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D 2.1.1 Note on literature review concerning market introduction and development of biorefinery concepts and related products

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1. Introduction

Currently crude oil refineries produce a variety of products for almost all areas of life with a high efficiency. The used fossil feedstock is still relatively cheap and in arbitrary quantities available. But it can be observed that the costs of fossil oil strongly increased in recent years and concerns about the security of the oil supply grow on a national and global scale. Additionally an increasing awareness of negative environmental effects of carbon dioxide emissions exists in public. This triple bottom line of environmental, economic and political drivers leads to a need to re-examine the petrochemical industry. It is proposed to develop comparable biorefineries making it possible to produce bio-based products, which can compete with their crude-oil-based equivalents. Especially this comparison of crude oil and biomass has lead to the fact that for possible converting plants for biomass the term "biorefinery" is used (Wagner 2005, NNFC 2005). New approaches are necessary for research, development and manufacturing in order to move away successfully from the use of fossil feedstock to production based on renewable raw materials.

This report intends to give a literature overview over the market introduction and development of biorefinery concepts in industry. As it is impossible to deal with all industries, which possibly could use biorefinery concepts, thus the focus is set on the following four economically important and promising sectors:

- Chemical industry
- Pulp and paper industry
- Starch and sugar industry
- Biofuels industry

In the following the structure of each of these branches is described by giving an overview over its size, production, actors, employment etc. Moreover the ongoing bio-refinery/bio-based activities of each sector are analysed in the report.

2. Methodology

The market introduction and development of biorefinery concepts and related products is analysed in this literature overview with desk research instruments. For this purpose existing sources and information related to the market introduction and development are collected and evaluated. Therefore literature and database searches are made as well as internet searches. Additionally, available statistical information of the associations of the relevant industry branches (e.g. CEPI, CEFS etc.) and of governments (e.g. EUROSTAT, DESTATIS) is analysed on a national, EU and a wider international level.

3. Market development of biorefinery concepts

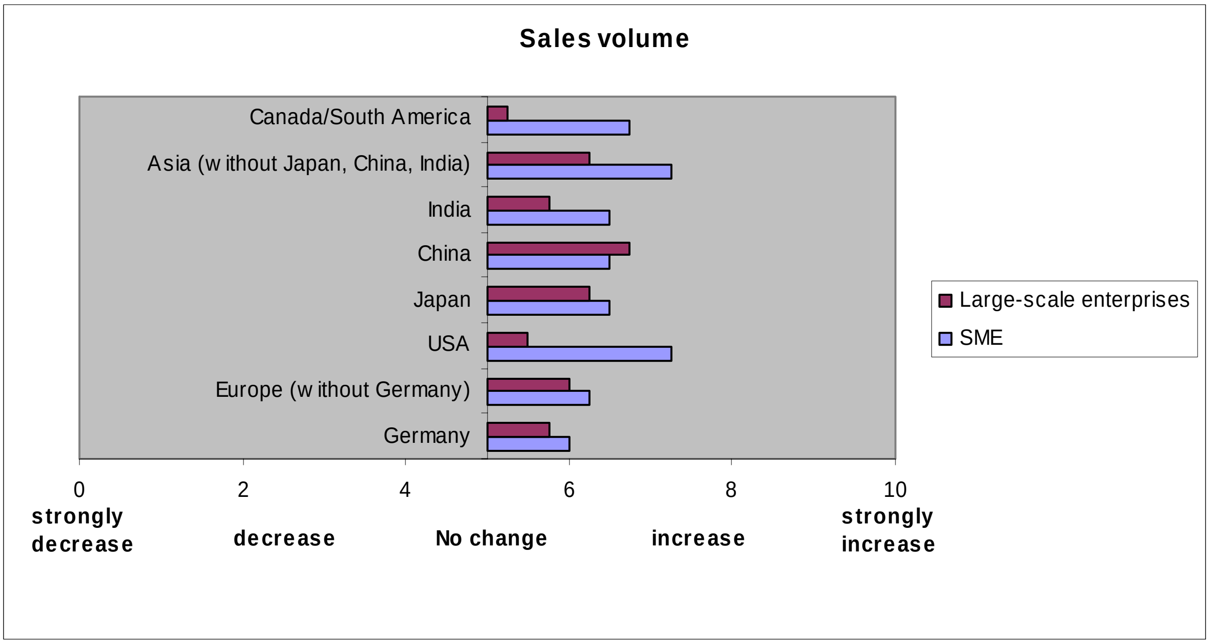
Bio-based products are understood as "commercial or industrial products (other than food or feed) that are composed in whole or in significant parts of biological products or renewable domestic agricultural materials (including plant, animal and marine materials) or forestry materials" (Office of the Federal Environmental Executive 2007).

In the following chapters four industry branches (chemical-, forestry-, starch/ sugar- and the biofuels industry) are described which produce many of such products and which could adopt very well the innovative biorefinery concept in their existing production system. In the first part of chapter 3 the Industrial White Biotechnology (IWBT) is described which covers the four industry branches in the "bio-based field".

3.1 Industrial white biotechnology (IWBT)

Up to now hardly any comprehensive surveys or analysis exist which describe the (potential) market situation of biorefinery concepts in Europe. Therefore it makes sense to consider the Industrial White Biotechnology (IWBT) in this context since the different bioprocesses of the IWBT can be integrated in the overall concept of biorefineries. According to a publication of Nusser et al. (2007) it is assumed that the market size of the IWBT will show a steady growth. As illustrated in figure 1 the sales volumes increased from 2000 to 2005 modestly in all world regions.

Figure 1: Change of sales volume of the industrial white biotechnology 2000 – 2005 in different countries

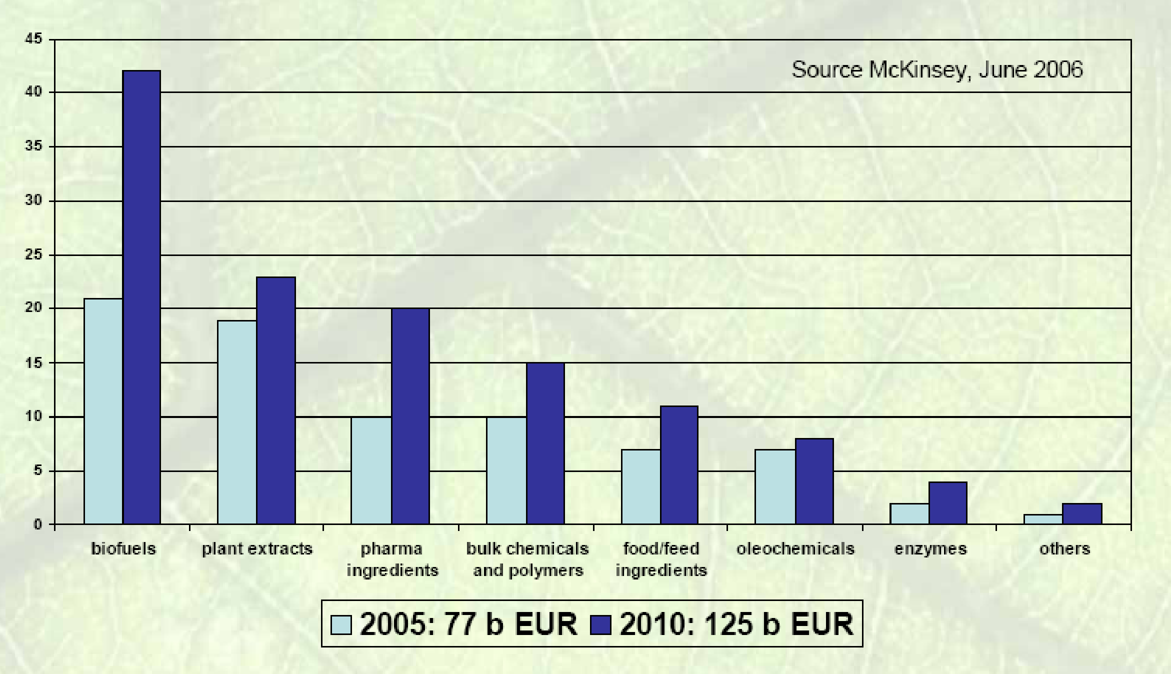


Source: Based on Nusser et al. 2007

From 2006 to 2010 the same growth rates for white biotechnology are expected. The largest turnovers are found in the USA and in the Asian countries (Nusser et al. 2007). It is assumed that white biotechnology will remain a dynamic growth market with stable growth rates until 2025. The most important fields of application in industrial white biotechnology will include the following branches: pharmacy, R&D-services, environment engineering, foods/beverages, fine- and special chemicals, biofuels, bioenergy and the agriculture. The application fields of lower importance are the branches of bulk-chemicals, plant construction, textiles, leather, paper, and forestry (Nusser et al. 2007).

With regard to the outlook of white biotech sales (incl. fuels) the consulting company McKinsey assumes that sales of the white biotechnology will increase worldwide from 77 billion € in the year 2005 to 125 in 2010. As illustrated in figure 2 the sector of biofuels, pharma ingredients and enzymes will double, whereof biofuels with estimated more than 40 billion € sales take the major part. The sector of bulk chemicals and polymers is estimated to grow by one third to 15 billion € sales. The sales of plant extracts and of oleo-chemicals will nearly remain constant until 2010.

Figure 2: Outlook of white biotech sales (incl. fuels) (in billion €)



Source: European Technology Platform for Sustainable Chemistry (SusChem) 2007

3.2 Chemical industry

The chemical industry is the most diverse industry in the world and a very heterogeneous branch of industry, which produces a wide range of products for different areas of life. It converts raw materials into approximately 100,000 commercially available different substances of which around 1,500 substances cover over 95 % of the total world production (UN Department of Economic and Social Affairs – Division for Sustainable Development 2004). According to the "European Chemical Industry Council (Cefic)" these outputs of the chemical industry can be covered in four ranges of products: base chemicals, speciality and fine chemicals, pharmaceuticals, and consumer chemicals.

Base chemicals cover petrochemicals, derivatives and basic inorganics. They are produced in large volumes and are sold to other industries or within the chemical industry itself. Base chemicals represent nearly 39 % of total EU chemicals sales. Specialties cover auxiliaries for industry, dyes & pigments, crop protection, oleo-chemicals and paints & inks. Fine chemicals can be separated in pharma-, agro-, and chemical intermediates. Specialty and fine chemicals are produced in small volumes but nevertheless represent 28 % of total EU chemicals sales. Pharmaceuticals represent both basic pharmaceutical products and pharmaceutical preparations but not pharmaceutical intermediates. They account for 23 % of total EU chemicals sales. Last but not least, consumer chemicals are sold to end-consumers: soaps and detergents, perfumes and cosmetics. They represent approximately 10 % of total EU chemicals sales (European Chemical Industry Council (Cefic) 2006a).

Compared to 2004 all chemical sub sectors (except specialty and fine chemicals) showed positive growth rates in 2005. Pharmaceuticals were the growth leader with 3.5 %, followed by basic inorganics (3.1 %) and consumer chemicals and polymers (3 %) while petrochemicals production grew by only 1.4 % (European Chemical Industry Council (Cefic) 2006b).

Bio-based chemicals

The chemical industry can be considered as a forerunner and one of the "main-actors" of the "bio-based Economy". In mid-term time horizon experts assume that biotechnology will be a crucial technology of the chemical industry (Nusser et al. 2007).

"Bio-based chemicals and materials are commercial or industrial non-food/feed products derived from biomass feedstock" (Zwart 2006). Like the outputs of the chemical industry, the market of chemicals derived from biomass feedstock can generally be divided into two big groups: On the one hand there are substances which obtain their structure of biomass. These are mostly speciality chemicals and complex structures with high-value but comprising only a little part of the worldwide production. On the other hand there are the bulk- and basic chemicals where the biomass is converted. The term bulk-chemicals comprises chemicals which hold a considerable market volume of several hundred thousand tons each year (e.g. ethylene, propylene, acetaldehyde, acrylic acid, acetic acid, butadiene) or rather chemicals where large rates of growth can be anticipated (e.g. lactic acid).

The most prevalent technologies for the conversion of biomass-polymers to gain bulk- or basic chemicals are:

- Biotechnology processes like fermentation (to produce e.g. lactic or citric acid) and biocatalysis
- Thermochemical processes like pyrolysis, hydrothermic liquefaction and gasification of biomass

By using these processes many fossil-oil-based basic elements of the synthesis-chemistry can be substituted or rather potentially new product-groups and platform-chemicals can be established by using biomass feedstocks.

The most prevalent technologies to gain substances which obtain their structure of biomass (speciality chemicals) are:

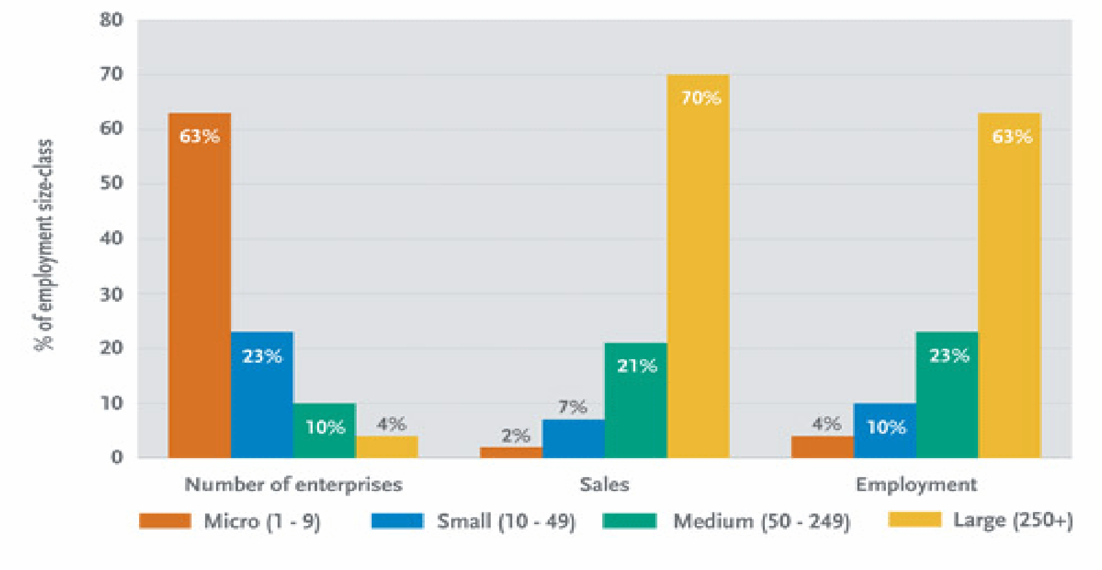
- Mechanical processes like sieving, crushing or squeezing
- Extraction processes like the use of solvents or the steam distillation to gain e.g. flavours and aromatic substances (fine chemicals)

France is the largest European producer of fine chemicals followed by Spain. 1995 the world market demand for essential oils was valued at 45,000 tons/year and for aromatic plants at 50,000 tons/year (Interactive European Network for Industrial Crops and their Applications (IENICA) 2000). Europe plays an important part of the international trade of medical and aromatic plants which represent 120,000 tons/year. The most important importers are Germany, Bulgaria and Poland. Albania, Turkey, Bulgaria, Greece and Spain are the main exporters of wild-growing plants (20,000 - 30,000 tons/year) (Bundesministerium für Verkehr, Innovation und Technologie Austria 2005). Although the production of fine chemicals will have a crucial impact on the market, experts and government representatives of the USA assume that the driving force for an enhancement of the bio-based economy will be the adoption of bulk- or basic chemicals.

Actors

As shown in figure 3 the EU chemical industry (excluding pharmaceuticals) comprises about 27,000 enterprises. 96 % of them have less than 250 employees and may be considered as small and medium-sized enterprises (SME). These account for 30 % of sales and 37 % of employment. Only 4 % of the EU enterprises employ more than 249 employees and generate 70 % of total chemicals sales (European Chemical Industry Council (Cefic) 2001).

Figure 3: The EU chemical industry: number of enterprises, sales and employment by size-class 2001



Source: European Chemical Industry Council (Cefic) 2001

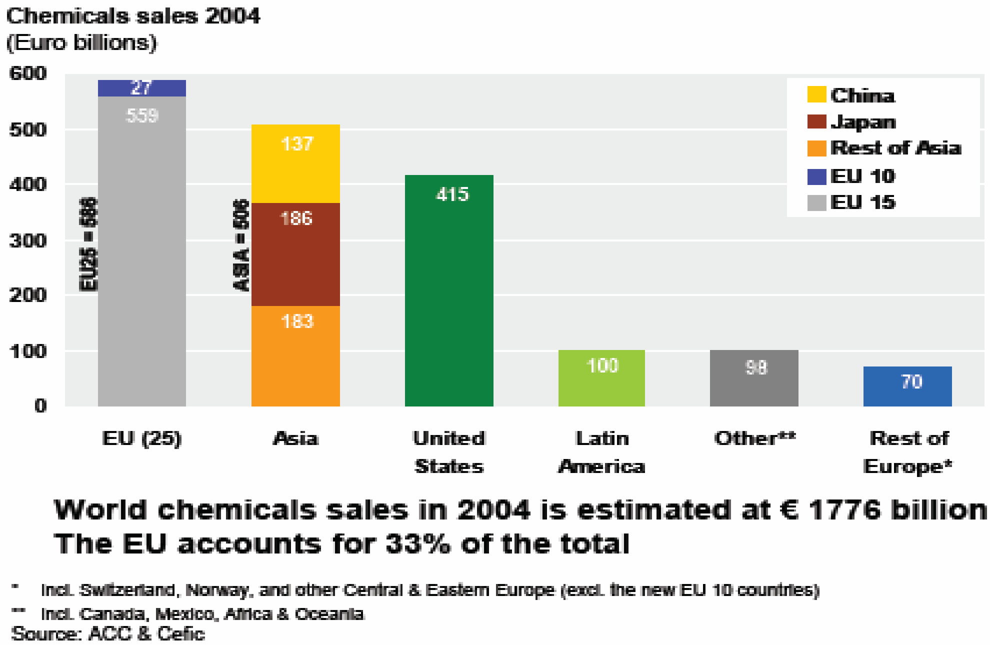
Actors who use and manufacture renewable resources (and who could potentially apply the biorefinery-concept) can be differentiated in large-scale as well as in small and medium-sized enterprises (SMEs): Large-scale enterprises operate mainly on the market of bulk-chemicals, e.g. for the production of biofuels or base chemicals. SMEs use their skills in innovative special markets as for instance for fine chemicals or pharmaceuticals (Bundesministerium für Verkehr, Innovation und Technologie Austria 2005).

In this context e.g. five companies can be mentioned which produce biotech-based polymers in Europe: Rodenburg BioPolymers from the Netherlands produces solanyl, based on starch; Tate and Lyle (UK) produces Bio-PDO; Uhde Inventa-Fisher GmbH (Germany) has an PLA pilot plant; Biomer (Germany) produces P 3HB; Boehringer Ingelheim (Germany) produces high-value/low-value PLA for products used in medical applications (ETEPS AISBL 2005).

Market volume and prices

As outlined in figure 4 the world chemicals sales in 2004 were estimated at 1,776 billion €, whereof the EU accounted for 33 % of the global sales (European Chemical Industry Council (Cefic) 2006b). The technology platform SusChem estimates that 5 % of the sales are generated from bio-based feedstock (European Technology Platform for Sustainable Chemistry (SusChem) 2007). The proportion of renewable resources of the whole industrial feedstock in the production of chemicals was 2005 estimated in Germany (as one of the member states of the EU with a large chemical industry) and in the United States at 10 %. (Bundesministerium für Verkehr, Innovation und Technologie Austria 2005).

Figure 4: World chemicals sales 2004



Source: European Chemical Industry Council (Cefic) 2006b

The study of Nusser et al. (2007) provides biomass-based products, which are derived from biomass that are converted by fermentational and enzymatic processes. These products (name of substances and the global production volume) are listed in table 1 whereby bulk chemicals are printed in bold letters.

