Use of renewable raw materials with special emphasis on chemical industry

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Context

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Executive Summary

The EEA wants to support the sustainable use of natural resources and further develop sustainable consumption and production patterns in the production sector. A broader use of renewable raw materials (RRM) and the substitution of fossil based materials and products by RRM could be an important step to that goal. RRM as a feedstock for the industrial production of materials, chemicals and other biobased products can save fossil resources and reduce negative impacts on the environment. Further, it can also be a strong driving force for innovation, as RRM are the only current alternative source of carbon to crude oil for the production of chemical products. Therefore, the goal of this study is to give an overview on the sources and the current uses of RRM in the chemical industry as well as an overview on environmental and macroeconomic aspects of the use of RRM.

To identify all the different uses of RRM, it is necessary to specify what materials fall within the definition of RRM. **Chapter 2** provides a definition of RRM developed by the nova-Institut in an expert consultation process. Section 2.2 gives a summary of 13 different kinds of raw materials, their resources, fields of application and the industries involved. These raw materials are described in detail in Section 2.2.1 to Section 2.2.13. For each identified RRM the key facts on total production volume, the main industrial production lines and actual quantities in industrial use in Europe are shown where available.

According to the Lead Market Initiative of the European Commission (2007), products based on RRM are seen as one of the most promising future markets, with a high potential for innovation. Therefore **Chapter 3** concentrates on innovative biomaterials. These products are often directly visible to the end-user, which means these biobased materials will play an important role in the promotion of RRM in industrial use, and will generate increasing demand for these materials. Innovative products that are already widely used, like Wood-Plastic-Composites and new products like biobased plastics that have a small but rapidly increasing market share, are described in detail. The use of Glycerol as platform chemical is presented as example of a developed product waiting for the best market conditions for market entrance. Finally, we use the biorefinery concept to demonstrate an innovative production process on the way from the laboratory to full scale industrial use.

Chapter 4 presents examples of the substitution of fossil-based materials by renewable-based materials. The stepwise replacement of tensides produced from chemical raw materials by tensides based on RRM demonstrates the influence of consumer demand. Due to the demanded biodegradability and better skin kindness, nearly 50 % of the tensides employed in the production of detergents and cleaners, cosmetics and pharmaceuticals come from renewable resources. In some cases the replacement of chemical-based materials by RRM is driven by cost savings. We use the production of Vitamin B_2 to illustrate this; the manufacturing cost of the biobased production is 40 % less, the process needs just 40 % of the raw material and produces 95 % less waste compared to the chemical process. Loose-fill-packaging material and ethanol, two more examples of biobased substitutes for chemical products, are also described in more detail.

Chapter 5 provides statistics on the volume and structure of the use of renewable resources as materials in Europe. The statistics offer an overview of existing and available data. Based on the available data, we conclude that the production and use of wood is, at 240 million tons (in 2005), by far the largest sector of industrial RRM use, followed by plant oils, sugar, starch and proteins, natural fibers and others. A short introduction on data availability on RRM production and consumption in Europe is followed by a description of the domestic production and consumption of oilseeds and plant oils, fibre crops, sugar beet and starch crops.

Section 5.3 focuses on the industrial use of RRM. The total use of RRM, without wood, in Europe is about 9 million tonnes. The chemical industry used 6.4 million tonnes; other industries processed 2.65 million tonnes. The raw materials are divided into vegetable oils and fats (31 %), starch (35 %), sugar (14 %), chemistry and natural cellulose fibres (16 %) and other (4 %).

About 822 million m^3 of wood resources were used in Europe in 2005. Industrial roundwood (482 million m^3) is the largest European wood resource, followed by industrial residues (118 million m^3) and forest restwood and bark (48 million m^3). Other registered sources account for 126 million m^3, resulting in a production/consumption balance gap of 47 million m^3. Approximately 341 million m^3 (41 %) were used for energy uses and 481 million m^3 (59 %) for material uses. From the whole wood resources 26 % were used in the sawmill industry, 11 % in the panel industry and 19 % in the pulp and paper industry.

The total acreage for renewable resources in the EU in 2005 amounted to approximately 5.07 million ha – approximately 5.2 % of agricultural land use. Of this, 900 000 ha were for the production of starch crops, 425 000 ha of oil seed, 137 000 ha of sugar beet, 113 000 ha of medicinal plants, 460 000 ha for cotton and 135 000 for other fibre plants. A total of 2.27 million ha was cultivated for material use and 2.8 million ha for energy use

A rough estimation of the economical value of biobased products allows the estimation of a total market value of the biobased or partially biobased products of EUR 450 000 million in the EU-25 manufacturing sector, whereas the market value of truly biobased products is around EUR 250 000 million. The dominant biobased products are pulp and paper (EUR 95 700 million), wood and ligneous material (EUR 55 500 million), pharmaceuticals (EUR 28 400 million), fibres (EUR 9 400 million) and detergents and solvents (EUR 4 100 million).

Due to data availability, Section 5.4 focuses on France, Germany, Great Britain and the Netherlands. These lead countries have sufficiently detailed base data on the industrial material use of renewable resources. Several country-specific studies and analyses are summarized for these four countries, but due to different study approaches a direct comparison was not possible.

Environmental and economical aspects of the use of RRM and the potential land use competition between industrial and energy use of RRM are discussed in **Chapter 6**. From an environmental point of view (Section 6.1) many biobased products show an improved greenhouse gas balance over the whole life cycle, and both production and disposal is normally less toxic and energy demanding compared to products based on fossil resources. However, the environmental advantage of biobased products has still to be determined for many production lines; a necessity to ensure that those RRM are used in the most efficient way. Life cycle assessment according to DIN EN ISO 14040 and 14044 is an adequate instrument for this.

From a macroeconomic perspective (Section 6.2), the material use of RRM has clear advantages over energy recovery, especially as the material used can eventually end up, after several material applications, as raw material for energy recovery. An increased material use of RRM, used in cascades, would not withdraw the biomass from energy recovery, but simply temporary elongate the supply. A more efficient use of the agricultural biomass contributes towards reducing greenhouse gas emissions, which makes agricultural land use in general more efficient and more sustainable.

The use of RRM for material use must not endanger food security or the goals of nature conservation and climate protection. With respect to an increasing world population, decreasing fossil and natural resources, biomass production for food, feed, fuel or fibre has to augment to meet the worldwide increasing demand. This increase may be achieved by higher yields and/or by taking additional land under agricultural cultivation. Landuse change and indirect landuse change (iLUC) can have strong environmental and social implications. It is a driver of biodiversity loss and of greenhouse gas emissions. These aspects are discussed in Section 6.1 and 6.3 in more detail. Section 6.4 describes the perspectives for industrial use of RRM in Europe.

Finally the findings are summarized in **Chapter 7, concluding that** the present study gives a general overview on the industrial material use of RRM in Europe and a first assessment of the environmental aspects of RRM. The environmental impacts of RRM are highly complex and affect global, national and regional levels. Therefore further research on the environmental implications of RRM is needed to provide a more sophisticated basis for political decision makers.

1. Introduction

The European Commission in its Lead Market Initiative (2007) identified biobased products, made from renewable raw materials such as plants and trees, as one of the promising future markets. The market segment includes products and materials such as bio-plastics, bio-lubricants, surfactants, enzymes and pharmaceuticals. The EEA wants to support the implementation and the further development of the EU Action Plan on Sustainable Consumption and Production and the review of the Thematic Strategy on the Sustainable Use of natural Resources. A broader use of renewable resources and the substitution of fossil based materials and products by renewable raw materials will be an important and necessary step for both objectives.

From an environmental point of view, renewable raw materials for chemical synthesis are considered on the one hand to reduce environmental impacts of the use of fossil resources, e. g. by fewer greenhouse gas emissions. On the other hand the benefits of using renewable raw materials for chemical industry might be challenged by land use competition and landuse change due to the worldwide increasing demand for biomass for food and fodder and for bioenergy/biofuels.

Renewable raw materials should be produced and used in a sustainable manner to avoid negative impacts on climate, air, water and soils. Toward this goal some approaches to determine and establish sustainability requirements for biomass production (esp. for energy use) in agriculture and forestry have recently been developed or are still under development (for instance the FSC label for wooden products or the so called Sustainability Ordinance for Biofuels of the German Federal Government[1]). The European Renewable Energies Directive (RES-DIR)[2] prescribes the Member States how to apply bioenergy sustainability requirements. Furthermore, the Commission issued the report “Accelerating the development of the market for Bio-based Products in Europe” [3], which was prepared by the inter-service task force in connection with the communication on the Lead Market initiative.

Some newly developed biotechnology based materials even have properties that make them superior to regular plastics. In some segments of chemicals they represent an important part of the start up material; in others they are hardly used. The same positive assessment applies for renewable materials to replace chemical products, e.g. plastic material.

However, a comprehensive overview on the sources and current uses of RRM in the chemical industry in Europe as well as on environmental and economic aspects of the use of RRM is not yet possible to give due to the limitations in available data. Therefore the EEA has asked for an overview on the sources, current and potential uses of RRM for the chemical industry. The EEA wants to disseminate the results of the prestudy in brochure form to promote the cultivation and use of renewable resources so that they may contribute to a more sustainable consumption and production.

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[1] Sustainability Ordinance of the German Federal Government on the sustainable production of biomass for the use of biofuels, which prescribes that only sustainably produced biofuels can be considered for the quotas acc. to Biofuel Quota Act or tax benefits (Biokraft-NachV, BMF vom 16. September 2009), http://www.bundesfinanzministerium.de/nn_53530/DE/Buergerinnen__und__Buerger/Mobilitaet__und__Reisen/090915__Biokraftstoff.html?__nnn=true

2 DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC: See under http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF

3 http://ec.europa.eu/enterprise/leadmarket/biobased_products.htm

2. Overview on the uses of renewable raw materials in the chemical and technical industry in Europe

According to the Lead Market Initiative of the European Commission (2007), products based on renewable raw materials (RRM) are seen as one of the most promising future markets. The use of RRM as a feedstock for the production of materials, chemicals and other biobased products can save fossil resources and reduce negative impacts on the environment. It can also support the agricultural and forestal sector, and lead to innovations in, for example, biomaterials or biobased chemicals. This study has identified potentials for a future increase of the biobased chemical and technical industry for several feedstocks.

In a first step of this study the relevant RRM and their application fields are identified. This qualitative data are then structured to form an impression about the whole bandwidth of industries dealing with RRM.

2.1 Definition of industrial use of renewable raw materials

To identify all the different uses of RRM it is necessary to specify what falls under the definition of RRM. In accordance with different experts we define RRM as:

> […] plant, animal and microbial biomass, which are - also through food chains – based on the photosynthetic primary production and are used by man outside the food and feed area for material or energy production.
>
> Industrial material use of RRM is the use of biomass as raw material for the (industrial) production of goods of any kind.

This definition was developed by the nova-Institute and is based on different published and in-use definitions on RRM (Raschka et al., 2009a, 2009b).

According to this definition RRM include all agricultural and forestal raw materials such as oils from oilseed crops, starch from cereals and potatoes, sugar from sugar beet, and cellulose from wood and straw, fibers from fiber plants and some agricultural resources. By far the largest part of all applied RRM is represented by wood, cultivated in forests and used in the forestal industry.

RRM can be converted into lubricants, solvents, surfactants, polymers and specialty chemicals through physical, chemical and biochemical processes in the chemical industry. They also can be used as drugs in the pharmaceutical industry, as fibers in the textile industry or as materials in a broad variety of applications.

2.2 Overview of industries and material uses of renewable raw materials

Table 1 gives an overview of the different industries and material uses of RRM. It shows the different kinds of raw materials, the fields of application and the industries involved. It does not show quantitative data; this can be found in the detailed overview given in the following sections.

Table 1 Industries and material uses of renewable raw materials

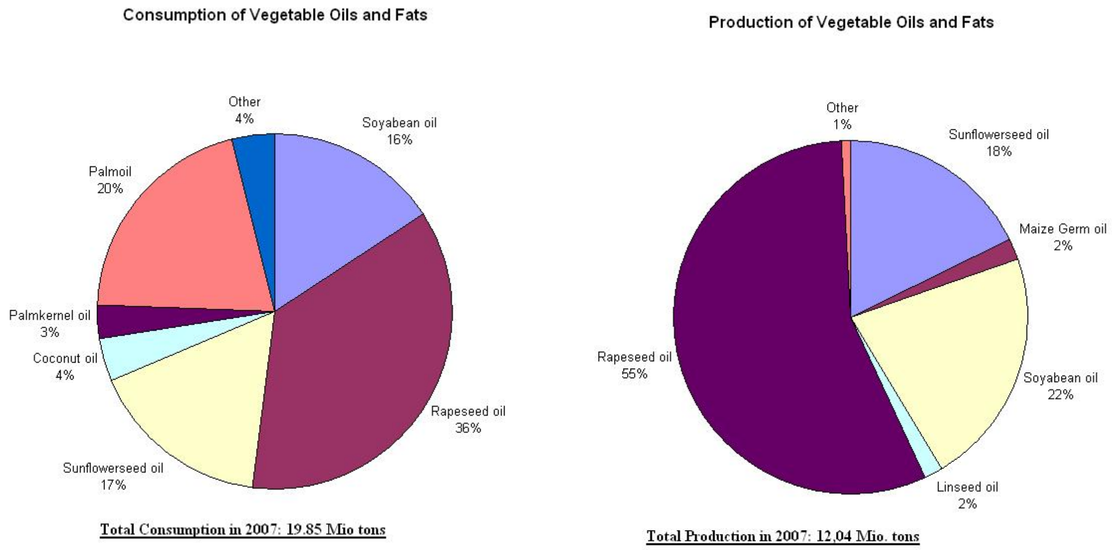
Raw Materials	Plants (and other resources)	Applications	Types of Industry
Plant oils, animal fats	In Europe: rape, sunflower, olive, (animal fats) Imported: soybean, oil palm	Lubricants, surfactants, binders, paint additives, polymers, polymer additives, linoleum, glycerol (via biodiesel)	Chemical industry, pharmaceutical industry, technical industry, plastics industry
Proteins: gelatine, caseine and other	(Animal tissue, milk protein, yeast extracts)	Pharmaceutical products, photo films, paper coating, glues, paints, polymers	Chemical industry, pharmaceutical industry, technical industry
Sugar, molasses, syrup	In Europe: sugar beet Imported: sugar cane	Bulk chemicals, fine chemicals, polymers, cosmetics (alky polyglycosides), pharmaceuticals, binders for betony e.g. , bioethanol	Chemical industry (fermentation), pharmaceutical industry, plastics industry
Starch Starch derivates, syrups	In Europe: wheat, potato, maize, other cereals Imported: rice, cassava	Paper starch, glues, binders, chemicals, cosmetics, polymers, textile starch, bioethanol	Pulp and paper industry, chemical industry (fermentation), pharmaceutical industry, plastics industry
Wood	In Europe: soft wood, hard wood Imported: tropical hard wood	Construction wood, packaging, furniture, derived timber products (chip board, wood plastic composites e.g.), paper, cellulose	Pulp and paper industry, timber industry, textile industry (cellulosic fibers), plastics industry
Natural fibers	In Europe: hemp, flax, nettle, cotton Imported: cotton, kenaf, jute, abaca, sisal, ramie	Textiles, technical textiles, non-wovens (insulating material e.g.), fiber reinforced plastics, paper	Textile industry, pulp and paper industry, plastics industry

Straw	Wheat and other cereals	Fertilizer, farm litter, insulating material, cellulose	Agriculture, construction industry
Natural rubber	Imported: natural rubber	Tires, rubber products, sanitary products (condoms e.g.), healthcare products (rubber gloves e.g.)	Tire industry, rubber industry
Cork	Cork oak	Corks (for wine), cork products, cork composites	Cork industry, construction industry, furniture industry
Natural paints	Different dye plants	Paints (especially for textiles)	Textile industry
Resins, Waxes	Different plants	Linoleum, other uses	
Tanning agents	Different plants with tannins	Leather tanning	Leather industry
Miscanthus	Miscanthus	Farm litter, chip boards	Agriculture, timber industry
Medicinal plants	Different medicinal plants	Drugs for pharmaceuticals, health food, cosmetics	Pharmaceutical industry

2.2.1 Plant oils

In 2007 the global production of natural oils and fats totalled around 160 million tonnes, of which 125 million tonnes were used in food and feed applications and only 16 million tonnes were used as RRM in industrial processes (Hill, 2008). Europe (EU-27) represents nearly 8 % (12.4 million tonnes) of the world production, mainly based on rape, sunflower and soya (see Figure 1). These are the only oil crops cultivated in significant quantities in Europe. Small quantities of linseed, olive and cotton are grown in Europe for oil and fat production (FEDIOL, 2009). Very small quantities of crambe, false flax and poppy, from which food oils are produced, are also cultivated either for market or agricultural experiments (e.g. Pude & Wenig, 2005; Heyland et al., 2006). Moreover, high quantities of soya, palm oil and laurin oils are imported to Europe.

Figure 1 Production and Consumption of Vegetable Oils and Fats in the EU-27 in 2007



Source: FEDIOL, 2009

The use of plant oils and animal fats as industrial materials includes the production of lubricants, tensides for detergents or pesticides, binders and paint additives, polymers and polymer softeners as well as special applications like linoleum or factice and bitumen alternatives based on rape oil. The exact applicaton of the oils within the oleochemical industry is determined by the composition of the fatty acids contained in the oil. Coconut oil and palm kernel oil, for example, are suitable for further processing into surfactants and cosmetics because of their high proportion of short or medium chain fatty acids (mainly C12 and C14). Palm, soybean, rapeseed and sunflower are used in polymer applications and lubricants because they contain mainly long-chain fatty acids (e.g. C18). Via the production of biodiesel from rape oil as a biofuel, there are Huge amounts of glycerol are used as a chemical platform in the production of biodiesel from rape oil (0.1 tonnes glycerol for 1 ton biodiesel). It can also be used in a large variety of applications including cosmetics, soap or softener for plastics.

