product(s) per complex?
14	What is/are the current application(s) of the byproduct(s) per complex?
15	What is/are the current destination(s) of the residue(s) per complex?

Table A.2 *Task 2-related questions*

No	Question	Unit
1	What is the start-up year of the reference case?	-
2	What is/are the input capacity/capacities of the feedstock(s) supplied[3] to the reference case?	kg/hr, tonnes/hr
3	What is/are the energy content(s) of the feedstock(s)[4] of the reference case?	GJ/tonne
4	What are the main product(s) capacity/capacities of the reference case?	kg/hr, tonnes/hr, litres/hr, MW
5	What is/are the energy content(s) of the main product(s) of the reference case?	GJ/tonne, kJ/litre
6	What is/are the byproduct(s) capacity/capacities of the reference case?	kg/hr, tonnes/hr, litres/hr, MW
7	What is/are the energy content(s) of the byproduct(s) of the reference case?	GJ/tonne, kJ/litre
8	What are the flow rates of the auxiliary input streams (nutrients, enzymes, chemicals, fossil fuels, water, air,...) of the reference case(s)?	kg/hr, tonnes/hr
9	What are the flow rates of the residues, effluents, exhaust gases, and other outputs not mentioned yet of the reference case(s)?	kg/hr, tonnes/hr
10	What is the energetic efficiency of the main product(s)[5] of the reference case?	%
11	What is the energetic efficiency of the byproduct(s)[6] of the reference case?	%
12	What is the energetic efficiency per unit operation of the reference case(s)?	%
13	What is the heat requirement of the reference case(s)?	kW_{th}, MW_{th}
14	What is the temperature level of delivered heat of the reference case(s)?	°C
15	What is the power requirement of the reference case(s)?	kW_e, MW_e

3 In case of biomass please note whether the reported capacity is based on biomass as received (please mention the moisture content of biomass as well), or it is based on dry biomass.
4 In case of biomass please note whether the reported energy content is based on biomass as received (please mention the moisture content of biomass as well), or it is based on dry biomass.
5 Ratio between the low heating value (LHV) of the main product(s) and the low heating value of the input streams
6 Ratio between the low heating value of the byproduct(s) and the low heating value of the input streams

16	What is the amount of generated heat in the reference case(s)?	kW_{th}, MW_{th}
17	What is the temperature level of generated heat in the reference case(s)?	°C
18	What is the amount of generated power in the reference case(s)?	kW_e, MW_e
19	What are the full-load hours of the reference case(s)?	hrs/yr
20	What is the economic lifespan of the reference case(s)?	yr
21	What are the annual sales of the enterprise?	M€/yr
22	What is/are the market price(s) of the feedstock(s) of the reference case(s)[7]?	€/tonne
23	What is/are the market price(s) of the main product(s) of the reference case(s)?	€/tonne, €/litre, €/MW
24	What is/are the market price(s) of the byproduct(s) of the reference case(s)?	€/tonne, €/litre, €/MW
25	What is/are the market price(s) of the auxiliary stream(s) of the reference case(s)?	€/tonne, €/litre, €/MW
26	What are the investment costs of the reference case(s)[8]?	M€
27	What are the fixed maintenance costs of the reference case(s)?	€/yr
28	What are the variable maintenance costs of the reference case(s)?	€/unit main product(s)

[7] In case of biomass please note whether the reported market price is based on biomass as received (please mention the moisture content of biomass as well), or it is based on dry biomass.

[8] This question would be difficult to answer for large-scale complexes, as these complexes are built in modules during a long period. Besides, when integrating a biorefinery concept only the information is required that is related to the defined system boundary within the complex.

Appendix B Data collection task 1

Table B.1 *Data bioethanol sector*

Country	Complex	Size enterprise	Feedstock (s)	Main product (s)	Byproduct(s)	Auxiliary input streams	Other outputs	Heat required?	Electricity required?	Heat generated?	Electricity generated?	Current application(s) main product(s)	Current application(s) byproduct(s)	Current destination(s) residue(s)
No. / name of complex	**Location**	**- micro - small - medium - large**				**- nutrients - enzymes - chemicals - fossil fuels - water - air - ...**	**- residues - effluents - exhaust gases - ...**	**if yes, heat source: - internal? - external?**	**if yes, electricity source: - internal? - exter-nal?**	**if yes: any application?**	**if yes: - used in-ternally? - or, also partly exported?**			
Belgium (BE)														
1 / Alco Bio Fuel NV	Ghent Harbour	Small	Cereals, of which mainly wheat and corn.	Bioethanol 120 ktonnes / 152 Mlltres	DDGS	Enzymes, process water (recycled on site), natural gas, electricity, yeast	CO2	Yes, source is hot vapour, created on site through turbines that transform gas into vapour	Yes. Sourced outside	Yes. The heat is recuperated into the process as much as possi-ble through heat exchangers	no	Bio-ethanol, used as a low blend into fossil gasoline	Animal feed	Bio-ethanol: Ant-werp and some Belgian depots, Germany and the Netherlands. DDGS: Belgium, the Netherlands and Germany
2 / BioWanze	Wanze	medium	Wheat (800.000 t), sugar beet (400.000 t, from Belgium, beet syrup coming from neighbouring sugar plant in Wanze)	Bioethanol 300 ktonnes / 380 Mlitres	Wheat bran, Gluten (10% wt), insoluble proteins ProtiWanze (wheat yeast concentrate, 250 ktonnes)	natural gas, Air, water, Enzymes, yeast	Effluents, ex-haust gases	Yes, internal from cogenera-tion	Yes, internal from cogene-ration	internal	Internally, partly ex-ported	Fuel (bioethanol)	Bran: Cogenera-tion, Gluten, pro-teins: food, animal feed, aquaculture ProtiWanze: ani-mal feed	
3 / Syral Belgium NV (new dedicated unit within existing Aalst starch plant)	Aalst	large	Wheat from Bel-gium and France	Starches, proteins, glucose syrup, bioethanol (40Mlitres)	co-products of the plant: animal feed, dry and liquid	Yeast, enzymes, N-source, acids, caustic	CO2-emission out of the fer-mentation	yes, steam pro-duced in the CHP of the plant (CHP = com-bined Heat-Power plant, cogeneration steam-electricity)	yes, electrici-ty from the CHP	energy balance is integrated in ths overall starch plant, so heat recupera-tion at maxi-mum	no	Food industry and industrial applica-tion (mainly paper industry) and pe-trochemical for the Bio-EtOH	Feed industry	Feed industry
Finland (FI)														
1	Finland's St1 Biofuels Hamina		waste	Bioethanol 44 Mlitres								Fuel (bioethanol)		
The Netherlands (NL)														
1 / Harvest (start: 2011)	Harbour of Amsterdam		Grain / potato	Bioethanol capacity 2011: 110 ktonnes / 139 Mlitres										
2 / Bioethanol Rotterdam (start: 2010)	Harbour of Rotterdam		Grain / potato	Bioethanol capacity 2011: 110 ktonnes / 139 Mlitres										
3 / Abengoa (start: 2009)	Harbour of Rotterdam		Grain / potato	Bioethanol capacity 2011: 450 ktonnes / 570 Mlitres										
4 / Dekro (start: 2010)	Energy Valley		Grain / potato	Bioethanol capacity 2011: 15 ktonnes / 19 Mlitres										
5 / Maatschap Bosma (start: 2010)	Province Drenthe		Grain / potato	Bioethanol capacity 2011:										

				5 ktonnes / 6 Mlitres										
6 / Pentagreen (start: 2010)	Energy Valley		Grain / potato	Bioethanol capacity 2011: 100 ktonnes / 127 Mlitres										
7 / LyondellBasell (start: 2008)	Harbour of Rotterdam		Bioethanol	ETBE capacity 2011: 600 ktonnes										
8 / SABIC (start: 2006)	Sittard		Bioethanol	ETBE capacity 2011: 155 ktonnes										
9 / N2Energy (start: 2010)	Overijssel		Oil residue / waste	Bioethanol capacity 2011: 35 ktonnes / 44 Mlitres										
10 / Abengoa Bioenergy	Rotterdam Europoort	medium	cereals	Bioethanol (2009) 480.Mlitres	distillers grains, CO2	natural gas						Fuel (bioethanol)	Greenhouses will use this CO2 for the growth process of plants and vegetables	
Spain (ES)														
1 / Galicia bioethanol, Abengoa Bioenergy	crta. Km 634, Teixeiro, Acoruña, Galicia	medium	Cereal, wine alcohol	Bioethanol 146 Mlitres (additionally 50 Mlitres ethanol is produced based on wine alcohol)	DDGS	natural gas, H_2O, enzyme, nutrients, yeast, NaOH, Cl_2O, NH_4OH, Air	Effluents, steam, CO_2, sludge	internal	internal	internal	Internally	Fuel (bioethanol)	Dry animal feed (DDGS)	Atmosphere, dump
2 / Biocarburantes Castilla y León SA, Abengoa Bioenergy	Crta. de Encinas a Cantalapiedra Km. 4.9, Babilafuente, Salamanca	medium	Cereal (87.5%), wine alcohol (12.5%), biomass	Bioethanol 175 Mlitres (additionally 25 Mlitres ethanol is produced based on wine alcohol)	DDGS	natural gas, H_2O, enzyme, nutrients, yeast, NaOH, Cl_2O, NH_4OH, Air	Effluents, steam, CO_2, sludge	internal	internal	internal	Internally and partly exported	Fuel (bioethanol)	Dry animal feed (DDGS)	Atmosphere, dump
3 / Bioetanol de la Mancha, Acciona-Uriel	El Vado de Barajas de Melo, Alcázar de San Juan, Ciudad Real	small	wine alcohol	Bioethanol 26 ktonnes / 33 Mlitres		natural gas, Air	Effluents, CO_2, sludge					Fuel (bioethanol)		Atmosphere, dump
4 / Ecocarburantes Españoles, S.A., Abengoa Bioenergy	Crta. Nacional, Km 343. Valle de Escombreras, Cartagena, Murcia	medium	Cereal, wine alcohol	bioethanol 100 Mlitres (additionally 50 Mlitres ethanol is produced based on wine alcohol)	CO_2, DDGS	natural gas, H_2O, enzyme, nutrients, yeast, NaOH, Cl_2O, NH_4OH, Air	Effluents, steam, sludge	internal	internal	internal	Internally and partly exported	Fuel (bioethanol)	Dry animal feed (DDGS), carbonated beverages, strontium carbonate (CO_2)	Atmosphere, dump
Spain (ES)[9]														
5 / Sniace Torrelavega, Sniace	Cantabria		Cereal	Bioethanol 196 ktonnes / 249 Mlitres (2009) 231.6 ktonnes / 294 Mlitres (2011)	DDGS	GN, H_2O, enzyme, nutrients, yeast, NaOH, Cl_2O, NH_4OH, Air	Effluents, steam, CO_2, sludge	internal	internal	internal	Internally	Fuel (bioethanol)	Animal feed	Atmosphere, dump
6 / Ecobarcial, Iberdrola-Sniace	Barcial del barco, Zamora		Cereal	Bioethanol 145 ktonnes / 184 Mlitres	DDGS	GN, H_2O, enzyme, nutrients, yeast, NaOH, Cl_2O, NH_4OH, Air	Effluents, steam, CO_2, sludge	internal	internal	internal	Internally	Fuel (bioethanol)	Animal feed	Atmosphere, dump
7 / Albiex, Promax Inversiones, Fami AC 2002, Serter, Novalia y	Villanueva, Extremadura	medium	Cereal	Bioethanol 110 ktonnes / 139 Mlitres	DDGS	GN, H_2O, enzyme, nutrients, yeast, NaOH,	Effluents, steam, CO_2, sludge	internal	internal	internal	Internally	Fuel (bioethanol)	Animal feed	Atmosphere, dump