Table 1: Chemicals which are currently produced by fermentational and enzymatic processes

Substance	Global production (million tons/year)	Substance	Global production (million tons/year)	Substance	Global production (million tons/year)
Glucose	**5 -20**	**Malic acid**	**0.025**	Vitamin B12	0.000020
Fructose	**Glucose fructose syrup: 10.1 (anhydrous mass, 1995)** Crystalline fructose: 0.24	Succinic acid	0.015	Biotin	Not specified
Sorbitol D-Glucitol	**1.1**	L-asparagine acid	0.013	Folic acid	Not specified
APG	**0.05 – 0.07**	Fumar acid	0.012	Pantothenic acid	Not specified
Methyl-α-D-glucoside	Not specified	L-phenylalanin	0.01	Koji acid	Not specified
5-hydroxy-methylfurfural	Not specified	Pullulan	0.01	1.2-propanediol	1.5
Ethanol	**32**	Cyclodextrin	0.005	1.3-propanediol	> 0.08
Acetone	**3**	Itacon acid	0.004	2-propanol	Not specified
L-glutamic acid	**1.5**	L-Arginin	0.0015	3-hydroxy-propion acid	Not specified
Vitamin B2	**0.03**	L-Alanin	0.0012	Glyoxyl acid	Not specified
1-Butanol	**1.2**	L-Tryphtophan	0.0012	Oxal acid	0.124 (1990)
Citric acid	**1.0**	L-Glutamin	0.001	Butyric acid	0.05
Glycerin	**0.75**	L-Hydroxyprolin	0.0001	2.3butanediol	Not specified
L-lysine	**0.7**	L-Leucin	0.0008	1.2.4-butanetriol	Not specified
Acetic acid	**7.0 0.19**	L-Prolin	0.008	Cis-cis-mucon acid	Not specified
Lactic Acid	**0.15**	L-Serin	0.0003	Alginate	0.03
Propyne acid	**0.13**	L-Histidin	0.0003	Curdlan	Not specified
Glucon acid	**0.1**	L-Isoleucin	0.00055	Chondroitin	Not specified
Vitamin C	**0.08**	L-Valin	0.00005	Heparin	Not specified
L-sorbose	**0.05**	Hyaluron acid	0.00005	Cyanophycin	Not specified
Antibiotics	Not specified	Bacterial cellulose	Not specified	Poly-hydroxy-alkanoate	0.001 (accumulative)
Industrial enzymes	Not specified	Gellan	Not specified	Scleroglucan	Not specified
Xanthan	**0.04**	Poly glutamine acid	Not specified	Shingan	Not specified
Sugar alcohols	**0.03**	Polylisine	Not specified	Indigo	0.03
L-threonine	**0.03**	Vitamin A	Not specified	Vitamin B1	Not specified

Source: Nusser et al. 2007

Table 2 shows market shares of biomass-based-products or related product groups in the USA in 2003 which could also be taken as an orientation for the EU and other industrial countries (Paster et al. 2003).

Table 2: Market shares of biomass-based product groups in the USA 2003

Product	Global production (million tons/year)	Percentage which is made of renewable resources (%)
Adhesives	5.0	40
Fatty acids	2.5	40
Tenside	3.5	35
Acetic acid	2.3	17.5
Plastificer	0.8	15
Charcoal	1.5	12
Detergents	12.6	11
Pigments	15.5	6
Dyestuffs	4.5	6
Wall paint	7.8	3.5
Inks	3.5	3.5
Plastics	30	1.8

Source: Paster et al. 2003

ERRMA published in 2002 a similar classification of the most important biomass products within the EU which is shown in table 3. The first column shows the market size in 1998 (million tons/year), the second column shows the proportions of the product groups derived from renewable resources. Additionally the potentials till 2010 are given in the third and fourth columns illustrated:

Table 3: Potential of the most important biomass products within the EU (2002)

Product groups	Total market volume (1998) (million tons/year)	Market volume of renewable resources (1998) (million tons/year)	Potential market volume of renewable resources till 2010 (million tons/year)	Market share of renewable resources till 2010 (%) based on volume of 1998
Polymers	33	0.025	0.5	1.5
Lubricants	4.24	0.1	0.2	4.7
Solvents	4	0.06	0.235	5.9
Tensides	2.26	1.18	1.45	64.2

Source: ERRMA (European Renewable Resources & Materials Association) – Working Group "Renewable Raw Materials" 2002

Although the chemical industry is a very heterogeneous branch which produces a wide range of products biopolymers are analysed more in detail since they are an interesting example of bio-based products. Plastics represent the fastest growing group of bulk chemicals with annual growth rates of 4.4 % per year (Crank et al. 2005). The production volumes of biotech-based polymers were estimated at 43,156 tons per year in 2005 (PlasticsEurope 2004).

The prices of most biotech-based polymers are still high compared to oil-based polymers. The market price for PLA was estimated at 2.2-3.4 €/kg and the prices of PHA were estimated at 20 €/kg in 2003 (Crank 2005). The high prices for biotech-based polymers are mainly due to high development costs and small capacities. On the basis of an average price of 766 € per ton for the six basic plastics (PE-HE, PE-LLD, PE-LD, PP, PS and PVC) it can be concluded that 2003 the biotech-based polymers PLA and PHA were about 4-26 times more expensive than the petrochemical-based basic chemicals (VKE 2004). However, Carole et al (2004) state that PLA is cost-competitive compared to conventional polymers. The production costs of PLA are the same as for PET but as PLA is produced in smaller quantities, economies of scale can't be adopted for PLA. Additionally, there is hardly any competition on the market and subsequently NatureWorks as the major supplier of PLA can make a price policy that is quite independent from the market of traditional plastics.

Compared to the products of the petro-chemistry most of the chemicals derived from biomass feedstock are presently not yet competitive. But experts assume that this will change with an increase of crude oil prices and additionally with increasing R&D activities in the field of renewable resources. Thus it is estimated that the amount of renewable resources used in the chemical production will decisively increase in future. On the long run experts assume that bio-based resources are the only sound basis which can replace crude oil and coal in the area of bulk products. The National Research Council of the USA supposes that in the year 2090 90 % of the fossil resources will be substituted by biogenic ones. In the year 2003 it was anticipated that the proportion of bio-based raw materials will increase from 10 % to 25 % in the coming 15 years. DuPont, one of the largest producer of plastics, for example plans to produce 25 % of its plastics on the basis of renewable resources till 2010 (National Academy of Sciences, National Research Council (USA) 2003).

Other investigations were made by the "European Renewable Resources & Materials Association (ERRMA). As a result of their survey carried out in the year 2002 in single member countries, they came to the conclusion that a tremendous extension potential exists till 2010. Although polymers derived from biomass feedstock represent only a little percentage ERRMA anticipated the largest increasing potential with 475,000 tons within this area. In the field of lubricants 400,000 tons, in the field of tensides 270,000 tons and in the field of solvents 175,000 tons are assumed to be additionally used until 2010 in Europe (FNR 2006).

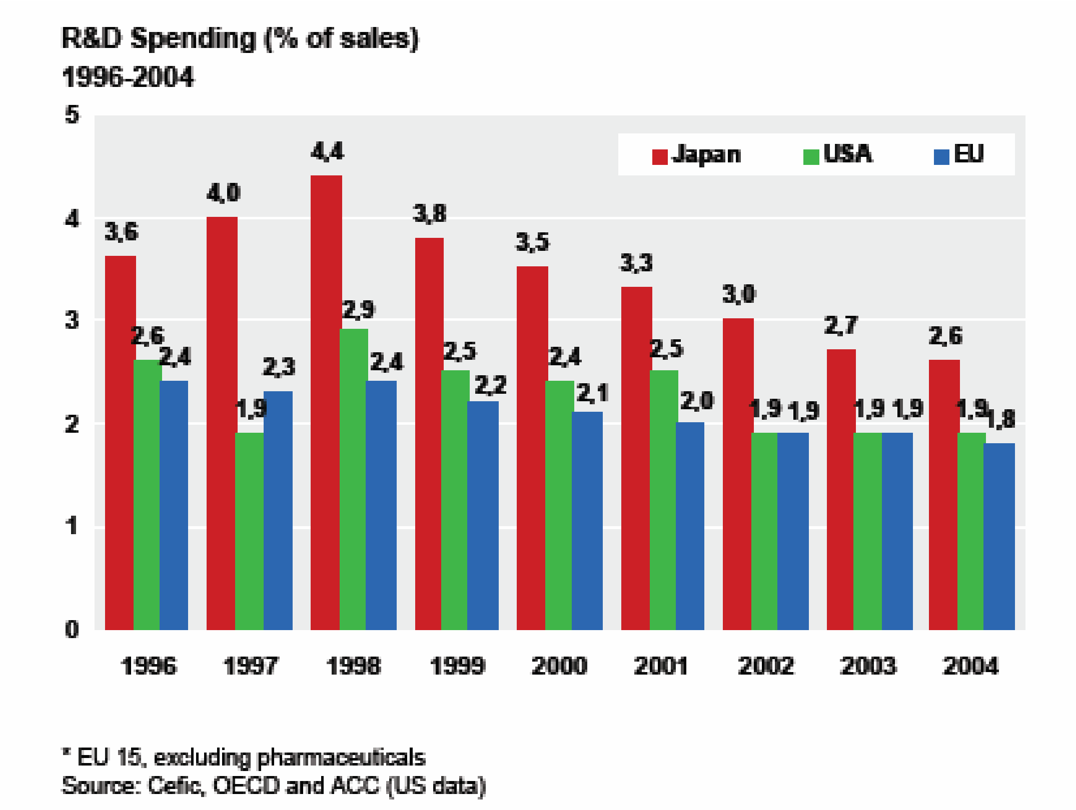
Within another study Zwart (2006) concludes in the report concerning the "worldwide status of biorefinery at the beginning of 2006" that the success of new bio-based products will largely depend on whether they can be produced economically as well as their performance in targeted application fields. Potential markets for bio-based products are wide-ranging including polymers, lubricants, solvents, adhesives, herbicides, and pharmaceuticals. Bio-based products have already penetrated most of these markets to some degree but new products and technologies are emerging with the potential to further enhance performance, cost-competitiveness and market share (Zwart 2006).

R&D activities

To develop innovative biorefinery concepts considerable R&D efforts are required. Thus it is interesting to regard the R&D spending of the chemical industry.

Analysing the ratio of R&D spending related to the sales of the chemical industry (excluding pharmaceuticals) it can be observed that the USA had a slightly higher ratio than the EU, but decreased to similar levels in recent years, whereas Japan has a significantly higher ratio as the other two regions. As shown in figure 5 nearly 2 % of sales were spent for R&D activities within the chemical industry of EU11 (covering important countries like Germany, France, UK, Italy, Belgium, The Netherlands, Ireland, Spain, Sweden, Finland and Denmark) (European Chemical Industry Council (Cefic) 2003). As an example of industrial R&D efforts it can be mentioned that the five most important US-enterprises of the chemical industry spent 3.6 billion US-Dollar for R&D activities in the field of renewable resources in the year 2000 (Bundesministerium für Verkehr, Innovation und Technologie Austria 2005).

Figure 5: R&D spending (% of sales) of the chemical industry within the triad USA, EU and Japan



Source: European Chemical Industry Council (Cefic) 2006b

In the year 2005 the Federal Ministry for Transport, Innovation and Technology of Austria expected that R&D activities in the following three fields will play a crucial role for the future development of the application of renewable resources (Bundesministerium für Verkehr, Innovation und Technologie Austria 2005):

- Chemical synthesis to achieve an efficient conversion of biomass and natural gases for a better application of molecules and products
- Biotechnological processes for the following three actors/groups:
    - Industry to define the R&D requirements in the field of developing new and effective bio-catalysts; process-technology and low-budget resources for bio-processes
    - Science to broaden the basic knowledge about industrial bio-processes and implementation of the results
    - Government to boost, support and participate to the research of biotechnology as well as to reduce the risk of technology-development by means of financial aid
- Material technology to develop new synthetic materials

Concerning support of research activities it is remarkable that between 2003 and 2005 in the USA biomass-related R&D activities were supported with 360 million US-Dollar every year (420 million US-Dollar in 2003 and abut 310 million US-Dollar in 2005). In contrast the EU spent about 75 million € for research activities related to biomass within the 6th Framework Programme of the EU in 6 years (Kamm 2005).

Framework conditions

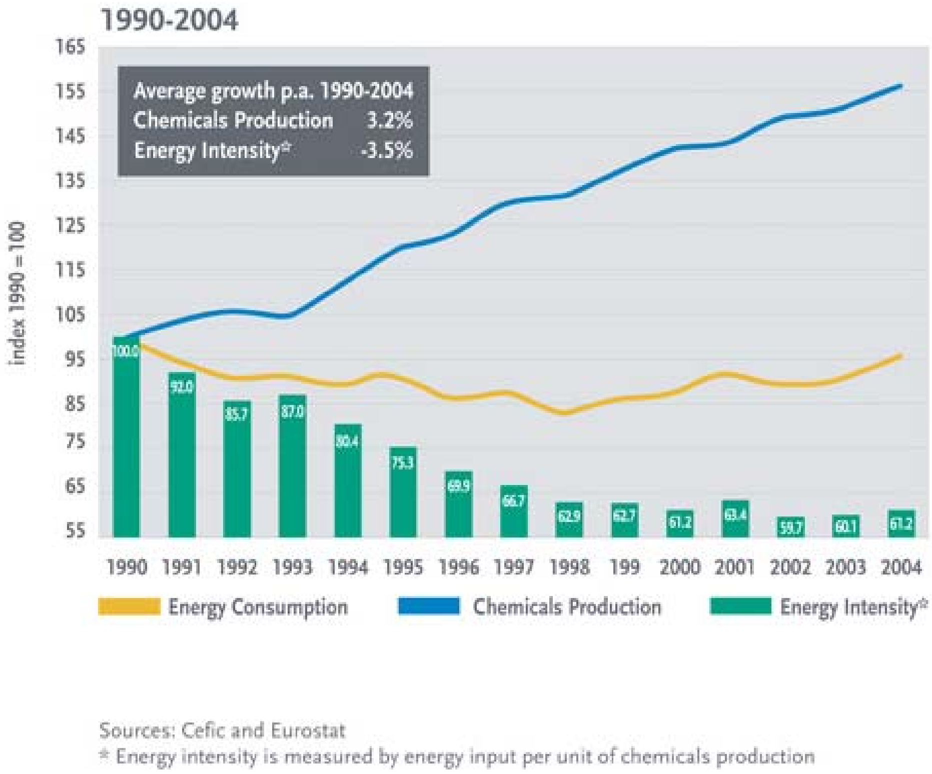
Different important factors influence the development of biorefinery-concepts for the chemical industry. One of them is the commitment of the chemical industry to a sustainable development. Since the “Brundlandt-Report” in 1987 or rather the “Conference in Rio” in 1992 the approach became an important principle in product development, in shaping of production processes and in in-house environment protection activities of this industrial brand. In this context the idea of a so called “Green

Chemistry", also known as sustainable chemistry, has been developed. The mission of green chemistry is "to promote innovative chemical technologies that reduce or eliminate the use or generation of hazardous substances in the design, manufacture and use of chemical products. (U.S. Environmental Protection Agency 2007).
According to this idea "Green Chemistry" means (German Federal Environmental Agency (UBA) 2007):

- to reduce resource and energy consumption
- to replace non-renewable with renewable resources
- to avoid contamination of the environment
- to replace problematic working materials with less problematic working materials
- to minimize all negative impacts of chemical substances or processes on the health of people and on the environment.

According to the statement of CEFIC the EU chemical industry has made significant efforts to improve energy efficiency as well as reducing its fuel and power consumption per unit of production. In 2004, energy consumption per unit of production was 39 % lower than in 1990 (figure 6).

Figure 6: Energy intensity in the EU Chemical Industry 1990-2004



Source: European Chemical Industry Council (Cefic) 2006a

However, it is censoriously to annotate that the reduction of energy intensity within the chemical industry is not at least a result of increasing energy prices during the last years. Additionally there is no must for the companies to adapt the concept of Green Chemistry or rather sustainable chemistry but the implementation is by the enterprises' own choice. Nevertheless, by the substitution of conventional with bio-based products there are high potentials for energy reduction: To break down fossil feedstocks into the desired products high pressures and temperatures are necessary, resulting in the consumption of large amounts of heat and power. In contrast, the bonds of plant materials are easier to break, and many bioconversions occur at or near room temperature, atmospheric pressures, and neutral conditions. This leads in some cases to lower energy requirements for conversion of biomass feedstock to products (Zwart 2006).

Political reforms and activities of the EU have impacts on the development of biorefinery concepts, too. With REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) for example, the European Commission aims at a basic reform to solve existing problems related to chemical substances. REACH is a EU regulation that covers the production and use of chemical substances. Within this regulation new chemical substances that have to be accredited have to pass sophisticated testing requirements with the result that a lot of enterprises use further on existing instead of new substances. Thus there are too less incentives for the development of new and maybe more ecological materials and substances like products that are made of renewable feedstocks (Bundesministerium für Verkehr, Innovation und Technologie Austria 2005).

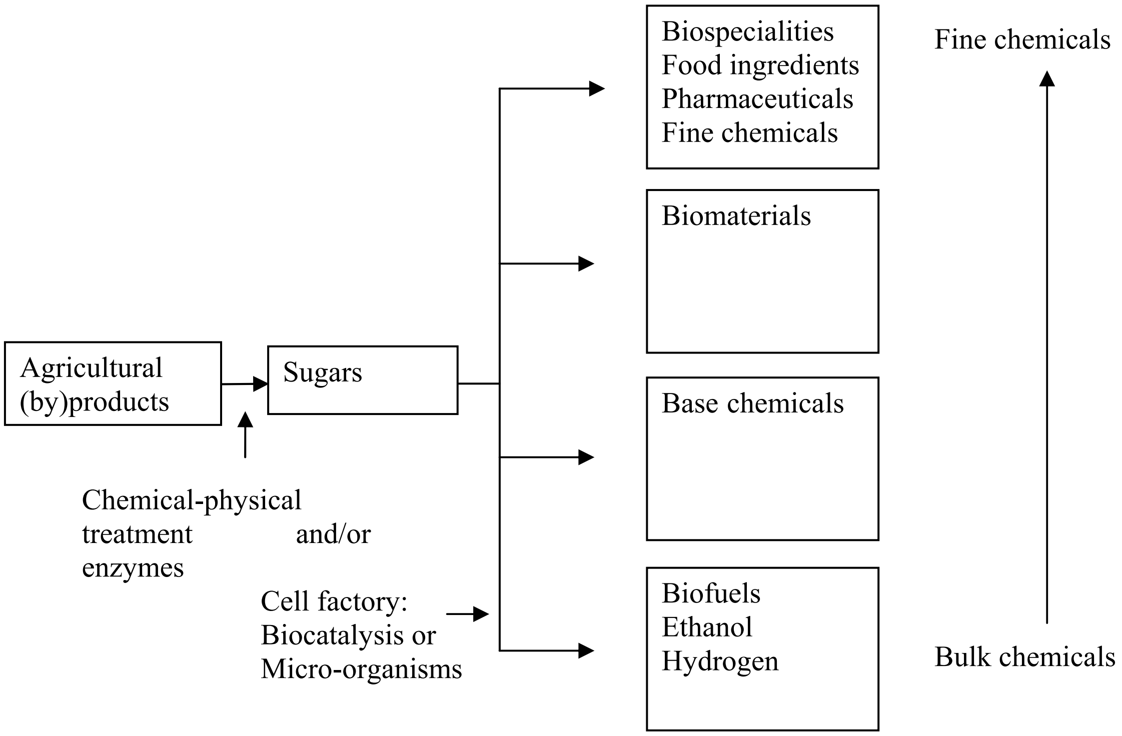
Other examples are the "White Paper – Energy for the future: Renewable sources of energy" (1997) and the "Green Paper - An European Strategy for Sustainable, Competitive and Secure Energy" (2006) of the European Commission which have established political targets for an energy production based on renewable materials. Furthermore, the European Parliament and the Council have formulated targets for the use of renewable resources for the production of transportation fuels in 2003. As a consequence, the oleo-chemistry for example had problems concerning the supply of rapeseed as one of their main feedstocks. Especially since the public support of biofuels in many European countries rapeseed oils are used in increasing amounts for the production of biodiesel with the direct consequence of increasing prices for rapeseed oil.

Biorefinery activities

The basic technology to enhance the use of biomass will be the adoption of biorefineries which is considered to detach crude oil based refineries. "A biorefinery is a facility that integrates biomass conversion processes and equipment to produce fuels, power, materials and/or chemicals from biomass" (Biorefinery.nl 2007). In contrast to already existing plants which use single bioprocesses or rather refer to single product lines the biorefinery-concept aims at integrating and connecting of different bioprocesses. The petroleum refineries could serve as a model. At this the (fossil) raw materials are holistic used to produce beside the intrinsic product several by-products. The targets for biorefinery concepts are the same. Biorefineries also use multiple forms of biomass to produce a flexible mix of products, including fuels, power, heat, materials and - the core of this chapter - chemicals (Biorefinery.nl 2007). Against this background it has to be noted that residues can be used as raw materials for biorefineries as well. Only a small proportion of the harvested and converted biogenic raw materials are brought to the market (depending on the product 10 % – 90 %). Hence there are high potentials of residues which can be used as raw materials in biorefinery plants. The "Lenzing AG" in Austria for example recovers out of residues acetic acid, furfurals and xylitol (Bundesministerium für Verkehr, Innovation und Technologie Austria 2005).

Biorefinery concepts don't aim primarily at developing new products. It rather aims to produce "old" substances in a new way and to awake "sleeping chemicals". In a biorefinery, biomass is converted into high-value chemical products and fuels (both gas and liquid). By-products and residues, as well as some portion of the fuels produced, would be used to fuel on-site power generation or cogeneration facilities. Figure 7 shows a typical value chain of the so-called white biotechnology which is comparable to the value chain of biorefineries.