The main product line of plant oils is the production of surfactants or tensides, which are primarily based on laurin oils (palm kernel oil and coconut oil). The word surfactant is short for ***surf***ace ***act***ive ***a***ge***nt***. One part of the surfactant molecule is hydrophilic and one part is hydrophobic and it interposes itself between water and water-insoluble substances. In 2002 the European market in surfactants totalled approximately 2.5 million tonnes, of which around 30 % come from vegetable resources[4]. Typically, the hydrophobic part can for example come from oleo-chemical raw materials derived from rapeseed, sunflower, palm, or other plants. Around 50 % of total production of the hydrophobic fraction is based on RRM (Holmes, 2005).

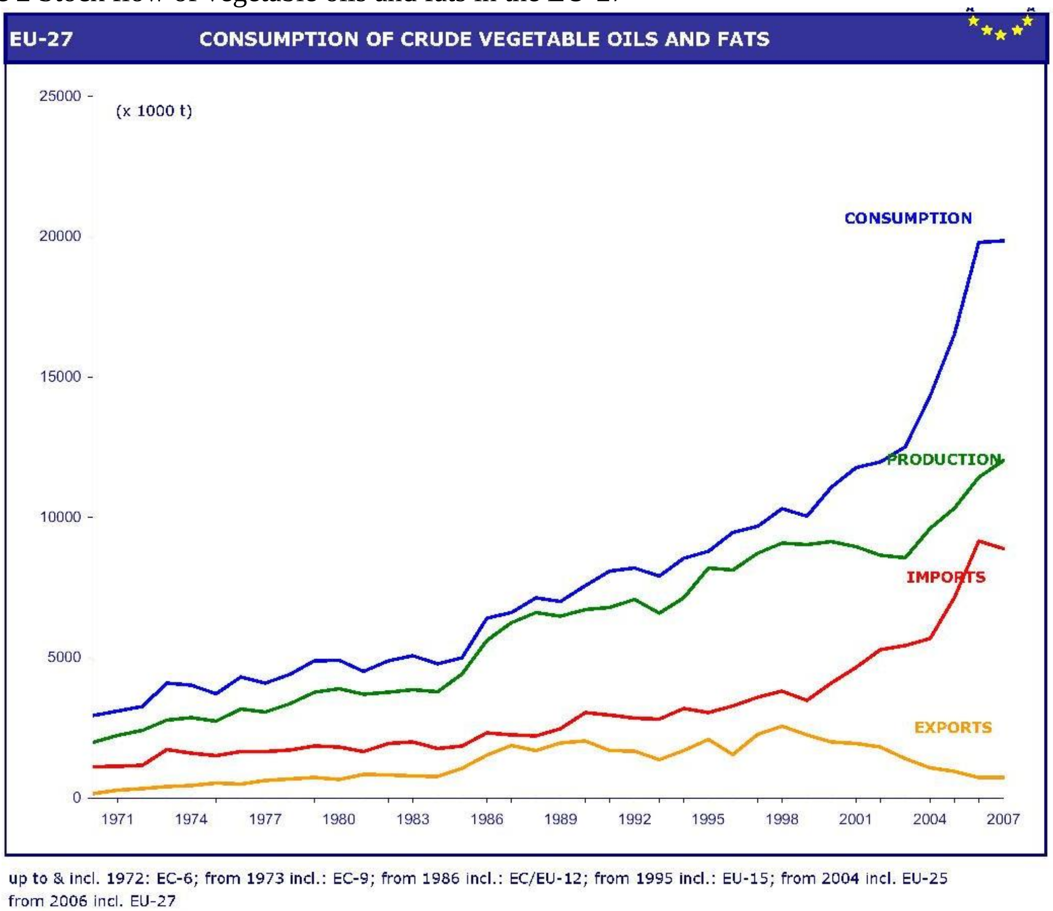
Tensides for detergents and cleaners is the most substantial group within the product line of surfactants (Peters, 2006), followed by the fraction used for the production of alkyl polyglycosides and other products in cosmetics and pharmaceuticals. About 20 % of the produced surfactants are utilized for the formulation of pesticides and only a small part is used in the textile and leather industry (Hill, 2008).

Lubricants are the second leading cluster of products made by plant oils. Lubricants are complex formulated products consisting up to 90 % base oils mixed with functional additives to modify the natural properties. In most bio-lubricants, vegetable oils are used as base oil, but only 50 % of the oil

[4] Report of the Taskforce on bio-based products: "Accelerating the development of the market for bio-based products in Europe" Preparation document to {COM (2007) 860 final}. Available under http://ec.europa.eu/enterprise/policies/innovation/files/leard-market-initiative/prep_bio_en.pdf

must be from renewable resources to achieve the label bio-lubricant (Oertel, 2007; Bremmer & Plonsker, 2008). However, no universal agreement exists on the origin and chemical composition on bio-lubricants, which means that analysis of the statistics, is difficult.

Figure 2 Stock flow of vegetable oils and fats in the EU-27



Source: FEDIOL, 2009

Bio-lubricants are utilized as hydraulic fluids, metal working fluids, grease, two-stroke engine oil, concrete mould release agents and chainsaw oils. They are mainly used in machinery and equipments operating in environmentally sensitive areas (e.g. agriculture and forestry machinery, jet-skis, snow mobiles etc.) The market share of bio-lubricants in Europe was estimated to be 2 % (127 000 tonnes) in 2006[5], but the usage is quite different around Europe. As mentioned above, no universal agreement about the definition of bio-lubricants exists and therefore figures about market share and production volume differ widely. For example Bremmer & Plonsker (2008) give a market share of bio-lubricants in Germany up to 15 % and for the Scandinavians about 11 % without stating production volumes. Other countries like France or Spain are below 1 % market share. Other publications refer to a market share of around 4 % in Germany; 46 500 tonnes of bio-lubricants out of 1.05 million tonnes of total lubricants consumption in 2005 (Peters, 2006; Wenig, 2007). Theissen (2006) calculates a consumption of 23 000 tonnes of bio-lubricants (market share 2.3 %) for Germany. Whereas Theissen (2006) explain the difference between his calculation and figures in Peters (2006) by highlighting difficulties in data collections especially in the field of chain saw oils.

Nevertheless, the market for bio-lubricants is seen as rapid growing market with growth rates above 3.5 % per year and market potential for some products of 100 %. For example chainsaw oil – which has a total annual consumption of up to 8 000 tons - because of its usage in environmental critical operation areas (Theissen 2006)).

[5] According to Frost and Sullivan Study 2007

In paints and varnishes, plant oils are used as binding additive or as other additive. Linseed is the main oilseed, followed by tung and soya oils, that is used in paints and inks. These are used because they contain high levels of polyunsaturated fatty acids, which aid drying. There is a general increase in use and demand for printing inks, paints, varnishes, coatings and wood impregnation products based on oils from renewable resources (Holmes, 2005).

Solvents are mainly used as parts of inks, paintings, surface coatings or for metal cleaning. Today the majority of solvents are based on petrochemical products, but modified vegetable oils have very good solvating properties and the use of such materials would be compatible with many areas of current solvent use. There is an increasing interest in the development of these solvents for environmental and health reasons. Today only 1.5 % or 60 000 tonnes come from renewable resources, but a potential increase up to 12 %-40% is projected depending on future environmental regulations[6].

In the production of plastics, plant oils are used mainly as softener in petroleum based plastics like polyvinylchloride or polyurethane.

2.2.2 Proteins

Agricultural protein plants such as lupine, protein pea and faba bean are not used as industrial materials and also play only a minor role in overall protein usage (Pude & Wenig, 2005).

To date animal proteins are only of importance for use in the chemical-technical and biotechnological industry. The majority of plant protein, which are mainly produced as a by-product of the oil mills from the production of vegetable oils (rapeseed and soya cake, extraction shreds) and from the extraction of starch from grain, is used in the feed industry. On average in Europe around 27 % oil shreds and cake (especially soy, sunflower and colza cake) or 40 % protein feed (also leguminous plants, corn gluten and fish meal) with an average protein content of about 20 % (FEFAC, 2008) are used.

Gelatin, made from pigskin and the bones of both cattle and pigs from butcher residues, is the main protein used in chemical-technical and pharmaceutical industry. Nevertheless, two thirds of the produced gelatin is used in the food industry and half of the rest is used in the feed industry. The main applications in the pharmaceutical and health industry are coatings for tablets and vitamin supplements (hard and soft capsules) and as gelatin suppository. In addition, gelatin is used as haemostatic sponges and blood plasma substitute. In analog photography, gelatin is used as the basis for photosensitive layers on the film and photo paper. Even modern printer paper for colour prints is coated with gelatin (GME, 2008).

Gelatin casein made from milk protein is an important protein source for the technical industry. It is primarily used as a coating material for glossy papers as well as additive to colors (about 1 – 2 % depending on the manufacturer). Moreover, it finds use as adhesive label glue on glass bottles. Yeast extract is another source of protein and is used in the pharmaceutical, food and biotechnological industries as a culture medium for microorganisms.

Agricultural protein plants such as lupine, protein pea and faba bean are mainly used as lifestock fodder and not yet in industry. As there seems to be a demand for proteins, for example for production of biopolymers and biodegradable material, there is a high potential for industrial use in future.

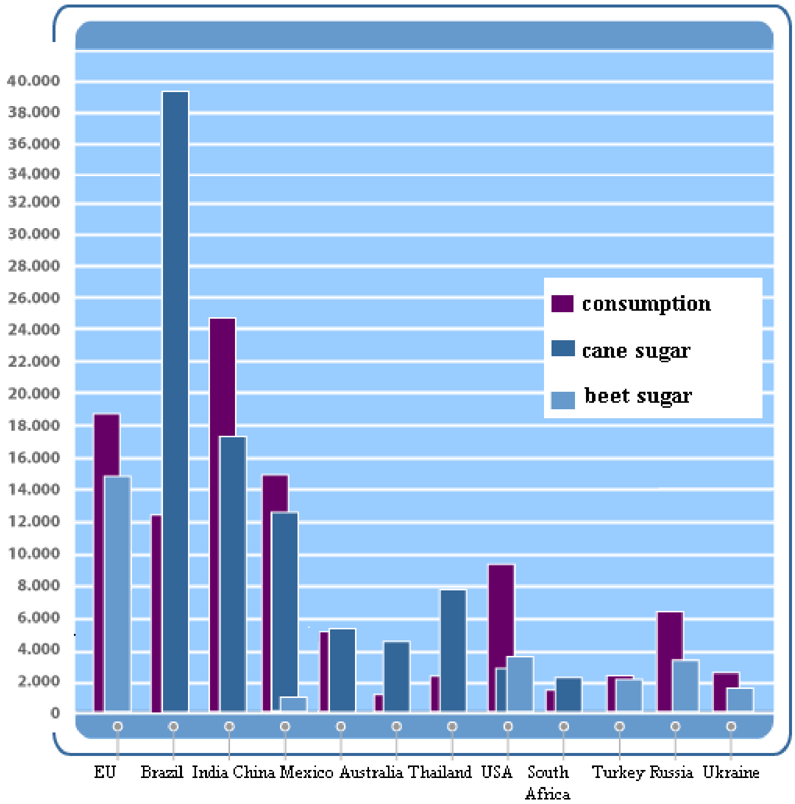
[6] Report of the Taskforce on bio-based products: “Accelerating the development of the market for bio-based products in Europe {COM (2007) 860 final}

2.2.3 Sugar

In Europe the only crop grown for the production of sugar is sugar beet while sugar from sugar cane is imported from different countries outside of Europe, mainly from Brazil or the United States.

The sugar beet is the source of crystal sugar as well as for molasses and syrup. Both are used for fermentation to produce bioethanol, which is mainly used as biofuel while around 10 % is used as a platform chemical in the chemical and technical industry.

Figure 3 Sugar production of selected countries for 2008/2009



Source: modified from Wirtschaftliche Vereinigung Zucker e.V. 2009

To date, the majority of sugar production in Europe is used by the food industry and only a smal part going to industrial use. Sugar is the main raw material for industrial biotechnology, and the sugar used in fermentation processes may come from sugar beet/sugar cane or may be produced from starch. Nearly half of the utilized sugar in the European industrial biotechnology comes from sugar plants (Graf von Armansperg & Patel, 2007). Sugar is used in the industrial biotechnology to produce antibiotics, vitamin B_2, Insulin, alcohols, enzymes, hormones lactic acids and polyhydroxyalkanoates.

As industrial biotechnology is a growing high-tech industry, the importance of sugar as raw material is expected to increase rapidly. Furthermore, sugar is used as raw material for additives in pharmaceutical and cosmetic products, in construction chemistry and as sucrose esters in the chemical industry.

2.2.4 Starch

The European Starch Industry is characterized by a high diversity of products in food, feed and non-food sector. Following the AAF[7], nearly 60 % of all produced starch (9.6 million. tonnes in 2007) are used in food applications and 40 % are utilized to produce starch and starch based sugar products like glucose, fructose, dextrose, sorbitol and others for the non-food and feed sector (Figure 4).

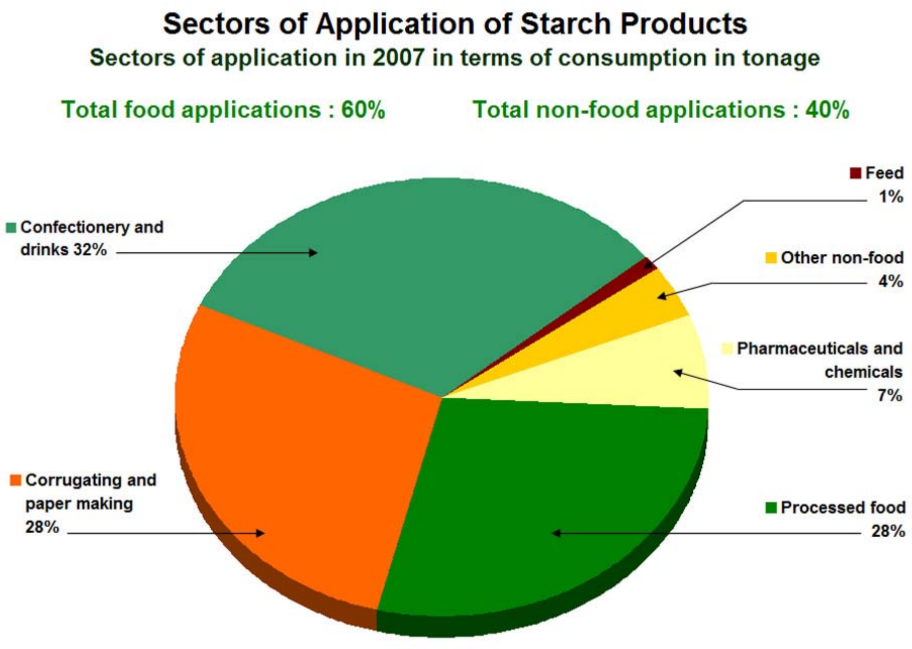
In Europe starch production is mainly based on wheat, maize and potatoes. Other cereals like rice, rye, barley and triticale or starch plants like Jerusalem artichoke are also used for starch production. As a by-product, the cereals straw can be used as, for example, insulation material (see below) or wheat gluten for food industry.

In 2007 approximately 3.8 million tonnes of the starch produced in Europe was used as industrial material (including the fermentation for bioethanol). About three quarters of this was consumed as paper starch to produce printable graphic papers in the paper industry. Another large segment is the production of corrugated boards where starch is used as glue for the papersheets. Starch is also used in the chemical industry, in the production of cosmetics and wellness products or as textile starch (calculated with data from AAF (2009)).

As with sugar, starch has a great potential in industrial biotechnology and is the second main raw material for the fermentation industry in Europe. Here it is the base for ketogulonic acid, sorbitol and antibiotics polylactide (PLA) and polyhydroxyalkanoate (PHA).

A ther next generation technology use of starch is the rapidly increasing sector of biobased plastics. Starch, modified starch and starch-plastic blends can be utilized as duroplastics (e.g. loose-fill packing material, trays as packing material for food or boxes in the Fast-Food sector) or as thermoplastic synthetic material (e.g. foil, plastic bags or packing material). The biobased plastic sector will be described in detail in the chapter dealing with innovative products of RRM.

Figure 4 Sectors of application of starch products in Europe for 2007



Source: AAF (2009)

[7] AAF: Association des Amidonniers et Féculiers, the trade association of the European Starch industry.