[9] Under construction or in draft

Explotaciones Energéticas Sinia XXI						Cl_2O, NH_4OH, Air								
8 / Dos Bio Ebro Puleva, Puleva	Miranda Ebro, Burgos		Sugar beet	Bioethanol 65-85 Mlitres								Fuel (bioethanol)		
Sweden (SE)														
1 / Lantmännen Agroetanol	Händelö	Large	Grain	Bioethanol 210 Mlitres	DDGS							Fuel (bioethanol)	Dry animal feed (DDGS)	Atmosphere, dump
2 / Sekab	Örnsköldsvik		Wood chips from pine trees	Bioethanol 6 Mlitres	DDB							Fuel (bioethanol)		Atmosphere, dump
United Kingdom (UK)														
1 / British Sugar,Wissington plant	Norfolk	Small-medium	sugar beet	Bioethanol 55 ktonnes / 70 Mlitres	biobutanol	Fossil fuels						Fuel (bioethanol)		
2 / Green Spirit Fuels	Henstridge		wheat	Bioethanol 110 ktonnes / 139 Mlitres	DDGS, CO2							Fuel (bioethanol)	Animal feed	
3 / Abengoa	Immingham		wheat	Bioethanol (2009) 400 ktonnes / 507 Mlitres	DDGS, CO2			internal	internal	internal	Internally and partly ex-ported	Fuel (bioethanol)	Dry animal feed (DDGS), to lique-fy the by-product on site (CO2)	
4 / Bioethanol LTd	Immingham		wheat	Bioethanol (2009) 200 ktonnes / 253 Mlitres		Natural gas						Fuel (bioethanol)		
5 / Vivergo	Hull		wheat	Bioethanol 330 ktonnes / 418 Mlitres		Fossil fuels						Fuel (bioethanol)		
6 / Ensus	Wilton		wheat	Bioethanol (2009) 315 ktonnes / 400 Mlitres	DDGS, CO2	Enzymes, water, yeast	Effluents					Fuel (bioethanol)	Animal feed (DDGS), Carbon dioxide for food & drink production	
7 / Vireol plc	Grimsby		Wheat/other grains	Bioethanol (planned) 150 ktonnes / 190 Mlitres								Fuel (bioethanol)		
8 / Vireol plc	Teesside		Wheat/other grains	Bioethanol (planned) 150 ktonnes / 190 Mlitres								Fuel (bioethanol)		

Table B.2 *Data biodiesel sector*

Country	**Complex**	**Size enterprise**	**Feedstock (s)**	**Main product (s)**	**Byproduct(s)**	**Auxiliary input streams**	**Other outputs**	**Heat required?**	**Electricity required?**	**Heat generated?**	**Electricity generated?**	**Current application(s) main product(s)**	**Current application(s) byproduct(s)**	**Current destination(s) residue(s)**
No. / name of complex	**Location**	**- micro - small - medium - large**				**- nutrients - enzymes - chemicals - fossil fuels - water - air - ...**	**- residues - effluents - exhaust gases - ...**	**if yes, heat source: - internal? - external?**	**if yes, electricity source: - internal? - exter-nal?**	**if yes: any application?**	**if yes: - used in-ternally? - or, also partly exported?**			
Belgium (BE)														
1 / Bioro	Ghent (port of Ghent)	Small (20)	Rapeseed oil Soybean oil	Biodiesel 250 ktonnes	Crude glycerin	Catalyst, HCl, NaOH, water, nitrogen	Effluent water and exhaust air	Yes, internal steam-boiler	Yes, external power grid	No	No	Blending with con-ventional diesel (Exported)	Compound feed, pharma-glycerine	-
2 / Oleon Biodiesel NV	Ertvelde (port of Ghent)	No own per-sonnel, 20 FTE pro-vided by Oleon NV	Mainly refined ra-peseed oil Occasionally soy-bean oil	Biodiesel 100 ktonnes	Glycerol	Methanol 10% Water	Waste water containing <1% methanol	Yes Partly internal from bioCHP based on resi-dues of other activities	Yes Internal from bioCHP based on resi-dues of other activities	No	No	Blending with con-ventional diesel (Exported)	Glycerin is refined to a quality suited for e.g. food and pharma	Proper biological waste water treat-ment
3 / Proviron Fine Chemicals nv	Ostend (port of Ostend)	Large, 290	Mainly refined ra-peseed oil, occasio-nally soybean oil and palmoil, both with sustainability certificates	Biodiesel 100 ktonnes	Glycerol	Methanol 10%		Yes, Internal source from fine chemicals exo-thermic produc-tion	Yes, distribu-tion	No	No	Blending with con-ventional diesel (mainly Belgium, partly neighbour-ing countries)	chemicals, feed-additives	
4 / Néochim	Feluy	Small (26)	Mainly refined ra-peseed oil Occasionally soy-bean oil	Biodiesel 200 ktonnes	Glycerol, fatty acid	Methanol 10%, Sodium Methy-late as chemicals and utilities (Electricity, cooling water, instrumentation air, steam, nitro-gen & deminera-lised water)	None	Yes, Internal source from integrated chem-icals production (exothermically reaction from Maleic Anhy-dride plant)	Yes, external source	No	No	Blending with con-ventional diesel for Belgium market and Export in Eu-rope	Glycerine is re-fined at the same location, fatty acid are exported	n.a.
Finland (FI)														
1 / Neste Oil	Porvoo	Integrated in Porvoo refin-ery (who has 2200 employ-ees, as Re-newable fuels division), receiving hydrogen from the Pro-voo oil refin-ery	Mainly palm oil (Some animal fat if available at com-petitive price)	NextBTL 170 ktonnes	Fuel gas, small amount of bio-gasoline	Acid (H_3PO_4), caustic (NaOH), natural gas, liq-uid nitrogen, power, catalyst, hydrogen (from the refinery)	Sludge, sour water	Yes, steam from the refinery	Yes, from the refinery			Pure or as blending component in con-ventional diesel fuel	All fuel gas is used in the CHP-Plant, producing about the amount of energy required for the process.	Water purification plant
2 / Neste Oil	Porvoo (under construction)		Palm oil	NextBTL Capacity 2009: 170 ktonnes										
France (FR)														
1 / Diester Industrie	Rouen		Rape seed / Sun-flower	Biodiesel 500 ktonnes										
2 / Diester Industrie	Le Mériot		Rape seed / Sun-flower	Biodiesel 250 ktonnes										
3 / Diester Industrie	Compiègne 1&2		Rape seed / Sun-flower	Biodiesel 220 ktonnes(2006)										
4 / Diester Industrie	Sète 1&2		70% Rape seed / 30% Sunflower	Biodiesel 500 ktonnes	Glycerin									
5 / Diester Industrie	Boussens		Rape seed / Sun-flower	Biodiesel 250 ktonnes										
6 / Diester Industrie	Coudekerque (=Capelle-le Grande?)		Rape seed / Sun-flower	Biodiesel 250 ktonnes										
7 / Diester Industrie	Montoire		Rape seed / Sun-	Biodiesel										

			flower	250 ktonnes										
8 / Diester Industrie	Bordeaux		Rape seed / Sun-flower	Biodiesel 250 ktonnes										
9 / Diester Industrie	Grand-Couronne 1+2		Rape seed / Sun-flower	Biodiesel 260 ktonnes(2007) 250 ktonnes(2008)										
10 / Diester Industrie/Cargill	Montoir/ St. Nazaire		Rape seed (600.000 t/y)	Biodiesel 250 ktonnes(2008)	350 ktonnes rape-seed meal (2007)									
11 / Cognis/Diester	Bordeaux/Boussens		Rape seed / Sun-flower	Biodiesel 120 ktonnes? (2008)										
12 / Ineos	Baleycourt (Verdun)		Vegetable oil	Biodiesel 230 ktonnes										
13 / Biocar – Lavéra plant	Lavéra (district of Mar-tique)	10 (BIOCAR is a branch of "Compagnie du Vent")	Mix of crude vege-table oils and me-thanol	Biodiesel (FAME) 200 ktonnes at end of 2010	20 ktonnes glyce-rin	Air, nitrogen, catalyst (sodium methylate), chemicals (acids and caustic so-da), powdery products	Gums, used bleaching earth	Yes, internal source (boilers)	Yes, external source	No	No	Blending with con-ventional diesel, for transport	Pharmaceutical and cosmetic or energetic	Waste recycling complex
14 / Centre Ouest Cereales	Chalanday		Vegetable oil	Biodiesel 120 ktonnes										
15 / SICA Atlantique	La Rochelle		Vegetable oil	Biodiesel 50 ktonnes										
16 / Saria	Montoir		Animal fat	Biodiesel 30 ktonnes in 2010										
17 / Saria Bionerval	Lisieux		Animal fat	Biodiesel 40 ktonnes										
18 / Daudruy	Dunkerque		Animal fat	Biodiesel 150 ktonnes										
19 / SCA Petrole et Derives	Cornille		Animal fat	Biodiesel 100 ktonnes in 2010										
20 / SARP Industrie mail	Limay		Recycled used fry-ing oil (used food oil by collected Ecogras)	Biodiesel 60 ktonnes in 2009								Blending with con-ventional diesel up to 30%, used to supply the vehicle fleets of Veolia Environmental Services and Ve-olia Transport.		
21 / Progilor Bouvart	Charny/Meuse		?	Biodiesel 60 ktonnes in Q1 2009										
22 / Total	Dunkerque		Palm oil and animal fat?	Biodiesel 200 ktonnes										
Spain (ES)														
1 / Biocarburantes de Galicia (BGAL)	Begonte, Lugo	small	Vegetal oil	Biodiesel 35.000 tonnes	glycerin	Chemicals, alco-hol , water	Effluents, fertili-zer					Fuel	Detergent, food-stuffs additives, cosmetic products, lubricant, fuel	
2 / Bionorte SA	San Martín del Rey Au-relio, Asturias	micro	Vegetal oil recycled	Biodiesel 4.000 tonnes	glycerin	Chemicals, alco-hol , water	Effluents, fertili-zer					Fuel	Detergent, food-stuffs additives, cosmetic products, lubricant, fuel	
3 / Biocarburantes de Castilla (Biocast)	Valdescorriel, Zamora		Vegetal oil	Biodiesel 20.000 tonnes								Fuel		
4 / Biocom Pisuerga	Castrojeriz, Burgos		Vegetal oil	Biodiesel 8.000 tonnes								Fuel		
5 / Bionor Transformación	Berantevilla, Alava	small	Raw and used oil	Biodiesel 30.000 tonnes	glycerin	Chemicals, alco-hol , water	Effluents, fertili-zer					Fuel	Detergent, food-stuffs additives, cosmetic products, lubricant, fuel	
6 / Biodiesel Caparroso EHN (Acciona Energía)	Caparroso, Navarra		Vegetal oil	Biodiesel 70.000 tonnes	glycerin	Chemicals, alco-hol , water	Effluents, fertili-zer					Fuel	Detergent, food-stuffs additives, cosmetic products, lubricant, fuel	
7 / Transportes Ceferino Martinez	Vilafant, Gerona		Vegetal oil	Biodiesel 5.000 tonnes								Fuel		
8 / Combunet S.L	Monzón, Huesca		Soy and rapeseed oil	Biodiesel 50.000 tonnes								Fuel		