Figure 7: Value chain of the white biotechnology



Source: Own illustration based on the European Technology Platform for Sustainable Chemistry (SusChem) 2007

Searching available literature sources biorefinery concepts were found in U.S. agricultural and forest products industries, where such facilities produce food, feed, fibre or chemicals, heat and electricity to run plant operations. An example is the “Archer Daniels Midland” (ADM) complex in Decatur which is one of the largest processor of corn, wheat, soybeans and cocoa on a global scale. The core product of the industry is starch and its products. But it is a declared aim to make the production of starch more attractive by looking and developing markets for co-products of the wet milling process. The company has a plant in Decatur where industrial enzymes, lactic and citric acid, amino acids as well as ethanol are produced in a corn wet-milling process. The chemical products, which are produced, are used in detergents, foods and plastics. The ethanol is used as a transportation fuel or as a solvent. A further example for a biorefinery concept is market by “Arkenol”. Thereby a variety of bio-based chemicals and transportation fuels are produced via an acid hydrolysis. A third example is the starch-based and first large-scale PLA facility of Cargill Dow, which is exploring the use of lignocellulosic biomass such as corn stove or wheat straw to produce lactic acid, poly-lactid-acid (PLA), ethanol and other industrial products. It was started up in 2002 with a 300 million pound capacity (Zwart 2006).

In Europe the following biorefineries (or more precisely plants that follow the biorefinery concept) could be identified which are listed in table 4:

Table 4: Selected biorefineries in Europe

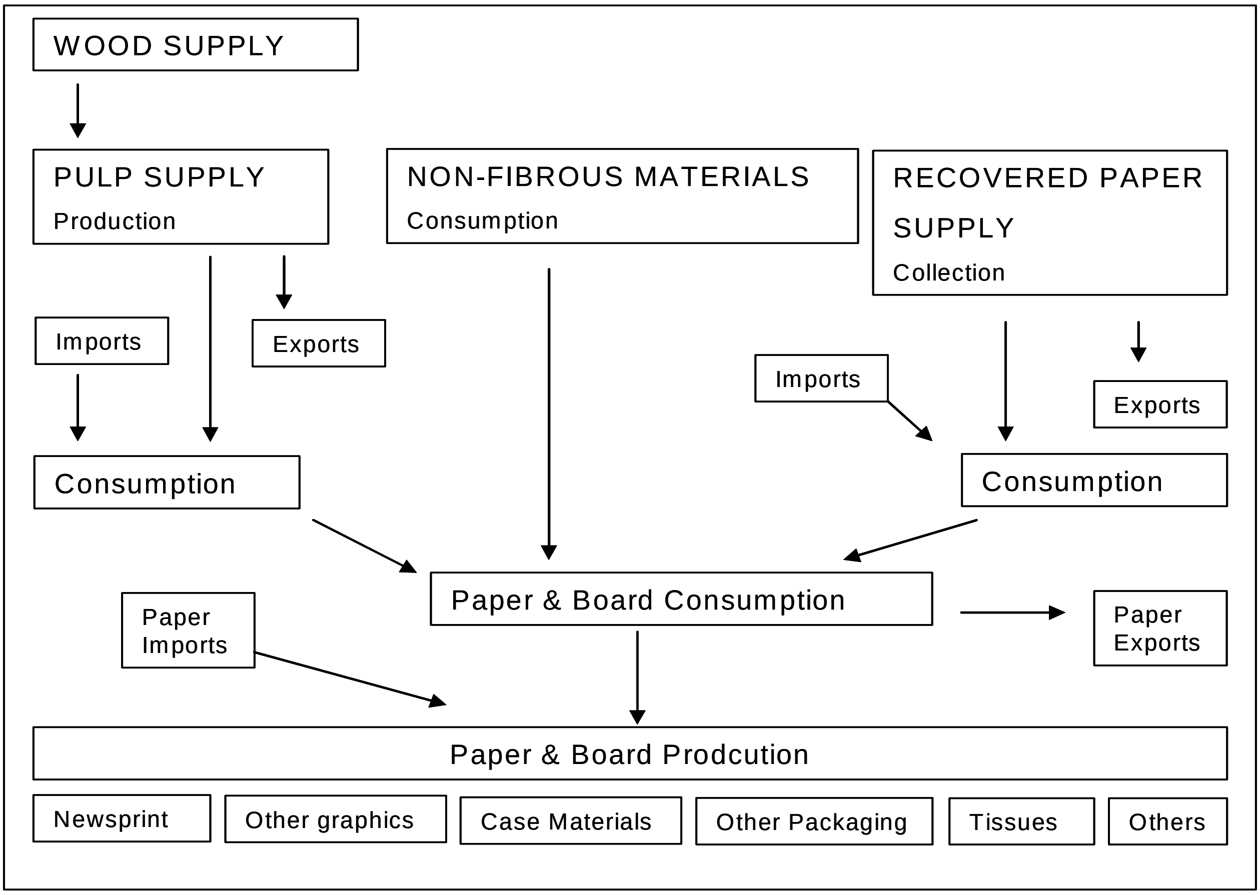
Name	Location	Raw materials, products
Green Biorefinery	Feldbach, Austria	Raw material: grass Products: lactic acid, amino acid, fibres, animal feeds and biogas
Bioraf Danmark	Frederiksberg, Denmark	Products: fibres, starch, oils, proteins
Biorefinery South Jutland	Denmark	Raw material: grass Products: lysine
Green Biorefinery Brandenburg	Germany	Raw material: grass Products: lactic acid, lysine, other fine chemicals
Grass-Refinery	Thurgau, Switzerland	Raw material: grass Products: fibres for insulant, protein concentrate, biogas
Icelandic BioRefinery	Iceland	Raw material: green biomass Products: ethanol, CO_2, proteins, spartein-derivatives Use of geothermal energy

Source: Nusser et al 2007

3.3 Forestry-industry: Pulp and paper industry

The paper industry uses for the manufacturing of paper two main raw materials: wood and recovered paper. The basic ingredient for the manufacturing of paper and paperboard is pulp. It is either produced from fresh wood, from woodchips, from sawmills, recovered paper or sometimes from textiles, agricultural by-products or industrial crops. The pulpwood, which is used for manufacturing of paper, came in former times from whole mature trees. Nowadays, usually parts of trees are used, which remain after the other parts have been used for other commercial purposes (CEPI 2007a; European Commission 2007a). Figure 8 gives an overview over the flows of material in the pulp and paper industry.

Figure 8: Flows of material in the pulp and paper industry.



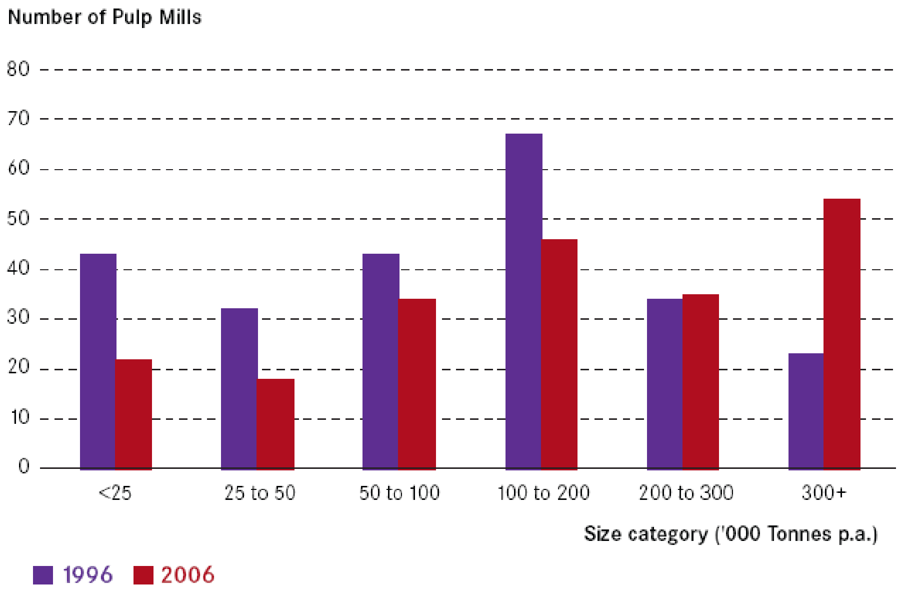
Source: modified after CEPI 2006

Industrial actors

Most of the European pulp, paper and paperboard producing companies are represented by CEPI, a non-profit-making organisation located in Brussels. It represents the European pulp and paper industry towards the European Institutions. Its members are 17 different national associations[1]. In the year 2006 CEPI represented 801 companies of the pulp and paper industry. The number of companies in this sector has decreased by almost 22 % over the last 16 years. The number of mills decreased as well: There were 1,555 mills in the year 1991, compared to 1,186 in the year 2006. The number of mills can be subdivided in the number of paper mills (2006: 977) and the number of pulp mills (2006: 209). Taking into account that the number of mills decreased over the last years and that in the same time the production increased (see below) it becomes clear that the size structure of the sector changed in the last decade. Figure 9 emphasises this fact in the case of the pulp producers. It shows that those pulp mills falling in the smaller size categories (by volume) decreased over the last decade and those falling in the bigger size categories (> 200,000 tons p.a.) increased. The same trend can be observed in the case of the paper mills (CEPI 2006).

[1] Members of CEPI 2006: Austria, Belgium, Czech Republic, Finland, France, Germany, Hungary, Italy, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, The Netherlands, United Kingdom.

Figure 9: Number of pulp mills by volume in CEPI countries 1996 to 2006



Source: CEPI 2006

The PricewaterhouseCoopers (PwC) Global Forest, Paper and Packaging Industry Survey – 2006 edition provides information about the 100 largest forest, paper and packaging companies in the world (ranked by sales revenue). Under the Top 10 companies of this sector four are from European countries: three Swedish and one Finnish. Table 5 shows the list with the 10 biggest companies within Europe. Located on rank one to four are the Scandinavian companies, which can also be found under the worldwide Top 10. Additionally two companies from Great Britain belong to the ten largest European forest, paper and packaging companies. Even so Germany is the largest paper and paperboard producer (by volume) within the EU (see below), the biggest independent German company is ranked at place 24.

Table 5: Top 10 European forest, paper and packaging companies (million €)

Rank	Company Name	Country	Sales 2005	Net Income 2005	ROCE (%)
1	Stora Enso	Finland	13,188	(126)	2.3
2	Svenska Cellulosa	Sweden	10,363	47	2.9
3	UPM	Finland	9,348	261	2.1
4	Metsäliitto	Finland	8,643	(50)	0.9
5	Anglo America (Mondi)	UK	5,59	238	5.2
6	Smurfit Kappa	Ireland	4,213	(177)	1.7
7	Sequana Capital	France	4,067	356	0.1
8	Norske Skog	Norway	3,209	(107)	2.1
9	DS Smith	UK	2,375	57	5.3
10	Cartiere Burgo	Italy	2,202	69	5.6

*ROCE: Return on capital employed

Source: PricewaterhouseCoopers 2006

In the year 2005 746,000 people worked in the manufacturing of pulp, paper and paperboard in the EU-25. This corresponds to 0.4 % of the employment of all sectors (agriculture, forestry, wood, paper and others). In absolute numbers of employees the highest part of the people working in this area is from Germany (140,000), France (93,000) and the United Kingdom (84,000). But the percentage of the people working in this sector (compared to the employees in all sectors) is higher in Finland (1.4 %) and Sweden (0.8 %) compared to Germany (0.4 %) or UK (0.3 %) (European Commission 2007b).

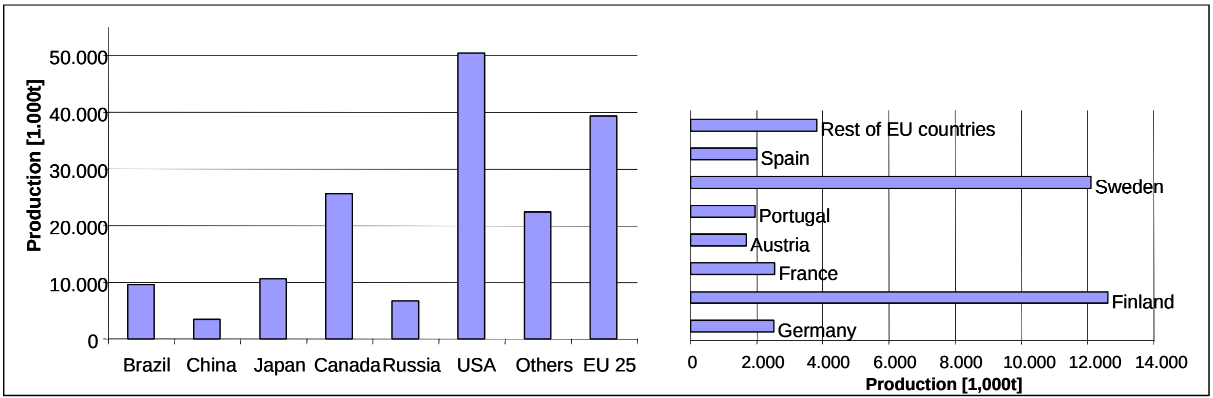
Market volume, production and costs

The turnover of the pulp and paper sector rose in the CEPI countries over the recent two decades. In the year 1991 the turnover amounted to 39,871 Million € and in 2006 to 78,554 Million €, which means an increase of 97 %.

Figure10 gives an overview over the worldwide pulp production in the year 2004. In that year the global production amounted to 167,784 million tons. The USA and the EU25 are the most important pulp-producers. Within the EU Sweden and Finland dominate the production of pulp, mainly due to their natural resource base of large forests and wood. The pulp production increased over the recent 10 years in the EU. It amounted in the EU15 in 1995 to 32,114 thousand tons and in the year 2005 to 35,994 thousand tons.

The most important importers of pulp are Germany, Italy and the United Kingdom. These countries import the biggest quantity from European countries. However, non-European pulp producers are important sources of EU pulp imports as well. The most important exporters are Finland and Sweden. They export the produced pulp mainly to other EU countries (European Commission 2007b; Verband Deutscher Papierfabriken e.V. 2006).

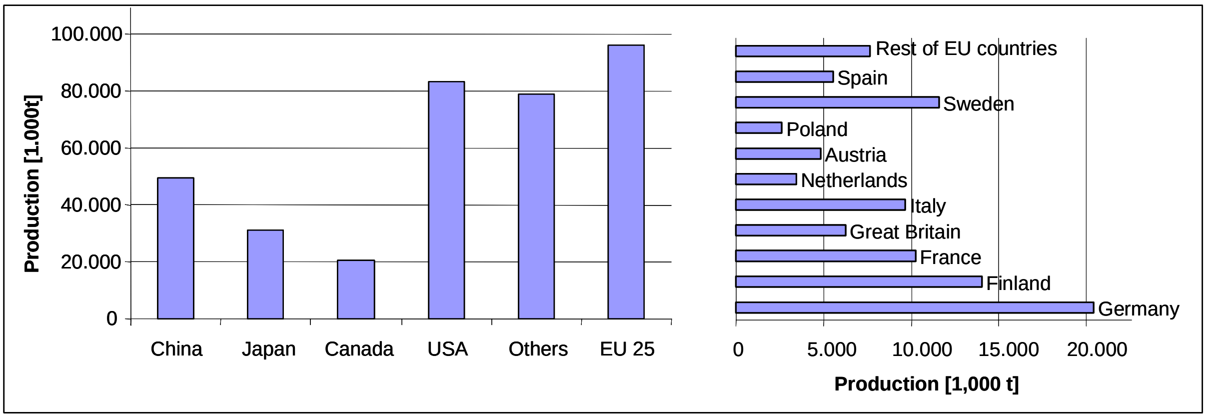
Figure 10: Pulp production in the year 2004: Worldwide and within the EU.



Source: Verband Deutscher Papierfabriken e.V. 2006

Figure 11 shows the production of paper and paperboard in the year 2004 worldwide and within the EU25. The production amounted in that year to 96,267 thousand tons in the EU25 and to 350,524 thousand tons globally. The most important producers worldwide are the EU25 and the USA. The biggest producer of paper and paperboard within the EU is Germany. Finland and Sweden are also important paper and paperboard producers, but their role is not as dominating as in the pulp production. The paper and paperboard-production increased over the previous 10 years by approximately 20,000 thousand tons. Herby the production was especially expanded in Germany, Spain, Italy and Sweden (European Commission 2007b). Differentiating between the main paper categories the production of graphic papers (~ 50 %) dominated within the EU25 in the year 2004, followed by the production of packaging (~ 40 %) and others (~ 10 %). From a worldwide perspective the manufacturing of packaging henpecks (graphic papers: 42 %; packaging: 49 %, others 9 %) (VDP 2006).

Figure 11: Paper and paperboard production in the year 2004: Worldwide and within the EU.

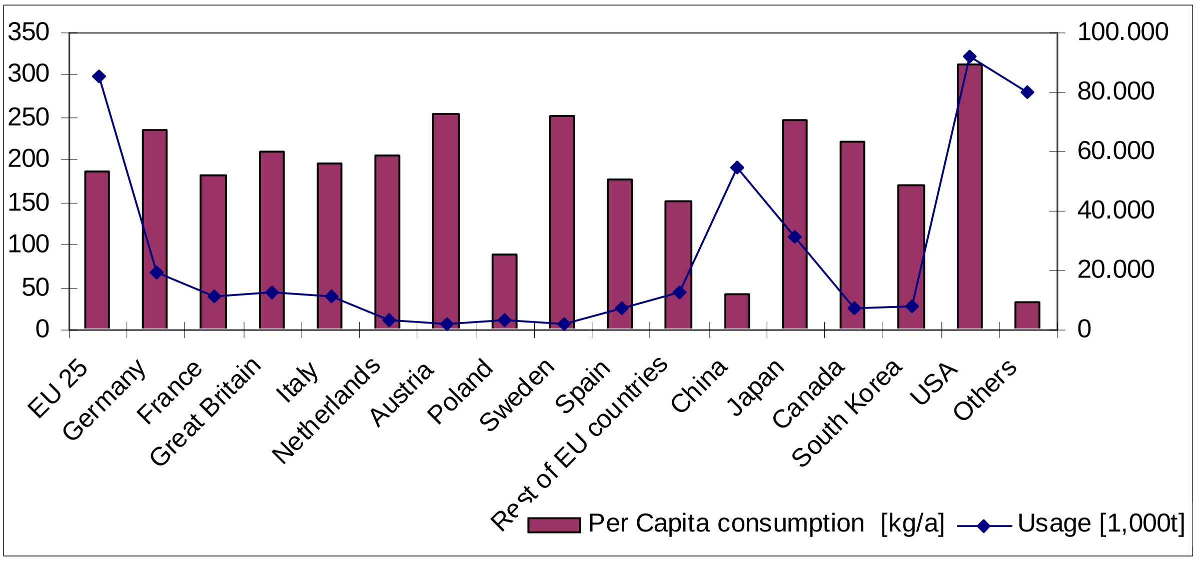


Source: Verband Deutscher Papierfabriken e.V. 2006

The main importers of paper and paperboard within the EU are Germany (2005: 9,681 thousand tons), France (2005: 6,058 thousand tons) and the United Kingdom (2005: 7,265 thousand tons). Italy imports a big part from non-European countries (2005: 3,649 thousand tons). Germany (2005: 796 thousand tons), Finland (2005: 2,037 thousand tons) and Sweden (2005: 3,535 thousand tons) are the most important exporters of paper and paperboard within the EU additionally to non-European countries (European Commission 2007b).

From a global perspective big differences can be observed in the per capita consumption of paper and paperboard: The highest per capita consumption exists in the USA, followed by Japan, Austria and Sweden (Figure 12). In contrast people in China and Poland consume relatively small quantities of paper and paperboard. Altogether the USA and the EU25 use the biggest quantity of paper and paperboard. Within the EU Germany, France and Italy are the most important paper consumers (VDP 2006).