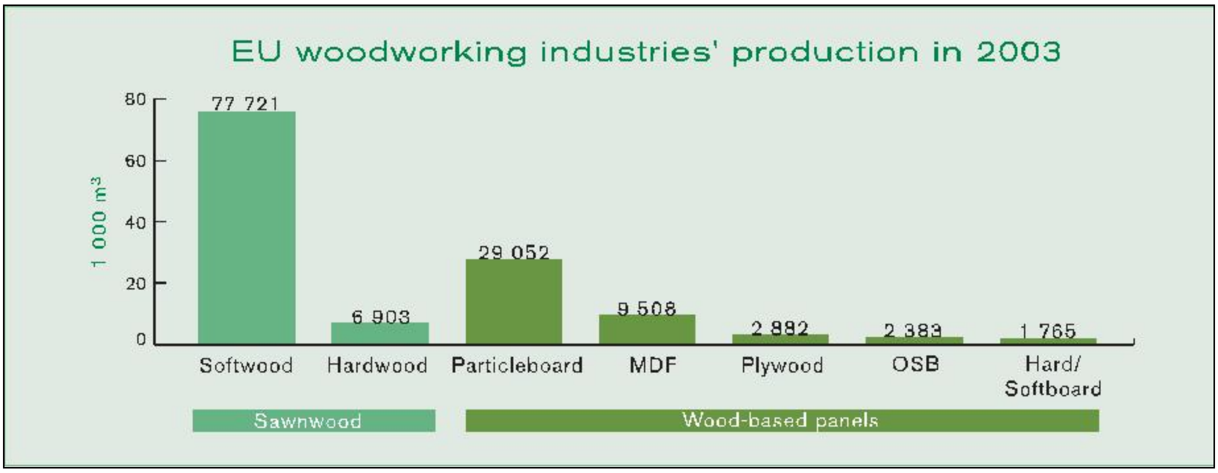
2.2.5 Wood

About 30 %, or 4 000 million ha, of the earths land is covered by forest[8]. About 3 000 million m3 are harvested worldwide annually, of which around 60 % are used as industrial roundwood and 40 % as fuelwood (FAO, 2006). This shows that wood is likely the oldest and quantitive biggest raw material section from renewable sources.

In Europe, wood is produced in forests and only a very small portion comes from short rotation plantations (notably Scandinavia and Belgium) or landscape management measures. The leading units are timber (hardwood and softwood) and forest wood residues while smaller units are composed of bark and landscaping residues, plus the production from sawmills and other industrial residues as well as an increasing proportion of scrap and used wood. Imports are mainly tropical hard woods (Bitter et al., 2008) while European hardwood and softwood is mainly traded inside Europe. Approximately 60 % of the available wood is materially used – significantly more that is used for energetic purposes (Mantau, 2008 for Germany, whole Europe according to nova-Institute) and therefore comparable to the worldwide relation.

Approximately one third of the wood in material use is processed by the sawmill industry and mainly used for sawn timber (planks, beams) and wood veneer. Wood shavings and other industrial residual wood, like wood chips, are applied in the wood-based panels industry and in the pulp and paper industry. In recent times this raw material is increasingly consumed in thermal use, e.g. in the form of pellets.

Figure 5 Production of the European woodworking industry in 2003



Source: CEI-Bois

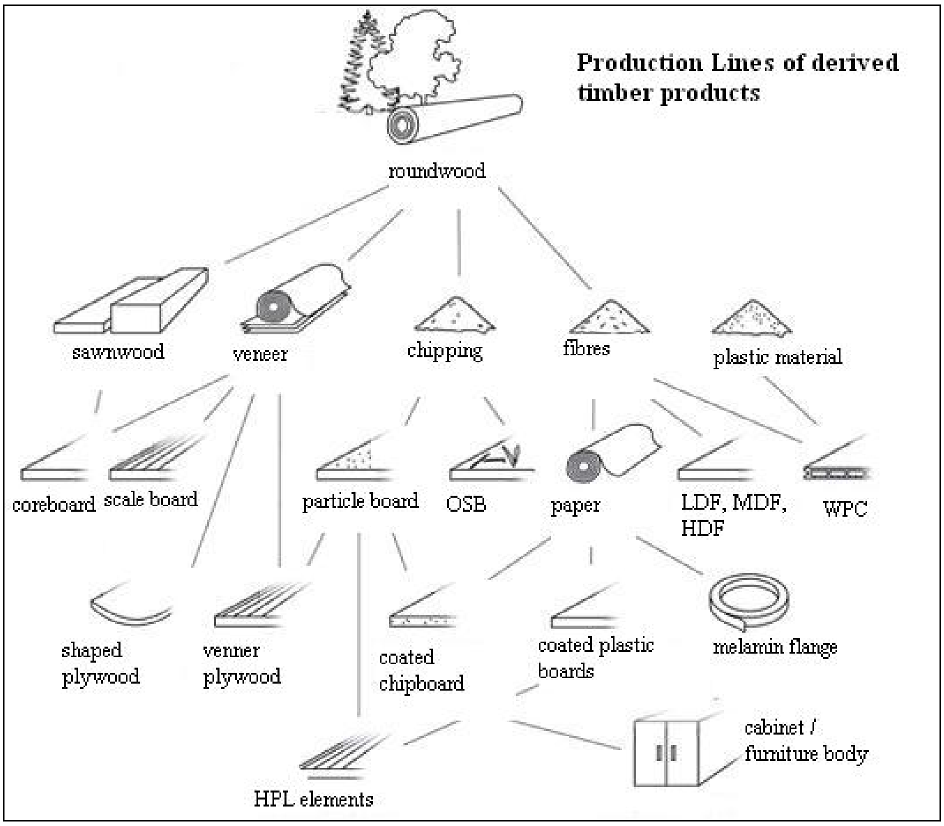
The wood-processing industry largely produces particle-boards using wood shavings and residuel wood. The predominant particle boards are Medium Dense Fiber Boards (MDF), Oriented Strand Boards (OSB) and plywood. Approximately 105 000 tons were used in 2006 to produce Wood-Plastic Composites (WPC); still a very small share of the European market. For comparison, nearly one million tonnes were produced in 2006 in North America (Gahle, 2008; VHI, 2008; Carus et al., 2008c).

The construction sector, including house construction and interior improvements (roof trusses, walls, ceilings and floors, doors and windows, etc.) uses 60% (or 50% according to Sauerwein, 2008) of the products from the wood processing industry. The furniture industry with about 20 – 40 % and is the second-largest demand for lumber, plywood and wood-based panels. The wood packaging industry is

[8] FAO definition of Forest: Land spanning more than 0.5 hectares with trees higher than 5 metres and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use (FAO 2006)

the second largest purchaser of softwood; solid wood, plywood and OSB are also used. The remaining 10 – 20 % is used in other applications such as the use of wood fiber insulation, specialty plywood panels for vehicles and Wood-Plastic Composites in the automotive industry. Wood fibers are also used for moldings and other materials (Wenig, 2007; Carus et al., 2008c).

Figure 6 Derived Timber Production line in the wood-processing industry



Acronyms: OSB (Oriented Strand Board), LDF (Low Dense Fiber Board), MDF (Medium Dense Fiber Board), HDF (High Dense Fibre Board), WPC (Wood Plastic Composites), HPL (High pressure laminate)

Source: modified from VHI 2009

A large part of the sawmill residues and other wood shares are used for the manufacture of paper pulp and wood pulp. They are processed together with recycled paper and small amounts of natural fibers for specialty papers (cigarettes papers, tea and coffee filters). The bulk of paper production is accounted for graphic papers, as well as paper and cardboard for the packaging industry. A smaller proportion is sanitary papers and special papers for technical and other uses (VDP, 2008). During the preparation of the cell and substance of wood, lignin is produced as a byproduct, which is to nearly 100 % directly converted to energy (Kibat, 2008).

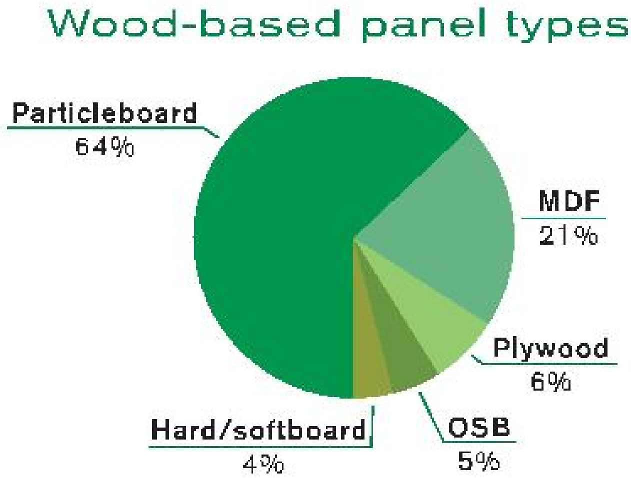
2.2.6 Chemical cellulose

About three million tonnes of the annual world production of 130 million tonnes of pulp is cellulose for uses in the chemical industry. About one third is used to produce cellulose derivates as ethers and esters and two thirds used to produce cellulose regenerates, mainly cellulosic fibers (Graf von Armansperg, 2006; Peters, 2006; IVC, 2008). Due to the required purity nearly 100 % of the chemical cellulose is imported in most parts of Europe. The sulphite pulp mainly produced in the pulp and paper industry is largely integrated into the paper making process while the sulfate or kraft pulp may be offered as market cellulose. High purity chemical cellulose is used in a wide range of applications, some of them also outside the classical chemical application. For example highly purified cellulose from Borregaard, Norway, among other things, is used for high-quality photo papers.

Chemical applications can be divided into derivate cellulose, temporary derivate cellulose and not derivate cellulose applications. The non-derivate applications include microcrystalline cellulose and cellobiose for the pharmaceutical and biotechnological industry.

In cellulose derivatives, ionic and non-ionic cellulose ethers and organic as well as inorganic cellulose esters can be distinguished. Organic ethers, such as the ionic carboxymethylcellulose (CMC) and non-ionic methyl-(MC), ethyl-(EC) or Hydroxyethylencelluloses (HEC) can be produced as fine powder which is soluble in water and can be used as thickening agent in printing colors, in glues in the paper industry, in cosmetics and foods, as wallpaper glue or as additive in cement and mortar.

Figure 7 Share of different wood-based panel types of the total production in Europe



Source: CEI-Bois, 2009

The main representative of the organic cellulose esters is cellulose acetate, which has many different uses. The most common application is the production of cigarette filters in the form of parallel fiber bundles (Tow). As fibers, organic cellulose esters are utilized in the textile sector, for example as materials for lining of jackets, and are used to produce plastic films and films for photographic applications as well as for biobased polymers.

Among the most important inorganic cellulose esters cellulose nitrate is customized mainly as coating, propellant and brilliant ink. Historic applications such as billiard balls or celluloid films are no longer of importance, but the manufacture of table tennis balls (imported from China) using cellulose nitrate continues as there are no alternatives with the same properties. Other cellulose esters used as polymers or bioplastics are cellulose propionate and cellulose acetobutyrate.

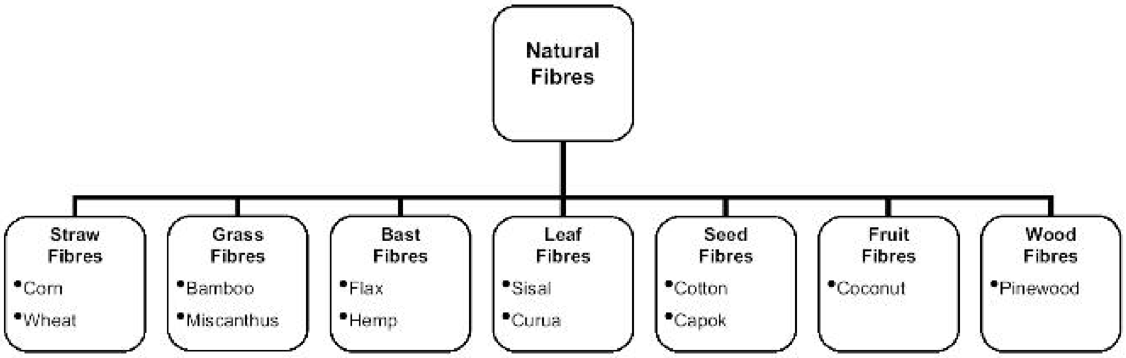
Cellulose ethers are mainly used for function polymers in the construction industry and in the pharmaceutical and cosmetics industry. They are applied as binders and thickeners, stabilizator and other additives. Among these, there is the carboxymethylcelluse (CMC), used in detergents, as thickeners in food, coatings and thickeners in pharmaceutics and cosmetics and as additive in the paper industry.

Among the Cellulose regenerates, rayon fibers and films (cellophane) play a central role. Cellophane is used in the packaging industry as packaging films. Cellulosic fibers from regenerates are applied mainly in the form of staple fibers to 100 % or mix with other fibers to produce textiles and nonwovens. Continuous fibers (filaments) for textile and technical applications are also produced. Textile filaments are used for ladies wear and sports coat inlays. Technical rayon has great importance as a resistance element in delivering high-speed tires (due to friction, the tires get very hot). The lyocell fibers from Lenzing, Austria are also important. They are spun from a physical solvent (N-methyl morpholine oxide, NMMO) and in development ionic fluids as solvent. They differ significantly from viscose, which consists of a derivatisation with Xanthogenate groups and then is regenerated, both from the properties as well as from the procedures. In addition, the classical production methods of viscose lead to high emissions of H_2S and CS_2.

2.2.7 Natural fibers

The market for natural fibers in Europe is mainly fulfilled by imports of intermediate and finished products while European production is only a very low proportion. In Europe there are only hemp, flax and nettle fibers as well as a limited acreage for cotton cultivated as fiber plants. In addition sheep and other animals are kept as a source for natural wool fibers. The largest part of Europe's available natural fibers is based on foreign trade. The largest amount of imported fibers and fiber products is cotton in form of raw fibers, waste textiles, intermediate products and finished textiles. In addition there are imports of jute and other exotic plants like sisal, abaca, kenaf, ramie and coir and its products. All natural fibers are used in materials for the technical industry.

Figure 8 Natural fibres classification



Source: Suddell 2009

With the extraction of natural fibers of hemp and flax, shives are gained as commodity, which are introduced both in material and in energy uses. The largest part is used as animal bedding in stables or for small pets. Other uses insulation insulation and stuffing material as well as building material when mixed with lime. A smaller percentage is used in horticulture and in the form of light chipboard. Only about 8 % of shives are burned and used as energy supply (Carus et al., 2008a).

The largest user of natural fibers is the textile processing industry. Here the fibers are used to produce yarns, fabric and clothing and home textiles. At all levels major flows of goods are taking place and come to Europe via imports.

A huge and increasing market is that of the nonwovens and felts. The automotive industry is a majour user of natural fibers in this form for door cladding, roof lining, seat upholstery and other components for the interior of cars and especially in the composite of the cockpit of trucks (Wenig, 2007; Carus et al., 2008c). Natural fibers are also used as a natural insulation. In Germany, one very special and successful niche application is nonwovens for growth pads of cress (Carus et al., 2008a).

A relative large market is the sector of specialty paper with natural fiber. Those are mainly used for food applications (teabags, coffee pads), cigarette papers, and technical filters. In addition a very small percentage of natural fibers is used in the production of natural fiber reinforced polymers and resins for injection molding and extrusion (Gahle, 2008).

2.2.8 Straw

The straw from cereals - mainly wheat, rye, barley and triticale - is a byproduct of the use of cereals for food and starch extraction. In Europe hundreds of millions of tones of cereal straw are produced annually. This is mainly wheat straw, but there are relevant quantities of straw from barley, rye, triticale and oats too. The majority of the straw remains on the field securing the nutrient cycles on the agricultural land. At maximum 30 % of the straw should be removed without damage to the soil formation (Münch, 2008). A small fraction is used for energy by burning heaters. The first power plants on the basis of straw combustion are in the planning and construction stage.

The largest part of straw taken from the acre serves as an animal bedding material for the large animal farming (cattle, horses and pigs). Smaller quantities are used in the mushroom cultivation as substrate or in orchards, especially as a cover for strawberries from cold. A very small proportion is used for restoration of frame houses as insulation and in house constructions based on straw. As lignocellulose material the cereal straw has a great potential in biorefineries for the future.

2.2.9 Natural rubber

All natural rubber in Europe is imported, mainly from the cultivation areas in Southeast Asia. All imported natural rubber is used in the technical industry while energy use is restricted to end of life incineration and special waste disposal areas.

The main application area of natural rubber is in the tire industry which uses an equal amount of synthetic rubber (Andrews, 2008; WDK, 2007; WDK, 2008). The shares of synthetic and natural rubber are determined by the requirements for the material in different kinds of tires. Thus for the production of truck tires a higher proportion of natural rubber is used than for the production of passenger car tires (WDK, 2008).

The rest of the imported natural rubber is used for a number of other technical elastomeric products. These include hoses, conveyor belts, adhesive tapes, shoes, scuba diving equipment, balloons, and hygiene items such as rubber gloves and condoms. In these applications the share of natural rubber compared to synthetic rubber is about one sixth (Andrews, 2008; WDK, 2007; WDK, 2008).

2.2.10 Cork

Nearly 80 % of the world production of cork from cork oak (about 300 000 t/a) are harvested in the Mediterranean region. Portugal is the main country of production, produces 52 % of the worlds supply (Pereira, 2008).

Cork is traditionally mainly used as (wine-) bottle stoppers; other applications include cork walls and floor coverings. Composites in a plastic matrix (Cork-Plastic-Composites) have also made in the last few years (Pereira, 2008). The use of cork is directly related to the production of bottle corks as all other applications use the remains obtained from bottle cork production. The decrease of bottle corks could be in line with other areas of application concerned.

2.2.11 Medicinal Plants

Aromatic and medicinal plants are cultivated on only a very small fraction of the total agricultural area in Europe, but they have a very high market value. Only a small proportion of medicinal plants used in Europe, however, come from domestic production, the majority (nearly 90 %) are imported, of which about 30 % come from crops and 70 % from wild collections (Pude & Wenig, 2005).

The use of medicinal plants is one of mankinds oldest usage of plants. Nowadays, whole plants or parts of the plants (like flower, leafs or roots) are used as phytopharmaceuticals and medicinal teas or as a pre-stage in pharmaceutical-chemical syntheses.

About 75 % of the use of medicinal plants is in the form of phytopharmaceuticals for humans. 18 % of medicinal plants are used in the field of "Health Food" and 7 % are used in cosmetics, mainly as additives for toothpaste or in massage oils (Raschka et al., 2009b).