9 / Stocks del Vallés BDP	Barcelona		Vegetal oil	Biodiesel 31.000 tonnes	glycerin	Chemicals, alcohol , water	Effluents, fertilizer					Fuel	Detergent, food-stuffs additives, cosmetic products, lubricant, fuel	
10/ BioTeruel	Albalate del Arzobispo, Teruel		Raw and used oil	Biodiesel 10.000 tonnes								Fuel		
11 / Bionet Europa	Reus, Tarragona		Raw and used oil	Biodiesel 50.000 tonnes	glycerin	Chemicals, alcohol , water	Effluents, fertilizer					Fuel	Detergent, food-stuffs additives, cosmetic products, lubricant, fuel	
12/ Grupo Ecológico Natural (GEN)	Llucmajor, Baleares		Refined oil	Biodiesel 37.000 tonnes								Fuel		
13 / Idae	Alcalá de Henares, Madrid		Pure vegetable oils	Biodiesel 5.000 tonnes								Fuel		
14 / Biodiesel Castilla La Mancha (Biodiésel CLM)	Santa Olalla, Toledo		Soy, used and rapeseed oil	Biodiesel 45.000 tonnes								Fuel		
15 / Biocarburantes CLM (Natura)	Ocaña, Toledo	medium	Soy, palm and rapeseed oil	Biodiesel 105.000 tonnes	glycerin	Chemicals, alcohol , water	Effluents, fertilizer					Fuel	Detergent, food-stuffs additives, cosmetic products, lubricant, fuel	
16 / Combustibles Ecológicos Biotel	Barajas de Melo, Cuenca		Refined oil	Biodiesel 72.000 tonnes	glycerin	Chemicals, alcohol , water	Effluents, fertilizer					Fuel	Detergent, food-stuffs additives, cosmetic products, lubricant, fuel	
17 / Ecoproma Montalbo	Montalvo, Cuenca		Vegetal oil	Biodiesel 50.000 tonnes								Fuel		
18 / Bercam	Los Yébenes, Toledo		Refined oil	Biodiesel 6.000 tonnes								Fuel		
19 / Biocemsa	Elda, Alicante		Soy, palm, sunflower and rapeseed oil	Biodiesel 20.000 tonnes										
20 / Biocom Energía	Algemesí, Valencia		Raw and used oil	Biodiesel 110.000 tonnes	glycerin	Chemicals, alcohol , water	Effluents, fertilizer					Fuel	Detergent, food-stuffs additives, cosmetic products, lubricant, fuel	
21 / Biocarburantes Almadén (Grupo Activos)	Almadén, Ciudad Real		Vegetal oil	Biodiesel 32.000 tonnes	glycerin	Chemicals, alcohol , water	Effluents, fertilizer					Fuel	Detergent, food-stuffs additives, cosmetic products, lubricant, fuel	
22 / Entabán Biocombustibles del Guadalquivir	Sevilla		Soy, sunflower and rapeseed oil	Biodiesel 50.000 tonnes								Fuel		
23 / UTE Isolux Infinita Renovables Corsan Covian	Fuentes de Andalucía, Sevilla		Refined oil	Biodiesel 150.000 tonnes								Fuel		
24 / Biodiesel Andalucía 2004 (BIDA)	Fuentes de Andalucía, Sevilla		80 % Raw and used oil and 20 % used oil	Biodiesel 36.000 tonnes								Fuel		
25 / Biocarburos del Almanzora (Biocarsa)	Cuevas del Almanzora, Almería		Vegetal oil	Biodiesel 6.000 tonnes	glycerin	Chemicals, alcohol , water	Effluents, fertilizer					Fuel	Detergent, food-stuffs additives, cosmetic products, lubricant, fuel	
26 / Linares Biodiesel Technologies	Linares, Jaén		Raw vegetable oil	Biodiesel 100.000 tonnes								Fuel		
27 / Egal Biodiesel	Cerceda, A Coruña		Vegetal oil	Biodiesel 40.000 tonnes								Fuel		
28 / Hispaenergy del Cerrato	Quintana del Puente, Palencia		Vegetal oil	Biodiesel 30.000 tonnes								Fuel		
29 / Saras Energía	Valle de Escombreras, Murcia		Vegetal oil	Biodiesel 200.000 tonnes								Fuel		
30 / Seneca Green Catalyst	córdoba		Used oil	Biodiesel 1.300 tonnes	Amino acid, emulsifier, lipid products							Fuel	Various	
Sweden (SE)														
1 / Perstorp AB	Stenungsund		Rapeseed	Biodiesel 160 000 ton										
2 / Lantmännen Ecobränsle AB (currently not in operation)	Karlshamn		Rapeseed	Biodiesel 45 000 m^3										
3 / Sunpine AB (Start: 2010)	Piteå		Tall oil	Biodiesel 100 000 ton										
4 / Prosbio	Enköping		Rapeseed	Biodiesel	Glycerin									

				1000 m^3										
5 / Prosbio	Finspång		Rapeseed	Biodiesel 300 m^3	Glycerin									
6 / Prosbio	Gotland		Rapeseed	Biodiesel 300 m^3	Glycerin									
7 / Prosbio	Götene		Rapeseed	Biodiesel 300 m^3	Glycerin									
8 / Prosbio	Linköping		Rapeseed	Biodiesel 300 m^3	Glycerin									
9 / Prosbio	Ystad		Rapeseed	Biodiesel 1000 m^3	Glycerin									
10 / Norup Gård	Knislinge		Rapeseed	Biodiesel 10 000 m^3										
11 / Aviosol	Överkalix		Wood	Biodiesel 5 000 m^3										
12 Sweden Bioenergy (planned production site but not known when the building starts)	Norrköping		Jatropha	Biodiesel 350 000 ton										
The Netherlands (NL)														
1 / Dutch BioDiesel (start: 2009)	Harbour of Rotterdam		Rapeseed oil	Biodiesel capacity 2011: 250 ktonnes										
2 / Biovalue2 (start: 2010)	Province Zeeland		Rapeseed	Biodiesel capacity 2011: 180 ktonnes	Glycerin based fuel additive, animal feed, farmaceutical acetates, artificial fertilizer	Methanol, Alkali, Acids, water, fuel	Wastewater	Yes/External	Yes/External	No	No	Fuel	Fuel, Animal feed, fertilizer, farmaceuticals	Treatment/Disposal
3 / Biofueling (start: 2010)	Province Zeeland		Rapeseed oil (60%), palm oil, soy oil, jatropha oil	Biodiesel capacity 2012: 200 ktonnes, (600 ktonnes in 2014)										
4 / Biovalue (start: 2007)	Energy Valley	Small	Rapeseed	Biodiesel 80 ktonnes, pure vegetable oil	Glycerin, rapeseed cake, K2SO4	Methanol, Alkali, acids, fossil fuel	Wastewater	Yes/External	Yes/External	No	No	Fuel, Human consumption	Chemical, animal feed, fertilizer	Treatment/disposal
5 / Biopetrol (start: 2008)	Harbour of Rotterdam		Rapeseed oil	Biodiesel capacity 2011: 400 ktonnes	Glycerin, rapeseed cake, K2SO4	Methanol, Alkali, acids, fossil fuel	Wastewater	Yes/External	Yes/External	No	No	Fuel	Pharmaceuticals, Chemical, animal feed, fertilizer	Treatment/disposal
6 / Rosendaal (start: 2008)	Province Zeeland		Rapeseed oil	Biodiesel capacity 2011: 250 ktonnes	Glycerin, rapeseed cake, raw lecithin	Methanol, Alkali, Acids, fossil fuel	Wastewater	Yes/External	Yes/External	No	No	Fuel	Pharmaceuticals, Chemical,food agent, animal feed, fertilizer	Treatment/disposal
7 / Wheb Biofuels (start: 2010)	Harbour of Rotterdam		Rapeseed oil	Biodiesel capacity 2011: 400 ktonnes	Glycerin									
8 / J&S Bio Energy (start: 2010)	Harbour of Amsterdam		Rapeseed oil	Biodiesel capacity 2011: 200 ktonnes										
9 / Neste Oil (start: 2011)	Harbour of Rotterdam	Large	Palm oil	Biodiesel capacity 2011: 800 ktonnes	Glycerin									
10 / CleanerG (start: 2009)	Zwijndrecht		Rapeseed, Palm and soy-bean oil	Biodiesel capacity 2011: 220 ktonnes	Glycerin	Methanol, Alkali, Acids, fossil fuel	Wastewater	Yes/External	Yes/External	No	No	Fuel		
11 / Ecoson (start: 2007)	Son		Animal fats residue / waste	Biodiesel capacity 2011: 5 ktonnes			Wastewater	Yes/Internal	Yes/Internal	Yes		Fuel		
12 / Greenmills (start: 2009)	Harbour of Amsterdam		Oil residue / waste	Biodiesel capacity 2011: 135 ktonnes										
13 / Biodiesel Kampen	Kampen		Oil residue / waste	Biodiesel										

(start: 2007)				capacity 2011: 50 ktonnes										
14 / BioDSL (start: 2008)	Breda		Oil residue / waste	Biodiesel capacity 2011: 10 ktonnes										
15 / SunOil (start: 2006)	Energy Valley		Oil residue / waste	Biodiesel capacity 2011: 70 ktonnes										
16 / BioMCN (start: 2009)	Energy Valley, Delfzijl		Glycerol (byproduct from biodiesel)	Biomethanol capacity 2011: 200 ktonnes										
17 / Noord Nederland Olie-molen (start: 2005)	Energy Valley		Rapeseed	PPO capacity 2011: 5 ktonnes										
18 / OPEK (start: < 2008)	Province Flevoland		Rapeseed	PPO capacity 2011: 0. 45 ktonnes										
19 / Ecopark (start: 2007)	Energy Valley		Rapeseed	PPO capacity 2011: 25 ktonnes										
20 / Coöperatie Carnola (start: 2006)	Province Limburg		Rapeseed	PPO capacity 2011: 2.5 ktonnes										
United Kingdom (UK)														
1 / Evergreen Energy UK Ltd	At organic farm in On-gar Essex		waste vegetable oil	170,000 Ltrs a week										
2 / Argent Energy Ltd	Motherwell (Scotland)		tallow and used cooking oil	Biodiesel 45 ktonnes	glycerol and potas-sium sulphate		biofuel oil						currently treated as waste under applicable legisla-tion and have to be disposed of	used as a fuel source for the boiler in the plant. The biofuel oil replaces the major-ity of the gas oil in the plant's boiler, providing a "closed loop" system.
3 / Biofuels Corporation Teesside 1 plant	Seal Sands, Middlesbrough (North East coast of England)		vegetable oil crops	250,000 mt biodiesel, equivalent to some 284 million litres of biodiesel										
4 / Rix Biodiesel Limited			Waste?	Only blending and reselling?										
5 / Goldenfuels	Oxford		Used cooking oil collected locally	Biodiesel	glycerin	Potassium hy-droxide, metha-nol	Wash-water							
6 / D & B Biofuels Ltd	Bidford-on-Avon, War-wickshire		Refined vegetable oils?	Biodiesel										
7 / Eco Bio-Diesel Ltd	Burnley, Lancashire		recycled vegetable oils	Biodiesel										
8 / Green*ergy* Immingham Biodiesel Plant	Immingham Docks, N E Lincolnshre (East coast of England)	Small (10 – 49)	Rape/Soy/Palm oils	FAME – 200,000 te/yr (2 biodiesel plants with combined capacity of 200 ktonnes)	Crude Glycerine	Methanol, cata-lyst		Yes, Steam in-ternal	Yes, external	No	No	Blending with ULSD	Animal feed and chemicals	On site effluent Treatment
9 / L C Jay Ltd														
10 / The Silver Group	midlands area		all types of SVO and WVO from around the world		Glycerin	Methanol, so-dium hydroxide								
11 / Armstrong Oils Ltd														
12 / Global Commodities Ltd	Thetford, Norfolk	Ceased trad-ing and are	recycled vegetable oil	Largest producer of biodiesel in the										