Figure 12: Usage and per capita consumption of paper and paperboard 2004

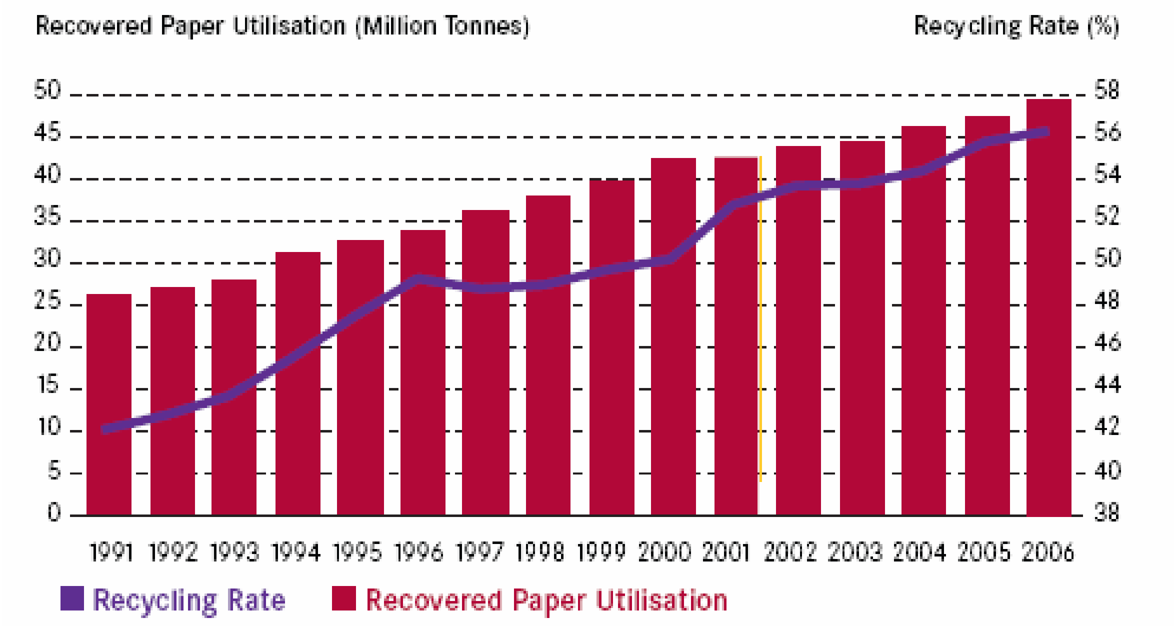


Source: Verband Deutscher Papierfabriken 2006

The consumption of paper is a key driver for the market development of pulp. The demand of pulp directly depends on the consumption of paper. It is possible to further increase the usage of recovered paper, so that the consumption of pulp increases not proportionally to the consumption of paper (FNR 2006a).

Figure 13 shows that the quantity of recovered paper which is utilised in the paper sector as well as the recycling rate continuously increased in the countries, which are members of the Confederation of European Paper Industries (CEPI). In these countries the utilisation of recovered paper rose in the previous years continuously and amounted to almost 48 million tons in 2006. The recycling rate increased in the last decade as well, as figure 13 shows.

Figure 13: Evolution of the recovered paper utilisation and the recycling rate in CEPI countries 1991-2005



Source: CEPI 2006

Differentiated by paper sector the highest utilisation rates occur in the "Case Materials Sector" (91.3 %) and the "Newsprint" sector (84.4 %) due to the fact that for these purposes no high-quality paper is needed. In contrast the least proportion is utilised by the "Other Graphic Papers" (9.7 %) (CEPI 2006).

The average cost structure of the paper industry shows that the biggest cost pool is allotted to "fibres" (32 %), indicating the high relevance of the raw material base for the competitiveness of this industry. Further 13 % fall upon energy, 12 % upon chemicals, 14 % on personnel, 18 % on capital costs and 11 % on other manufacturing costs (CEPI 2007). The market pulp prices for the paper production are subject to large price fluctuations. As the paper consumption fluctuates according to the economic trend, increasing or decreasing price effect occur in the case of the preliminary product pulp (FNR 2006a).

As the forest, paper and packaging sector is a large consumer of energy, the financial results are significantly impacted by an increase in energy costs. Since the year 2005 a significant increase in energy costs could be observed globally (PwC 2006). In the year 2005 almost half of the energy carriers in primary energy consumption (fossil and non-fossil) in CEPI countries are from biomass. The share of biomass in total primary energy consumption increased over the last years slightly. (The other important energy carriers in primary energy consumption are gas with a share of approximately 40 %.) (CEPI 2006). But even so the European Paper Industry is the biggest user and producer of renewable energy sources the Renewable Energy Policies also represent a challenge for the Industry: They are being implemented through national subsidies for renewable energy sources. This fact puts the paper industry at a further price disadvantage in the procurement of wood and recovered paper for papermaking (CEPI 2005).

CEPI states that despite expense of compliance with environmental legislations and high production cost, the European paper industry is a technological leader that has maintained its competitiveness.

Further increasing raw material and production costs as well as the appearance of paper industries in parts of Latin-America and Asia mean that the perspectives for the future are less clear. Another important issue in opening up new markets for the European industry are further trade liberalisations (CEPI 2005). According to Jaakko Pöyry Consulting 2005 the following competitiveness factors affect the European paper industry (Figure 14).

Figure 14: Strengths, weaknesses, opportunities and threats of the European Paper Industry

STRENGTHS	WEAKNESSES
- Large regional markets - Efficiency of production facilities - Envrionmental performance - Health & safety standards - Skilled personnel and management - Quality of products and customer service - European forest clusters	- High wood costs - High and increasing energy costs - Relatively high labour costs and rigidities in labour markets - Over-regulation and red tape - Management of capacities - Fragmented structure of the industry
OPPORTUNITIES	**THREATS**
- Increased and better mobilisation of wood - R&D and other know-how advancement - Market growth in Eastern Europe, South America, Asia and Russia - Specialisation - Consolidation - Improvement of transport infrastructure - Ability to develop new value added products	- Increasing energy and transport - Increasing wood costs and lower supply - The promotion of renewable energy sources - Distortion of the European fibre balance: wood and recovered paper - Incresing competition from other raw materials - Less ambitious standards in competing areas - Declining investments in R&D - Declining availability of workforce

Source: CEPI 2005

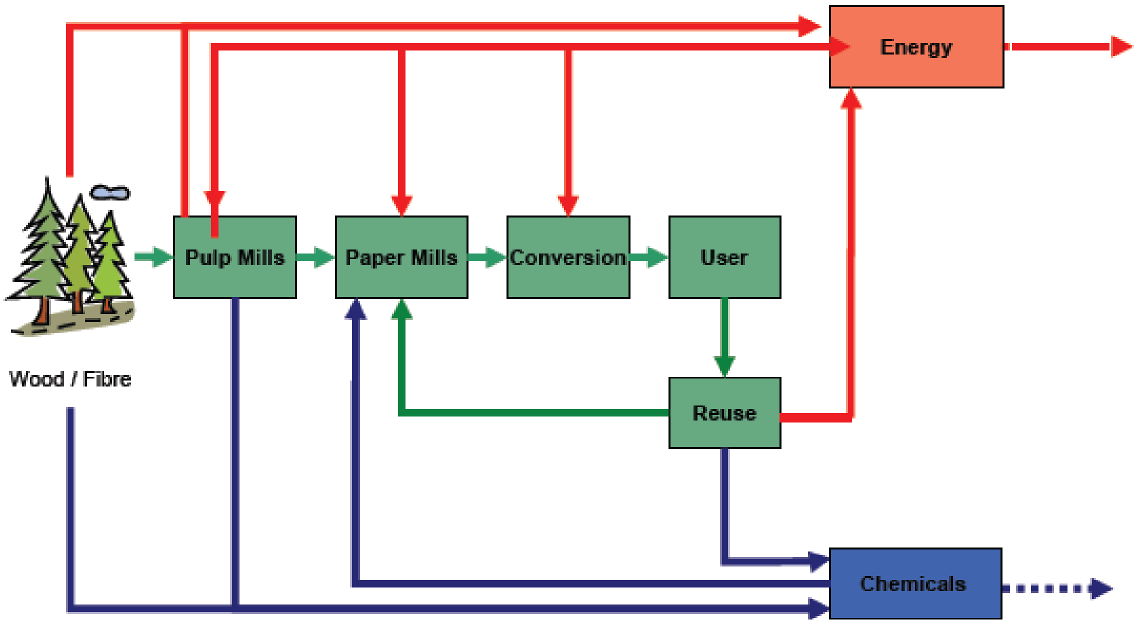
Improving environmental performance, especially reducing energy consumption, improving water use efficiency and minimising air pollution are targets for the paper industry, which require further technological development. The industry makes in a number of ways investments in innovations: For example direct industry investment in production development, suppliers´ development in new equipment and machines and financial support to research institutions. Because of this, providing figures for the R&D activities in this area is not easy. Within CEPI countries around 3,500 people were active in R&D and innovation in 2005. Further 1,150 scientists and 550 technical staff in institutes and universities worked in close connection with the paper chain. Additionally, the paper industry co-operates with those throughout the forest-based sector chain to launch the Forest-Based Sector Technology Platform (see below) which outlines a long-term strategy. It is based on research and innovation to drive the sector forward. So the future competitiveness and sustainability of the paper industry shall be ensured (CEPI 2005).

Biorefinery activities in the forest sector

At the moment efforts are made from pulp and paper companies to co-operate with chemical companies to explore a new, integrated biorefinery model which would connect pulp mills to chemicals manufacturers. It is proposed that the pulp mills gasify biomass materials (wood chips, agricultural waste, etc.) to create synthesis gas, which then could be converted into different green fuels and chemical feedstock like acetic acid, methanol, methyl acetate. Additionally, the waste heat from the syngas process can be tapped for energy. So the need to purchase natural gas and electricity can be reduced for the pulp and paper mill. With this model new value streams can be created for pulp and paper companies. The biomass gasification strategy includes that a pulp and paper plant and a chemical plant are located next to each other, which makes in so far economic sense, as pulp and paper mills are already big customers of chemical companies. A leader in pushing this new biorefinery model is the US forestry company Potlach Corporation, working on a pilot biorefinery in Cypress Bend where forest and agricultural waste is converted into biofuels and other chemicals (Inside green business 2007).

When producing chemical pulp only about half of the utilized wood becomes fibre. The rest of the wood material, which consists mainly of carbohydrates, lignin, suberin and resin, is usually used as fuel at the mill and end up to a large extend as low-value heat with no practical use. The spectrum of organic structures in the streams is expected to be processed to valuable chemicals within "pulp mill biorefineries", beside the normal products of a pulp mill (see Figure 15) (WaCheUp 2006). A pulp mill biorefinery can be defined as "full utilization of the incoming biomass and other raw materials, including energy, for simultaneous production of fibres for paper products, chemicals and energy" (Axegård 2005). Thereby the following boundary restrictions apply: a technical and economically viable and environmentally sound technical solution is needed. Additionally, it must be possible to integrate the pulp mill biorefinery with power and mechanical pulp mills and it must produce normal wood to fibre products. In addition to the mentioned aspects the following factors argue for the possibility to use pulp mills in future as a biorefinery. There exists a negative price trend on pulp and the paper industry needs new revenues. On the other hand the needed infrastructure already exists as well as a large potential for energy and chemicals (Axegård 2005). According to Pursula (2006) the key drivers for forest biorefineries are the need to reduce oil-dependency as well as aspects of sustainability (climate change). Additionally there exists a need to renew the Forest Industry with new businesses and products in order to enhance the competitiveness of the industry and forestry (Pursula 2006).

Figure 15: Example of a potential pulp mill biorefinery



Source: Axegård 2005

According to Sipiliä (2005) several options exist for bio-energy co-products from Forest-Products-Platforms: First, it is possible to substitute fossil fuel by biofuels (biofuel gasification for lime-kiln fuel and fluid bed boilers). The second option is to increase the back-pressure power from biofuels. This can be reached for example by energy production with higher power-to-heat ratios in steam turbines or by a biomass gasification integrated Combined Cycle (black residues and solid residues). The third option is to export biofuels or produce and export upgraded biofuels. For example, it is possible to produce methanol via gasification or ethanol form wastepaper and export it. Additionally, it would be possible to produce pyrolysis-based bio crude oil and pellets as well as synthesis gases and synfuels. The fourth option mentioned by Sipiliä is to substitute paper-components and produce bio-energy. So it would be possible to substitute (industrial and municipal waste-derived) fibre and produce bio-energy (combined heat and power (CHP)). Another possibility is to integrate agrofibre, CHP and synfuels production.

But there are several risks which are associated with the forest biorefinery, especially as the pathway possibilities of forest biorefineries are large. They will depend on factors like wood species, technology in place, location of the mill or production level. All of these options imply process technology risks (limited process yields, materials of construction, process thermal efficiencies etc.). To mitigate technical and economic risks associated with the implementation of forest biorefineries in companies one can set at two aspects: product design considerations and process design considerations. Important for the success of a forest biorefinery will be process flexibility. Product opportunity analysis (e.g. SWOT and competitiveness analysis) can be helpful in product design considerations. At the process design stage a number of complex issues have to be addressed. For example, an improvement of the existing processes must be made by mills as they evolve towards a biorefinery (certain process configurations, optimization of process energy efficiency, analysis of energy systems). Additionally plant-wide analysis are necessary to make sure that existing pulp and paper operations continue to operate efficiently and produce target product qualities (Stuart 2006).

In the following some examples of ongoing activities (research and industry) are described in the field of forest/pulp and paper biorefinery within the EU.

Forest-Based Sector Technology Platform:

In 2005 the European forest-based sector launched Vision 2030. It is part of the European technology platform initiative. In the Forest-based Sector Technology Platform (FTP) major European stakeholders have joined to establish a vision for the future. These stakeholders from the industry, forest owners, researchers, public bodies as well as representatives of the European Commission have formulated the Strategic Research Agenda (SRA) for the forest-based sector. The goal of the SRA is to increase the competitiveness of the sector by developing innovative services and products.
Within the forest-based value chain the Research Area 1-8 (pulp, energy and chemicals form wood biorefinery) aims at the development of innovative products for changing markets and customer needs at two stages: pulp/paper products and specialities. The vision of the forest-sector research area is a fully integrated production of pulp, energy and chemicals from wood. This could make a substantial contribution to a bio-based economy. To achieve this it is envisioned to use new forest-based value chains, which base on biorefinery concepts. The close integration of chemical pulp manufacturing and different base or platform chemicals as well as optimised production of biofuels is critical for this purpose (European Commission 2006a). The work which is done within this research area is applied research, process design (fractionation, separation) as well as demonstration project(s). A further essential element concerning new types of forest-based value chains is the conversion of isolated chemicals and fibrous elements to value-added speciality chemicals/other products. The Research Areas 1-9 (“Green” speciality chemicals) and 1-10 (new generation of composites) deal with these aspects. Fundamental/basic research, applied research, product and process design and demonstration are necessary in these areas.

Within the framework of the Forest-Based Sector Technology Platform the following research priorities have been identified in the field of forest bio-refineries:

- Selective efficient separation and conversion processes
- Biorefinery as the source for wood-based solid and liquid biofuels
- Recycled fibre biorefinery
- Above sector synergies with the agricultural and chemical sector
- Socio-economic impacts of biorefinery development (Karlsson 2007)

WaCheUp

The EU-project WaCheUp especially deals with pulp mill biorefineries and has the goal to upgrade low-value residual products from pulp and cork manufacturing into value-added bio-based chemicals with methods that can be efficiently integrated with the pulp/cork mill. The project covers the whole process chain – physical separation to final product – and includes additionally system studies. Within the project research is done on the field of raw materials and primary separation technologies, development of processing technologies and technologies for the valorisation of components as well as on the field of application development. Some preparation work for this project has already been done in two previous projects: KAM (The Ecocyclic Pulp Mill) and FRAM (The Future Resource Adapted Pulp Mill) (STFI 2005).

RENEW– sustainable energy systems for transport

“Renew” is a pan European project which consists of six subprojects. One of the subprojects has the objective to cover the technical and commercial impact of locating a plant producing DME/ methanol from black liquor[2] at the pulp mill of Södra Cell located in Sweden (Mörrum). Thereby three crucial scientific activities are planned: (1) creation of plant data to get a basis for the simulation of a commercial/demo plant concept, (2) creation of laboratory data from pulp cooking tests, (3) creation of engine test results when run with DME, which has the same quality as in real DME producing plant. All these results will deliver input data for the preliminary engineering design of an integrated demo plant at the pulp mill in Mörrum (Energy Laboratory 2007).

Pilot project concerning “use for material purpose”

With the increasing importance of the white biotechnology the demand for carbohydrates rises. The aim of a cooperative project, which is financed by the German Federal Ministry of Food, Agriculture and Consumer Protection, is to supply this rising demand by hardwood. Therefore the Gesellschaft für Chemische Technologie (DECHEMA), the German Federal Research Centre for Forestry and Forest Products, Fraunhofer-Institut für Chemische Technologie ICT, Degussa GmbH, Bayer Technology Services GmbH, Solvent Innovation GmbH and other partners try to develop procedures for the efficient separation of wood components with established and new processes. The project is financially supported for the next three years with 1.9 million € (Agra-Europe 2007).

Industrial Example: Dömsjö Fabriker

Domsjö is a biorefinery located in Örnsköldsvik, Sweden. It extracts and refines an increasing number of components from the raw material wood. They also produce ethanol for manufacturing fuel and carbon dioxide to be used industrially. The main product is special cellulose which is produced according to nearly fourty different specifications. At the moment, further investments are being planned in advanced wood chemistry and increased production to create security when facing the increasing costs on wood and energy (Dömsjö 2007).
The desk research concerning forest biorefinery has shown that there exists a diversity of projects dealing with different questions related to this field. Some examples are shown within this literature overview. One can also find a variety of presentations from different congresses/conferences where scientists and industrial actors show different examples of new (technological) ideas and strategies or describe (potential) R&D activities or pilot-phase-activities in the field of pulp/forest biorefineries. However concrete data or studies related to the production or commercialisation of these concepts can hardly be found. Therefore, the authors conclude that most of the activities related to forest-biorefinery concepts are still in an early stage of development.

3.4 Starch and sugar industry

3.4.1 Starch industry

Native and modified starches, products of the saccharification of starch as well as by-products of the production (e.g. wheat gluten) are used in almost every branch of the food and feed industry and the chemical, technical and pharmaceutical industry.

Framework conditions

Important framework conditions for the starch industry are formed by the EU market organisation of corn and sugar (isoglucose). The production of potato starch is limited through a quota system,

[2] Black liquor is a recycled by-product, which is formed during the pulping of wood in the papermaking industry.

whereby the quotas are allotted to the starch manufacturing plants. The quota is 1,949 million tons of potato starch in the EU25. Support is only paid for those quantities of potatoes, which are covered by a cultivation contract between a starch manufacturer and a potato producer (FNR 2007, European Commission n. d.). After the mid-term-review of the Common Agricultural Policy 2003 the support for potato producers and for corn producer was decoupled (40 % for potatoes and 100 % for corn).

Industrial actors

In the year 2005 24 companies and 68 plants existed in the European starch sector. The number of companies decreased over the last decade as well as the number of plants. In the mentioned year approximately 20,000 people were employed in the starch industry (Fachverband der Stärkeindustrie 2006). The industry invests approximately 150 million euros in R&D per year (EuropaBio, ESAB n. d.).

At the moment experts do not expect that new suppliers of starch and starch derivates will occur on the market. Especially big plants need acreages of a corresponding size close-by, so it is not very possible that new potato starch plants will be built in the next years. A further trend on the supply side is the parallel development of ethanol production capacities. Important on the supply side is additionally that maize can be grown cheaper outside the EU. In contrast cultivating wheat is internationally competitive within the EU.

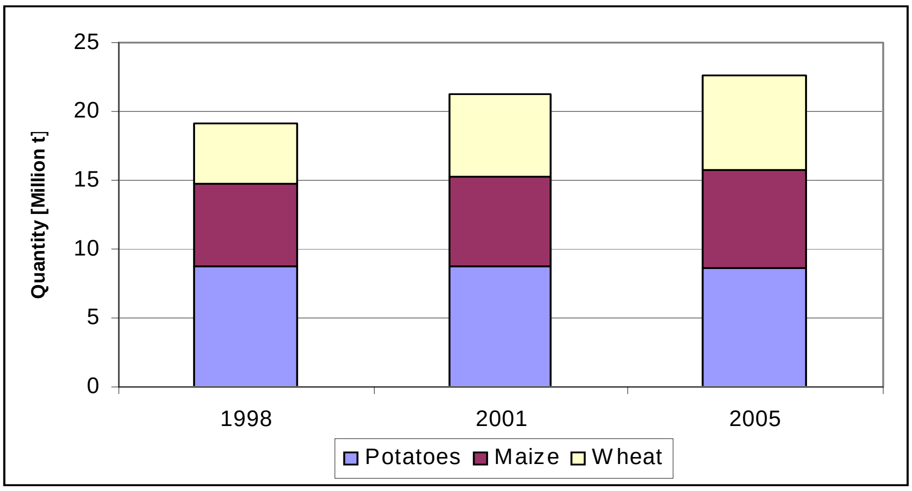
The most important starch producer within the EU is Cargill with a market share of 34 %. Currently the smaller producers of starch are more specialised than the bigger ones. Moreover wheat and maize starch producers act mainly globally while potato starch producers are above all characterised by direct relationships with farmers. Furthermore it is interesting that every actor in the market distributes his products on his own (FNR 2007).

Market volume, production and costs

The starch industry realised a turnover of 6,500 million € in 2001 (Fachverband der Stärkeindustrie 2006). According to EUROSTAT the manufacturing of grain mill products, starches and starch products achieved a valued added of 6,026 million € in the EU25 in the year 2003 (EUROSTAT 2006).