2.2.12 Miscanthus

Miscanthus (*Miscanthus x giganteus*) is a new niche crop known for its rapid growth and the associated biomass production and should be planted in the future primarily as a favorable feedstock for bioenergy. It plays only a minor role as an industrial material, but is mentioned because of the potential future use in the chipboard production (already in measurable scale), in the pulp and paper industry, and especially as lignocellulose feedstock in biorefineries. The yield of Miscanthus is about 15 to 22 tonnes dry mass per hectare and it has an expected useful life of 20 years (Pude & Wenig, 2005). Therefore, it might be an interesting biomass supplier for the future if cultivation risks due to low frost resistance are overcome by choosing adequate plant material.

2.2.13 Dyes, resins and tannins

The use of RRM for the production of dyes is primarily of historical interest. Plants like common madder (*Rubia tinctorum*), weld (*Reseda luteola*), woad (*Isatis tinctoria*) and safflower (*Carthamus tinctorius*) were cultivated as sources of dye (Pude & Wenig, 2005).

Today dyes from plants and animals play only a minor role compared to chemical dyes. There is, however, an increasing demand for use of natural colours in sensitive areas where a direct contact to the coloured surface is expected. Textile paints for baby clothes, interior paints, children's paints and colored children's toys are made from natural dyes, as well as leather colouration, paper and foodstuffs (Pude & Wenig, 2005).

Natural resins are mainly used as raw materials for the manufacture of paints and adhesives for example for linoleum production.

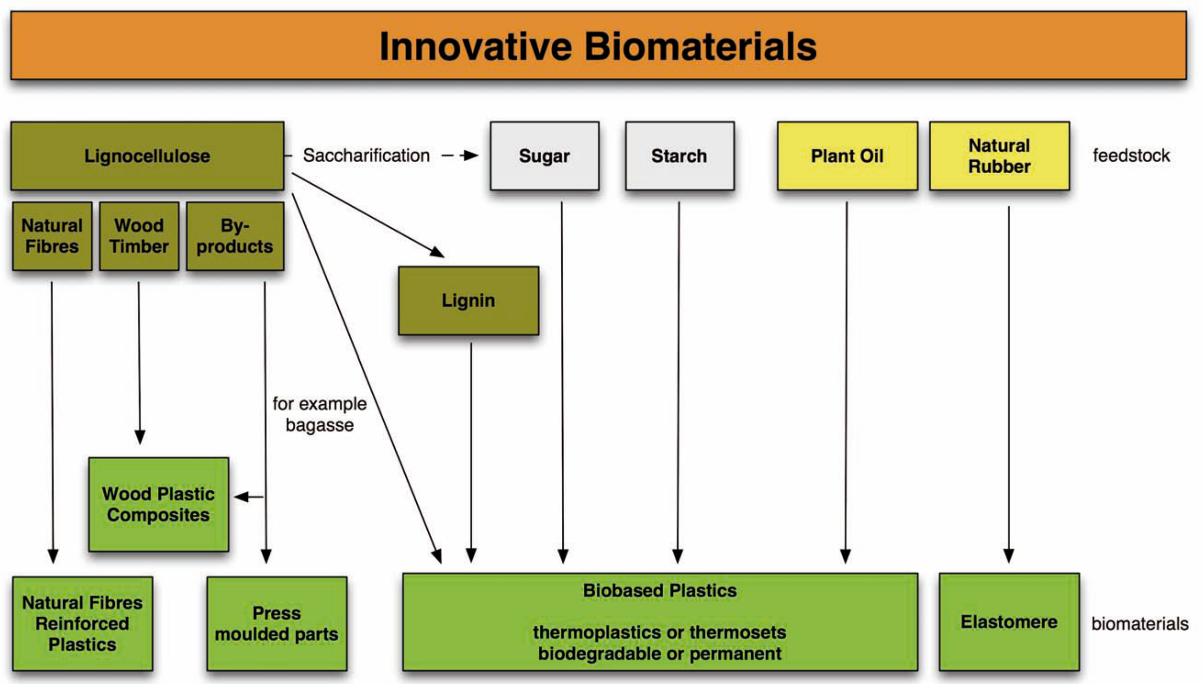
Natural tannin agents or tannins are mainly used in the leather industry.

3. Innovative applications of materials from renewables raw materials

The use of RRM as a feedstock for the industrial material use to produce materials, chemicals and other biobased products can save fossil resources and reduce negative effects on the environment. More challenging conditions for the exploitation of fossil resources, and therefore higher resource prices, begin to be a main driving factor for innovations. In many cases biobased products show an advanced greenhouse gas balance over the whole life cycle and the production and disposal is normally less toxic and energy demanding compared to products based on fossil resources.

As RRM are the only alternative carbon source to crude oil for the production of chemical products, there is a high research potential expected in the chemical industry. The chemical industry would rather design novel production processes for platform and bulk chemicals out of RRM for further processing, than develop innovative applications of materials from RRM. There is high potential in industrial biotechnology as demonstrated and described in several studies in the last years (e.g. Patel et al., 2006; Brellochs et al., 2001; OECD, 1998, 2001, 2004). On the other hand, estimations of the future economic market share differ widely as demonstrated by Walz et al. (2008), as the potential of the white biotechnology depends on the further development of innovative products and production concepts (see Chapter on e.g. Biobased plastics).

Figure 9 Innovative applications of renewable raw materials



Source: Raschka et al., 2009a

This chapter concentrates on innovative biobased materials as these products are often directly visible to the end-user. Therefore these biobased materials will play an important role in the promotion of RRM in industrial use, and will generate an increasing demand for these materials. Figure 9 gives an overview of selected innovative biomaterial. Figure 10 shows some rough quantitative production statistics of these biomaterials in Europe (where ascertainable). It must be pointed out that the data are (1) from different years and (2) cover different areas due to a lack of data. But it can be assumed that the production quantities will be at least stable and more likely increasing. For this reason the production quantities of innovative biomaterials in the EU-25 in 2007 are assumed to be much higher than the mentioned 350 000 tons.

Biomaterials like bioplastics, natural fiber reinforced plastics and wood-plastic composites are estimated as a market segment with a particularly high potential for future markets.

Figure 10 Statistics on the consumption of selected biomaterials in the EU (where ascertainable, be aware of different years and areas)

Summary: Biomaterials in the EU

New Biomaterials – Technique	Quantities – Region
Biodegradable bioplastics (mostly packaging)	60,000 – 70,000 t (Western Europe 2007)
Bioplastics in permanent applications	30,000 – 40,000 t (Germany 2007)
NF compression moulding in the automotive industry	29,000 t (Germany 2005)
Wood fibre compression moulding in the automotive industry	40,000 t (Germany 2005)
Cotton fibre compression moulding (lorries)	79,000 t (Germany 2003)
WPC injection moulding and extrusion (construction, furniture, automobiles)	80,000 – 105,000 t (EU 2006)
NF injection moulding and extrusion	3,000 – 4,000 t (EU 2006)
Total biomaterials	More than 350,000 t in the EU

Source: nova-Institut 2004, 2006, 2007

Source: Raschka et al., 2009a

3.1 Biobased Plastics

A generally recognized definition on bioplastics does not exist yet. The literature describes two types of plastics fall under the term bioplastic (following European Bioplastic e.V., 2008):

- Plastics based on renewable resources
- Biodegradable polymers which meet all criteria of scientifically recognized norms for biodegradability and compostability of plastics and plastic products. These may be produced from crude oil also.

Plastics are composed of the actual polymer and several additives, such as processing aids, stabilizers and colorants. Despite the possibility to produce the polymers as well as the additives from renewable resources, in this study bioplastics are understood as plastics where at least the (bio-) polymers are based on renewable resources (biobased plastics). This definition allows for both biodegradable and non-biodegradable plastics.

Biomass-based polymers are not a new idea. For example Cellulose-based polymers are used in a wide range of applications; it is the major ingredient of paper and through further processing it can be transformed to cellophane and rayon. Viscose, also based on cellulose, is an important fibre in use since the beginning of the 20th century. However, cellulose has lost its markets mainly to polyolefins.

With the growth of the petrochemical industry, the traditional use of biomass-based polymers has mostly substituted by petrochemical-based polymers.

Two generations of biobased plastics currently exist. The first generation of biobased plastics is produced directly from naturally or chemically modified polymers like starch or cellulose. This category includes thermoplastic starch or cellulose-derivates. The second generation is based on monomers extracted from RRM, processed through polymerisation to polymers and plastics. Polylactid acids (PLA) and Polyhydroxy-alkanoates (PHA) belong to this category (Beucker et al., 2007). The biobased polymers of the second generation are produced mainly in industrial biotechnology applications. Hüsing et al. (2003) or Patel et al. (2006) give an overview on different production lines and applications.

Table 2 Main types of biobased plastics

Renewable base	**Properties**	**Application**
Starch-based polymers	Short-living, biodegradable and compostable	films, moulding, extrusion
Polyhydroxy-alkanoates (PHA)	Long-living, depending on composition fast biodegradable to non-biodegradable, limited compostable	moulding, films
Polylactic acid (PLA)	Weatherproof, not biodegradable, not compostable	films, moulding, fibers
Cellulose-derivatives	Biodegradable, limited compostable, producing clear films with good mechanical properties	films, injection moulding

Source: based on European bioplastics e.V., 2008 and Beucker et al., 2007

As shown in Table 2, there are four main types of biobased plastics currently on the market. They are used mainly for food packaging, bags, fast-food packaging and disposable tableware, hygiene products, packaging for biological waste, plant pots and biodegradable mulch films.

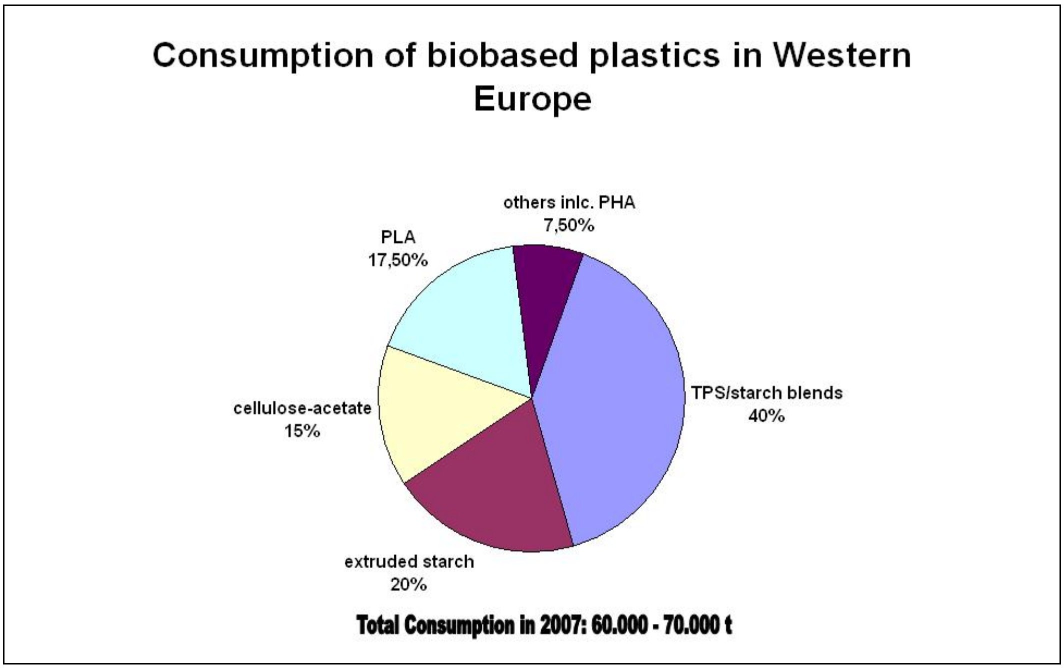
Highly innovative uses of biobased plastics include textiles and the use in natural fibre reinforced plastics.

Biobased plastics processed from starch-based polymers accounted for nearly 60 % of bioplastics in 2007, followed by those produced from Polylactid Acids (PLA) with 15 – 20 % and those produced from cellulose-acetates with around 15 % (Figure 11).

In 2007, the consumption of biobased plastics in Western Europe totalled between 60 000 – 70 000 tonnes (nova-Institute, 2008; Raschka et al., 2009b), while European Bioplastic e.V. (2008) estimated a consumption of nearly 100 000 tonnes for Europe as a whole. With a total European plastic market of 48 million tonnes, this translates to a market share below 0.5 %. But compared to figures from the European Commission[9] from 2005 of 50 000 tonnes of bioplastics, the market has doubled in size between 2005 and 2008.

[9] Report of the Taskforce on bio-based products: "Accelerating the development of the market for bio-based products in Europe" {COM (2007) 860 final}

Figure 11 Market share of the main biobased plastics in Western-Europe



Source: nova-Institute 2008

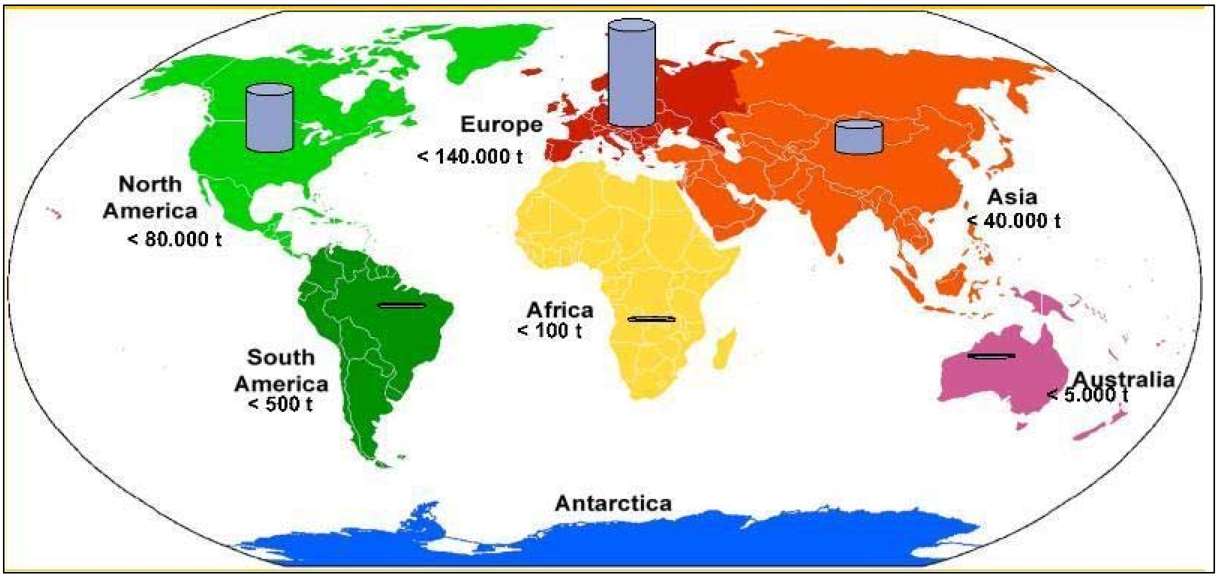
The nova-Institute (Carus et al., 2008b; nova-Institute, 2008), calculates worldwide production capacities for biodegradable plastics in 2007 at a maximum of 265 000 tonnes per year. The highest capacities were found in Europe followed by North America (Figure 12). Whereas the production capacities in Europe are mainly based on starch-based polymers and cellulose-acetates (nearly 75 %, see Figure 11), the production capacities in North America are dominated by Polylactid acids (PLA). Discrepancies with former estimations of production capacities, especially for North America, result from technical and legislative problems installing PLA- plants with high production capacities. For example Nature Works, owned by Cargill, announced several times the start of PLA production in a plant in Blair (Nebraska) with a potential production of 140 000 metric tons per year. But due to several problems the production reached just 50 000 to 70 000 metric tons in 2008. The full production capacity could have been reached in July 2009 (Bio-Polym Blog, 2009).

In the same way, the estimations of several associations of biobased plastic producers should be read carefully. For example, European Bioplastics (2008) forecasts an increase in the worldwide production capacity of bioplastics to 765 000 t/a in 2009 and 1.5 million t/a in 2011 including petrochemical-based biodegradable plastics (with 36 000 tons in 2009 and 42 000 tons in 2011), based on information from member surveys, market studies, company announcements and expert interviews. But the estimated production capacity of 765 000 t/a for 2009 has not been reached to date.

In many countries like the European Union, USA, Australia, India or China, an increasing public awareness for biobased plastics is recognisable, especially in the packaging market segment. The first political provisions are already on the way, like the ban of non-biodegradable plastic bags in France and Italy (starting in 2010).

The rapidly increasing market and the advanced public awareness make biobased plastics the segment with highest potential for the use of RRM.

Figure 12 Estimated worldwide production capacity for biobased plastics



Source: Carus et. al.,2008b

3.2 Natural Fibres reinforced Plastics

The term Natural Fibre-Reinforced Plastic (NFRP) describes a class of materials built from natural fibres embedded in a polymer matrix. Typical natural fibres used for NFRP are flax and hemp, as well as jute, kenaf and sisal. There is high potential for innovation in the use of biobased polymers as polymer matrix, which make these NFRP nearly 100 % from RRM.