		going into liquidation		UK, produces in excess of 10 mln litres of biodiesel a year										
13 / Green Bio Ltd														
14 / Biopower London (no information provided)	London		domestically produced feedstock's including rape, as well as recycled restaurant oils										All of the by-products from our production process are themselves recycled for use in the manufacture of other products	
15 / Bio Driven	Canterbury in Kent		sustainable waste oils avoiding Palm oil											
16 / Sundance Renewables	South Wales (A not-for-profit social enterprise, organised as a workers co-operative)	Micro	used cooking oils (locally sourced)	Biodiesel and bio heating fuel - expanding capacity to 5 million litres/year	Glycerol	process heat from co-product, welsh water, renewable electricity, methanol , caustic soda and sulphuric acid plus UCO	waste water discharged to sewer, no fugitive emissions	process heat provided by oil co-product	yes - electricity for motors/ pumps/ lighting provided by Green Tariff Company Good Energy	Yes - some heat exchangers used in process	No	transport fuel and heating oil	heating oil - glycerol goes to anaerobic digesters	packaging also recycled locally and contaminated plastics sent to pyrolysis plant
17 / D1 Oils	Northeast England	Closed in 2008 due to imports of heavily subsidised biodiesel from the US (B99)		Biodiesel 320 ktonnes end of 2008										
18 / Ineos Enterprises	Grangemouth (Scot)	On hold since November 2008		500 ktonnes (2008)										

Table B.3 *Data pulp & paper sector*

Country	**Complex**	**Size enterprise**	**Feedstock (s)**	**Main product (s)**	**Byproduct(s)**	**Auxiliary input streams**	**Other outputs**	**Heat required?**	**Electricity required?**	**Heat generated?**	**Electricity generated?**	**Current application(s) main product(s)**	**Current application(s) byproduct(s)**	**Current destination(s) residue(s)**
No. / name of complex	**Location**	**- micro - small - medium - large**				**- nutrients - enzymes - chemicals - fossil fuels - water - air - ...**	**- residues - effluents - exhaust gases - ...**	**if yes, heat source: - internal? - external?**	**if yes, electricity source: - internal? - exter-nal?**	**if yes: any application?**	**if yes: - used in-ternally? - or, also partly exported?**			
Belgium (BE)														
1 / Burgo Ardennes		360 000 tons of pulp	Wood	Pulp and paper		Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally and partly exported	Paper		
Finland (FI)														
1 / Metsä-Botnia	Kaskinen	450 000 tons of pulp (shut down early 2009)	Wood	Pulp		Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally and partly exported	Paper		
2 / Metsä-Botnia	Joutseno	630 000 tons of pulp	Wood	Pulp	Crude tall oil and turpentine	Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally and partly exported	Paper		
3 / Metsä-Botnia	Äänekoski	500 000 tons of pulp	Wood	Pulp		Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally and partly exported	Paper		
4 / Metsä-Botnia	Kemi	540 000 tons of pulp	Wood	Pulp	Crude tall oil and turpentine	Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally and partly exported	Paper		
5 / Metsä-Botnia	Rauma	580 000 tons of pulp	Wood	Pulp		Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally and partly exported	Paper		
6 / Stora Enso (Fine paper Mill	Oulu	1 045 000 tons of paper (900 000 tons of pulp)	Wood	Pulp and paper		Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally	Paper		
7 / Stora Enso – Packaging boards Enocell Pulp mill	Eno	650 000 tons of pulp	Wood	Pulp		Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally and partly exported	Paper		
8 / Sunila	Kotka	370 000 tons of pulp	Wood	Pulp	12 000 tons of crude tall oil and 1 000 tons of crude turpentine	Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally and partly exported	Paper		
9 / UPM Kaukas – Kaukas Lappeenranta Paper Mill	Kaukas Lappeenranta	720 000 tons of pulp	Wood	Pulp and paper		Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally	Paper		
10 / UPM	Kymi	800 000 tons of paper (650 000 tons of pulp)	Wood	Pulp and paper		Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally	Paper		
11 / UPM Wisaforest	Pietarsaari	800 000 tons of pulp	Wood	Pulp		Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally and partly exported	Paper		
12 / UPM	Jämsänkoski	800 000 tons of paper	Wood	Paper	Biofuel plant							Paper		
13 / UPM	Kaipola	700 000 tons of paper	Wood	Paper	Biofuel plant							Paper		
		Total pulp												

		capacity: 6.79 million tons												
Spain (ES)														
1 / Ence	Huelva	365 000 tons of pulp	Wood	Pulp		Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally and partly exported	Paper		
2 / Ence	Navia, Asturias	300 000 tons of pulp	Wood	Pulp		Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally and partly exported	Paper		
3 / Ence	Pontevedra	380 000 tons of pulp	Wood	Pulp		Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally and partly exported	Paper		
4 / Rottneros	Miranda	149 000 tons of pulp	Wood	Pulp		Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally and partly exported	Paper		
Sweden (SE)														
1 / Billerud	Gruvön	685 000 tons of paper (450 000 tons of pulp)	Wood	Pulp and paper		Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally	Paper		
2 / Billerud	Karlsborg	300 000 tons of pulp	Wood	Pulp and paper	Crude tall oil and turpentine	Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally	Paper		
3 / Billerud	Skärblacka	400 000 tons of paper (250 000 tons of pulp)	Wood	Pulp and paper		Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally	Paper		
4 / Domsjö Fabriker – Örnsköldsvik (Sulphite mill)	Örnsköldsvik	225 000 tons	Wood	Special cellulose	40 000 ton lignosulfonate 14 000 ton ethanol	Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally and partly exported	Paper		
5 / Iggesund Paperboard – Iggesund Mill	Iggesund	310 000 tons of paper (220 000 tons of pulp)	Wood	Pulp and paper		Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal	Yes, district heating	Yes, used internally	Paper		
6 / Korsnäs – Gävle Mill	Gävle	700 000 tons of pulp	Wood	Pulp and paper		Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal	Yes, district heating	Yes, used internally	Paper		
7 / Korsnäs – Frövi Mill	Frövi	280 000 tons of pulp - 400 000 tons of paper	Wood	Pulp and paper		Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally	Paper		
8 / Mondi Packaging Dynäs	Väja	246 000 tons of paper (175 000 tons of pulp)	Wood	Pulp and paper		Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally	Paper		
9 / M-Real	Husum	690 000 tons of pulp	Wood	Pulp and paper		Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally	Paper		
10 / Munksjö – Aspa Mill	Aspa	180 000 tons of pulp	Wood	Pulp	Crude tall oil and crude turpentine	Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally and partly exported	Paper		
11 / Munksjö Paper	Billingsfors	60 000 tons of pulp	Wood	Pulp and paper		Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally	Paper		
12 / Nordic paper Seffle	Säffle	50 000 tons of pulp	Wood	Pulp and paper		Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally	Paper		
13 / Rottneros – Vallviks Mill	Vallviks	190 000 tons of pulp	Wood	Pulp		Water, chemicals (NaOH, Na_2SO_4,	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally and partly ex-	Paper		

						$MgSO_4$), oil					ported				
14 / SCA Graphic Sundsvall – Östrand Mill	Östrand	430 000 tons of pulp	Wood	Pulp		Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal	Yes, district heating	Yes, used internally and partly exported	Paper			
15 / SCA Packaging	Munksund	340 000 tons of paper (250 000 tons of pulp)	Wood	Pulp and paper		Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally	Paper			
16 / SCA Packaging	Obbola	420 000 tons of paper (300 000 tons of pulp)	Wood	Pulp and paper	Crude tall oil	Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally	Paper			
17 / Smurfit Kappa Kraftliner	Piteå	700 000 tons of paper (500 000 tons of pulp)	Wood	Pulp and paper	Crude tall oil and turpentine	Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal	Yes, district heating	Yes, used internally	Paper			
18 / Stora Enso – Nymölla Mill (Sulphite mill)	Nymölla	470 000 tons of paper (350 000 tons of pulp)	Wood	Pulp and paper		Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally	Paper			
19 / Stora Enso – Skutskär Mill	Skutskär	540 000 tons of pulp	Wood	Pulp		Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally and partly exported	Paper			
20 / Södra Cell	Mönsterås	750 000 tons of pulp	Wood	Pulp		Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal	Yes, district heating	Yes, used internally and partly exported	Paper			
21 / Södra Cell	Mörrum	425 000 tons of pulp	Wood	Pulp		Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal	Yes, district heating	Yes, used internally and partly exported	Paper			
22 / Södra Cell	Värö	400 000 tons of pulp	Wood	Pulp		Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal	Yes, district heating	Yes, used internally and partly exported	Paper			
23 / Wermland Paper	Bäckhammar	170 000 tons of pulp	Wood	Pulp and paper	Crude tall oil and crude turpentine	Water, chemicals (NaOH, Na_2SO_4, $MgSO_4$), oil	Dust, sludge, COD effluent	Yes, internal	Yes, internal		Yes, used internally	Paper			
		Total pulp capacity: 7.89 million tons													
24 / Lignoboost	Bäckhammar	4 000 tons of lignin	Wood	Lignin											
25 / Chemrec – Black liquor gasifier	Piteå	20 tons of BLS/d	Wood												