In the EU starch is produced from maize, wheat and potatoes (Fachverband der Stärkeindustrie 2006). The technology which is used to produce the starch differs depending on the used raw material. But all processes have in common, that they use the principle of "wet milling". Herby the starch is elutriated from the epithelium of the hackled raw material. So it is possible to obtain starch with large purity. Figure 16 gives an overview of the raw material use in the European starch industry.

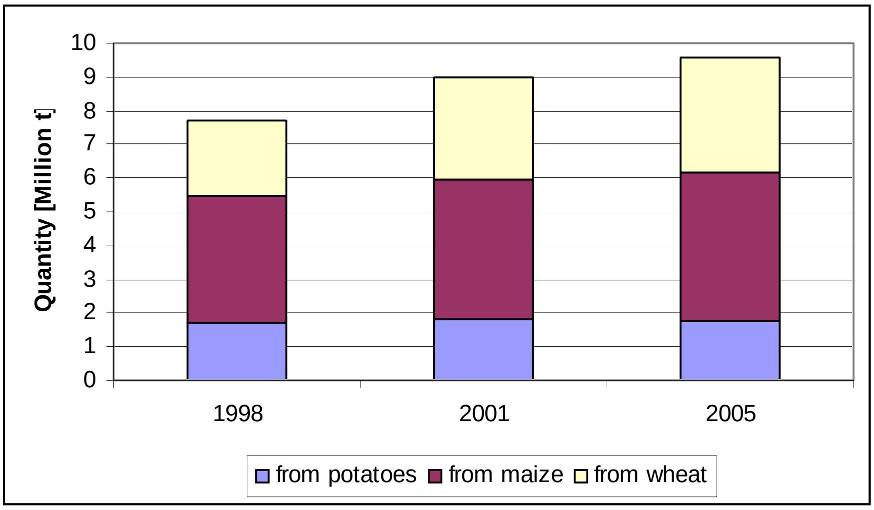
Figure 16: Raw material use in the European starch industry



Source: Fachverband der Stärkeindustrie 2006

The quantity of processed raw material steadily increased over the last decade. In the year 2005 22.6 million tons of agricultural raw materials were used, herby dominated the processing of potatoes (8.7 million tons). Maize (7.05 million tons) and wheat (6.9 million tons) were used in approximately the same quantity in the year 2005. While the processing of potatoes decreased relatively since 1998, the processing of wheat increased during this time period. Figure 17 gives additionally an overview over the production of starch in the EU. In the year 2005 9.6 million tons starch were produced within the EU differentiated in the raw materials potato starch (1.7 million tons), maize starch (4.4 million tons) and wheat starch (3.4 million tons). The production of starch steadily increased in the last decade following the use of raw materials. In relative terms the production of starch from potatoes lost importance (1998: 22 %; 2005: 18.1 %) and the production from wheat gained more importance (1998: 29 %; 2005: 36 %) (Fachverband der Stärkeindustrie 2006). The increase in the production of wheat starch in the EU was especially induced after the establishment of a new wheat starch plant (FNR 2007).

Figure 17: Production of starch in Europe



Source: Fachverband der Stärkeindustrie 2006

From an economic point of view wheat starch is an interesting starch variety since by-products like gluten can improve the profitability of wheat starch. But there exists a fierce raw material competition with the food and feed industry and high raw material prices for wheat might be the consequence. Potato starch is mainly produced within the EU. It is expected that it will develop more into a high-quality niche-product and a premium-product (high purity, special properties) in future. But the production of starch from potatoes is only possible in regions where strong interactions between agricultural cultivation and starch production exist. The competitiveness of maize starch can be improved through by-products as well. In the case of starch from maize a scarcity of maize is expected due to the rising bio-energy/bioethanol production. This will have consequences in terms of higher prices for the starch market as well (FNR 2007).

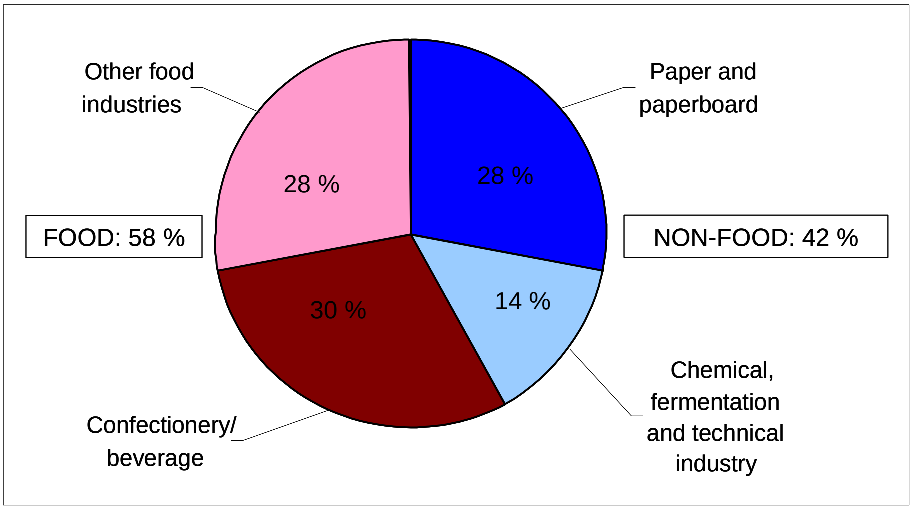
The export of starch products to non-EU countries decreased slightly in recent years. It amounted to 1 million tons in the year 2005, with native starch being the most important export product.

In the year 2005 the consumption of starch and starch derivates amounted to 9 million tons, an increase of almost 2 million tons compared to 1998. Differentiated by product groups the biggest part of starch is used for manufacturing saccharized products (59 %). Additionally, 23 % of starch and starch derivates are used for the manufacturing of native starch and further 20 % for the manufacturing of modified starches (Fachverband der Stärkeindustrie 2006).

Figure 18 shows the consumption of starch and starch derivates differentiated after economic sectors. More than half of the produced starch is utilized in the food industry and there especially in the confectionery/beverages industry (e.g. as sweeteners or to get certain nutritional or product qualities).

Additionally a significant amount of starch products is used in non-food sectors. Especially the paper and paperboard industry is one of the main consumers of starch products and derivates. It uses mainly maize and wheat starches because they are cheaper than potato starch (Fachverband der Stärkeindustrie 2006).

Figure 18: Starch consumption differentiated by economic sectors

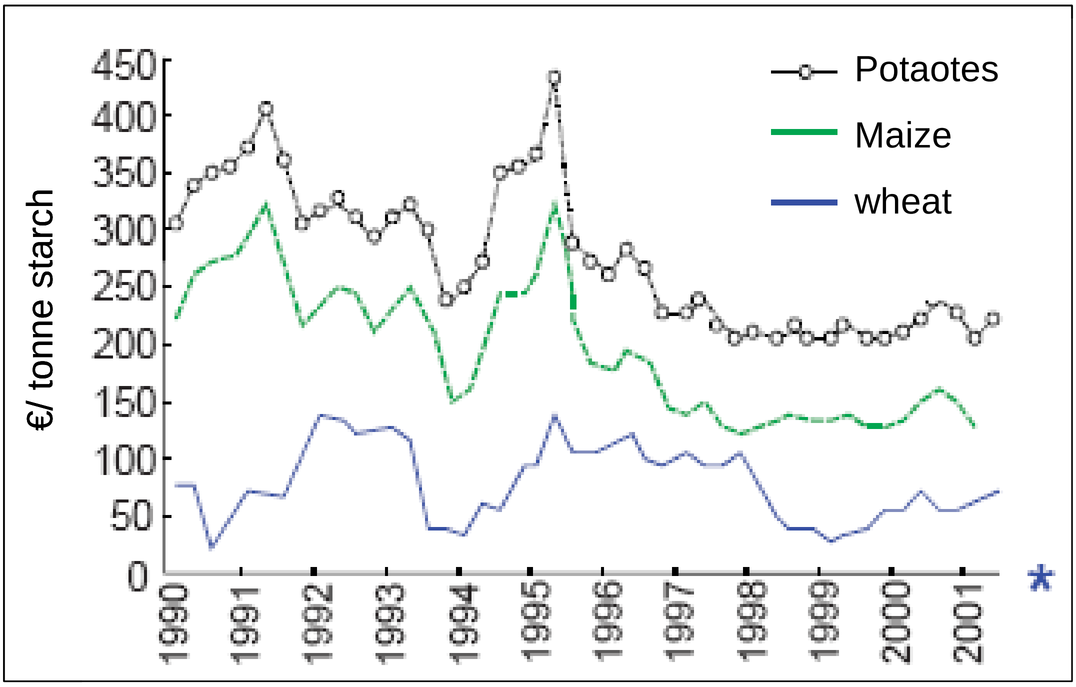


Source: Fachverband der Stärkeindustrie 2006

It is expected that the chemical industry will increase its starch consumption in future due to the rising crude oil prices. Especially in the field of bio-plastics experts see high future growth opportunities which will support the starch market as well. The paper industry can be assessed as a mature market but future growth in this market is possible due to a rising global economy. The starch consumption of the food, beverages and tobacco industry will strongly increase according to changing nutrition habits in particular of middle class inhabitants in emerging economies. Furthermore, new application fields are expected to emerge in future for starch and starch products (e.g. polymers for the paper industry) (FNR 2007).

Figure 19 shows the development of the raw material costs of starch since 1990 (thereby this cost share is subtracted which can be assigned to the produced by-products, e.g. to gluten from wheat starch). Potato starch exhibits the highest and wheat starch the lowest raw material costs. During the years 1990-2001 the cost trends of the three different starch products were almost parallel. During the years 2001-2006 the development of the costs was similar to the development in the years 1998-2001 - the only exception was the costs for wheat starch in the year 2003. The price for starch is composed of different factors like transport, raw material, labour and energy costs. Hereby the share of energy costs accounts to 10 %-20 %. The rising energy costs lead to higher starch prices and influence cultivation and production structures with low productivity more significantly. The rising crude oil prices have influence on the starch producers worldwide. In the case of maize the prices will rise due to the competition in the field of bioethanol and usage of biomass (FNR 2007)
The labour costs are three times as high when producing potato starch compared to maize or wheat starch production.

Figure 19: Development of raw material costs of starch since 1990



Source: cited in FNR 2007

The revenues of by-products are important for the economic success of the starch industry: in case of wheat starch production by-products are e.g. gluten, proteins and bran, in case of maize starch production these are oil and gluten, while for potato starch production proteins are the main by-products. The proportion of revenues deriving from by-products amounts to 60 % -95 % in wheat starch production, whereas they are only 5 % - 8 % in potato starch production (FNR 2007).

3.4.2 Sugar industry

Framework conditions

The sugar sector is regulated in a common market organisation (CMO) since 1968 in the EU. The main purpose of the CMO was to ensure self supply of the community market and a fair income for producers. Within the framework of this CMO the protection of the internal market was guaranteed by intervention buying of sugar and a minimum price for beet: Thereby the intervention price was the price at which intervention agencies had to buy in the eligible sugar and the minimum price is the price at which sugar factories had to buy beet from growers. The community prices were only guaranteed for production within quotas. The quotas were split into A quotas and B quotas, which were set per member state. The single member states allocated their quota by sugar companies and the factories converted their quota into "delivery rights" for the single growers. The CMO allowed exceeding the quota, but the production which was above the quota was not supported nor could it be freely marketed within the community. It had either be "carried over" to the following year or else exported without a refund (so-called C sugar). Protection against external competition was provided by import levies. Furthermore export refunds were paid, which covered the difference between the community price and the world price for sugar. Since the year 1968 the CMO was modified several times (European Commission 2004).

In the sugar financial year 05/06 the EU modified the market organisation for sugar [VO (EG) Nr. 318/2006)] again (Sommer 2006). Already in September 2003 the EU-Commission submitted a report over the common sugar market organisation with several reform options. Doing this the discussion process concerning a fundamental reform of the market organisation was opened. In February 2006 the new sugar market organisation was finally adopted. The new regulation is in force since the financial year 06/07.

It is based on three fundamental elements:

1. Reduction of the beet price (by 37 %) and the sugar price (by 36 %).
2. Reduction of the sugar production under the framework of a structural fund.
3. Partly compensation of the loss of income of the beet growers.

In the adapted market organisation the intervention system is abolished (with a transition period until 2009/10) and the intervention price is substituted by a reference price. Table 6 gives an overview over the development of the prices of sugar and sugar beet in the next five years (Wirtschaftliche Vereinigung Zucker e.V. 2007). The differentiation in A and B quotas is abolished as well. The previous A and B quotas are now summed up to a uniform quota.

Table 6: Development of prices of sugar beet and sugar in the coming years

Prices		2006/07	2007/08	2008/09	2009/10
Reference price white sugar	€/t	631,9	631,9	541,5	404,4
Cumulative reduction	%	0	0	14,4	36
Structure royalites	€/t	126,4	173,8	113,3	0
Net reference price	€/t	505,5	458,1	428,2	404,4
Cumulative reduction	%	20	27,5	32,2	36
Raw sugar reference price	€/t	496,8	496,8	448,8	335,5
Sugar beet minimum price	€/t	32,9	29,8	27,8	26,3
Cumulative reduction*	%	24,6	31,7	36,3	39,7
*compared to 43.63 €/ton A/B sugar beet in 2005/06					

Source: Wirtschaftliche Vereinigung Zucker e.V..2007

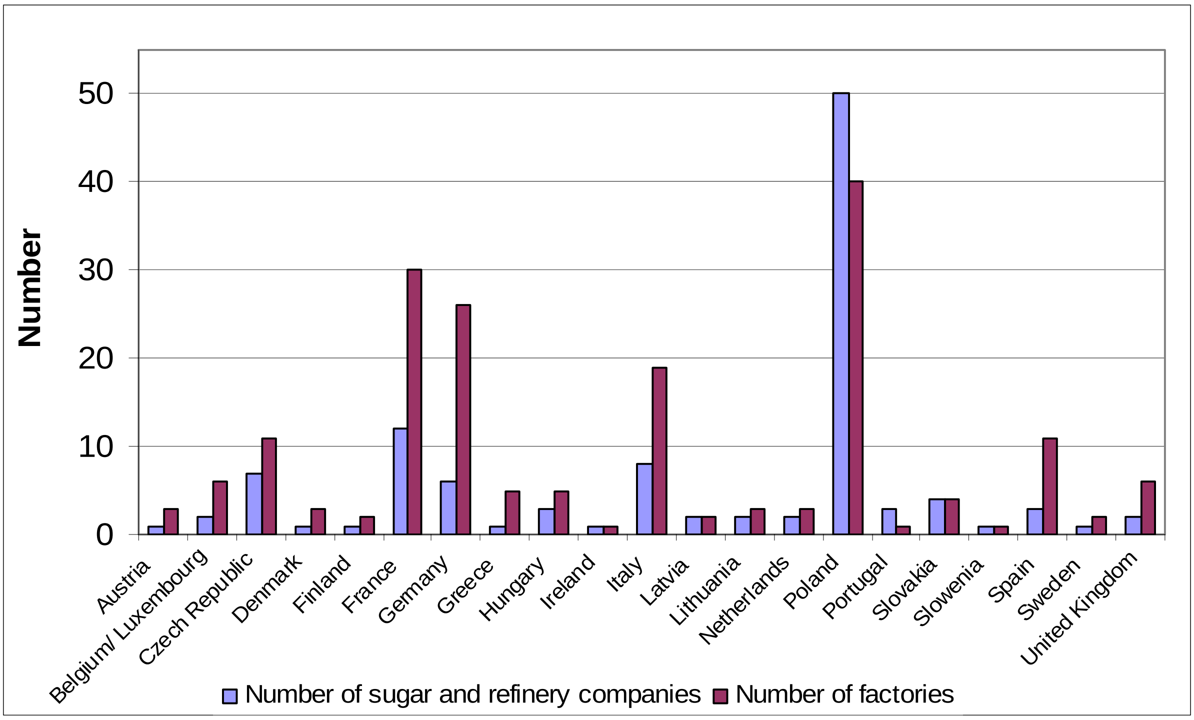
One aim of the structural fond is to concentrate the sugar production of the EU on competitive regions and producers in future. As a result the beet and sugar production is expected to withdraw completely from some European regions. In the course of this development the number of sugar factories will decrease. In the same time the sugar industry has to prepare for cuts in their revenues (Zuckerverband 2007).

Industrial actors/Size structure industry

In the year 2005/06 113 sugar and refinery companies and 184 factories existed in the EU. The number of companies and factories decreased in previous years as well as the production of sugar. Especially small-scaled production units have been closed, while in contrast medium and large sized entities have gained importance. This process has allowed productivity enhancement and increased economies of scale. In contrast the establishment of new plants is exceptional, because it is very capital-intensive (European Commission 2003).

Most of the sugar producing companies/factories are located in Poland, even though France and Germany are the biggest sugar producers in the EU. This fact gives further information on the structural conditions in the different countries. The sugar processing industry in Poland is structured in small-scaled units: in 2005/06 all factories had a daily capacity which was less than 8,000 tons. In contrast in France 16 % of the factories and in Germany 23 % are found in this size class, while 30 % of the French sugar-producing factories and 16 % of the German ones had a daily production capacity which was higher than 15,000 tons. These facts show that the sugar industry of these two countries is much more concentrated compared to Poland (CEFS 2007). Characteristic for Poland is additionally, that national ownership is predominant (European Commission 2003). In the EU the biggest sugar producing companies are Südzucker Group (24.6 % of EU sugar quota), Tereos (10.0 % of EU sugar quota), Nordzucker (9.8 % of EU sugar quota) and British Sugar (8.5 % of EU sugar quota) (DZZ magazine 2007).

Figure 20: Number of sugar refinery companies and factories within the EU in the year 2005/06



Source: Comité Européen des fabricants de sucre (CEFS) 2007

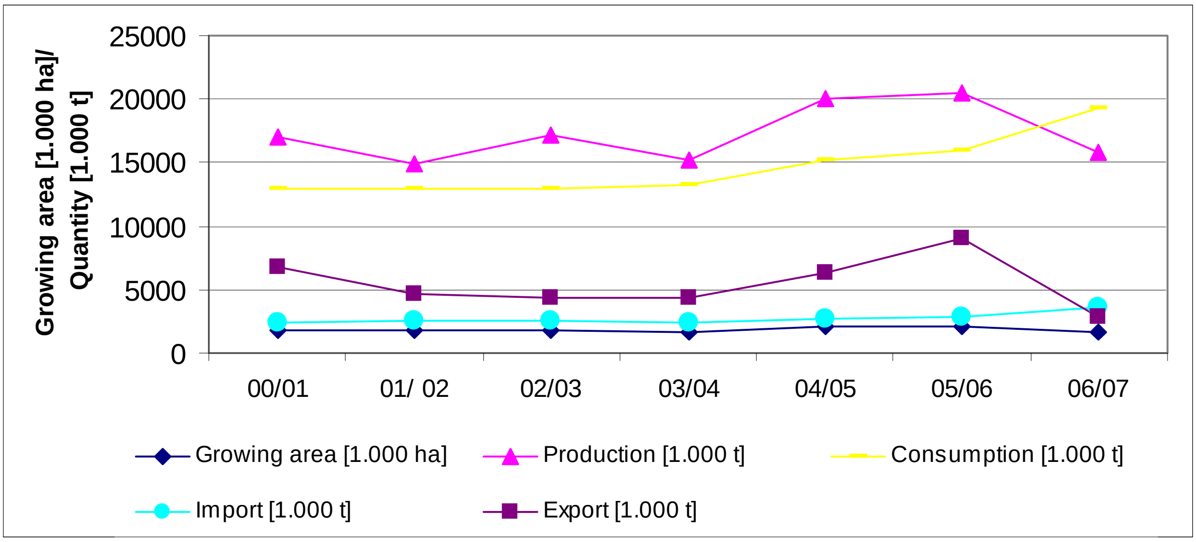
When taking into account that only very few companies/factories exist in other European countries (outside Poland, France and Germany), it becomes clear that the sugar industry is relatively highly concentrated. Additionally, the degree of integration with the upstream sector is high. This fact can be explained by institutional, technical and economic factors. Sugar beet cannot be transported over long distances, because of technical and economic reasons. So the processing industry is always located close to growing areas of sugar beet. On the downstream side some forms of integration have developed, too. But these are not as strong as with the sugar growers (European Commission 2003).

In the EU sugar sector more than 48,000 people were directly employed during the beet processing campaign 2005/06. The campaign lasts on average 90 days because of the perishable nature of sugar beet. Between the beet processing campaign about 30,000 of people worked in the same year in the sugar industry. The number of employees – during and between the campaigns - decreased over the previous years as well.

Market volume and production

Figure 21 gives an overview over the sugar supply and the growing area of sugar beet in the EU in the years 2004 to 2007.