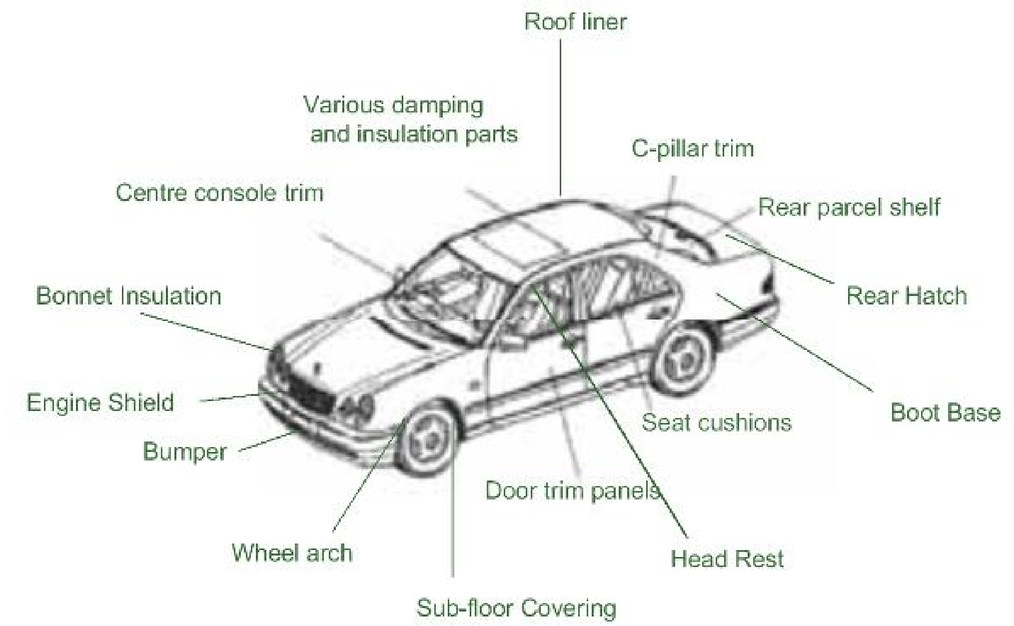
Construction elements and press mouldings from NFRP offer a high stiffness and resistance in combination with low density and weight. Further, they break without sharp edges and, in comparison to pure plastic or glass fibre reinforced plastics, they do not shatter.

There properties make NFRP materials ideal for the automotive industry, where fuel saving through weight reduction is important. NFRP materials are used mostly in the medium-sized and luxury class as they are not yet cost effective for compact cars. Figure 13 shows the construction elements potentially made from NFRP in a typical medium-sized car. For example, in 2005 the German automotive industry used nearly 19 000 tonnes of natural fibres (without wood fibres), which means that at an average 3.5 kg of flax and hemp fibres are used for each new car (Wenig, 2007).

Beside the motor industry there is an increasing interest in some other industries for the use of NFRP. For example there is already a office chair, hard hat, briefcase and spectacle case made from NFRP press mouldings in production and several other applications (like canoes or parts for windmills) in the construction or test phase (Carus et al., 2008c).

In 2005, nearly 96 % of all used NFRP were produced as press mouldings (Carus et al., 2008c). But the development of granulated materials of Polypropylene and natural fibres allowed the use of injection moulding. The majority of small plastic parts are made with this technique. The possible use of NFRP for injection moulding offers a great potential for natural fibre products and a rapidly growing market. In 2003, the first material made with this technique using NFRP went in serial production. One year later, ten construction elements were already on the market and several companies were applying for patents (Carus et al., 2008c). In 2006 between 3 000 and 4 000 tonnes of natural fibre granulates were used in Europe, and the broad potential application area for NFRP means that a rapidly increasing market for these products is expected in coming years (Carus et al., 2008c).

Figure 13 Use of nonwovens, felts and mouldings in the automotive industry



Source: Suddell, 2009

3.3 Wood-Plastic Composites

Wood-Plastic-Composites (WPC) are a special case of natural fibres reinforced plastics. They are thermoplastic processible compounds with different proportions of wood, plastic and additives. WPC can be treated using thermoplastic forming processes like extrusion, injection moulding or press moulding (Vogt et al., 2006).

Production of WPC is increasing rapidly; since 1990 it mounted up from zero to over 1.1 million tonnes in 2006. The North American market with 900 000 tonnes is by far the largest, followed by Europe (105 000 tonnes) and Asia (nearly 100 000 tonnes) (Carus et al., 2008c).

In Europe WPC consist of 50 – 90 % wood fibres and polypropylene or (in less amount) polyethylene as polymer matrix, whereas the North American market is dominated by WPC with 50 % wood fibres and 50 % polyethylene (Vogt et al., 2006).

Advantages of WPC's are the three-dimensional plasticity and higher stiffness compared to derived timber products. Additionally, by using special additives, they offer a high UV-stability and a better moisture resistance (Vogt et al., 2006). These features lead to a growing market and the rapid development of new products and fields of application.

Typical uses of WPC's are deckings, handrails, noise protection walls, fences and harbour docks. Newly developed WPC's, consisting of 50 % wood fibres and 50 % polyvinyl chloride, are mainly used for construction of window and door frames. The European market is also focused on automotive as application like trims and mouldings as well as for indoor furniture and construction material and small parts like handles (Carus et al., 2008c).

3.4 Industrial use of Glycerol as platform chemical

Glycerol, commonly known as glycerin, has multiple direct uses like anti-freeze, utilization in the cosmetic and pharmaceutical industry or as additive for inks and dyes. Glycerol is produced mainly as by-product of splitting fats and oils and, increasingly, as by-product in biodiesel production.

Approximately 10 % of the world production comes from synthetic pathways where propylene is converted via allylchloride, epichlorhydrine and hydrolyse to glycerol (Patel et al., 2006).

An innovative application of glycerol is its use as substrate for fermentative processes. One potential production line using glycerol as feedstock is the production of 1,3-propandiol (PDO) by fermentation. The main use of PDO is as co-monomer for the manufacture of new polyesters like Polytrimethylenterephthalat (PTT). This polymer can be applied as textiles fiber or plastics and has a high substitution potential for PET and nylon. Further PDO derivates are polyurethans and copolyester ethers (Hüsing et al., 2003; Brellochs et al., 2001).

Another innovative production line is the transformation of glycerol to propylene glycol, which has a wide range of application and is used in everything from pet food and paints to polyester resins, lubricants, antifreeze and cosmetics (Ebert, 2007). Approximately 2 400 million pounds of propylene glycol are currently made each year, almost exclusively from petroleum-based propylene oxide. Propylene glycol is a less toxic alternative to ethylene glycol in antifreeze, but is currently more expensive and, as a result, has a very small market share. Also the use of propylene glycol base deicers is a future market, especially in bio-sensitive areas. Several companies are developing antifreeze and de-icers products based on propylene glycol from renewable resources e.g. a Joint Venture of Ashland and Cargill announced in May 2007 a 65 000 tonnes plant at a yet-to-be finalized location in Europe; the process is a highly efficient vapor-phase hydrogenation technology for use in converting glycerine to propylene glycol (Ebert, 2007).

In March 2007 DOW Epoxy announced the construction of a world-scale (150 000 tonnes) glycerine-to-epichlorhydrine (GTE) plant in Shanghai. The plant is slated to start up in the 2009-2010 timeframe. In 2006 DOW launched a stand alone, full-process GTE demonstration unit at its Stade site in Germany. This breakthrough technology provides significant costs and environmental advantages versus the conventional process technologies (via propene and allylchloride)[10].

Solvay announced a new epichlorhydrine plant at Tavaux (France)[11]. The first industrial unit (Epicerol ™ project) with an initial 10 000 tonnes capacity has been in operation since April 2007. An investment in a new Epicerol production facility is moving forward in Map Ta Phut (Thailand). The startup of this plant is foreseen mid of 2010, with a capacity of 100 000 tonnes. Environmental advantages are a large reduction in chlorine consumption and less chlorinated organic compounds as by-products, lesser need for effluent streams, non toxic or flammable basic materials and the process based on renewable materials.

3.5 Biorefinery concept

Several definitions and descriptions of the term biorefinery can be found in literature. In the following a biorefinery is understood as "a facility that integrates biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass. The biorefinery concept is analogous to today´s petroleum refineries" (NREL[12]). The future biorefinery concept of science and industry is defined as a biorefinery that converts a variety of feedstocks, including residues, into a portfolio of products with improved energetic chain efficiency, improved economy and improved environmental effects, compared to standalone processes often producing only one or two products (IEA[13]). This concept, also called the third generation biorefineries, is not only able to produce a variety of biobased chemicals, fuels, intermediates and materials, but also use various types of feedstocks (Kamm & Kamm, 2004a).

A typical example of a first generation biorefinery is a dry milling ethanol plant, which uses cereals as feedstock and a fixed production line consisting of ethanol, feed co-products and carbon dioxide

[10] http://news.dow.com/dow_news/prodbus/2007/20070326b.htm
[11] www.solvaypolyglyerol.com
[12] NREL: The American National Renewable Energy Laboratory
[13] IEA Bioenergy Task 42: http://www.biorefinery.nl/fileadmin/biorefinery/docs/publications/presentations-kickoff/_1__Introduction_Kick_off_IEA42_150307.pdf

(Kamm et al., 2006). A phase two biorefinery is the wet milling technology which allows the production of various end-products depending on product demand using one feedstock (mainly grain). These biorefineries can be integrated in industrial product lines with existing agricultural production units (like sugar plants) (Kamm & Kamm, 2004a).

To date, the third generation biorefineries have not yet been built, but are in research and development. Currently four concepts of third generation biorefineries are in discussion and under development (based on Kamm et al., 2006; Kamm & Kamm, 2004b):

1. Lignocellulosic Feedstock (LCF) biorefinery

   This type is regarded as having the highest potential because it can use a wide range of feedstock material (straw, reed, grass, wood, residuals from the pulp, paper and timber industry etc.). Further the conversion products have a good position both in tradional petrochemical and future biobased product markets (Kamm & Kamm, 2004b). As lignocellulose consists of the primary chemical fractions hemicellulose, cellulose and lignin, a variety of products may be produced using this feedstock. From lignin, a phenol polymer, one may produce natural binders or sulphur-free solid fuel. Hemicellulose as sugar polymer can be processed to Furfural for example, the starting material for nylon. Cellulose as glucose polymer can be used as feedstock for fermentation processes and offer a wide range of secondary products like ethanol, lactid acids etc.

2. Whole-crop biorefinery

   Raw materials used in this type are cereals like wheat, rice or rye. After mechanical separation into corn and straw, the straw may be treated as feedstock in a LCF biorefinery. The corn can be converted to starch, which offers three different processing lines. First, the starch can be treated by biotechnological conversion to glucose, which is used as feedstock for fermentation. Second, the chemical conversion of starch to several products like sorbitol or Acetate-starch. And third, using starch as feedstock for the production of bioplastics.

3. Green biorefinery

   The Green biorefineries use green biomass like grass or green crops (lucerne, clover etc.). The green biomass is separated into a fibre-rich press cake and a nutrient rich green juice by pressing. The press cake may be used as fodder, as feedstock for biogas production or as feedstock in a LCF biorefinery string. The juice contains proteins, free amino acids, organic acids and several other substances. The main focus of the treatment of the green juice will be on the production of lactid acids and its derivates, ethanol for industrial use, amino acids and proteins. Further it offers valuable products like dyes and flavourings. The advantage of this type is the high biomass profit per hectare, low raw material costs and a good coupling with agricultural production.

4. Two-platform concept

   In this concept, the biomass can be either converted biochemically to a so called sugar platform or may be converted thermochemically to synthesis gas. The sugar platform enables access to a wide range of family tree-capable chemicals, because it can be more or less easily converted into molecules with different numbers of C atoms from which several chemicals can be created. The synthesis gas can be converted to methanol or ethanol and offer therefore a huge range of further treated products based on these starting materials.The advantage of this concept is that the production of energy, fuels and biobased products is possible using low-tech technology, but the production using these kind of biorefinery is yet not economically rentable.

The concept of biorefinery is a promising field of industrial use of biomass in the future. Yet nearly all innovative concepts are still in the research phase and their feasibility is shown in the laboratory. As yet they are far away from the industrial production and profitability.

4. Replacement of oleobased chemicals and chemical based products by renewable based materials

4.1 Tensides

As described in Chapter 2.2.1 tensides or surfactants are the main product lines of the oleochemical industry. The main use of surfactants is as ingredient in detergents and cleaners (54 %); as auxiliaries for textiles, leather and paper (13 %); in chemical processes (10 %); in cosmetics and pharmaceuticals (10 %); in the food industry (3 %) and in other areas (10 %) (Holmes, 2005). In 2002 the European market in was approximately 2.5 million tonnes. of which around 30 % come from vegetable resources[14]. Of tensides used for the production of detergents and cleaners, cosmetics and pharmaceuticals, it is estimated that 50 % or more of the oleochemicals processed tensides come from renewable resources (Peters, 2006). This is because of their biodegradability and the fact that most oleochemical surfactants show better skin kindness (Wenig, 2007).

Alkylpolyglycosids based on sugar are an innovative surfactant class. They are used increasingly in personal hygiene products due to their special cutaneous tolerance (Wenig, 2007). Further research is underway that will allow process surfactants based on starch or sugar to be combined with oleochemical tensides, giving products created entirely from RRM. This is far in the future.

4.2 Vitamin B_2

Vitamin B_2 or riboflavin is a substance present in most animal and plant cells. It is essential for a large amount of biochemical reactions. Whereas plants and microorganism can satisfy their demand by biosynthesis, animals and human need to ingest the vitamin through their food. Therefore riboflavin is an important food and feed supplement. In Europe nearly 85 % of vitamin B_2 is used for fodder, 10 % to 15 % is utilized as supplement for food production and a very small part is used as additive in cosmetics or pharmaceuticals (Hoppenheidt et al., 2005).

Riboflavin can be produced by chemical-technical processes or by biotechnology methods. In the first half of the 20th century technical production by fermentation was substituted by the chemical-technical treatment, mainly of economic reasons. The chemical process uses glucose as starting material which is converted, through a sequence of several chemical steps, to ribose and then to riboflavin (Figure 15).

From 1990 on most chemical production of riboflavin was substituted by an improved and cost efficient fermentation process. The biological process is a single step process either using bacteria (Bacillus subtilis) and glucose as starting substance (Roche) or like BASF using plant oils like soy bean from renewable resources and fungi (Hoppenheidt et al., 2005; OECD, 2001).

For the producers of riboflavin the biological process offers several advantages. The manufacturing cost are 40 % less, the process need needs just 40 % of the raw material and produce 95 % less waste compared to the chemical process (Balkenhohl, 2006).

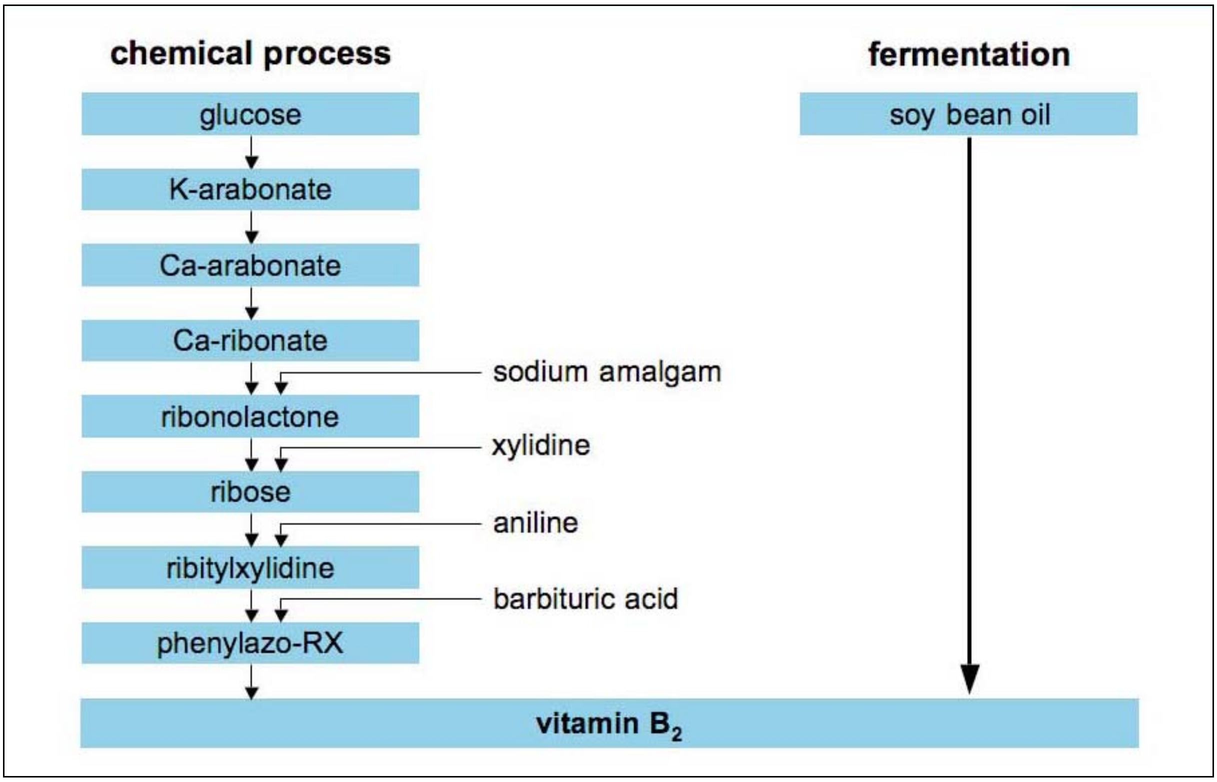
Life cycle analyses of both the biological processes and the chemical process demonstrates the environmental advantages of the biological processes, and shows that the single step fermentation process needs a considerably lower amount of chemical additives (Hoppenheidt et al., 2005).