Table B.4 *Data conventional oil refinery sector*

Country	**Complex**	**Size enterprise**	**Feedstock (s)**	**Main product (s)**	**Byproduct(s)**	**Auxiliary input streams**	**Other outputs**	**Heat required?**	**Electricity required?**	**Heat generated?**	**Electricity generated?**	**Current application(s) main product(s)**	**Current application(s) byproduct(s)**	**Current destination(s) residue(s)**
No. / name of complex	**Location**	**- micro - small - medium - large**				**- nutrients - enzymes - chemicals - fossil fuels - water - air - ...**	**- residues - effluents - exhaust gases - ...**	**if yes, heat source: - internal? - external?**	**if yes, electricity source: - internal? - exter-nal?**	**if yes: any application?**	**if yes: - used in-ternally? - or, also partly exported?**			
Belgium (BE)														
1/ Total Antwerp Refinery (Total)	Antwerp, Amberes	Large	Crude oil 360,000 bbl/d (57,000 m³/d)	Fuels		Air, water, steam, hydro-gen, chemicals (catalysts)	Exhaust air (CO_2, CO, SOx, NOx, particu-late)	yes	yes		Yes, partly exported	Transport fuels, heating oil		
2/ ExxonMobil Antwerp Refinery (ExxonMobil)	Antwerp, Amberes	Large	Crude oil 333,000 bbl/d (52,900 m³/d)	Fuels	Petrochemical, asphalts	Air, water, steam, hydro-gen, chemicals (catalysts)	Exhaust air (CO_2, CO, SOx, NOx, particu-late)	yes	yes		yes	Transport fuels, heating oil		
3/ Antwerp N.V. Refinery (Petroplus)	Antwerp, Amberes	Large	Crude oil 35,000 bbl/d (5,600 m³/d)	Fuels	Asphalts	Air, water, steam, hydro-gen, chemicals (catalysts)	Exhaust air (CO_2, CO, SOx, NOx, particu-late)	yes	yes			Transport fuels, heating oil		
4/ BRC Antwerp (Petroplus)	Antwerp, Amberes	Large	115,000 bbl/d (18,300 m³/d)	Fuels		Air, water, steam, hydro-gen, chemicals (catalysts)	Exhaust air (CO_2, CO, SOx, NOx, particu-late)	yes	yes			Transport fuels, heating oil		
Finland (FI)														
1 / Porvoo Refinery (Neste Oil)	Porvoo	Large	Crude oil 160,000 bbl/d (25,000 m³/d)	Fuels		Air, water, steam, hydro-gen, chemicals (catalysts)	Exhaust air (CO_2, CO, SOx, NOx, particu-late)	yes	yes			Transport fuels, heating oil		
2 / Naantali Refinery (Neste Oil)	Naantali	Large	Crude oil 40,000 bbl/d (6,400 m³/d)	Fuels		Air, water, steam, hydro-gen, chemicals (catalysts)	Exhaust air (CO_2, CO, SOx, NOx, particu-late)	yes	yes			Transport fuels, heating oil		
The Netherlands (NL)														
1 / Shell Pernis Refinery (Royal Dutch Shell)	Pernis	Large	Crude oil 416,000 bbl/d (66,100 m³/d)	Fuels		Air, water, steam, hydro-gen, chemicals (catalysts)	Exhaust air (CO_2, CO, SOx, NOx, particu-late)	yes	yes		yes	Transport fuels, heating oil		
2 / Rotterdam Botlek (Exxon Mo-bil)	Botlek, Rotterdam	Large	Crude oil (195,000 bpd)	Fuels	Coke	Air, water, steam, hydro-gen, chemicals (catalysts)	Exhaust air (CO_2, CO, SOx, NOx, particu-late)	yes	yes		Yes, internal	Transport fuels, heating oil		
3 / Vlissingen Refinery (Total/Dow)	Vlissingen	Large	Crude oil (160,000 bpd)	Fuels		Air, water, steam, hydro-gen, chemicals (catalysts)	Exhaust air (CO_2, CO, SOx, NOx, particu-late)	yes	yes			Transport fuels, heating oil		
4 / Europoort-Rotterdam (BP)	Europoort Rotterdam	Large	Crude oil (400,000 bpd)	Fuels		Air, water, steam, hydro-gen, chemicals (catalysts)	Exhaust air (CO_2, CO, SOx, NOx, particu-late)	yes	yes			Transport fuels, heating oil		
5 / Rozenburg refinery (Q8, Kuwait Petroleum Company)	Rozenburg	Large	Crude oil (80,000 bpd)	Fuels		Air, water, steam, hydro-gen, chemicals (catalysts)	Exhaust air (CO_2, CO, SOx, NOx, particu-late)	yes	yes			Transport fuels, heating oil		
Spain (ES)														
1/ Bilbao Refinery (Repsol YPF)	Bilbao	Large	Crude oil 220,000 bbl/d (35,000 m³/d)	Fuels	Asphalts, coke	Air, water, steam, hydro-gen, chemicals (catalysts)	Exhaust air (CO_2, CO, SOx, NOx, particu-late)	yes	yes	yes	Yes, partly exported	Transport fuels, heating oil		
2/ Puertollano Refinery (Repsol YPF)	Puertollano, Ciudad Real	Large	Crude oil 140,000 bbl/d (22,000 m³/d)	Fuels	Asphalts, lubes, petrochemicals, coke	Air, water, steam, hydro-gen, chemicals	Exhaust air (CO_2, CO, SOx, NOx, particu-	yes	yes	yes	Yes, partly exported	Transport fuels, heating oil		

						(catalysts)	late)							
3/ Tarragona Refinery (Repsol YPF)	Tarragona	Large	Crude oil 160,000 bbl/d (25,000 m^3/d)	Fuels	Petrochemicals	Air, water, steam, hydro-gen, chemicals (catalysts)	Exhaust air (CO2, CO, SOx, NOx, particu-late)	yes	yes	yes	yes	Transport fuels, heating oil		
4/ a Coruna Refinery, (Repsol YPF)	Coruña	Large	Crude oil 120,000 bbl/d (19,000 m^3/d)	Fuels	Asphalts, coke	Air, water, steam, hydro-gen, chemicals (catalysts)	Exhaust air (CO2, CO, SOx, NOx, particu-late)	yes	yes	yes	Yes, partly exported	Transport fuels, heating oil		
5/ Cartagena Refinery, (Repsol YPF)	Cartagena, Murcia	Large	Crude oil 100,000 bbl/d (16,000 m^3/d)	Fuels	Asphalts, lubes	Air, water, steam, hydro-gen, chemicals (catalysts)	Exhaust air (CO2, CO, SOx, NOx, particu-late)	yes	yes	yes	yes	Transport fuels, heating oil		
6/ Tenerife Refinery, (CEPSA),	Tenerife	Large	Crude oil 90,000 bbl/d (14,000 m^3/d)	Fuels		Air, water, steam, hydro-gen, chemicals (catalysts)	Exhaust air (CO2, CO, SOx, NOx, particu-late)	yes	yes			Transport fuels, heating oil		
7/ Palos de la Frontera Refinery (CEPSA)	Palos de la Frontera, Huelva	Large	Crude oil 100,000 bbl/d (16,000 m^3/d)	Fuels	Petrochemicals	Air, water, steam, hydro-gen, chemicals (catalysts)	Exhaust air (CO2, CO, SOx, NOx, particu-late)	yes	yes			Transport fuels, heating oil		
8/ Gibraltar-San Roque Refinery (CEPSA)	Gibraltar-San Roque, Huelva	Large	Crude oil 240,000 bbl/d (38,000 m^3/d)	Fuels	Petrochemicals	Air, water, steam, hydro-gen, chemicals (catalysts)	Exhaust air (CO2, CO, SOx, NOx, particu-late)	yes	yes			Transport fuels, heating oil		
9/ Castellon Refinery (BP)	Castellón, Alicante	Large	Crude oil 100,000 bbl/d (16,000 m^3/d)	Fuels		Air, water, steam, hydro-gen, chemicals (catalysts)	Exhaust air (CO2, CO, SOx, NOx, particu-late)	yes	yes			Transport fuels, heating oil		
Sweden (SE)														
1/ Nynashamn Refinery (Nynäs Petroleum)	Nynaeshamn	Large	Crude oil 90,000 bbl/d (14,000 m^3/d)	Fuels		Air, water, steam, hydro-gen, chemicals (catalysts)	Exhaust air (CO2, CO, SOx, NOx, particu-late)	yes	yes			Transport fuels, heating oil		
2/ Preemraff Göteborg (Preem),	Göteborg	Large	Crude oil 125,000 bbl/d (19,900 m^3/d)	Fuels		Air, water, steam, hydro-gen, chemicals (catalysts)	Exhaust air (CO2, CO, SOx, NOx, particu-late)	yes	yes			Transport fuels, heating oil		
3/ Preemraff Lysekil (Preem),	Lysekil	Large	Crude oil 210,000 bbl/d (33,000 m^3/d)	Fuels	Petrochemicals	Air, water, steam, hydro-gen, chemicals (catalysts)	Exhaust air (CO2, CO, SOx, NOx, particu-late)	yes	yes			Transport fuels, heating oil		
4/ Shell Göteborg Refinery (Royal Dutch Shell)	Göteborg	Large	Crude oil 70,000 bbl/d (11,000 m^3/d)	Fuels		Air, water, steam, hydro-gen, chemicals (catalysts)	Exhaust air (CO2, CO, SOx, NOx, particu-late)	yes	yes			Transport fuels, heating oil		
United Kingdom (UK)														
1/ Lindsey Oil Refinery (Total)	Killingholme	Large	Crude oil 223,000 bbl/d (35,500 m^3/d)	Fuels	Asphalts	Air, water, steam, hydro-gen, chemicals (catalysts)	Exhaust air (CO2, CO, SOx, NOx, particu-late)	yes	yes		Yes, partly exported	Transport fuels, heating oil		
2/ Milford Haven Refinery (Murco)	Milford Haven, Dyfed	Large	Crude oil 100,000 bbl/d (16,000 m^3/d)	Fuels		Air, water, steam, hydro-gen, chemicals (catalysts)	Exhaust air (CO2, CO, SOx, NOx, particu-late)	yes	yes			Transport fuels, heating oil		
3/ Pembroke Refinery (Chevron)	Pembroke	Large	Crude oil 220,000 bbl/d (35,000 m^3/d)	Fuels		Air, water, steam, hydro-gen, chemicals (catalysts)	Exhaust air (CO2, CO, SOx, NOx, particu-late)	yes	yes			Transport fuels, heating oil		
4/ Stanlow Refinery (Royal Dutch Shell)	Stanlow	Large	Crude oil 246,000 bbl/d (39,100 m^3/d)	Fuels	Petrochemicals	Air, water, steam, hydro-gen, chemicals (catalysts)	Exhaust air (CO2, CO, SOx, NOx, particu-late)	yes	yes			Transport fuels, heating oil		
5/ Teesside Refinery (Petroplus)	Teeside	Large	Crude oil 117,000 bbl/d (18,600 m^3/d)	Fuels		Air, water, steam, hydro-gen, chemicals (catalysts)	Exhaust air (CO2, CO, SOx, NOx, particu-late)	yes	yes			Transport fuels, heating oil		
6/ Fawley Southampton Refinery (ExxonMobil)	Fawley Southampton, Hampshire	Large	Crude oil 347,000 bbl/d (55,200 m^3/d)	Fuels	Lubes, asphalts, petrochemicals	Air, water, steam, hydro-gen, chemicals (catalysts)	Exhaust air (CO2, CO, SOx, NOx, particu-late)	yes	yes		yes	Transport fuels, heating oil		

7/ Humber Refinery (ConocoPhillips)	South Killingholme	Large	Crude oil 221,000 bbl/d (35,100 m³/d)	Fuels	Petrochemicals, coke	Air, water, steam, hydrogen, chemicals (catalysts)	Exhaust air (CO_2, CO, SO_x, NO_x, particulate)	yes	yes			Transport fuels, heating oil		
8/ Coryton Refinery (Petroplus)	Essex	Large	Crude oil 208,000 bbl/d (33,100 m³/d)	Fuels	Lubes, asphalts	Air, water, steam, hydrogen, chemicals (catalysts)	Exhaust air (CO_2, CO, SO_x, NO_x, particulate)	yes	yes		yes	Transport fuels, heating oil		
9/ Grangemouth Refinery (Innovene - part of Ineos and formerly BP),	Grangemouth	Large	Crude oil 205,000 bbl/d (32,600 m³/d)	Fuels		Air, water, steam, hydrogen, chemicals (catalysts)	Exhaust air (CO_2, CO, SO_x, NO_x, particulate)	yes	yes			Transport fuels, heating oil		