Figure 21: Sugar supply in the EU in the years 2000 to 2007



Source: cited in Sommer 2007

The growing area of sugar beet amounted to 1.7 million hectare (ha) in the EU in the year 2006/07. Absolutely it decreased compared to the previous years as a consequence of the modification of the market organisation. But in the whole the reaction on the adopted market organisation, which was the basis of the cultivation plan for 2006/07, was less significant than expected. Only Ireland, Italy and Greece reduced the acreage significantly more than in the European average. Absolutely the reduction of acreage in France and Germany preponderated - besides Italy.

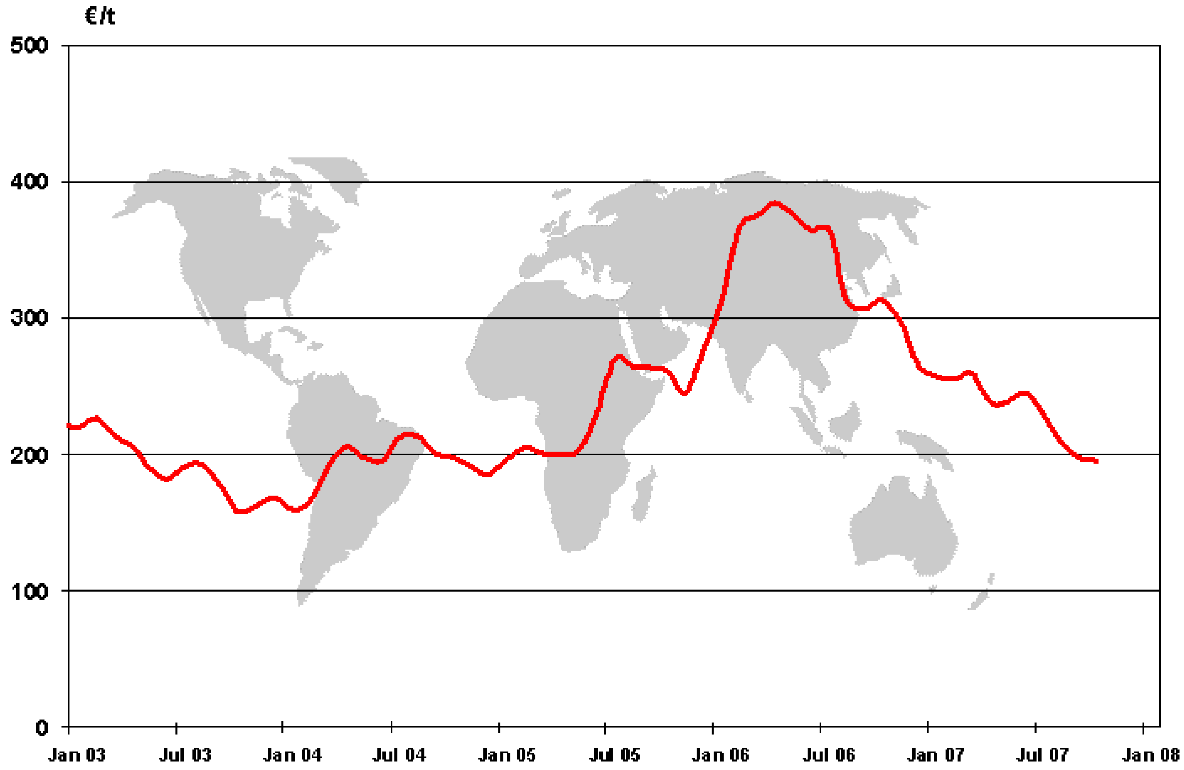
The production of sugar amounted to 15.8 million tons in the year 2006/07. The most important producers within the EU are France (23 %), Germany (21 %) and Poland (11 %). The production dropped rapidly from the year 2005/06 to the year 2006/07. Especially France and Germany, the two biggest sugar producers within the EU, significantly reduced their production (Sommer 2007). The reduction is on the one hand a reaction on the stop of exports (the EU is only allowed to export a maximum of 1.375 million tons per year since 2006/07) and on the other hand a consequence of the increasing duty-free imports of the sugar produced in the least developed countries (Zuckerwirtschaft 2007; Sommer 2007). The increase of the imports and the enormous decrease of exports can be noticed in figure 21 as well. While in the year 2005/06 almost 9 million tons of sugar was exported, it was less than 3 million tons in the year 2006/07. In contrast to the production the consumption of sugar within the EU increased over the last years. It amounted to 19.3 million tons in the year 2006/07.

From the beginning of the year 2006/07 the EU is allowed to export a maximum of 1.3 million tons sugar per year. Because of this the further developments on the sugar market will depend - besides harvest variations caused by the weather - on the developments in Brazil, who is the biggest producer of sugar cane worldwide (Sommer 2007). Brazil features the lowest production costs for sugar cane and has a high expansion potential. A big part of its sugar cane production is used for the production of ethanol for the fuels sector. If the world market price for sugar increases significantly, it is possible for Brazil to reduce the ethanol production from sugar cane in the short term and increase the sugar export. On the other hand it is possible that sugar cane is temporarily used in the ethanol sector and not in the sugar sector if the crude oil prices increase very much (Isermeyer et al. 2005). As Brazil is the biggest producer of sugar cane worldwide, its activities affect the world market price for sugar significantly.

But it is supposed that the influence of high fuel prices will loose importance in future. The fact that ethanol is in many countries produced from maize or other corn species has a share in this. Additionally, it is worked hard to develop processes which make it possible to produce ethanol from inferior raw materials (Sommer 2007).

Generally the sugar price is influenced by a variety of factors. On the one hand they are a result of the actual supply and demand situation, but on the other hand they highly reflect speculation activities on the commodity market. Additionally they are influenced by the exchange rate of currencies. From the beginning of the 1970 until the mid 90s the sugar prices showed cyclical movements, which were mainly the results of the increasing consumption in the developing countries and the expansion of the production in Brazil (Isermeyer et al. 2005). Since 1995 the world sugar prices had a decreasing trend until 2003 which can be above all explained by a global surplus of production over consumption (Commission of the European Communities 2005). Figure 22 shows the world market prices of white sugar from January 2003 until November 2007. Obvious is that in the sugar year 2005/06 the prices increased significantly. This price increase mainly occurred due to speculation activities of capital-intensive funds which expected a significant decrease in sugar supply not least due to the modification of the EU CMO for sugar. At the end of September 2006, when it became obvious that the stocks on the world market will increase in the following year again, the scalpers dropped out of the contracts and as a consequence the prices fell drastically (Sommer 2007). Due to a global overproduction the prices show a decreasing price trend since then.

Figure 22: World market prices for white sugar (monthly mean)



Source: Verband Süddeutscher Zuckerrübenanbauer 2007

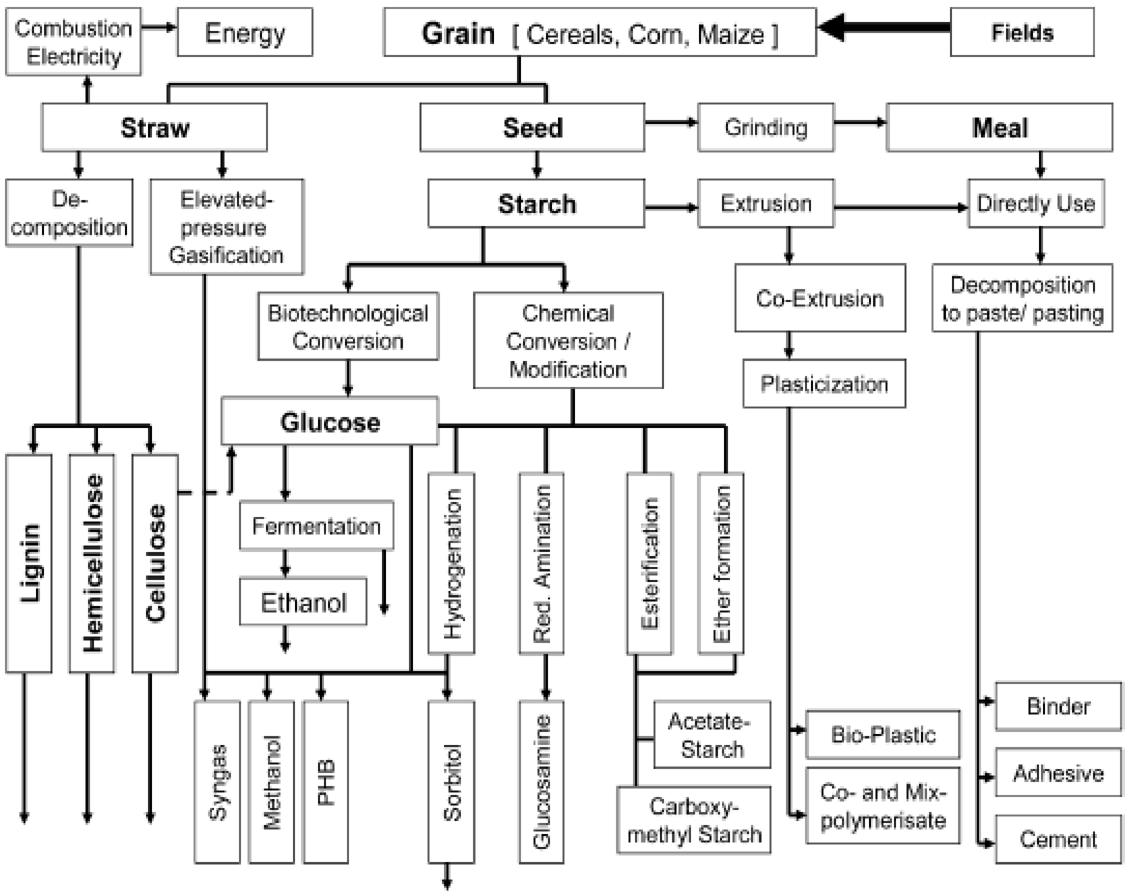
Biorefinery activities in the starch and sugar industry

In the year 2003 the total industrial use (use of the chemical, paper and natural fibre industry) of renewable raw materials was approximately 9 million tons in the EU25. Thereby 14 % (1.26 million tons) were allotted to sugar and 34 % (3.06 million tons) to starch. Altogether 137,000 ha non-food crop land was used in the EU25 in the year 2005 to grow sugar crops and 900,000 ha to grow starch crops for industrial purposes (Schütte 2007).

Starch

Figure 23 gives an overview over the pathways, which are possible for the further processing of starch in a biorefinery with plasticization, chemical modification or biotechnological conversion being the possible processing pathways.

Figure 23: General scheme for a whole crop biorefinery



Source: Kamm B. 2004

Products - Polymers

The production of biopolymers is one option to use starch to manufacture bio-based products. In general it is possible to differentiate between three market-relevant production processes for the manufacturing of bio-plastics: fermentation, compounding and extrusion. Typical thermoplastic polymers on the basis of a fermentation process are e.g. polylactid acid (PLA), polyhydroxyalkanotes or polyfatty acids like polyhydroxybutyrat (PHB). Starch is mixed with different additives in the compounding process and afterwards it is plasticized under heat and pressure. The results are thermoplastic starch blends (TPS). These TPS can show varying starch-contents with an average of about 50 %.

A look at the materials, which are used for the production of degradable packaging, shows that starch-based polymers dominate the market: In the year 2002 almost 75 % of the degradable packaging was produced on the basis of starch and starch blends. Additionally, 13 % were manufactured on the basis of Cellulose/PLA and further 12 % on a petrochemical basis (Karus 2003). But, according to FNR (2007), polymer products from pure starch are not the future of polymers produced from renewable resources. Although the quantity of polymer materials from starch is expected to grow further, the production of polymers which are manufactured on the basis of other renewable resources is expected to grow more strongly. Furthermore it is expected that the demand for bio-based compounds will grow: Especially in the field of horticulture and landscape management degradable products made from starch can offer advantages. Polymer materials made from PHB are at the moment particularly interesting for special market niches (e.g. military technology market).

Prices for plastics have risen according to the share of crude oil (material and energetic) used for production. The share of crude oil (material and energetic) varies by different plastics. In general this share is higher by more expensive plastics than by cheaper bulk plastics (e.g. polypropylene). However the proportional increase of prices is restricted in higher value products. Additionally the availability of preliminary products is important for the development of the prices of plastics (FNR 2007).

In the year 2005 the prices for the raw materials of standard thermoplastics ranged between 900 and 1,000 €/t (PE/ PP) or 1,500 €/t (PS) respectively in the same period. In contrast the raw material prices for bio-plastics were between 3,000 and 5,000 €/t.

Thus it is necessary to establish a cost-efficient production in a common industrial scale for most of the existing bio-plastics. High future expectations are set in biotechnological processes as well as in starch-based, high-quality blends. As soon as the production can be realized in an industrial scale, it is probable that the costs for bio-plastics will fall significantly. Experts suppose that in this case it would be possible to produce starch-based plastics with less than 2,000 €/t which would be in a similar range as the costs for standard thermoplastics. Not least if crude oil prices will further increase in the coming years, bio starch-based plastics might become competitive in specific market niches in the coming years.

At present four attractive market segments exist for starch-based biopolymers:

- food packaging
- mulch foils and plant pots (horticulture/landscape)
- durable products for the consumer food industry
- interior equipment for the automotive industry

Table 7 shows the potentials for bio-plastics in different sectors in the European economy which were identified in the year 2001 by the Committee of Professional Agricultural Organisation in the EU (COPA) and the General Committee for the Agricultural Co-operatives in the EU (COGECA) (FNR 2006c).

Table 7: Potential for bio-plastics in Europe (Estimation from COPA and COGECA 2001)

Catering	450,000 t/a
Bags to gather biological waste	100,000 t/a
Biodegradable mulch films	130,000 t/a
Biodegradable films for nappies	80,000 t/a
Nappies made completely of BDP	240,000 t/a
Light packages, trays, tubs	400,000 t/a
Vegetable packages	400,000 t/a
Components for vehicle tyres	200,000 t/a
Total	**2,000,000 t/a**

Source: cited in FNR 2006c

Altogether the worldwide production capacity for biodegradable products is currently approximately 300,000 t. Most of the production capacities were put into operation after the turn of the century. Industrial actors who produce starch-based bio-plastics are e. g Novamont (Italy), Stanelco (UK) or BIOP (Germany) (European Bioplastic 2007). An example for a starch-based bio-plastic is Mater-Bi®, a product of Novamont which is a destructible, complex and thermo-plastically processable starch. It is used for films, tires, injection moulding and foams which are used in composting, packaging, hygiene, catering or agriculture (Zwart 2006). Further examples for plastic producers who use starch as raw material are the Dutch company Rodenburg Biopolymer or the German Biotec GmbH. The main part of the bio-plastic production is carried out by large scale enterprises or by their subsidiaries. But additionally one can find SME using innovative processes, smaller production units and short process chains. Their products are possibly competitive today (Karus 2003).

In Germany the market potential for the year 2010 can be estimated to more than 180,000 tons bio-polymers (resp. > 250 Million €) and growth rates which are higher than 15 %. This would mean a potential sales and income of 340,000 tons (resp. 100 million €) from starch for the German agricultural and forestry industry. Especially the increasing crude oil/plastic prices lead to a growing interest for bio-polymers - particularly as these become cheaper and more diverse applicable (FNR 2007).

Sugar

An advantage of sugar beet with respect to the production of chemicals and biopolymers is that it is an established crop throughout Europe, which produces high yields of dry biomass per ha. Additionally the crop as well as its use for the production of refined sugar and co-products for the food and feed market is underpinned by a considerable science base. Sugar beet is already used as feedstock for bio-energy biorefineries. Hereby it would be possible to optimise its use if the biomass production and the yield of fermentable materials could be optimised (Beilen 2007a).

Concerning the industrial non-food use of sugar beet the R&D needs differ very much from those that have underpinned the development of the crop to date, which was focused on the needs of the food and/or feed industry. Moreover they will need to be refocused if the potential of beet as an energy/industrial crop is to be pursued widely within the EU (Beilen 2007a).

The processing of sugar beet to refined sugar/co-products has been optimised in recent years. Now new processing schemes for the use of sugar beet in the production of energy products (bioethanol/biobutanol) are under development. But a further modification and new design of processing technologies seems to be necessary if the beet is developed further for multiple uses combining bio-energy with the production of novel chemicals. Necessary changes for low value co-products should be minor and relatively easy to implement. In the case of high-value products the processing would focus on the main novel products with waste streams injecting into the production of bio-energy or biofuels. But there are a number of weaknesses of the sugar beet. Under these fall the inherent difficulties of developing a transgenic crop, the need to prevent transgene flow as well as the high inputs, which are needed to receive high yields. The closed supply chain can either be estimated as an advantage or a disadvantage.

With the reform of the Sugar Regime within the CAP it is probable that less sugar is refined form sugar beet within the EU. But it is possible that part of the crop is used in biofuel production. This offers the chance to develop new markets for sugar beet. Especially when considering the agronomic know-how available concerning the cultivation and the technologies available for the improvement of the crop it should be examined to increase sustainability, make novel modifications and develop the beet as a new industrial platform (Beilen 2007a).

In figure 24 an overview is given over the strengths, weaknesses, opportunities and threats of sugar beet used for the production of chemicals and biopolymers.

Figure 24: SWOT analysis of sugar beet for the production of chemicals and biopolymers

STRENGTHS	WEAKNESSES
- Yield per ha highest of all convential crops in the EU - Valuable rotation crop (uses excess nitrogen) - Great opportunity to optimise for new uses by breeding - Abundant natural genetic variation, routine transformation, other tools available	- Food and feed crop - High input crop (energy, fertiliser, pesticides) - Soil compaction, water/ wind erosion - High harvesting costs (below ground biomass) - Outcrossing and transgene spread

OPPORTUNITIES	THREATS
- CAP-reform leads to search for other non-food uses - Great potential in breeding for biomass and fermentable sugar - Outside quota	- CAP-reform eliminates prodcution and processing capacity - Sugar beet for chemicals and polymer production very likely requires genetic modification

Source: Beilen 2007b

Beilen (2007b) summarizes the following science recommendations for sugar beet: In the breeding and GM-technology it is necessary to aim at new targets and do research in the fields of metabolic engineering, plant health, longer growth seasons, lowered inputs and prolonged storage. When genetic modification is used transgene flow has to be prevented and safety issues must be considered. Concerning processing integration of co-products is necessary.

In general the further development of sugar beet is likely due to the trend to produce bioethanol with valuable co-products. Strong incentives are made from and for the processing industry. The sugar beet offers abundant scientific and technological potential for the production of chemicals and biopolymers.

Sugar from sugar beet and sugar cane is an important raw material for the production of bio-plastics (see chapter “starch”) (Karus 2003). Sugar (saccharin) can be used as a nutrient in the production of PLA or others polymers. Whether it is used for such processes is in the end an economic question, which depends on the sugar-framework within the EU and the demand for bioethanol. A further negative aspect affecting the profitability is the coupling of fuel and sugar prices which can already be observed in Brazil and which is expected in the EU if the crude oil prices further increase in future (FNR 2007).

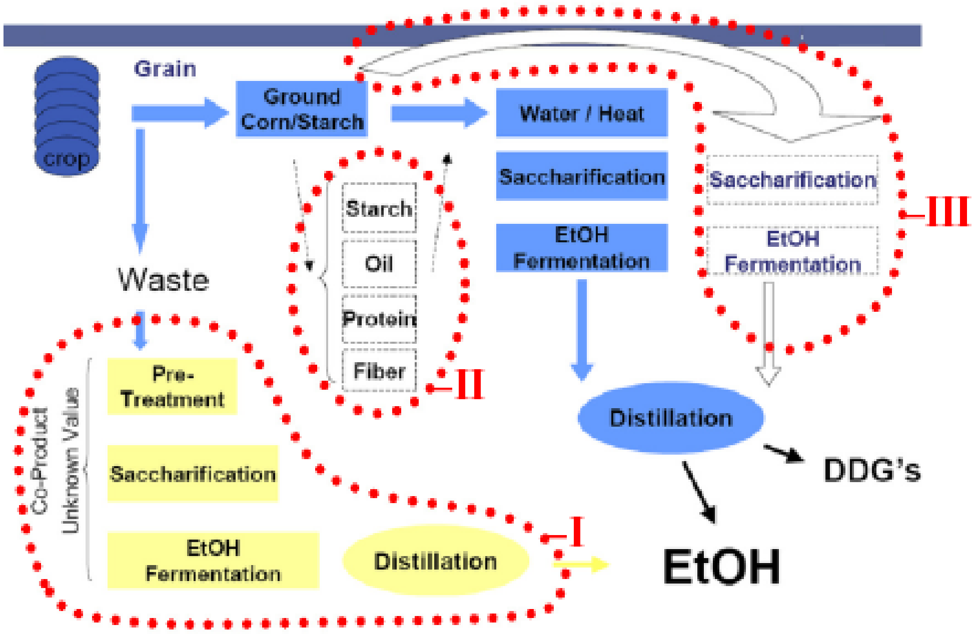
In the EU a further application for starch crops and sugar beet is the production of bioethanol. Whereas the worldwide leading bioethanol producers – Brazil and the USA – produce it mainly from sugar cane and molasses/corn, the conditions in Europe (climate, landscape, soil composition etc.) favour the production from starch crops (wheat) and sugar beet. Bioethanol is produced by a fermentation process (Glucose -> CO_2 and ethanol). If the used raw material crops contain starch, it has to be converted to sugar in a first step. When starch is used as the starting material the process is more expensive and complex compared to this using sugar beet (EUBIA 2007a, Zwart 2006).