[14] Report of the Taskforce on bio-based products: "Accelerating the development of the market for bio-based products in Europe {COM (2007) 860 final}

4.3 Loose-fill-packaging material

Biodegradable and biobased loose-fill packaging material (LFPM) is a duroplastic bioplastic. The material is made of extruded starch, nd accounts for 20 % of the Western European bioplastic market and is therefore the second largest market segment (nova-Institute, 2008). But loose-fill packaging material is just one product line of the extruded starch segment. Petroleum-based LFPM is typically made of polystyrene, which are not bio-degradable but recyclable to a high degree. The older production lines of biobased LFPM were biodegradable but not made of RRM to full extent, because they needed chemical additives to simplify the processing and to make them more resistant to air humidity (Lörcks, 2005). Newer processing-techniques and product developments now allow the production of LFPM 100 % from renewable resources without chemical additives and with lower energy consumption than the petro-based production. The biodegradability, the naturally static-free qualities and the 100 % biobased production attract an increasing amount of companies all over the world to use biobased LFPM, especially those which offer "green" products (Wenig, 2007; Benson, 2007).

Figure 14 Processes for the production of riboflavin



Source: Balkenhohl 2006

The market share of starch-based loose-fill packaging materials is, like the whole bioplastic market, rapidly and steadily increasing. Benson (2007) states a market share of 20 %, but without stating if this percentage is drawn on the US market or the world market. Other figures, especially for Europe, are available only for the whole bioplastics segment. But due to the rapidly increasing number of companies producing starch-based LFPM (own Internet survey, June 2009) and the steadily increasing demand for biobased products, it can be expected that biobased LFPM already substitute a reasonable amount of petro-chemical based LFPM.

4.4 Ethanol

The following chapter is based mainly on Patel et al (2006). Ethanol is currently produced from biomass in large quantities by fermentation. In 2003, world ethanol production was estimated at nearly 31.5 million tonnes (Patel et al, 2006). Less than 10 % of the world ethanol production is currently produced by chemical synthesis from crude oil or gas. Biotechnical ethanol production is the large-scale fermentation using agricultural biomass as feedstock (sugarcane, sugar beet or starch plants), followed by purification of the resulting ethanol by distillation.

Approximately 70 % of the ethanol produced is used as fuel or fuel additive like the ethanol-derived ethyl-tert-butylether (ETBE), 10 % of the world production is used in the food industry as ingredient of alcoholic drinks or disinfectant. Industrial use of ethanol accounts for 21 % of the world production, and is the only area where synthetic ethanol producers hold significant market shares. There are currently several plants under construction or recently activated which produce ethanol explicitly for industrial use. For example, in 2007 DOW and Crystalsev, one of Brazil's largest ethanol players, announced plans for a world-scale facility to manufacture polyethylene from sugar cane. It is expected to start production in 2011 and will have a capacity of 350 000 metric tonnes[15].

The most important applications within this industrial segment is the utilization as solvent, as disinfectant or as building block for the chemical synthesis. The main ethanol-derivates are ethylene (also used as chemical building block), ethyl esters such as ethyl acetate or ethyl lactate used as green solvents, ethyl ethers and ethylamine.

[15] news.dow.com/dow_news/prodbus/2007/20070719a.htm

5. Statistics on production and use of renewable raw materials in Europe

This chapter provides statistics on the volume and structure of the material use of renewable resources in Europe. It is based on screening and evaluation of data from various studies, expert interviews and observations of the internal sector of the individual commodities and sectors assigned, undertaken by the nova-Institute, and further investigations. This means that the statistics offer an overview of existing and available data. A new, detailed survey for the material use of renewable resources was not intended in this context.

5.1 Data availability on the use of renewable raw materials in Europe

Data for Europe is limited to estimates based on the evidence of experts, which are rarely updated. A periodic gathering of these figures does not take place so the available data is insufficient and inadequate for a full analysis. For this reason, it is only possible to give a general survey, rather than a comprehensive overview on industrial material use of RRM in Europe.

Focusing on energy use and future demands of biofuels, Thrän et al. (2006) analyzed “Sustainable Strategies for Biomass Use in the European Context” and tried to get an overview on biomass supply from agricultural and forestal sources in Europe. Rothermel (2008) and Schmitz (2008) used estimations on the use of RRM in Europe made in 2003 – there are no updated overviews available since then. Additional there are data for some industries, like the pulp and paper industry (CEPI, 2008) or the wood industry as a whole (Mantau, 2008), from different years.

The IENICA-INFORRM project (Interactive European Network for Industrial Crops and Applications; funded in the Fifth Framework Programme of the European Commission under the Quality of Life Programme) contains data on the use of RRM in the EU-15 states[16], assessing states[17] and some associated states[18] up to 2005. Some of these national factsheets show data until 1999; only a few were updated in 2004 with 2003 data.

Newer extensive and meaningful data on material use of RRM are only available in some industrial areas and not in all states of the European Union. The following statement of the nova-Institute on their attempt to provide European data on industrial use of RRM demonstrates the actual situation on the data availability:

> *In this study we can only use those from industries and nations where they are available in a minimum quality to validate. Though we contacted a lot of experts on material use of RRM in different countries[19], only very few could provide us data on biobased products. Most experts told us that there is no statistical data on material use of RRM in their countries and only some data on energy use.*
> *Some of those experts like Jean-Francois Dallemand (European Commission) told us that it would be very interesting to have this data but they could not help us.*
> *Dallemand invited us to a meeting in December (2009) on biomass resource assessment and competition to discuss the small base of data available in Europe. He does not know any study concerning the material use of renewables in Europe as a whole until now. Experts form Denmark, Greece and Turkey guided us to databases with general information on agriculture like it can be found*

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[16] Austria, Belgium, Denmark, Finland, France, Germany, Greece, Republic of Ireland, Italy, the Netherlands, Portugal, Spain, Sweden, UK
[17] Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Lithuania, Poland, Romania
[18] Israel, Switzerland, USA, Canada
[19] We contacted about forty persons in whole Europe including Jean-Francois Dallemand (European Commission), Iris Andersen (GB), Stephen Ryman (GB), Jeremy Tomkinson (GB), Hilaire Bewa (FR), Martin Banse (NL), Bodil Pallesen (DK), Venturi Gianpetri (IT), Mikael Lindström (SWE), Klaus Niemelä (FIN), Tiina Pajula (FIN), Ioan Sbera (ROM), Eriks Kursiss (LV), Gatis Deksnis (LV), Krystof Biernat (PL), Migdal Antoni (PL), Anna Voseckova (CZ), Bernhard Rice (IRL), John Finnan (IRL), Susana Silva (PT), Rui Reis (PT), Kazim Acatay (TR), Levent Onal (TR) and many more

in the German "Statistische Bundesamt". In contrast, there are a number of countries like Bulgaria, Turkey, Greece and others with good or very good and thorough presentation of the energetic use of renewable resources, especially against the background of biofuel quotes which had been decided for the year 2020 by the Commission of the Renewable Energy Directive; Because of their focus on energy use they are not applicable for gaining data on industrial material use. (Raschka et al., 2009a)

5.2 Domestic production and consumption of renewable raw materials

Data are available on a European level or a national level from different associations for different RRM. The following sections will give an overview on the main RRM produced in Europe.

Wood

The use and production of wood was 240 million tonnes[20] in 2005; by far the largest sector of industrial material use. Therefore it will be described in full in section 5.3.2.

Oilseeds and Plant Oils

The EU Oil and Proteinmeal Industry (FEDIOL) provides World, European and national data on plant oil and oilseed production, imports and exports[21]. Data provided there are not divided based on different forms of usage.

In 2007 a total 24 260 000 tonnes of oilseed was produced in the EU-27. The main producers were France (6 139 000 tonnes), Germany (5 357 000 tonnes), Great Britain (2 125 000 tonnes), Poland (1 891 000 tonnes) and Hungary (1 600 000 tonnes).

The plant oil production in EU-27 in 2007 (based on produced and imported oilseeds) was 12 040 000 tonnes, mainly based on rape oil (6 778 000 tonnes), sunflower (2 149 000 tonnes) and soya (2 593 000 tonnes). The main production countries of plant oils are Germany (3 612 000 tonnes), France (1 509 000 tonnes), the Netherlands (966 000 tonnes), Spain (895 000 tonnes) and Great Britain (793 000 tonnes). A significant amount of the rapeseed oil is used for non-food-purpose, mainly for the production of biodiesel.

In contrast the consumption of plant oils in the EU-25 in 2007 was about 19 855 000 tonnes, so a large amount of oils and oilseeds is traded. Detailed data on European oil and oilseed production can be found at http://www.fediol.be.

Fiber crops

Hemp and flax are the main European fiber crops. A relatively small (compared to worldwide production) quantity of cotton is also grown. All fiber crops are used in industry, mainly for the production of textiles as cloth and for technical textiles (wovens and non-wovens) and for composites with natural fibers (see above). According to the European Commission 633 600 tonnes of flax straw and 173 800 tonnes of flax fibers were produced in the EU-25 in 2006, mainly in France (486 000 tonnes of straw and 137 000 tonnes of fibers) and the Netherlands (31 800 tonnes of straw and 6 400 tonnes of fibers). Additionally 81 600 tonnes of hemp straw was produced to utilize fibers, mainly in France (49 000 tonnes), the Czech Republic (9 900 tonnes), Germany (8 700 tonnes), Poland (5 200 tonnes) and Great Britain (4 200 tonnes)[22].

Carbohydrates: Sugar beet and Starch crops

Starch crops, mainly wheat, maize and potato, are cultivated in all European countries in large amounts. Additional sugar beets are cultivated as the only source of sugar in Europe. They are all

[20] Corresponding to 481 million m^3 (Mantau 2008), roughly converted using 1 m^3 = 0.5 tons
[21] Statistics of FEDIOL could be found on their webpage www.fediol.be
[22] Data from "Agricuilture in the European Union – Statisticaland economic information 2007"

generally used to produce food and only a small percentage of the amounts are used for technical applications.

According to the European Commission (2009) there was a total production of wheat of 108 605 000 tonnes in 2006 in the EU-25, mainly in France (33 267 000 tonnes), Germany (22 366 000 tonnes) and Great Britain (14 735 000 tonnes). The total production of maize in 2006 was 44 795 000 tonnes, mainly produced in France (12 906 000 tonnes), Italy (9 671 000 tonnes), Romania (8 985 000 tonnes) and Hungary (8 252 000 tonnes). Potatoes were produced in an amount of 52 300 000 tonnes in 2006, mainly in Germany (10 031 000 tonnes), Poland (8 982 000 tonnes), France (6 354 000 tonnes) and the Netherlands (6 240 000 tonnes).

According to the AAF[23] 9.6 million tonnes of starch were produced in 2007 from 21.5 million tonnes of raw material. The consumption of starch and starch derivates in 2007 was 9.3 million tonnes, of which 40 % were for non-food applications.

A total of 17 834 000 tonnes of sugar was produced from sugar beet in the EU27 in 2007/2008, mainly in France (4 680 000 tonnes) and Germany (4 110 000 tonnes). In 2006/07 more than 626 722 tonnes of sugar (and starch based isoglucose) were subsidised by the European Commission for the use in the chemical industry (Barjol, 2008)[24].

5.3 Industrial material use of renewable raw materials in Europe

5.3.1 Overview (excluding wood)

In 2003 it was estimated that the use of RRM in industry would be about 9 million tonnes (excluding wood). The chemical industry was estimated to use around 6.4 million tonnes and other industries 2.6 million tonnes (Schmitz, 2008). The raw materials are divided into vegetable oils and fats (31 %), starch (35 %), sugar (14 %), chemistry and natural cellulose fibres (16 %) and other (4 %) (Schmitz, 2008).

The total acreage for renewable resources in the EU in 2005 amounted to approximately 5.07 million ha – approximately 5.2 % of agricultural land use. Of this, 900 000 ha were for the production of starch crops, 425 000 ha of oil seed, 137 000 ha of sugar beet, 113 000 ha of medicinal plants, 460 000 ha for cotton and 135 000 for other fibre plants. A total of 2.27 million ha was cultivatedfor material use and 2.8 million ha for energy use (Schmitz, 2008).

According to Rothermel (2008) about 8 % of the European raw materials in the chemical industry are based on renewable resources. More specifically, 6.4 million tonnes of RRM and about 74 million tonnes of fossil raw materials were used in the chemical industry in the EU-25 in 2003. Half of these RRM is composed of plant oils and fats, followed by cellulose, starch and sugar. In the German chemical industry he estimates that about 2.3 million tonnes RRM and 17.5 million tonnes of fossil raw material were used, giving RRM's a 10% share of the market (Rothermel, 2008).

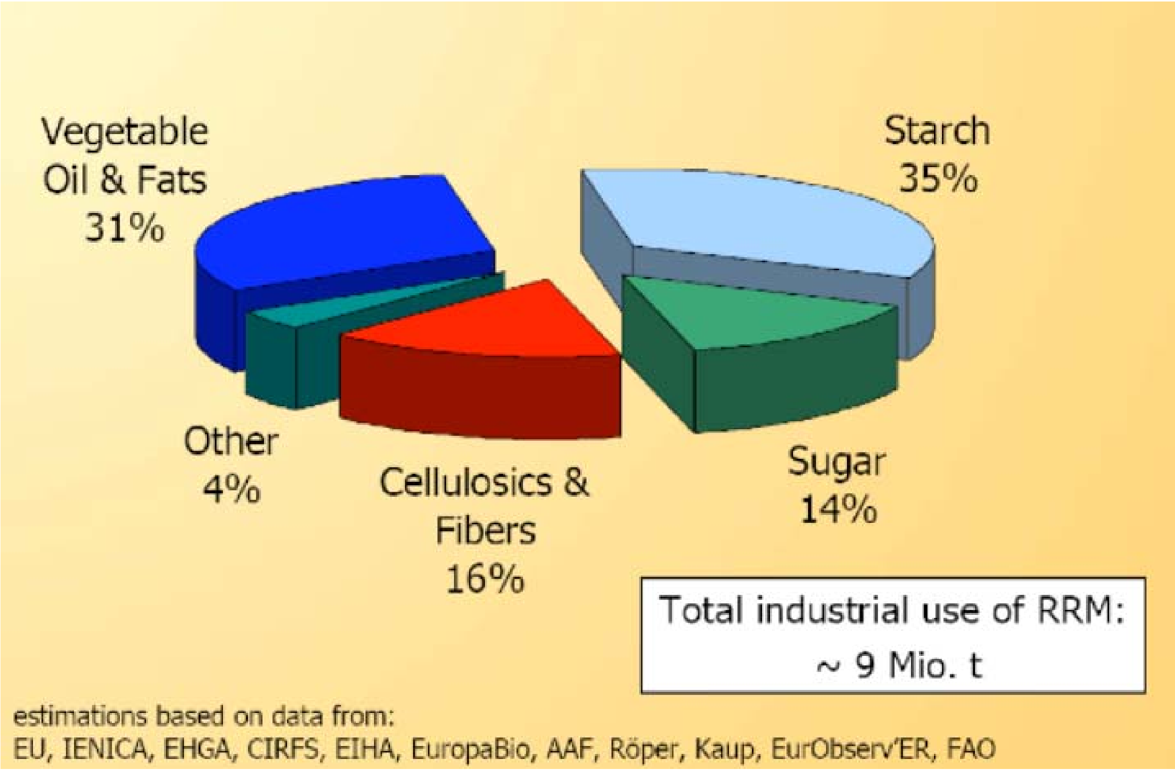
The market value of the European biobased industry with entirely or partially biobased products was conservatively estimated at around 450 000 million euro in the EU-25 manufacturing sector, but could be a third more; around 610 000 million euro. Pulp and paper (EUR 136 650 million), wood and ligneous materials (EUR 68 100 million), Paints and Inks (EUR 17 700 million) and Pharma and neutraceuticals (EUR 116 300 million) are the dominating sectors (Nowicki et al., 2008).

The current value of the truly biobased part of these goods are estimated to be 250 000 million euro and could be up to 315 000 million euro. The dominant biobased products are pulp and paper (EUR 95 700 million), wood and ligneous material (EUR 55 500 million), pharmaceuticals

[23] Association des Amidonniers et Féculiers, the trade association of the European Starch industry
[24] Data from „Agriculture in the European Union - Statistical and economic information 2007“ http://ec.europa.eu/agriculture/agrista/2007/table_en/index.htm

(EUR 28 400 million), fibres (EUR 9 400 million) and detergents and solvents (EUR 4 100 million) (Nowicki et al., 2008).

Figure 15 Industrial material use of renewable raw materials in Europe



Source: Schmitz 2008

According to Nowicki et al. (2008) it is estimated that the potential for biobased components in manufactured goods could rapidly grow by 86 000 million euro through substitution of products or by 120 000 million euro by novel product development.

Innovative biomaterials like bioplastics, nature fiber reinforced or wood plastic composites are estimated as a market segment with high potential for future markets.

5.3.2 Wood use in Europe

About 822 million m^3 of wood resources were used in Europe in the year 2005. Industrial roundwood (482 million m^3) is the largest European wood resource, followed by industrial residues (118 million m^3) and forest restwood and bark (48 million m^3). Other registered sources cover 126 million m^3, resulting in a production/consumption balance gap of 47 million m^3.

341 million m^3 (41 %) were used for energy uses and 481 million m^3 (59 %) for material uses. From the whole wood resources 26 % were used in the sawmill industry, 11 % in the panel industry and 19 % in the pulp and paper industry (Mantau, 2008).