Table B.5 *Data power production sector (direct and indirect co-firing of biomass in coal-based power plants)*

Country	**Complex**	**Size enterprise**	**Feedstock (s) / co-fired fuel (s)**	**Main product (s)**	**Byproduct(s)**	**Auxiliary input streams**	**Other outputs**	**Heat required?**	**Electricity required?**	**Heat generated?**	**Electricity generated?**	**Current application(s) main product(s)**	**Current application(s) byproduct(s)**	**Current destination(s) residue(s)**
No. / name of complex	**Location**	**- micro - small - medium - large**				**- nutrients - enzymes - chemicals - fossil fuels - water - air - ...**	**- residues - effluents - exhaust gases - ...**	**if yes, heat source: - internal? - external?**	**if yes, electricity source: - internal? - external?**	**if yes: any application?**	**if yes: - used internally? - or, also partly exported?**			
Belgium (BE)														
1 / Ruien (indirect co-firing)	Ruien	Large	Wood chips from recycled fresh wood, bark and hard and soft board residues	Electricity: 540 MWe							yes	Bioenergy (electricity)		
Finland (FI)														
1 / Direct co-firing plant	Aanekoski		wood waste, peat, oil	Electricity heat: 76 MWth						yes	yes	Bioenergy (electricity / heat)		
2 / Direct co-firing plant	Forssa													
3 / Direct co-firing plant	Kaipola													
4 / Direct co-firing plant	Kajaani		peat, wood, sludge	Electricity: 85 MWe heat: 240 MWth						yes	yes	Bioenergy (electricity / heat)		
5 / Direct co-firing plant	Kokkola		peat, RDF, wood	Electricity heat: 98 MWth						yes	yes	Bioenergy (electricity / heat)		
6 / Direct co-firing plant	Kuhmo		peat, wood waste	Electricity heat: 18 MWth						yes	yes	Bioenergy (electricity / heat)		
7 / Direct co-firing plant	Lieska		peat, bark, sawdust	Electricity: 8 MWe heat: 22 MWth						yes	yes	Bioenergy (electricity / heat)		
8 / Lohja Paper Mill (direct co-firing plant)	Lohja		wood waste, paper waste	Electricity heat: 36 MWth						yes	yes	Bioenergy (electricity / heat)		
9 / Direct co-firing plant	Mikkeli		lignite, wood waste, oil, gas	Electricity heat: 84 MWth						yes	yes	Bioenergy (electricity / heat)		
10 / Outokumpo Oy (direct co-firing plant)	Outokumpu		peat, wood waste	Electricity heat: 17.5, 24 MWth						yes	yes	Bioenergy (electricity / heat)		
11 / Pieksamaki District Heating (direct co-firing plant)	Pieksamaki		peat, wood waste, heavy fuel oil	Electricity heat: 20 MWth						yes, district heating	yes	Bioenergy (electricity / heat)		
12 / Alholmens Kraft CHP (direct co-firing plant)	Pietarsaari			Electricity heat						yes	yes	Bioenergy (electricity / heat)		
13 / Direct co-firing plant	Rauhalahti municipal CHP plant		peat, wood waste	Heat						yes, district heating		Bioenergy (heat)		
14 / Rauma Paper Mill (direct co-firing plant)	Rauma		bark, sludges, fibre wastes	Electricity heat: 60 MWth						yes	yes	Bioenergy (electricity / heat)		
15 / Direct co-firing plant	Rauma		peat, sludge, bark	Electricity heat: 160 MWth						yes	yes	Bioenergy (electricity / heat)		
16 / Seinajoki Energy (direct co-firing plant)	Seinajoki		peat, wood waste, heavy fuel oil	Electricity heat: 20 MWth						yes	yes	Bioenergy (electricity / heat)		
17 / Direct co-firing plant	Varkaus													
18 / Indirect co-firing plant	Kymijärvi, Lahti			Electricity							yes	Bioenergy (electricity)		
The Netherlands (NL)														
1 / Hemwegcentrale 8 (direct co-firing)	Amsterdam	Large	Sewage sludge	Electricity: 600 MWe heat:						yes	yes	Bioenergy (electricity / heat)		
2 / Borssele 12 (direct co-firing)	Borssele	Large	kernels, paper sludge, shells, fibers	Electricity: 403 MWe							yes	Bioenergy (electricity)		
3 / Amercentrale 8 (direct co-firing)	Geertruidenberg	Large	paper sludge	Electricity: 600 MWe heat:						yes	yes	Bioenergy (electricity / heat)		
4 / Maasvlaktecentrale 1+2 (direct co-firing)	Maasvlakte, Rotterdam	Large	biomass pellets (paper sludge, compost residue)	Electricity: 2 x 518 MWe							yes	Bioenergy (electricity)		

5 / Gelderland (direct co-firing)	Nijmegen	Large	pulverised wood	Electricity: 602 MWe							yes	Bioenergy (electricity)		
6 / Amercentrale 9 (indirect co-firing)	Geertruidenberg	Large	Waste wood	Electricity: 600 MWe							yes	Bioenergy (electricity)		
Spain (ES)														
1 / Hunosa power station (direct co-firing)	La Pereda		Coal wastes, wood waste	Electricity heat: 50 MWth						yes	yes	Bioenergy (electricity / heat)		
Sweden (SE)														
1 / Avesta Energiverk (direct co-firing)	Avesta		peat, wood	Electricity: heat: 15 MWth						yes	yes	Bioenergy (electricity / heat)		
2 / Stora Enso Fors Mill (direct co-firing)	Fors		wood, bark	Electricity: 9.6 MWe heat: 55 MWth						yes	yes	Bioenergy (electricity / heat)		
3 / Västhamnsverket CHP (direct co-firing)	Helsingborg		wood	Electricity: 180 MWe							yes	Bioenergy (electricity)		
4 / Karlstad Energiverk (direct co-firing)	Karlstad		wood waste	Electricity: heat: 90 MWth						yes	yes	Bioenergy (electricity / heat)		
5 / Tekniska Verken Ltd 1 (direct co-firing)	Linköping		rubber waste	Electricity: heat: 83 MW						Yes	yes	Bioenergy (electricity / heat)		
6 / Tekniska Verken Ltd 2 (direct co-firing)	Linköping		wood	Electricity: heat: 65 MW						Yes	yes	Bioenergy (electricity / heat)		
7 /Brista Kraftvärmeverk (Direct co-firing plant)	Märsta		wood, various wastes	Electricity: 40 MWe heat: 80 MWth						yes	yes	Bioenergy (electricity / heat)		
8 / EON Händelö (Direct co-firing plant)	Norrköping		wood	Electricity: heat: 125 MWth						yes	yes	Bioenergy (electricity / heat)		
9 / Nyköping Energi (direct co-firing)	Nyköping		wood waste, peat, oil	Electricity: 35 MWe heat: 100 MWth						yes	yes	Bioenergy (electricity / heat)		
10 / Jämtkraft (Direct co-firing plant)	Östersund		wood, peat, bark, wood waste, oil	Electricity: heat: 25 MWth						yes	yes	Bioenergy (electricity / heat)		
11 / Hedensbyn (direct co-firing)	Skelleftea		peat 20%, pellets 80%	Electricity: 47 MWe heat: 25 MWth						yes	yes	Bioenergy (electricity / heat)		
12 / Soderenergi AB (direct co-firing)	Södertälje		wood waste, peat, oil	Electricity: heat: 120 MWth						yes	yes	Bioenergy (electricity / heat)		
13 / Hässelbyverket (direct co-firing)	Stockholm		wood pellets, olive waste	Electricity: 279 MWe heat:						yes	yes	Bioenergy (electricity / heat)		
14 / Uppsala Energi (direct co-firing)	Uppsala		peat, wood	Electricity: 320 MWe heat:							yes	Bioenergy (electricity)		
United Kingdom (UK)														
1 / Direct co-firing plant	Scotland		wood, oil	Electricity heat: 43 MWth						yes	yes	Bioenergy (electricity / heat)		
2 / Slough Heat and Power Ltd. (direct co-firing)	Slough		RDF from waste paper and plastics	Electricity: 35 MWe heat:						yes	yes	Bioenergy (electricity / heat)		
3 / West Burton (direct co-firing)		Large		Electricity: 1980 MWe							yes	Bioenergy (electricity)		
4 / Kingsnorth (direct co-firing)		Large	Cereal residues	Electricity: 2034 MWe							yes	Bioenergy (electricity)		
5 / Longannet (direct co-firing)		Large	Sewage sludge	Electricity: 2400 MWe							yes	Bioenergy (electricity)		
6 / Drax (direct co-firing)		Large	Various	Electricity: 4000 MWe							yes	Bioenergy (electricity)		
7 / Eggborough (direct co-firing)		Large	Various	Electricity: 1960 MWe							yes	Bioenergy (electricity)		
8 / Ferrybridge (direct co-firing)		Large	Various	Electricity: 2035 MWe							yes	Bioenergy (electricity)		
9 / Fiddlers Ferry (direct co-firing)		Large	Various	Electricity: 1995 MWe							yes	Bioenergy (electricity)		
10 / Ratcliffe (direct co-firing)		Large	Various	Electricity: 2010 MWe							yes	Bioenergy (electricity)		
11 / Rugeley (direct co-firing)		Large	Various	Electricity: 1000 MWe							yes	Bioenergy (electricity)		
12 / Aberthaw (direct co-firing)		Large	Wood	Electricity: 1455 MWe							yes	Bioenergy (electricity)		
13 / Cockenzie (direct co-firing)		Large	Wood	Electricity: 1200 MWe							yes	Bioenergy (electricity)		

14 / Cottam (direct co-firing)		Large	Wood	Electricity: 2000 MWe							yes	Bioenergy (elec-tricity)		
15 / Didcot (direct co-firing)		Large	Wood	Electricity: 2100 MWe							yes	Bioenergy (elec-tricity)		
16 / Ironbridge (direct co-firing)		Large	Wood	Electricity: 970 MWe							yes	Bioenergy (elec-tricity)		