Several examples for existing starch-based biorefineries can be found in the USA: To mention here are:

- *Archer Daniels Midland* (ADM) as one of the largest agricultural processor of corn, wheat, soybeans and cocoa (Zwart 2006).
- *Arkenol*, a technology and project development company who focuses on the construction and operation of biorefineries on a worldwide basis. The companies’ aim is to produce a variety of bio-based chemicals and transportation fuels (see also page 16) (Arkenol n.d.).
- *Cargill* Dow is a joint venture of Cargill Incorporated und Dow Chemical, which was founded in 1977 (see also page 16).

- *Genencor International*, a Danisco division working in the biotechnology field, mainly focuses on the improvement of the grain milling process and considers biorefineries to be the upgrading of all kinds of enzymes to fuels, polymers, chemicals and speciality products. The most important feedstock and end products are starch grain and ethanol. The economics of existing grain mills shall be improved by improving the front and the back-end of the processes by means like energy savings, capacities increase, cost reduction, valuable co-products and others. Figure 25 shows a possible biorefinery based on the grain milling process (Zwart 2006).

Figure 25: Biorefinery based on the grain milling process



Source: Zwart 2006

Shell Global is working on bio-strategies dealing with starch containing crops. Hereby the focus is set on the production of bioethanol via fermentation (Zwart 2006). *DuPont* also uses a fermentation process to produce 1,3-Propandiol from maize starch. By polymerising these monomers Sorona®, a polymer with softer fibres than nylon, is produced (Maurer 2005).

3.5 Biofuels

The transport sector accounts for more than 30 % of the total energy consumption in the EU. Concerning its energy input it is to 98 % dependent on fossil fuels with a high share of imports and thus extremely vulnerable to any market change. Furthermore, this energy sector is deemed to be one of the main reasons for CO_2 emissions (Federal Environment Agency (Austria) 2004). Because of the disadvantages of fossil fuels, biofuel is considered within the EU and worldwide to play a crucial role to reduce the greenhouse gas emissions, to create new jobs (especially in rural areas) and to increase energy security by providing a viable alternative to fossil fuels.

Biofuels are transportation fuels made from organic materials. They can broadly be defined as solid, liquid or gas fuel consisting of or derived from biomass. Biofuels can be distinguished into "first and second generation biofuels". The current first generation biofuel involves available biofuels that can be used in pure form or when blended to certain extend with fossil fuels (i.e. RME/biodiesel or bioethanol). Currently the second generation biofuels are still under development (i.e. ethanol and ETBE from lignocellulosic biomass, FT- and HTU-diesel, bio-hydrogen or bio-methane) (Zwart 2006).

Today, bioethanol is the world's main biofuel. Biodiesel which until recently was produced almost solely in the EU is now gaining a foothold in many regions across the world. Biogas comes a poor third and has so far made a breakthrough only in Sweden (Commission of the European Communities 2006). Therefore the core of this chapter covers mainly bioethanol and biodiesel with a specific focus on the situation in the EU.

Biodiesel is a renewable fuel produced from esterified vegetable oils (or fatty acids methyl esters, FAME) such as rape seed oil, sunflower seed oil, soybean oil but frying oils or animal fats can be used for this purpose as well. In the transport sector biodiesel may be effectively used both when blended with fossil diesel fuel and in pure form. Biodiesel also can be used as efficient heating oil (European Biodiesel Board 2007a).

Bioethanol is mainly produced by fermentation of sugars derived from sugar beet, sugar cane, wheat or corn. It can be used in petrol engines as a replacement for benzine but it can also be mixed with benzine to any percentage. Generally it is impractical to use neat ethanol in spark-ignition engines due to its low vapour pressure and high latent heat of vaporisation which make cold start problematic. The most cost-effective measure is the blending of ethanol with a small proportion of a volatile fuel such as fossil benzine. Thus, various mixtures of bioethanol with fossil benzine or diesel fuels have been used. The most well-known blends by volume are for example E85G (85 % ethanol, 15 % benzine) or E5G to E26G (5 %-26 % ethanol, 95 %-74 % benzine) (European Biomass Industry Association 2007). The so-called flexible-fuel vehicles (FFV) are automobiles that can typically use different sources of fuel, either mixed in the same tank or with separate tanks and fuel systems for each fuel. They are currently supplied in Europe in limited numbers mainly by Ford and Saab (FNR 2006b).

Framework conditions

As in the case of the chemical, the forestry, the sugar and the starch industry, framework conditions have crucial effects on the deployment of biofuels. Today's motorised transport is dependant world-wide on the limited supply of fossil oil and is regarded as one of the main causes of the anthropogenic greenhouse effect since EU transport is responsible for an estimated 21 % of all greenhouse gas emissions that are contributing to global warming (Commission of the European Communities 2006). To counter this, the European Parliament and the Council have formulated targets for the future proportion of biofuels within the EU in 2003. With the reference value of the market shares of 2 % of biofuels in the year 2005, the target value in the year 2010 should be 5.75 %. Therefore, the Council Directive 2003/96/EC, which adjust the Community framework for the taxation of energy products and electricity within the EU, admits the member states to exempt the mineral oil taxes for biofuels (European Union 2003).

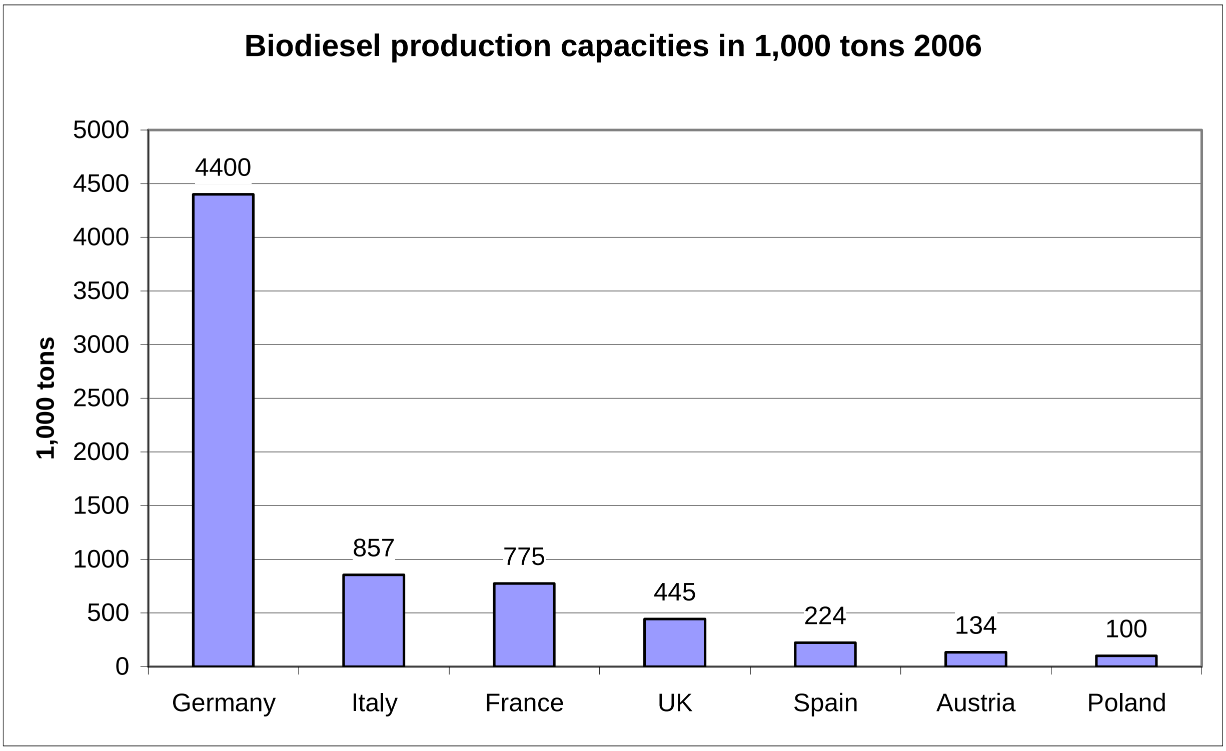
Although the implementation of this target value in the single member states is differing, several member states have increased their targets for biofuels and implemented different instruments (e.g. quota regulations) to reach the goal already in 2005/2006. France for example wants to reach the goal of 5.75 % already in 2008. 2010 it should be 10 % of biofuels in the French fuels market. To reach this goal the Government of France defined that the taxation for biodiesel amounts 16.69 Eurocent in contrast to fossil diesel with 41.69 Eurocent (2006). In addition, the market in France is more regulated compared to Germany and the UK where the markets are more opened. As a result cheaper biofuel imports from e.g. the USA are currently a problem for the biofuel producers of Germany and the UK. Belgium strives for 2010 an amount of 5.75 % of biofuels. Like in France the market is more regulated and thus more independent from imports of foreign countries. UK adapted goals to reach a proportion of 2.5 % till 2009 and 3.75 % till 2010. Also Austria strives a target of 5.75 % for 2008. To reach this biofuels with an admixture to fossil fuels are partly exempted to mineral oil taxes and pure biofuel is totally exempted in Austria. In the Czech Republic pure biofuel is also totally exempted of mineral oil taxes and as a result the production capacities strongly increased since 2005. Germany implements the EU-Directive by defining quota for admixing biofuels to conventional fuels. In the year 2007 4.4 % biodiesel (till 2010 5.75 %) should be admixed to the conventional diesel. Benzine should be admixed with 2 % bioethanol. In Italy both quota should reach 1 %. Poland and Hungary imposed the conditions that 75 % of the raw materials must come from the European farmers. Irelands aims to subsidize renewable energy within the next five years (from 2006) with 265 million € whereof 200 million € should be spent for the tax exemption of biofuels. (Renewable Energy Policy Network for the 21st Century (REN21) 2006, Neue Energie 2007).

Market structure and actors

Like already mentioned the most common first generation biofuels in Europe are biodiesel and bioethanol. As the European markets for biofuels are heavily influenced by political targets and decisions umbrella organisations like the “European Bioethanol Fuel Association” and the “European Biodiesel Board” intervene in political debates but also publish information on market activities.
The most important suppliers of biodiesel are the oil-mills. In the year 2004 the European Commission estimated 66 production sites of biodiesel across the EU and they were scheduled to expand to 75–80 plants by the end of 2005 (Commission of the European Communities 2006). In the year 2007 there are approximately 120 plants in the EU. These plants are mainly located in Germany, Italy, Austria, France and Sweden (European Biodiesel Board 2007a).

The production capacity of biodiesel in several European countries amounted to nearly 7 million tons in 2006 (see figure 26). Around 63 % of this capacity was installed in Germany while the other countries showed much smaller biodiesel production facilities. In 2007 biodiesel plants in the EU produced up to 6.1 million tons of biodiesel annually (European Biodiesel Board 2007).

Figure 26: Biodiesel production capacity in several European countries 2006 (1,000 tons)



Source: Based on Verband der deutschen Biokraftstoffindustrie e.V. 2007

Besides biodiesel, bioethanol is another main pillar of biofuels within the EU. As illustrated in table 8 the installed bioethanol production capacity within the EU is estimated to 2.5 million tons (what equals to 3.2 billion litres) in 2007. The largest production capacities are located in France, Germany and Spain. “Tereos” and “Christanol” are the companies with the largest production capacity in France. In Germany the main companies in this branch are “Verbio” and the “CropEnergies AG”. In Spain three enterprises (“Ecocarburantes Españoles”, “Bioetanol Galicia” and “Biocarburantes Castilla & Leon”) branch off the market of bioethanol production.

Table 8: Installed bioethanol production capacity in the EU in 2007

Member states	Company	Production capacities in million l (in million kilo)	Feedstock
Bulgaria	Euro Ethyl GmbH (Silistra)	10 (8)	Cereals
Czech Republic	Agroetanol TTD	20 (16)	Sugar beet
France	Tereos (Artenay, Morains, Origny Sainte-Benoîte)	40 (32)	Sugar beet
	Tereos (Provins)	30 (24)	Sugar beet
	Tereos (Morains)	40 (32)	Sugar beet
	Tereos (Origny Sainte-Benoîte)	300 (239)	Sugar beet/ wheat
	Tereos (Lillebonne)	250 (200)	Wheat
	Cristanol (Arcis sur Aube)	100 (80)	Sugar beet
	Cristanol (Betheniville, Bezancourt)	150 (120)	Sugar beet
	Cristanol/Deulep	40 (32)	Sugar beet
	Saint Louis Sucre (Eppeville) Ryssen	90 (72)	Sugar beet
	CropEnergie Ryssen (Dunkerque)	30 (24)	Raw alcohol
	Amylum		
Germany	Verbio Vereinigte BioEnergie AG (Zörbig)	100 (80)	Cereals
	Verbio Vereinigte BioEnergie AG (Schwedt)	230 (183)	Cereals
	KWST (Hannover)	40 (32)	Cereals/ wine alcohol
	CropEnergies AG (Südzucker) (Zeitz)	260 (207)	Cereals
	SASOL (Herne)	76 (61)	Cereals
Hungary	Hungrana (Szabadegyhaza)	75 (60)	Cereals
	Györ Distillery (Györ)	40 (32)	Cereals
Italy	Alcoplus (Ferrara)	42 (33)	Cereals
	Silcompa (Correggio)	60 (48)	Raw alcohol
	IMA (Bertolino Group)	200 (160)	Wine alcohol
Latvia	Jaunpagastas (Riga)	12 (10)	Cereals
Lithuania	Biofuture	31 (25)	Cereals
Netherlands	Royal Nedalco	35 (28)	Cereals
Poland	Akwawit (Leszno)	100 (80)	Cereals
	Cargill Polska (Wroclaw)	36 (29)	Cereals
Romania	Amochim	18 (14)	Cereals
Spain	Ecocarburantes Españoles (Cartagena)	150 (120)	Cereals/ wine alcohol
	Bioetanol Galicia	176 (140)	Cereals/ wine alcohol
	Biocarburantes Castilla & Leon (Salamanca)	195 (155)	Cereals
Sweden	Agroetanol (Norrköping)	50 (40)	Cereals
	SEKAB	100 (80)	Wine alcohol
Total		3,206 (2,553)	

Source: European Bioethanol Fuel Association 2007a

In table 9 the bioethanol plants are listed which are under construction till mid 2008. This list shows that the production capacity will grow by more than 2.7 million tons (what equals to 3.4 billion litres). This complies a doubling with the current production capacity. The plant of "Ensus" with the largest production capacity will be located in the UK with 400 million litres, but significant production capacities will be added in France, Belgium or the Czech Republic as well. Main reasons for this development are the higher targets of many EU countries concerning the use of biofuels and rising crude oil and energy prices in recent years.

Table 9: Additional bioethanol installed production capacity by mid 2008 (all under construction) in the EU

Member states	Company	Production capacities in million l (in million kilo)	Feedstock
Austria	Agrana	240 (191)	75% wheat, 15% maize
Belgium	BioWanze SA (Wanze)	300 (239)	Sugar and cereals
	Alco Bio Fuel (Gent)	100 (80)	Wheat
	Amylum (Aalst)	35 (28)	Wheat
Bulgaria	Euro Ethyl GmbH (Silistra)	30 (24)	Maize
	Crystal Chemicals	13 (10)	
Czech Republic	PLP (Trmice)	100 (80)	Cereals (possibly sugar as well)
	Agroetanol TTD (Dobrovice)	60 (48)	Sugar beet
	Korfil a.s. (Vrdy)	100 (80)	Cereals
	Ethanol Energy (Vrdy)	70 (56)	Cereals, maize
France	AB Bioenergy France (Lacq)	250 (200)	Maize, wine alcohol
	Saint Louis Sucre / Ryssen (Dunkerque)	100 (80)	Sugar beet, molasses
	Roquette (Beinheim)	200 (160)	Wheat
Germany	Nordzucker AG (Klein-Wanzleben)	130 (104)	Sugar beet
	Wabio Bioenergie (Bad Köstritz)	8.4 (6.7)	
	CropEnergies (Zeitz)	100 (80)	Sugar beet
	Danisco (Anklam)	52 (41)	Sugar beet (thick juice)
Greece	Helenic Sugar EBZ	150 (120)	Sugar beet, molasses, cereals
Hungary	Hungrana Kft.	175 (139)	Maize
Netherlands	Nedalco (Sas van Gent)	200 (160)	Cellulose
Slovakia	Enviral	138 (110)	Maize
	Slovnafta (Bratislava)	75 (60)	Wheat
Spain	Biocarburantes Castilla & Leon (Salamanca)	5 (4)	Ligno-cellulose
	Spain SNIACE II (Zamora)	150 (120)	Wheat
Sweden	Agroetanol	155 (123)	Cereals
UK	British Sugar (Downham)	70 (56)	Sugar beet
	Ensus (Teesside)	400 (318)	Wheat
Total		3,406 (2,712)	

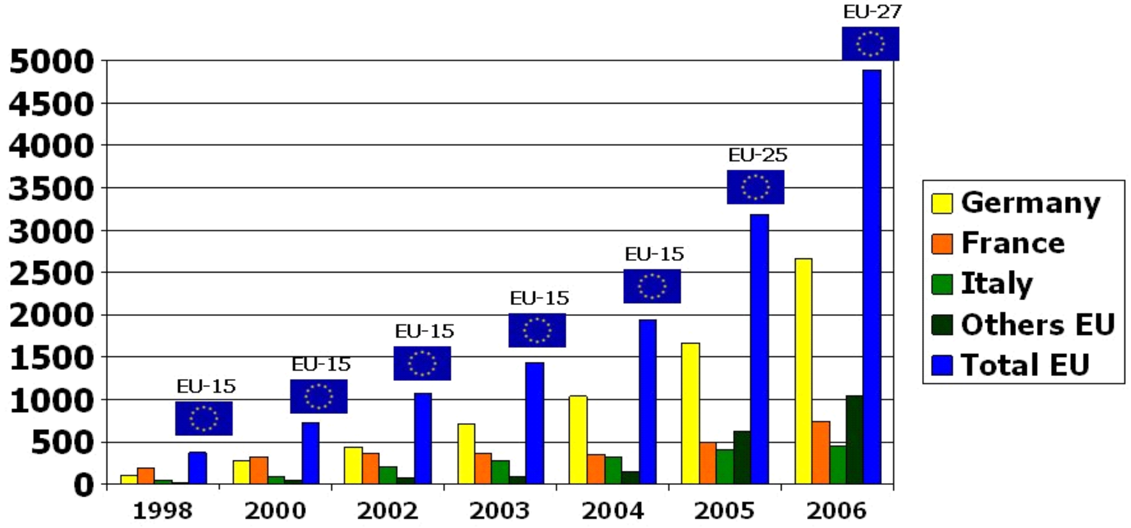
Source: European Bioethanol Fuel Association 2007b

Market volume and prices

Currently experts predict that a 100 % independent supply with bio-based fuels is hardly attainable in the populous countries of the EU. Nevertheless biofuels produced in several countries of Europe can reach a considerable share of the total fuel supply (in Germany for example up to 25 % in the year 2020 is feasible) (FNR 2006b).

With regard to the market volume and prices three groups of biofuels are to observe: biogas, biodiesel and bioethanol whereas the first-mentioned plays a minor part. The EU production of bioethanol and biodiesel amounted e.g. in the year 2004 to 2.4 million tons: 0.5 million tons of bioethanol and 1.9 million tons of biodiesel. This was an increase of more than 25 % compared with the year 2003 (Commission of the European Communities 2006). At the end of 2005 sole the biodiesel production was larger than 3 million tons and already 2006 the total biodiesel production of the EU27 exceeded 4.8 million tons that represents an increase of around 60 % from the figures of 2005. As illustrated in figure 27 the large part of the located capacities was in Germany with over 2.5 million tons biodiesel in 2006 (FNR 2006). In addition, France and Italy have notable capacities for biodiesel production.