Table 3 Estimated market values of biobased products in the EU-25

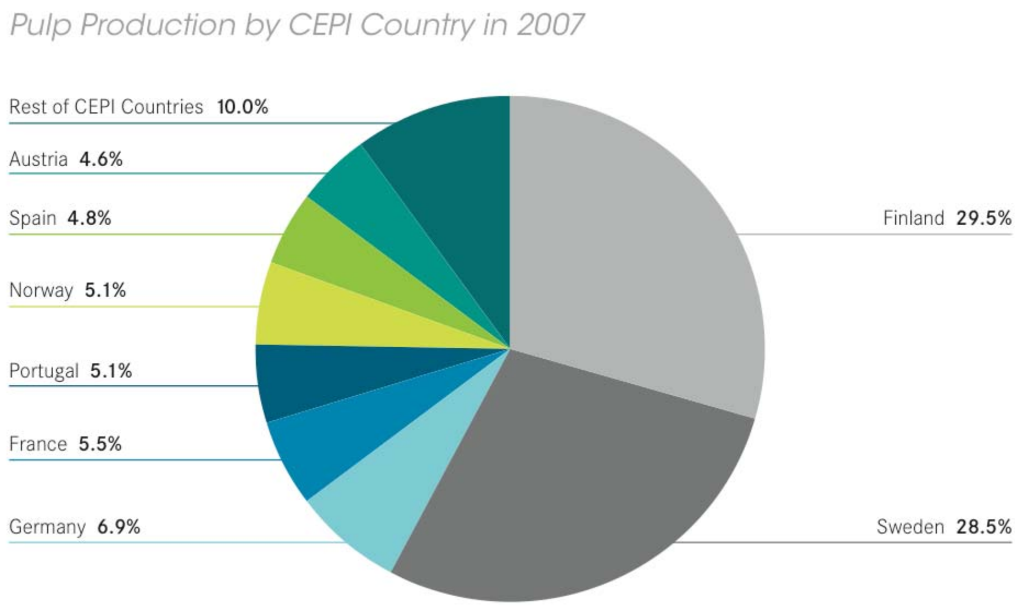
	Number of items	% item values recorded	Total value for EU-25 a) (thousand €)	Actual biobased value b) (thousand €)	Potential bio-based value b) (thousand €)
Production type 4: Biomass separated to materials	323	78	250,585,486	187,714,799	211,567,228
Production type 5: Biomass separated to substances	101	60	47,920,145	23,154,004	38,543,354
Production type 6: Biomass fragmented to building blocks	356	33	155,235,368	34,451,552	81,640,191
Totals	780	55	453,741,000	245,320,355	331,750,773

a) For known figures; b) Based on expert judgement of the non-food, non-feed component.

Source: Nowicki et al., 2008

In 2004 the sawnwood sector accounted for 12 % of the overall EU woodworking industry, with about 85 million m^3 of sawn wood products (about 77.7 million m^3 softwood and 6.9 million m^3 hardwood) in the EU-15. The wood-based panels industry had a total production of 45.6 million m^3 (29 Million m^3 particleboards, 9.5 million m^3 MDF, 2.9 million m^3 plywood, 2.4 million m^3 OSB and 1.8 million m^3 hard and softboards) (CEI-Bois, 2009).

Figure 16 Share to pulp production (total 43.5 million tons) by Country



Source: CEPI, 2008

In 2007 the European pulp and paper industry used 119.3 million tonnes of wood to produce 43.5 million tonnes of pulp. They also used 17 million tonnes of non-fibrous materials and 49.6 million tonnes of recovered paper to produce 102.6 million tonnes of paper and board. The main pulp producer countries in Europe are Finland (29.5 % of the total production) and Sweden (28.5 %). Other countries like Germany, France and Austria produce less than 10 % each (Figure 18)

Since 2000 there has been a registered increase of 11.8 % in paper production, from 91.7 million tonnes to 102.6 million tonnes. In addition, 17.5 million tonnes were exported and 6.1 tonnes were imported meaning that overall 90.1 million tonnes were used in the European (CEPI) countries (CEPI, 2008). The main paper products were case materials, paper for newsprints and graphic papers (Table 4).

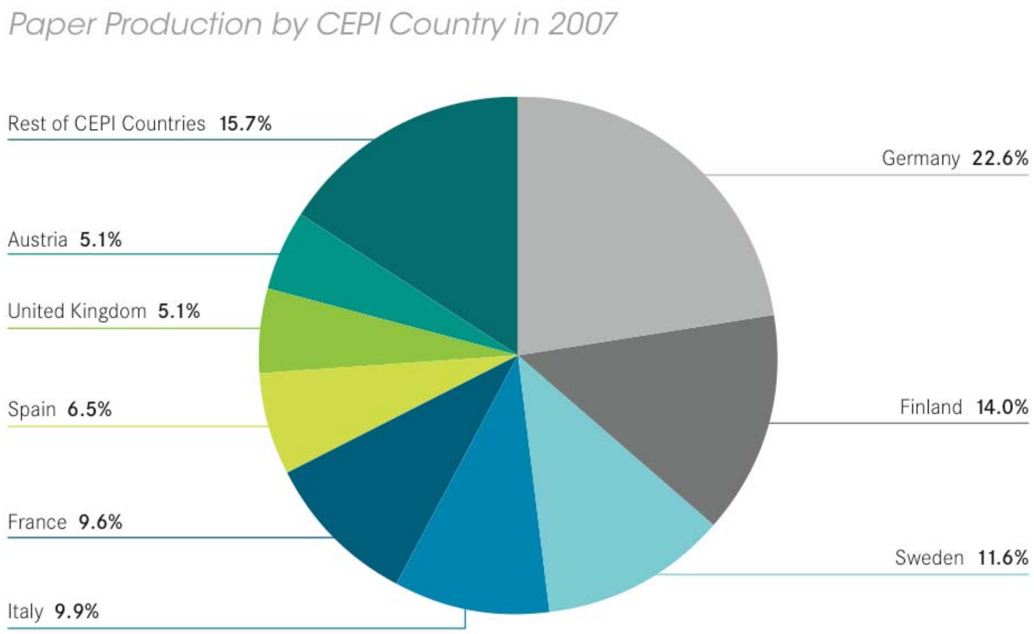
Table 4 Paper production in European Countries for the year 2007

	Production (million tons)
Newsprint	**10.4**
Other graphic papers	**32.4**
Case Materials	**22.9**
Other packaging	**14.0**
Tissues	**6.7**
Others	**3.7**

Source: Raschka et al., 2009a

Contrary to the low share to pulp production (6.9 %) Germany has the largest paper production with nearly 24 million tonnes (out of 106.5 million tonnes, 22.6 %) in 2007. Finland and Sweden follow with a production share of 14 % and 11.6 % respectively (Figure 19). According to the CEPI preliminary statistics for 2008 the production of pulp decreased by more than 4 % to about 41 million tonnes and that of paper by about 2 % compared with 2007 (CEPI, 2009).

Figure 17 Share of paper production (total 106.5 million tons) by country



Source: CEPI, 2008

5.4 Industrial material use of renewable raw materials (RRM) in different countries of Europe

Due to the European data availability (see above) this part will be focused on France, Germany, Great Britain, and the Netherland as lead countries with a detailed and new sufficient database on the industrial material use of renewable resources.

The IENICA project reports include data on agricultural statistics and the industrial material use in the EU-15 states[25], assessing states[26] and some associated states[27] for which data were collected until 2005 and are available in the open access on their internet presentation at http://www.ienica.org. The quantitative data given were mainly concentrated on the agricultural production of crops probably used in the technical industry; qualitative data were also collected on different types of industrial material uses. These types were the uses of oil crops, fibre crops, carbohydrate crops and speciality crops.The data of the use these crops for whole Europe in the IENICA report were already stated in chapter two and will not mentioned here again.

Due to different study approaches a stringent format for all countries is not possible. For example, the study in France was based on products (e.g. biolubricants, biopolymers) whereas the study in Germany was based on raw materials (e.g. plant oils, natural fibres). Therefore a direct comparison of the data is not possible. However, the different statistics do give a good overview of the industrial use of RRM in different European countries.

5.4.1 Industrial material use of RRM in France

Bewa (2007) provided a study on the current and prospective markets for industrial bioproducts, excluding wood and pulp, textiles and health products. Therefore they concentrated on the defined groups biofuels, lubricants, surfactants, biomaterials, solvents, pigments (including inks, paints and varnishes), paper and cards and cosmetics. The datasets are based on 2005.

As in all European countries, the largest amounts of products from RRM in France were products from wood. Around 10.9 million tonnes of paper and cards, and 2.6 million tonnes of paper pulp were reported in the study.

The second largest quantity of biobased products in France are cosmetics, with an estimated volume of 2 million tonnes with integredients from RRM (up to 5 000 different plant feedstocks). The third largest quantity of biobased products was biosurfactants from plant oils and sugar with a volume of approximately 100 000 to 120 000 tonnes, nearly 40 % of which were used in detergents.

Biosolvents and biolubricants are huge sectors as well. Nearly 3 000 tonnes of bio-fluxing agents and 2 000 tonnes of biosolvents for cleaning purposes were produced in France. Additionally 1.5 million litres of plant protection oils from rape seed and sunflower were stated in the study. Approximately 1 000 tonnes of biolubricants from plant oils and animal fats, mainly used as hydraulic oil or chain oil were used in 2005.

Around 10 000 tonnes of vegetal inks and paints and approximately 15 000 tonnes of fatty chains were produced from plant oils, mainly rape seed, sunflower and imported soya beans.

With a production of 6 500 tonnes, the biobased polymers, including 3 500 tonnes of polymers from starch and 2 500 tonnes of polylactid acids, are smaller than the fibre-plastic composites sector. Here, the nonwovens used in the automotive industry (50 % natural fibres and 50 % PE/PP) are, at 5 000-10 000 tonnes, the largest fraction, followed by wood-plastic composites (50 % wood meal) at

[25] Austria, , Belgium, Denmark, Finland, France, Germany, Greece, Republic of Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden, the United Kingdom
[26] Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Lithuania, Poland, Romania
[27] Israel, Switzerland, USA, Canada

2 000 – 4 000 tonnes. 1 000 tonnes of technical parts with 10-20 % hemp fibres were additionally used in the automotive industry. Vegetal insulation material (5 000 tonens) and hemp concrete (4 000 tonnes) are also noteworthy fractions of plant based composite materials. Packaging materials with around 10 – 20 % hemp fibres are the smallest portion of natural fibre-plastic-composites, as only 200 – 500 tonnes were produced in 2005.

5.4.2 Industrial material use of RRM in Germany

Due to a study on the industrial material use in Germany made by nova-institute in 2008/2009 (Raschka et al., 2009a, 2009b) a very good database on the uses of RRM in the German industry is available.

Again, wood is by far the largest fraction with 45 million tonnes converted to different products like construction wood, furniture, pulp and paper, wood-plastic-composites and derived timber products.

Up to 1.15 million tonnes of plant oils and animal fats and 250 000 tonnes glycerol were processed into biolubricants, surfactants, binders, oil based biopolymers and linoleum, making the oils and fats the second largest section of raw materials. Around 800 000 tonnes of starch used as paper starch, glues, binders textile starch or for the production of biopolymers were used. Additionally 85 000 tonnes of sugar was used as feedstock for the processing of bulk chemicals, fine chemicals, pharmaceuticals and bioethanol.

270 000 tonnes of imported natural rubber was converted into tires, sanitary products and healthcare products like rubber gloves. 35 000 tonnes of cork, all of which were imported, were mainly processed to bottle cork and cork composites. The entire production of 160 000 tonnes of natural fibres was used for industrial purposes. Main products were textiles, technical textiles, non-wovens (insulating material etc.) and fibre reinforced plastics. No concrete figures were declared for straw, but a potential of 6 million tonnes demonstrate the possibilities this raw material seems to offer.

Around 30 000 tonnes of proteins were used in pharmaceuticals, paper coating, glues, paints and for the polymer production. Medicinal plants (up to 24 500 tonnes) and other natural materials (37 500 tonnes) like resins and waxes are in the same dimension of industrial use.

In total, about 48.1 million tonnes of RRM (including wood, but not straw) is used in the German technical industry; without wood the figure is only 3.2 million tonnes. By comparison, about 37.6 million tonnes including wood or about 10 million tonnes without wood are used for energy production (including 6 million tonnes of biomass for biogas). This means that in Germany 56 % of the RRM are used for material uses (including wood), without wood there is a part of 24 % for material uses in this country.

5.4.3 Industrial material use of RRM in Great Britain

For the National Non-Food Crops Center (NNFCC) Arthur D. Little Limited (2008) worked out a market analysis of key renewable materials and product sectors for Great Britain. They did not try to find out the amounts of the whole use of RRM, so they focused on some topics with main interest for the British industry. Besides bioenergy they analyzed three main groups of material use of renewables:

- **renewable construction materials**: Natural insulation, Hemp lime, Straw bale construction and sustainable timber and wood products;
- **biobased bulk chemicals**: mainly bioethanol, biobased polymers and chemical co-products from biofuel production processes like glycerol;
- **health and nutritional products**: plant derived pharmaceuticals, herbal remedies and traditional medicines, nutraceuticals („functional food“).

Unfortunately the study does not give a quantitative overview of the industrial use while it is focused on potentials due to scenarios for the different product groups. In the following sections some passages of the study will be summarized.

Renewable construction

Very few verifiable figures are available for the renewable construction materials market. This is due to the high consolidation in the renewable construction materials market, and the lack of public prominence given to such products. The IENICA report (Holmes, 2005) on industrial crops in the United Kingdom does not even list construction materials as a significant use for hemp in 2003 (although insulation is mentioned as a potential emerging application). The potential market for these materials is high. Increasing demand for public housing means that 134 000 new houses are planned to be built in the United Kingdom per annum, with as much as 25 % the housing stock due for replacement before 2050. However, the proponents of renewable construction materials currently represent a small proportion of the construction industry, and are mostly confined to environmentally aware consumers and specialist construction firms.

Biobased bulk chemicals

In the case of bulk chemicals the study only shows data on and potentials for bioethanol, biobased polymers and chemical co-products from biofuel production processes.

The market for bioethanol as fuel is expanding rapidly, with planned production capacity of bioethanol in the UK anticipated to reach some 1 200 million liters in the next 2 – 3 years. However, with no equivalent legislation underpinning the development of biobased bulk chemicals market, bioethanol is not likely to find significant purchase in the UK as a chemical feedstock.

Biobased polymers are an emerging sector, with a current global consumption of approximately 94 000 tonnes. Though this is a small fraction of the overall plastics market, there is scope for significant expansion due to substitution of petrochemical thermoplastics. The UK manufacturing base is limited in this area, and the market is currently dominated by a small number of large companies in Western Europe and the United States (e.g. Dow; NatureWorks). Unless legislative incentives are introduced to encourage biopolymer uptake, production economics and the absence of a favourable starting position means that the UK is unlikely to develop a significant biopolymer industry.

Examples of chemicals produced as biofuel co-products include glycerol, which is produced as a co-product from the transesterification step of biodiesel manufacture. While there is a global market for glycerol, the market is small and saturated. However, Glycerol can be used for the production of propanediol, epichlorohydrin, propylene glycol, branched polyesters and glyceraldehyde. These applications are typically at the research stage at present and are a focus on BERR technology funding. A number of glycerol-to-propylene glycol commercialization efforts are underway around the United States and Europe, and the United Kingdom is in position to capitalize on this market.

Health and nutritional products

The health and nutritional products sector is not directly comparable with the other sectors considered since it does not represent a bulk commodity market.

Compared to other international markets, notably the United States and Japan, the UK's market for plant-derived health and nutritional products is small. The UK market for nutraceuticals is the largest segment at around GBP 1 000 million, whilst the herbal remedies market is smaller but considered to hold the highest potential for growth, largely through the uptake of botanical medicines, which are not currently on the UK market but are approaching it through clinical trials.

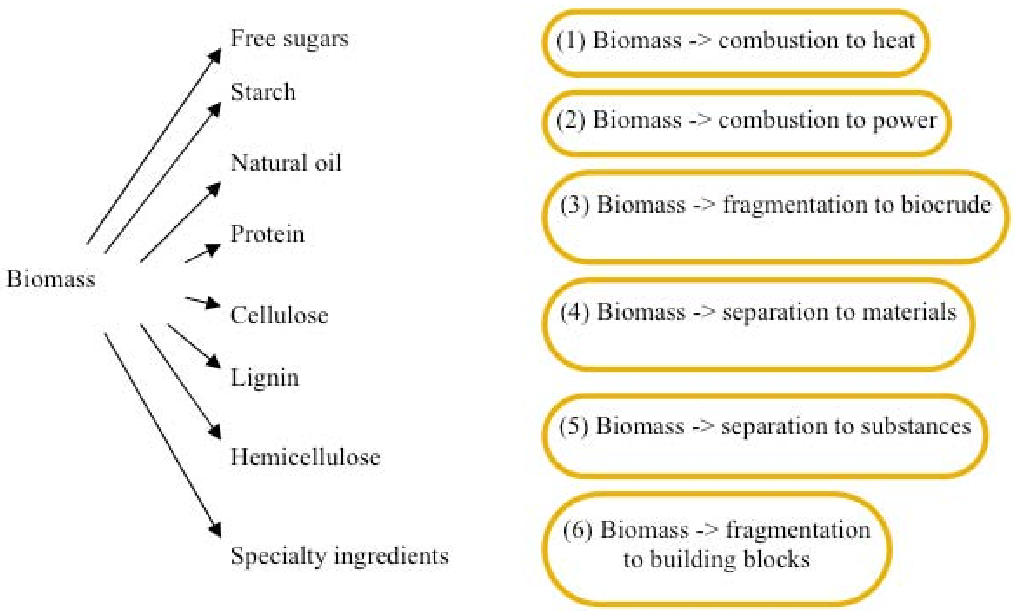
5.4.4 Industrial material use of RRM in the Netherlands

For the Netherlands Nowicki et al. (2008) published a state-of-the-art assessment on the biobased economy at February 2008. They focused on the market value of biobased products and found out, that the Netherlands is already producing a greater than proportional share of the EU-25 output. They estimated that the current level of the production of materials that are entirely or partially biobased has a market value of around 450 000 million euro in the EU-25 manufacturing sector and that the real value could be around 610 000 million euro. The truly biobased part is conservatively estimated at 250 000 million euro and could be up to 315 000 million euro.