Table B.6 *Data food industry sector*

Country	Complex	Size enterprise	Feedstock (s)	Main product (s)	Byproduct(s)	Auxiliary input streams	Other outputs	Heat required?	Electricity required?	Heat generated?	Electricity generated?	Current application(s) main product(s)	Current application(s) byproduct(s)	Current destination(s) residue(s)
No. / name of complex	**Location**	**- micro - small - medium - large**				**- nutrients - enzymes - chemicals - fossil fuels - water - air - ...**	**- residues - effluents - exhaust gases - ...**	**if yes, heat source: - internal? - external?**	**if yes, electricity source: - internal? - exter-nal?**	**if yes: any application?**	**if yes: - used in-ternally? - or, also partly exported?**			
Belgium (BE)														
1 / Verbinnen	Olen	medium	chicken	Meat	proteins	Heat, water	Water	yes	yes			food	food	
2 / Cargill	Mechelen (European headquarter)	Large		Starch, sweeteners, derivativers										
3 / Duvel	Locations in BE, UK, US, FR, CZ	large	Gerst/Mout, hop	beer	Draf (solid fraction after brewing)	Water, steam	effluent	yes	yes	yes	Partially by suncollecors	food	Draf – application in feed	
4 / DSM – Citrique Belge	Tienen	Large	Molasses	citric acid and/or associated co-products	CITROCELL (Aspergillus niger mycelium), CITROCOL, Syngenite and Citrogypsum	Mould *Aspergillus niger* Water	Non-hazardous waste		Yes external			Food Pharmacy Detergents	Mainly feed and industrial applications	Off-site incineration Landfill Off-site recovery
5 / Lotus bakeries	9 locations in BE, NL and FI	Medium/large ?	Flour, sugar, fats/oils	Bakery products		Water, ingredienst	Exhaust gas	yes	yes			food		
6 / Puratos	Groot-Bijgaarden	Large	Flour, yeast, cacao, cacao butter	Bakery ingredients and semi-finished products (emulsifiers, enzymes, sourdoughs and yeasts, bread improvers and mixes), chocolate				Yes	yes			Bakery Patisserie Chocolate		
7 / Syral	Aalst	Large	Maize, wheat	starches, sweeteners, proteins, polyols, potable alcohol & bio-ethanol	Fibre-rich ingredients, (Maize germs, Corn gluten feed, Fresh maize fibers, Wheat gluten, Wheat feed, Wheat solubles) organic soil fertilizer							confectionary, dairy, milling & baking, beverages, animal feed, fermentation, paper & corrugated etc....	Food Cattle, pigs and poultry feed and petfood	
8 / Tiense Suikerraffinaderij	Tienen	Large	Sugar beet	Sugar and sugar specialties	Mollasse	Water, quick lime, carbon dioxide	Vegetable rest fraction (leaves, pulp) Calcium carbonate, impurities	Yes	Yes			Food	Production of alcohol, yeast, animal feed and citric acid	Animal feed
9 / Candico (daughter company of Tiense suikerraffinaderij)	Antwerpen	Medium	Sugar cane	Brown candy sugars, unrefined cane sugars, organic cane sugars	Soft sugarcandy, candy syrup			Yes	Yes			Food, breweries, bakeries	Bakery	
10/ Beneo-orafti	Tienen	Medium	Chicory roots	Chicory-based food ingredients, Active food ingredients such as inulin and oligofructose Organic sweeteners		Water, enzymes	Vegetable rest fraction	Yes	Yes			Food		
Finland (FI)														
1 /	Kosenkorva, Altia 1888 Corp.	250+	Barley	Grain Sprirts, Technical EtOH	Starch, Animal feed	Water, Enzymes, Yeasts	CO2, Husks, Exhaust gases, waste water	Yes/External	Yes/External	Yes/Internally	Yes/Internally	Beverage production, Technical EtOH	Animal feed, Starch for brewing	Husks are burned, Exhaust gases to atmosphere
2 /	Rajmaki, Altia 1888 Corp.	250+	Grains, Grain spirit ready made, beverage (packaging)	Beverage (wodka, wine, liquers)	?	Flavors	Waste water	?	?	?	?	Human Consumption	?	?
3 / Atria PLC	Nurmo	250+	Meat (pork, bovine,	Meat products	?	Water, ammonia,	Wastewater,	Yes/External	Yes/Internal	No	No	Human consump-	?	Wastewater treat-

			poultry)			flavors	mixed wastes (landfill), plastics, scrap metal, manure, ammonia					tion		ment, landfilling, burning (plastics), recycling (scrap metal)
4 / Raisio, Raisio Malt		250+	Barley	Barley malt	Barley animal feed	Enzymes, water	Husks and residues, wastewater	Yes/external	Yes/external	No	No	Beer production	Animal feed	Disposal
5 / Valio	Haapavesi	Medium	Milk	Cheese	Whey	Cheese culture, saltt, water	wastewater	Yes/external	Yes/External	No	No	Human consumption	?	?
6 / Valio	Lapinlahti	250+	Milk	Cheese	Dairy products	Cheese culture, salt, renet	wastewater	Yes/external	Yes/external	No	No	Human Consumption	Human Consumption	?
7 / Valio	Seinajoki	250+	Milk	Butter, dairy products	Whey	?	?	Yes/external	Yes/external	No	No	Human Consumption	Human Consumption	?
8 / Valio	Helsinki	Medium	Milk, Fruit	Milk and Juice base drinks, Whey	?	?	?	Yes/external	Yes/external	No	No	Human Consumption	?	?
The Netherlands (NL)														
1 / Ten Kate	Musselkanaal	Medium	Slaugther by products, raw slaughterhouse fast	Fats, oil, proteins	None (chk app 1)	Steam, water	Water from cleaning	Yes, external (chk app 1)	Yes, external (chk app 1)	no	no	Food, feed, biodiesel, industry	Chk app 1	-
2 / Cargill	About 12 locations in NL (app 2)	Large (2300)	Grains, oilseeds, cacoa beans	Cacao, starch(derivatives), sugar/sweeteners		Water, chemicals	Effluents	Yes	Yes	App2	App2	Food, feed, agri, industry		
3 / Cosun	More locations in NL	Large (4300)	Potatos, sugar beets	Sugar, inulin, potatoproducts, ingrediensts for food industry		Water ,gas, oil	effluent	Yes, int/ext	Yes, int/ext (WKK)	Yes, int	Yes, int	food	Non food	
4 / CSM / purac	More locations in NL	Large (8700)		Bakery products, lactic acid (derivatives)	App 4, total by-products is 250000 tonnes	Water. Enzymes, chemical, gas	effluent	Yes, int	yes			Food, chemical, pharmaceutical industry		79000 tonnes
5 / DSM	More locations in NL	large		Enzymes, chemicals, food ingredients		Chemicals, enzymes, water	Effluent, exhaust gasses	yes	yes			Nutrition (food and feed ingredienst) ,Pharma ,Performance Materials, Polymer Intermediates ,Base Chemicals and Materials		
6 / Unilever	Many	large	many	many	Many, for example bleaching earth	Agri, Water, chemicals …..	Effluents, exhaust gasses….	yes	yes	yes	yes	Food, cosmetics	For example spentbleaching earth in brick production	
7/ Lamb weston	3 locations in NL	large	potatos	Potato based food ingredients	Starch, Organic potato material like leaves and peel	Water, oil for frying process	effluent	yes	yes			Food ingredients	Food ingredients, biogas	
8/ Mars	3 locations in NL	large	many	Chocolate prodcuts, foodproducts, feed		Water, chemicals, ingredients	Effluent, exhaust gas	yes	yes			Food, feed		
9/ Friesland foods	More locations in NL	large	Milk, soy, fruits	Food products (mainly dairy)		water	effluent	yes	yes	yes		food		
10 / Plukon	More locations in NL	large	Poultry	Fresh and frozen chicken products		Water	Waste water, effluents	yes	yes	no	no	food		
Spain (ES)														
1 / Baron de Ley S.A.		Medium	Grape	Wine	?	Water, Fuel (fossile)	Water, plastic and glass packaging, cardboard, wood	Yes/external	Yes/external	No	No	Human Consumption	?	?
2 / Bodegas Riojanas		Medium	Grape	Wine	?	Water, Fuel (fossile)	Water, plastic and glass packaging, cardboard, wood	Yes/external	Yes/external	No	No	Human Consumption	?	Wastewater treatment
3 / Compania Vinicola del Norte de Espana	Haro	Medium	Grape	Wine	?	Water, Fuel (fossile)	Water, plastic and glass packaging, cardboard, wood	Yes/external	Yes/external	No	No	Human Consumption	?	Wastewater treatment
4 / Natra	Valencia	Medium	Milk powder, Cocoa paste	Chocolate	Cocoa butter, Sugar, Sweeteners	Water, Alkali, Fossil fuels	Waste water, paper packaging	Yes/external	Yes/external	No	No	Human Consumption	Semi-products, Human consumption	Wastewater treatment, disposal
5 / SOS Cuetara		250+	Olives, Oil seeds,	Vegetable oils	Heavy-duty cook-	Water, alkali	Wastewater, oil	Yes/external	Yes/external	No	No	Human Consump-	Human Consump-	Wastewater treat-

			Palm oil		ing oil, Antioxi-dants, Cattle feed	acids, fossil fuel	residues					tion	tion, cattle feed	ment, disposal
6 / Ebro Puleva	More locations													
7 / Puleva Biotech	More locations													
Sweden (SE)														
1 / Arla	12 production facillities in different countries (DK, SE, FI, UK)	large	milk	Dairy products		water	effluent	yes	yes	Yes (wood chipping)		food		
3 / Abba seafood	Few locations in SE	Medium/large	fish, mussels and prawns	Food products based on fish, mussels and prawns	Organic material not used in food	water	effluent	yes	yes			food		
3 / Danisco/genencor			Marine vegation, fruits	Food ingredients, enzymes	For example pec-tin, xylose	Water, packag-ing	Effluent, exhaust gasses	yes	yes	Heat recovery		Foodingredientss	Food ingredient	Landfill, incinne-ration
4 / Danisch crown		large	Live animals	Meatproducts	Fat, proteins, bio-diesel	water	Effluent, exhaust gasses	yes	yes	yes	yes	Food	Food, feed, bio-diesel,	
United Kingdom (UK)														
1 / British Sugar	4 production facilities in UK	Large	Sugar Beat	Sugar (granular, liquid, pharma…)	Bioethanol, Sy-rups, Invert Su-gars…	Water, Fossil fuel, lime, soil	Wastewater, lime, soil	Yes/external	Yes/external	Yes	No	Food, Confectio-nary, pharmaceuti-cals, healthcare	Fuel, Food	High quality soils, Wastewater treat-ment
2 / Nestle	8 production facilities in UK	Large	Food, pet food, Coffee	Beverages, Cerials, Meat, Confectio-nary, Pasta, Cheese, Yogurts, Coffee		Water, Fossil fuel	Wastewater	Yes/external	Yes/external	No	No	Food		
3 / Unilever UK		Large	Foods and beverag-es											
4 / (ref.) British Salt		Large	Sodium Chloride (raw)	Sodium Chloride (different grades)		Water, Fossil fuel, Steam	Wastewater, Ca2+, Mg2+	Yes/external	Yes/External	No	No	Food, Chemical, Animal feed, Tex-tile, water processing		Underground dis-posal, wastewater treatment
5 / Dairy Crest	16 Locations in UK	Large	Milk	Cheese, Spreads, Milk, Ingredients		Water, Fossil Fuel	Wastewater	Yes/external	Yes/External	No	No	Food		