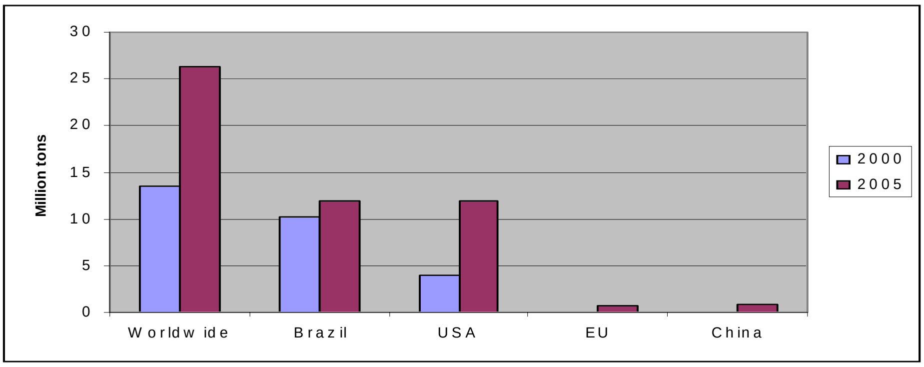
Figure 27: EU and member states' biodiesel production (1,000 tons)



Source: European Biodiesel Board 2007b

Regarding the worldwide significance of biofuels the most important one is bioethanol. With about 13.5 million tons (what equals to 17 billion litres) ethanol Brazil and the United States in each case produced most of them in 2006 (European Technology Platform for Sustainable Chemistry (SusChem) 2007). Figure 28 shows the development of the global bioethanol production from 2000 to 2005.

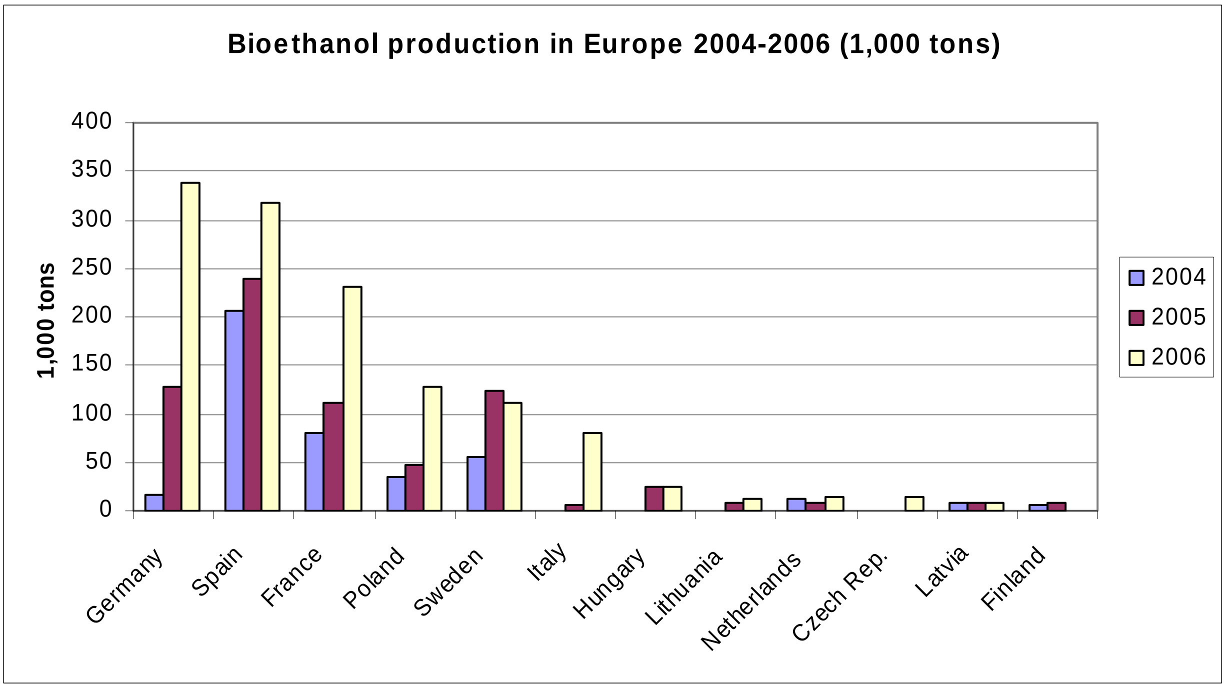
Figure 28: Global production of bioethanol in million tons 2005 (Compared to 2000)



Source: REN21 2006

As illustrated in figure 29 within the EU the production of bioethanol nearly tripled from 2004 with around 0.4 million tons (what equals to 500 million litres) to more than 1.2 million tons (what equals to 1,500 billion litres) in the year 2006. Until 2005 Spain was the main producer of bioethanol with a production volume of around 0.24 million tons (which equals to 303 million litres), but in 2006 Germany took the leading position with a production of about 0.34 million tons (which equals to 430 million litres).

Figure 29: Bioethanol production in Europe 2004-2006 (1,000 tons)



Source: European Biomass Industry Association 2007

Biofuels are pioneers on the fuel market and as such they are more expensive than fossil energy sources (FNR 2006b). The costs of using biofuels depend on the share of imports, the competitiveness of agricultural markets and the cost of fossil oil.

In the EU25 production costs of bioethanol from wheat amounted to 0.54 € per litre in 2005 (Sen 2006). The production costs of fossil benzine were by factor 1.6 lower (at 50 US $/barrel crude oil). Since a litre of bioethanol contains less energy (67 %) the production costs of bioethanol were 2.3 times higher than pure fossil benzine. According to the EU Strategy for Biofuel (2006) with the technologies currently available, EU-produced bioethanol was estimated to break even at oil prices of around 90 € per barrel, while biodiesel becomes competitive with oil prices of about 60 € per barrel (Sustainable Green Fleets (Sugre) 2007).

These figures have to be cautiously interpreted since the production costs to produce bioethanol will also increase by increasing raw material prices, e.g. for wheat (as one of the most important raw material to produce bioethanol within the EU). In the year 2002 within the EU15 prices for wheat were at 120 €/ton (UK Department for Transport 2002). On 18.01.2008 wheat costs 250 €/ton at the MATIF in Paris (Ministerium für Ernährung und ländlichen Raum Baden-Württemberg 2008).

Second-generation biofuels are not yet commercially available but they are expected to be commercialized between 2010 and 2015. It is estimated that their production will be more expensive than first-generation biofuels. Their costs are expected to fall by around 2020, a time period in which both first generation and second-generation biofuels can be expected to be on the market (Sustainable Green Fleets (Sugre) 2007). For the next 10 to 20 years conventional benzine and diesel will remain the most important fuels in the EU, but the relevance of bioethanol and biodiesel will significantly increase during this time period.

In Europe biogas is already used as fuel. Due to several laws (e.g. tax exemption) biogas used for refuelling is applied in The Netherlands (solely landfill gas), in Switzerland and in Sweden. In Sweden for example the motor vehicle taxes are reduced at 30 % for motor vehicles that fuel biogas and in addition petrol stations are committed to provide biogas (Neue Energie 2007). Nevertheless, from these subsidies for biogas the production of biofuels derived from biogas-plants plays only a minor role in Europe and worldwide (FNR 2006).

Feedstock

Besides biodegradable residues from industry and households (e.g. straw, timber, manure, rice husks, sewage, and food waste) many different plants and plant-derived materials can be used for the production of biofuels. In the USA agricultural products specifically grown for the biofuel production include primarily corn and soybeans.

Biodiesel is produced from vegetable oils which are derived from the seeds or the pulp of a range of oil-bearing crops. Currently rapeseed is the main feedstock for biodiesel production in Europe (European Biomass Industry Association 2007b). Biodiesel from rapeseed oil shows good stability and winter performance. This is one of the reasons for its wide application in Central and Northern Europe but other oils have also been used successfully as biodiesel feedstock in Europe. Especially sunflowers are to mention which are cultivated for the production of biodiesel in southern France or Italy.
Biodiesel production in the EU uses today around 3 million ha of arable land (European Biodiesel Board 2007c). For the production of one ton of Rapeseed Methyl Ester (RME), about 2.5 tons of rapeseed is needed which requires an arable land area of 0.77 ha. More detailed data concerning the situation in the single member states are given in table 10.

Table 10: Potential biodiesel yields from rapeseed and sunflower in selected EU member states

	Rapeseed		Sunflower	
	Litres/ha	toe/ha	Litres/ha	toe/ha
Austria	1,055	0.84	113	0.09
Belgium	1,360	1.08	-	-
Germany	1,327	1.05	1,116	0.88
Denmark	1,193	0.94	-	-
Greece	-	-	500	0.40
Spain	608	0.48	429	0.34
Finland	540	0.43	-	-
France	1,343	1.06	1,041	0.82
Ireland	1,287	1.02	-	-
Italy	1,023	0.81	1,156	0.92
The Netherlands	1,298	1.03	-	-
Portugal	-	-	340	0.27
Sweden	846	0.67	-	-
United Kingdom	1,188	0.94	-	-
Czech Republic	1,105	0.88	961	0.76
Estonia	536	0.42	-	-
Hungary	n.a.	n.a	770	0.61
Lithuania	662	0.52	-	-
Latvia	627	0.50	-	-
Poland	923	0.73	-	-
Slovakia	607	0.48	777	0.62

toe = ton of oil equivalent

Source: European Biomass Industry Association 2007b

Ethanol, the most important biofuel worldwide, is produced by fermenting the sugar contained in plants (FNR 2006b). Sugar, starch and cellulose-bearing plants are suitable, mainly wheat, rye and sugar beet. In principle, almost any plants can serve as feedstock for ethanol manufacturing. In practice, the choice of raw material depends on what grows best under the prevailing climate conditions, landscape and soil composition, as well as on the sugar content and ways of processing of the various plants available. The result is a wide variety of ethanol feedstocks and hence production processes. In the USA and Europe, ethanol is manufactured mainly from maize, grain and sugar beet, whereas Brazil favours the fermentation of cane sugar (FNR 2006b). Sugar beet is grown in most of the EU25 countries and produces substantially more ethanol per hectare than wheat as shown in table 11.

Table 11: Potential bioethanol yields from wheat and sugar beet in selected EU member states

	Common wheat		Sugar beet	
	Litres/ha	toe/ha	Litres/ha	toe/ha
Austria	1,792	0.92	6,677	3.42
Belgium	2,847	1.46	6,970	3.57
Germany	2,620	1.34	6,384	3.27
Denmark	2,561	1.31	6,399	3.28
Greece	916	0.47	4,926	2.52
Spain	1,052	0.54	6,181	3.16
Finland	1,057	0.54	3,440	1.76
France	2,554	1.31	7,980	4.09
Ireland	2,996	1.53	4,710	2.41
Italy	1,637	0.84	4,346	2.23
The Netherlands	2,839	1.45	6,472	3.31
Portugal	499	0.26	5,234	2.68
Sweden	2,069	1.06	5,266	2.70
United Kingdom	2,686	1.38	6,355	3.25
Czech Republic	1,568	0.80	4,982	2.55
Estonia	659	0.34	-	-
Hungary	1,365	0.70	n.a.	n.a.
Lithuania	1,050	0.54	2,964	1.52
Latvia	908	0.46	3,036	1.55
Poland	1,215	0.62	3,555	1.82
Slovenia	1,330	0.68	4,040	2.07
Slovakia	1,360	0.70	3,486	1.78

toe = ton of oil equivalent

Source: European Biomass Industry Association 2007a

According to Haagensen (2006), wheat is in Europe the most important raw material to produce bioethanol. A cost-efficient production from wheat starch has been made possible by converting the starch into glucose using amylases (enzymes). It can be purchased at low prices due to the efficient production of amylases by genetically modified micro-organisms in large scale fermentations (Haagensen 2006).

R&D activities

The European Commission has announced within the 7th Framework Programme to continue its support for the development of biofuels and strengthening the competitiveness of the biofuel industry. Within this programme (2007-2013) research activities will concentrate mainly on bringing down the unit cost of fuels by improving conventional technologies and developing second-generation biofuels and by applying life sciences and biotechnology related approaches to improve biomass production systems (Commission of the European Communities 2006).

Recent R&D activities mainly focus on ”second generation biofuels” whereas the potentials of lignocellulosic bioethanol should mainly be analysed. Therefore, lignin and cellulosic rich feedstocks such as short rotation energy crops (e.g. willow, miscanthus or eucalyptus), agricultural residues (e.g. straw and sugar cane bagasse), forest residues, waste woods or municipal solid wastes are used. There are several reasons for shifting to ethanol production from lignocellulosic biomass. With lignocellulosic biomass a far greater source of biomass could be used for bioethanol production. Using lignocellulosic biomass crops, more areas of the world could be cultivated and with this the problem of biofuels competing for land with food crops would be reduced. It is more abundant and less expensive than food crops, especially when it concerns a waste stream with very little or even negative economic value. Furthermore, it has a higher net energy balance which makes it more attractive from an environmental point of view. Thus this option is far more favourably regarded by politicians in the EU as a CO_2 -friendly alternative to fossil transport fuels than corn, wheat or sugar beet bioethanol (European Biomass Industry Association 2007c).

The major barrier to the development of second generation biofuels processes is their capital costs. Due to the relatively inaccessible molecular structure or rather to the complexity of lignocellulosic biomass which is greater than in traditional feedstocks it is currently more expensive due to the added processing and more costly enzymes involved in production (European Biomass Industry Association 2007a). Additionally, this technology is not available on a commercial scale yet. Scaling up still proves difficult and commercially unattractive. Thus the “National Non-Food Crops Centre” (NNFCC) estimates that to establish second generation biodiesel plants 500 million € are required (National Non-Food Crops Centre (NNFCC) 2007). Therefore an important issue is the development of cost-effective and environmentally sound pre-treatment and hydrolysis technologies. Experts assume that second generation biofuels will not achieve relevance on the market before 2010 (FNR 2006b). In contrast to Coal-to-Liquid (CTL) and Gas-to-Liquid (GTL) no commercially operated Biomass-to-Liquid (also called synfuel or sunfuel) plant exists currently in the world (Zwart 2006). Nevertheless, some pilot-plants have been built up within Europe using this technology of which some examples are listed in the following (FNR 2006):

- Pilot-plant in Guessing, Austria, (8MW) with R&D- components to produce MeOH, FT-KW und SNG.
- Projecting a plant for DME-production derived from black liquor (Chemrec AB in Sweden)
- EU-Project CHRISGAS: Biomasse-IGCC and others for the BTL-Production in Vaernamo in Sweden
- EU-Project RENEW: technology-development (and others in Leipzig) under the guidance and integration of partners of the automotive-branch, like VW, DaimlerChrysler, Renault and Volvo

“Biorefinery”-activities

The development of biofuels and strengthening the competitiveness of the biofuel industry is targeted within the 7th Framework Programme. Within this programme (2007-2013) research activities will also concentrate on the concept of biorefineries that aims at the integral use of the biomass and maximising the cost-effectiveness of the final product to which are inter alia biofuels (Commission of the European Communities 2006).

“EUBIA” considers the development and deployment of integrated biorefineries based on sweet sorghum. The economics of such bio-complexes could be interesting and lead, thanks to the many co-products generated, to a bioethanol market price of 450-500 € per ton (European Biomass Industry Association 2007a).

Noticeable is the appraisal of experts which assume that the branch of biofuels will be the trailblazer for the establishment of large bio-processing plants. The experience and know-how of this segment will facilitate the adoption of the production of bulk-chemicals. This approach encloses the further development and practical proving of biorefinery concepts. Like already mentioned this means that different methods and processes will be integrated in one overall concept, i.e. the biorefinery concept (Nusser et al. 2007).

4. Summary

In Europe there exist several refineries that convert biomass into marketable products of different kinds like e.g. chemical products or biofuels. Such plants could be regarded as the forerunner of biorefineries. But running biorefineries, in the sense that these facilities “use multiple forms of biomass to produce a flexible mix of products, including fuels, power, heat, chemicals and materials" (Zwart 2006), exist in Europe only in the function of pilot plants. Some examples of such biorefineries are listed in chapter 3 for the most important industry branches which can adopt biorefinery concepts.

This note gives a literature overview of selected industry branches which could successfully introduce and develop biorefinery concepts and related products in the market. Thus the industrial structure, the market situation and development, the framework conditions as well as R&D activities of the chemical industry, the forestry-industry (pulp and paper industry), the starch industry and the biofuels industry are analysed in this literature overview based on available information in scientific literature, project reports and statistical information.

The chemical industry's contribution to the EU gross domestic product amounts to 2 % and it is employer of about 4 million people (European Chemical Industry Council (Cefic) 2002). As described in chapter 3 the chemical industry already produces bio-based chemicals like polymers and oleo-chemicals. Currently 5 % of worldwide chemical sales are estimated to be generated from bio-based feedstocks. The consulting company McKinsey estimates a doubling of sales in the field of pharma ingredients, polymers and enzymes from 2005 to 2010. Different framework conditions could have inhibiting (e.g. the current arrangement of “REACH”) or boosting (e.g. the idea of a “Green Chemistry”) impacts for the further development of the application of biorefinery concepts within the chemical industry. Furthermore substantial R&D efforts are required to boost the future penetration of biorefinery concepts in the chemical industry: these R&D expenditures are often higher than for crude-oil based pathways for which optimization processes have been already realised in recent decades.

Besides traditional products biorefinery concepts which could fully use the incoming biomass of different feedstocks can contribute to develop value-added products (like e.g. speciality chemicals) in the pulp and paper industry of the EU which is already on of the main industry sectors which uses this concept. The largest producer of pulp within the EU is Finland and Sweden, while paper and paperboard are mainly produced in Germany, Finland and Sweden. The turnover of the pulp and paper industry amounted to over 78 billion € in 2006. Several factors favour the adoption of biorefinery concepts in the paper and pulp industry like e.g. the need of the industry for innovative and value-added products (against the background of negative price trend on the markets of paper, paperboard and pulp) or the globally increasing demand for energy and chemical specialities. In addition, this industry already has an existing infrastructure for the adoption of biorefinery concepts but high capital costs impede a fast adoption of new concepts within the industry.

Sugar and starch are one of the main feedstocks that could be used in biorefineries. As illustrated in chapter 3 the total industrial use of renewable raw materials was approximately 9 million tons in the year 2003. Thereof 14 % were allotted to sugar and 34 % to starch. Starch is the source material for the production of polymers or bio-plastics. In the year 2005 the costs of raw material for bio-plastics were more than double compared to the raw material prices of standard thermoplastics. But with a further increasing of crude oil prices the relative costs of bio-plastics most probably will decrease and thus contribute to a further market acceptance of bio-plastics in future. Sugar is already widely used as raw material for sugar refineries. It is also an important raw material for the production of bio-plastics. Additionally it can be used as a nutrient in the production of PLA or other polymers. Another application for sugar is the production of bioethanol. It is expected that after the reform of the sugar market organisation less sugar is refined from sugar beet within the EU and thus the crop can increase its relevance as raw material base of bioethanol.

In the recent five years the produced amount of biofuels increased significantly on a global scale. The consulting company McKinsey estimates that the global sales of biofuels will further increase from over 20 billion € to more than 40 billion € in the years 2005 to 2010 (European Technology Platform for Sustainable Chemistry (SusChem) 2007). The most important reason of this development is the political target of several parts of the world to stimulate the use of biofuels due to e.g. climate change, security of supply and financial reasons. It is the aim of the EU to increase the use of biofuels to 5.75 % till 2010. Current R&D activities are mainly focused on second generation biofuels (e.g. BTL fuel). Due to the already existing and planned plants experts assume that the know-how and experience of the biofuel branch will facilitate the adoption of further developed biorefinery concepts.

In conclusion it has to be stated that there exist some refineries that convert biomass into several (mainly traditional) products like e.g. starch and sugars or oleochemicals. However there were hardly any biorefineries found that apply innovative biorefinery concepts (in the sense that they use a multiple mix of biomass to produce a flexible portfolio of products, including fuels, power, heat, chemicals and materials) as basis of their business activities in Europe. The main barrier is currently the large capital costs of relatively unproven biorefinery concepts. The costs for an extension of existing facilities are higher than the expected benefits that could potentially arise by facilities that can fully use the biomass. Additionally, agriculture and forestry-based raw materials are expensive (and often rise in price as well in case further demand is created e.g. due to the production of bio-energies) and thus currently the markets of bio-based products are often limited to specific market niches. Often there is low demand for such products not least due to higher market prices and/or no specific advantages for industrial or private users beside the bio-based character of such products (Menrad et al. 2006) or the market is not fully exploited yet. A further problem is that there is no systematically organised value chain, which ranges from raw material production over the processing industry to the retailer/wholesaler and the end consumers (BioMatNet 2007). Drivers for the application of biorefinery concepts are in particular political targets (and corresponding regulation) e.g. in the fields of biofuels as well as increasing prices for energy and raw materials (mainly crude oil and gas).

Under current market conditions biorefineries can utilise its size, location and flexible production methods to develop niche markets. The products derived from biorefineries can compete economically, if they are significantly better than those produced by conventional production systems. Furthermore, it is necessary to develop and implement target-oriented and co-ordinated marketing activities within a specific application field of bio-based products. In particular, actors with a bottleneck-function (like e.g. handicrafts people, industrial advisors) should be informed about the characteristics and advantages of the different bio-based products so that they are able to convince the final customers about the advantages of such products (Menrad et al. 2006). Nevertheless, it can be concluded that there exist additional opportunities to adopt biorefinery concepts economically successful in Europe in the four analysed industry branches in the medium to long-term.

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