Table B.7 *Data agrosector*

Country	**Complex**	**Size enterprise**	**Feedstock (s)**	**Main product (s)**	**Byproduct(s)**	**Auxiliary input streams**	**Other outputs**	**Heat required?**	**Electricity required?**	**Heat generated?**	**Electricity generated?**	**Current application(s) main product(s)**	**Current application(s) byproduct(s)**	**Current destination(s) residue(s)**
No. / name of complex	**Location**	**- micro - small - medium - large**				**- nutrients - enzymes - chemicals - fossil fuels - water - air - ...**	**- residues - effluents - exhaust gases - ...**	**if yes, heat source: - internal? - external?**	**if yes, electricity source: - internal? - exter-nal?**	**if yes: any application?**	**if yes: - used in-ternally? - or, also partly exported?**			
Belgium (BE)														
1 / Syral	Aalst	Large	Wheat	Starch, glucose syrups, gluten	Wheat bran	Enzymes, acids, natural gas, wa-ter		Yes; internal (CHP)	Yes; Internal (CHP)	Yes; starch/protein/co-product drying	Yes; internal use and partly exported (grid)	Food industry	Animal feed	-
2 / Remy Industries	Wijgmaal	Medium	Rice	Starch				Yes				Food industry		
3 / Cosucra	Warcoing	Medium	Chicory root, pea	Inuline, starch, proteins	Chicory pulp, Pea fibres			Yes				Food industry	Food industry	
4 / Orafti	Tienen	Medium	Chicory root	Inuline, oligofruc-tose	Chicory pulp			Yes				Food industry		
5 / Tiense suiker	Tienen + various smaller sites	Large	Sugar beet	Sugar (600.000 T)	Molasses, beet pulp	CaO, CO2	CaCO3	Yes				Food industry	Fermentation, animal feed, soil improvement	
6 / Iscal Sugar	Fontenoy, Moerbeke	Medium	Sugar beet	Sugar (190.000 T)	Molasses, beet pulp	CaO, CO2	CaCO3	Yes				Food industry	Fermentation, animal feed, soil improvement	
7 / Oleon	Oelegem, Ertvelde	Large	Vegetable oil (rape-seed (200.000 T), soy, palm…), ani-mal fats	Fatty acid deriva-tives (400.000 T)	Glycerol (60.000 T)	Various chemi-cals		Yes				Various non-food		
8 / Mosselman	Ghlin	Medium	Vegetable oil (rape-seed, soy, palm…), animal fats	Fatty acid deriva-tives (10.000 T)	Glycerol (60.000 T)	Various chemi-cals						Various non-food		
9 / Vandeputte Oleochemi-cals	Mouscron	Small	Vegetable oils	Soaps, detergents, linseed oil deriva-tives	Linseed cake							Various non-food (detergents, paints, coatings…)	Animal feed	
10/ Fuji Oil	Gent	Medium	Vegetable oils (palm, coco, palm kernel)	Functional fats (100.000 T)								Food industry (chocolate)		
11/ Anonymous (future project)	Wallony	Large	CO2	Algae biomass	Proteins	N/P/K sourcs, water	Minerals	Yes; internal (waste heat)	Yes; external	No	No	Bioenergy, bio-chemicals, bioma-terials, animal feed…	Animal feed…	
Finland (FI)														
1 / Finnamyl	Kokemäki		Potato	Starch										
2 / Sucros (might close down in Spring 2009)	Säkilä	Medium	Sugar beet 550.000 T)	Sugar (100.000 T)	Molasses (23.500 T), beet pulp (28.500 T)	CaO, CO2	Lime					Food	Fermentation, animal feed, soil improvement	
3 / Elixi Oil	Somero	Small	Linseed	Linseed oil	Linseed cake							Food	Food	
4 / Mildola	Kirkkonummi	Small	Rapeseed	Rapeseed oil	Rapeseed cake							Food	Animal feed	
5 / Raisio		Large	Cereals (500.000 T), rapeseed (145.000 T)	Oils & fats (mar-garines…), oat flour…								Food, animal feed, energy (oil for biodiesel)		
The Netherlands (NL)														
1 / Avebe	Foxhol, Ter Apelkanaal, Gasselternijveen	Large	Potato	Starch, Protein				Yes; Natural gas	yes					
2 / Cargill	Sas Van Gent	Large	Wheat	Starch, starch hy-drolysates, pro-teins (gluten)	Wheat bran							Food, paper, adhe-sives…	Animal feed	
3 / Cargill	Bergen op Zoom	Large	Maize	Starch, starch hy-drolysates	Corn gluten feed & meal, corn steep liquor							Food, paper	Animal feed	
4 / Tate & Lyle	Zaandam	Large	Maize	Starch, glucose	Corn gluten feed							Food, paper, adhe-	Animal feed	

				syrups (est. 200.000 T)	& meal, corn steep liquor							sives		
5 / Suikerunie (>Cosun)	Dinteloord, Vierverlaten	Large	Sugar beet	Sugar (800.000 T)	Molasses, Beet pulp	CaO, CO2	Lime					Food	Animal feed, Soil improvement	
6 / Uniquema/Croda	Gouda	Large	Vegetable oil (rapeseed, soy, palm…), animal fats		Glycerol	Various chemicals						Various non-food		
7 / Sensus (>Cosun)	Zwolle, Roosendaal		Chicory root	Inuline, oligofructose	Inuline pulp							Food	Animal feed	
8 / Nedalco (>Cosun)	Bergen op Zoom, Sas van Gent	Large	Molasses, wheat	Ethanol	Vinasse							Food, technical, biofuels	Animal feed	
9 / Akzo Nobel / Ingrepro	Delfzijl	Small	CO2	Algae biomass	Proteins	N/P/K nutrients, water		Yes	Yes	No	No	Bioenergy, biochemicals, biomaterials, animal feed…	Animal feed…	
10 / Airport company / Aquaphyto	Schiphol	Small	CO2	Algae biomass	Proteins	N/P/K nutrients, water		Yes	Yes	No	No	Bioenergy, biochemicals, biomaterials, animal feed…	Animal feed…	
Spain (ES)														
1 / Syral	Zaragossa	Large	Maize	Starch, starch hydrolysate	Corn gluten meal & feed, Corn steep liquor	Enzymes		Yes	Yes			Food, paper, adhesives	Animal feed	
2 / Roquette	Laisa	Large	Maize	Starch, starch hydrolysate	Corn gluten meal & feed, Corn steep liquor	Enzymes		Yes	Yes			Food, paper, adhesives	Animal feed	
3 / Cargill	Martorell	Large	Maize	Starch, starch hydrolysate	Corn gluten meal & feed, Corn steep liquor	Enzymes		Yes	Yes			Food, paper, adhesives	Animal feed	
4 / Azucarera Ebro (>Ebro Puleva)	6 sites in Spain	Large	Sugar beet	Sugar (378.000 T in 2009)	Molasses, Beet pulp	CaO, CO2	Lime					Food	Animal feed, Soil improvement	
5 / Holcim / Greenfuel (development project)	Aurantia	Small	CO2	Algae biomass (25.000 T)	Proteins	N/P/K nutrients, water		Yes	Yes	No	No	Bioenergy, biochemicals, biomaterials, animal feed…	Animal feed…	
Sweden (SE)														
1 / Lyckeby	Kristianstadt	Medium	Potato	Starch (65.000 T)	Potato pulp, fruit juice							Food, paper industry, other industrial	Animal feed, fertilisers	
2 / Stadex (> Avebe)	Malmö	Mediuù	Potato	Starch	Potato pulp, fruit juice							Food, paper industry, other industrial	Animal feed, fertilisers	
2 / Danisco sugar Ortofta	Eslöv	Medium	Sugar beet	Sugar (300.000 T)	Molasses (110.000 T), beet pulp (200.000 T)	CaO, CO2	Lime			Yes, supplied to local communities		Food	Animal feed, Soil improvement	
3 / AAK	Karlshamn	Large	Palm oil (850.000 T), shea nut, rapeseed	Oil and fat specialties; biodiesel production	Glycerol, rapeseed cake							Food, cosmetics, industrial applications	Animal feed	
United Kingdom (UK)														
1 / Cargill	Manchester	Large	Wheat	Starch, starch hydrolysates, proteins	Wheat bran, wheat liquefact							Food, paper, adhesives	Animal feed, ethanol production (with Nedalco)	
2 / Roquette	Corby													
3 / Syral	Greenwich	Large	Wheat	Starch, starch hydrolysates, proteins	Wheat bran, wheat liquefact							Food, paper, adhesives	Animal feed, ethanol production (with Nedalco)	
4 / British sugar	Bury St. Edmunds	Large	Sugar beet (1.950.000 T)	Sugar (200.000 T)	Molasses (35.000 T), molassed sugar beet feed (140.000 T)	CaO, CO2	Lime (70.000 T)	Yes, internally (gas turbine)	Yes, 14,5 MW Internally (gas turbine)		Yes, 50 MW exported to the grid	Food	Animal feed, Soil improvement	
5 / British Sugar	Cantley	Large	Sugar beet (1.300.000 T)	Sugar (150.000 T)	Molasses, molassed sugar beet feed (80.000 T)	CaO, CO2	Lime	Yes, internally (heavy fuel and coal)	Yes, 13 MW Internally (heavy fuel, coal)			Food	Animal feed, Soil improvement	
6 / British Sugar	Newark	Large	Sugar beet (1.400.000 T)	Sugar (155.000 T)	Molasses (45.000 T), molassed sugar beet feed (100.000 T), pressed feed (25.000 T)	CaO, CO2	Lime (45.000 T)	Yes, internally	Yes, 10 MW Internally		Yes, sold to the grid	Food	Animal feed, Soil improvement	
7 / British Sugar	Wissington	Large	Sugar beet (3.000.000 T)	Sugar (300.000 T), bioethanol (70.000	Feed pellets (140.000 T)	CaO, CO2	Lime (100.000 T), CO2	Yes, internally (50 MW gas	Yes, internally (50 MW	Yes, sold to horticulture green-	Yes, sold to the gris	Food	Animal feed, Soil improvement,	

				m^3)				turbine, 30MW steam turbine; cogeneration)	gas turbine, 30MW steam turbine; co-generation)	housen (incl. CO_2)	(50MW)		CO_2 for horticul-ture	
8 / Tate & Lyle	London, Manchester	Large	Sugar cane	Sugar (1.300.000 T)								Food		
9 / Uniquema/Croda	Bromborough	Large	Vegetable oil (rape-seed , soy, palm…), animal fats		Glycerol	Various chemi-cals						Various non-food		
10 / Oil power plant / ano-nymous (algae project)	South-west	Small	CO_2	Algae biomass (5.000 T target)	Proteins	N/P/K nutrients, water		Yes	Yes	No	No	Bioenergy, bio-chemicals, bioma-terials, animal feed…	Animal feed…	
France (FRA)														
1 / Roquette	Lestrem	Large	Wheat (1.300.000 T), maize (1.000.000 T)	Starch, starch hy-drolysates, pro-teins, fermentation products	Bran, gluten meal & feed, CCSL	Enzymes, water, various chemi-cals						Food, paper, adhe-sives, fermenta-tion…	Animal feed	
2 / Roquette	Beinheim, Vecquemont	Small units	Potato, Pea	Starch	Potato pulp, pea fibres							Food, paper, adhe-sives	Food, Animal feed	
2 / Syral	Nesle	Large	Wheat (1.000.000 T)	Starch hydroly-sates, ethanol, protein	Wheat bran, DGS	Enzymes, water		Yes; natural gas	Yes; internal, cogeneration	Yes; cogenetra-tion plant	Yes, cogene-ration plant	Food, fermentation	Animal feed	
3 / Syral	Marckolsheim	Medium unit	Wheat, maize	Starch, starch hy-drolysates	Bran, gluten meal & feed, CCSL	Enzymes, water						Food	Animal feed	
3/ Saint Louis (Südzucker)		Large	Sugar beet	Sugar (946.000 T)	Molasses, Beet pulp	CaO, CO_2	Lime					Food	Animal feed, fer-mentation, soil improver	
4 / Tereos	10 sites in France	Large	Sugar beet (10.000.000 T)	Sugar (est. 2.000.000 T)	Molasses, Beet pulp	CaO, CO_2	Lime					Food	Animal feed, fer-mentation, soil improver	