The study is based on the NACE classification, a system for products that is organized with 60 Divisions, 222 Groups and 503 Classes of products. The analysis began with a preliminary identification of 936 potentially biobased products in 26 classes (avoiding all classes that are related to food or feed) within 8 divisions.

This first round of identification of potentially biobased products went through further screening in order (a) to *keep* only those products that were to some degree used for other purposes than food or feed and (b) to *eliminate* those products which would definitely not be likely to contain some biobased component in the future. As an outcome of this screening process, 780 products are retained for further analysis. In order to organize the products into internally consistent groupings, two layers of sieving have been carried out. The first is by production process. Here, 6 types of production process have been identified. Of these 6, the last three are directly relevant for the manufactured products analyzed (Nowicki et al., 2008).

Figure 18 Types of production processes for biobased products



Source: Nowicki et al., 2008

The team discussed all groups and identified the value of all groups within for Europe, special data for the Netherlands are not given.

The total market value of the European biobased industry with entirely or partially biobased products was estimated to be around 450 000 million euro in the EU-25 manufacturing sector. Pulp and paper (EUR 136 650 million), wood and ligneous materials (EUR 68 100 million), Paints and Inks (EUR 17 700 million) and Pharma- and neutraceuticals (EUR 116 300 million) are the dominating sectors (Nowicki et al., 2008).

The current value of the truly biobased part of these goods are estimated with 250 000 million euro. Dominating biobased products are pulp and paper (EUR 95 700 million), wood and ligneous material (EUR 55 500 million), pharmaceuticals (EUR 28 400 million), fibres (EUR 9 400 million) and detergents and solvents (EUR 4 100 million) (Nowicki et al., 2008).

Van Groenestijn et al. (2008) gave an overview of high value added applications of biomass and biorefinery and explored the opportunities of a biobased economy for the Netherlands. Without showing quantitative data, they identified 34 products or product categories on which to focus. The main conclusion of their analysis is that the best chances for a biobased economy are found in some specific products in the group of biopolymers and base chemicals. Those were Polylactic acid (PLA), agro fiber composites, thermoplastic starch and modified starch for biopolymers and succinic acid, bioethanol, itaconic acid, isosorbide, tetrahydrofuran and 1,4-butanediol as base chemicals.

6. Opportunities and perspectives of employing renewable raw materials

6.1 First evaluation of environmental effects

The use of RRM for material use must not endanger the goals of nature conservation and climate protection. Neither the production process of the raw material nor the industrial processing of the material should have negative environmental impacts. If agriculturally produced feedstocks are materially used, risks to sustainability should be excluded.

Having in mind the increasing worlds´ population and the decreasing fossil and natural resources, biomass production for food, feed, fuel or fibre will have to increase to meet the worlds´ augmenting demand. If only the food requirements of the world´s growing population are to be met, global food production will need to increase by around 50 % by 2030. This increases the demand for agricultural land, which is already becoming scarcer, and increases the likelihood of land-use conflicts in future. (WBGU, 2009)

On a global scale, the necessecary biomass supply growth may be achieved by higher yields by intensifying agricultural production and/or by taking additional (underused or unused) land under agricultural cultivation. A substantial rise in the use of biomass from agriculture, forestry and waste will put additional pressure on farmland and forest biodiversity as well as on soil and water resources. Moreover, landuse change and indirect landuse change (iLUC) can have strong environmental and social implications. It is a driver of biodiversity loss and of greenhouse gas emissions[28]. When assessing the use of RRM as a feedstock for the industrial production of materials, chemicals or other biobased products, it is important to take account of the global implications as e.g. landuse changes (direct and indirect). To limit these complex implications of biomass production a global solution approach has to be found.

In the following, the environmental impacts of the material use of RRM are compared to energy recovery of RRM by looking at the life cycle assessment (LCA) of product lines from biomass. There is a clear scientific and political consensus that the life cycle assessment (LCA) is the most accepted method for systematically analysing the environmental impacts of products, in the ideal case from “cradle to grave”. The LCA accounts for all environmental impacts of a product, arising from production, use and final disposal and including linked processes in the production chain. The methodology for calculating life cycle assessments is defined in DIN EN ISO 14040 and 14044 and consistently improved. For instance, the European platform on Life Cycle Assessment of the European Commission website (http://lct.jrc.ec.europa.eu) is an important platform on the actual LCA-discussion.

[28] The term indirect land use change (iLUC) refers to the potential effects which may be caused by cultivating biomass (for bioenergy or biomaterials) on land which previously was used for other cultivation, e.g. feed, food or fibre production. The previous use is displaced by the new biomass cultivation. Since it is reasonable to assume that the demand for feed, food or fibre formerly produced on the land would remain, the respective production would have to occur somewhere else, possibly in different areas. These different areas may have high carbon stocks (e.g. forests) which are reduced if used for cultivating the displaced production, thus causing CO2 emissions. These potential CO2 emissions are indirectly caused by the biomass cultivation which displaced the former use, and hence, could be allocated to it. The amount of potential CO2 emissions may be considerable, depending where and how the displacement might occur. Besides CO2, indirect land use change might negatively affect biodiversity if displaced production moves into biodiversity-rich areas. (Fritsche et al, 2009)

Since the early 1990s, a variety of life cycle assessments for biobased materials and products, as well as for bioenergies, have been compiled. But the data availability on which to base an LCA of material use of renewable resources is considerably lower than that for energetic value chains. Moreover, some methodological aspects for calculating LCAs have to be further developed for most biobased materials.

Life cycle assessments consider typically all relevant mass and energy flows and their environmental impacts. In terms of saved primary energy, avoided THG-emissions or toxicity products from RRM usually perform better than the respective oil based products. However, in other parameters like ozone depletion, ammonia and nitric oxide emissions, eutrophication and acidification, almost all product lines from agricultural raw materials perform worse than their conventionally produced products. Other impacts like biodiversity loss and land degradation have to be evaluated on a single case basis normally.

Up to now, there have been only a few meta studies of the environmental consequences of the material use of RRM (Deimling et al., 2007; Oertel, 2007). In a parallel project, the nova-Institute, in collaboration with Prof. Martin Patel, Juliane Haufe from the University of Utrecht, have for the first time systematically compared material and energetic renewable resource value chains (Carus, 2009). The most important first results are summarised below.

Methodology

First, it is important to establish how the results of ecological balance sheets of energetic and material uses can be compared and whether it is at all meaningful to do so. In ecological balance sheets, two products or services which both can meet a particular demand are compared. In this way, biodiesel with fossil diesel and natural fibre insulation materials with mineral wool can be compared – but not biodiesel with a natural fibre insulation material.

In order to compare different applications of biomass, a common base is needed – like 1 hectare of arable land. Then, the potential GHG savings from 1 hectare used to produce rapeseed for biodiesel (instead of fossil diesel) can be compared with potential GHG savings from 1 hectare used to produce hemp for making insulation material (instead of mineral wool). In this way, material and energetic uses as well as open-space photo-voltaic-systems can be compared with one another.

To choose space as a reference figure makes sense also when considering that in resource management, the goal is to use the scarce resource space in the best way possible. In this context, it is crucial to find an absolute figure that allows comparing GHG-savings per area directly.

Data records of ecological balance sheets for material uses

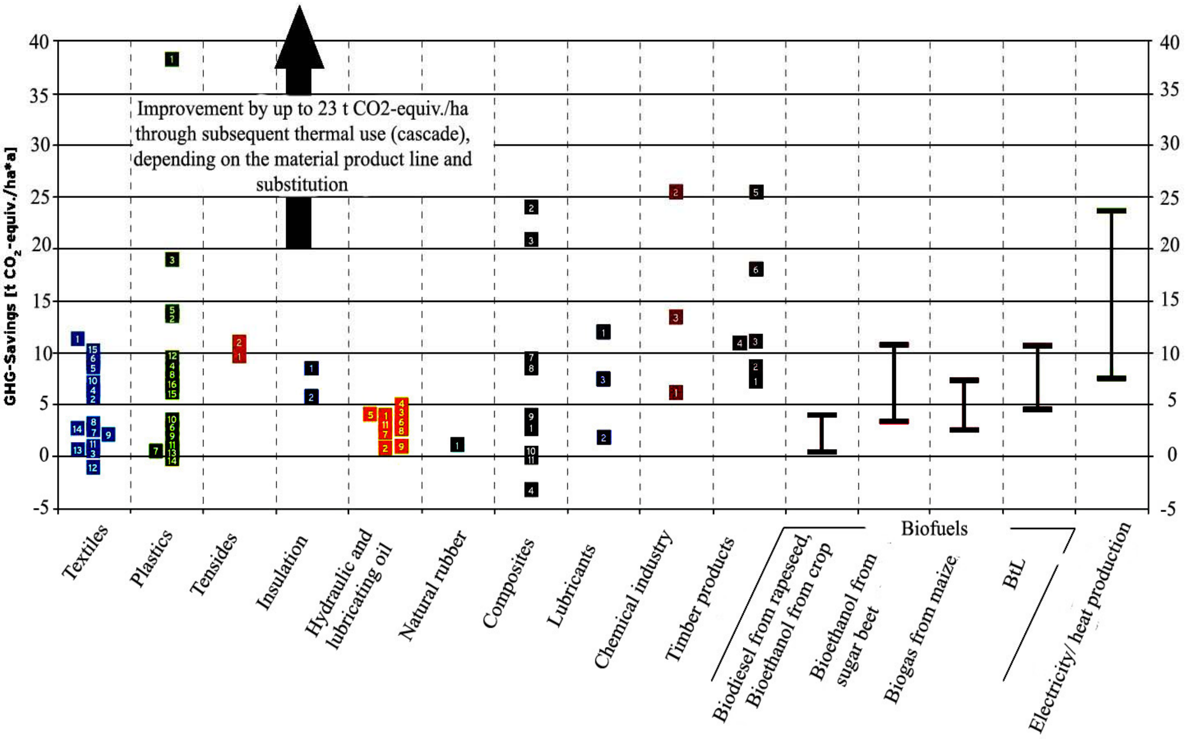
Compared to bioenergy, the data record for material uses is much scarcer. However, the problems to be solved are also much higher in this field. In the field of bioenergy there is, with plant oil fuels, biodiesel, bioethanol, Biomass-to-Liquid (BtL), biogas and solid fuels, a very manageable number of product lines with straightforward fossil substitutes. For all lines, there is a multitude of ecological balance sheets.

In the field of material uses, we find several hundred different product lines. For many, no ecological balance sheets have ever been conducted, for others it is difficult to find fossil substitutes (e.g. for paper), yet for others there are few ecological balance sheets that are often hardly comparable.

First results show trends

The following graph shows the analysis, in terms of GHG-emission savings, of all available (and more or less robust) material ecological balance sheets and a range for bioenergy which is obtained from meta studies (IFEU, meo).

Figure 19 GHG-emission savings for material uses and bioenergy



Source: Raschka et al, 2009b

The graph shows large spreads in the GHG-balances for material product lines and also some clusters. The cluster for tensides is based, for example, on the use of palm oil and coconut oil, respectively. The majority of studies for material product lines show at least similar, often even significantly greater effects (in terms of GHG savings) than first generation biofuels. The best material GHG-balances lie even significantly above the balances of first and second generation biofuels, on a level with best biomass combustion and a few even above.

Even though these calculations lie on an unsatisfying data base, they provide quite a positive picture for material uses. This picture is further improved if the effect of the long-term CO_2-storage and the potential for cascading utilisation (first material uses, then energetic use) is taken into account. However, in this respect it is methologically still unclear how the CO_2-storage effect, which leads to an immediate relief of the atmosphere, can be adequately valuated.

Under the viewpoint of GHG-savings per area it makes sense to pay more attention to the material use of RRM. In general, for many biobased product lines an objective analysis of ecological consequences and evidence of its expected ecological advantage must still be provided, based on representative boundary conditions. By now, life cycle assessments according to DIN EN ISO 14040 and 14044 for at least the main and/or most important production lines, on a quantity basis, are needed. This will provide information that can objectify the discussion on the use of RRM either for industrial purposes or energetic use. Further it is important that used RRM originate from verifiable sustainable agricultural production with defined ecological sustainability criteria.

These necessities were also stated in a recently published report of the German Federal Environment Agency for the individual case of bioplastics (Beier, 2009). For these concrete biobased products the

German Federal Environment Agency concludes, from the hitherto existing life cycle assessments of bioplastics, that biological degradable bioplastics are exspected to be superior to fossil based plastics, unless;

- The raw materials used origin from sustainable agricultural production with defined ecological sustainability criteria,
- residual materials of agriculture and food production are increasingly used
- the product design allows a multiple utilisation of the product
- at the end of its life span the product can in a high quality manner be recycled or energetically recovered

Central environmental aspects and requirements are that the product is long-lasting and that it can be recycled.

In general, for many biobased product lines an objective analysis of ecological consequences and evidence of its expected ecological advantage must still be provided, based on representative boundary conditions.

6.2 First assessment of macroeconomic effects

Comparing the cultivated area for material use with energy recovery of RRM it is obvious, that the area under cultivation for bioenergy has been increasing steadily over the last ten years, whereas the area under cultivation for industrial use of RRM stagnated or even decreased in the same period. This trend can be observed explicitly in Germany but also in several EU member states. Due to policy instruments supporting bioenergy, it is more profitable for farmers to produce biomass for bioenergy use than for material use. These policy instruments directly impact the commodity prices for RRM and thus the land use competition between energetic and material use of RRM. The initial objectives of the bioenergy support policies were to maintain and develop employment in rural areas and to generate income in rural areas.

The public support for using RRM for bioenergy is established by law in Germany as well as in some member states of the EU, at the same time there is no comparable, systematic public support of the industrial use of RRM. Support for material use of RRM has been reduced to only a few cases in recent years. On EU-level there exists a processing aid for hemp and flax fibres (90 €/t for hemp and flax short fibres and 200 €/t for flax long fibres), which will be phased out at the end on 2012. In some single countries market introduction programs for natural fibre insulation materials (2003 - 2007) and bio-lubricants (2001 - 2008) have existed, but are now expired.

Comparing public support for different uses of renewable resources shows that the material use of RRM has been neglected compared to bioenergy use. A thorough analysis of the macroeconomic effects of RRM could help to assess whether higher support for energy uses than for material uses is justified. Several quite different studies exist on the macroeconomic effects of using RRM for energy recovery and material use. These have been recently evaluated and analysed by nova-institute (Carus, 2009). The most important macroeconomic effects of the material and the bioenergy use of RRM considered here are the employment creation and the generated turnovers along the value added chain. The value chain starts with the primary production and ends where the raw material still constitutes a significant share of the added value. Calculations are made on the available database for the German economy. The main results and conclusions of the nova evaluation (Carus, 2009) can be found in the following and in chapter 6.3.

In many cases public support measures for the use of renewable resources for energy purposes contribute 50 % and more to the revenues in Germany. Public support measures for material use of RRM are, compared to that, very scarce and often non-existent. Employment effects and the added value are typically significantly more positive for the material use of RRM than for the energy recovery of biomass.

Calibrated to the same raw material throughput (e.g. in tonnes per year) or hectare, the material use can typically tie up 10-15 times more work force and can generate around 10 times more added value than energy use. This has been shown for single competing value chains as well as for the entirety of employees in the field of material and energy use of renewables.

Example:
Using wood to produce paper and pulp instead of to produce energy results in an increase in added value by a factor of 6 and an increase in employment by a factor of 10. In general, the material use of wood compared to the energy use of wood raises employment about a factor of 7 along the whole value chain when calibrated to the same mass flow. The added value of material use of wood can be raised about a factor of 4 to 9.

The main reason for this increase is the length and complexity of process chains in material uses compared to renewable energies uses. The example of wood amply illustrates this. The route from the tree to pellets and then to combustion is conceivably simple. If furniture is made from wood or if it is used in housing construction, we find long process chains instead.

This does not only mean that from a macroeconomic viewpoint one should pay more attention and support to the material use, but that when energy use deprives or limits the material use of RRM – e.g. as a consequence of strong subsidisation – there can be devastating sociological and economic consequences, as is clearly illustrated in the case of, for example, derived timber products. The employment effects attributed to energy recovery from RRM only remain “net” effects if the material use of RRM is not obstructed.

Looking back, the original objectives of most of the public support programmes for bioenergy were to create income and employment in rural areas. Important political objectives, like climate protection or the reduction of import dependency, were added later on. Looking at the material use chains of RRM, in many cases the biggest part of employment and of value added takes place in manufacturing companies and in industry. As a result, rural areas often profit less from the material use of RRM than expected from its total economic benefit. Positive effects on the regional value added can be usually created easier by bioenergy use of RRM. From a regional political perspective, this might explain why the energy use of RRM is quite attractive. Nevertheless, the positive macroeconomic effects of the material use of RRM should always be clearly considered when public support programmes on RRM are being developed or revised.

6.3 Landuse competition between material use and energy recovery of renewable raw materials

Fertile land is a scarce commodity, and land use competition is a phenomenon resulting from that scarcity. Landuse competition in agriculture takes place on a global scale, on national states level, on regional and local level. Landuse competition is determined in the end of the cost –benefit ratio of the respective agricultural activity.

The cost–benefit-ratio of all agricultural land use activities can be affected by financial incentives like, for example, public support programmes for special production lines. Also new product demands or specific agricultural production standards with defined requirements for the protection of soil, water, biodiversity and for greenhouse gas reductions and others will lead to a revaluation of the costs and benefits of every agricultural land use activity. This will impact commodity prices and consequently affect or even potentiate the land use competition between different production lines. As already mentioned in chapter 6.2, in Europe the political and public support of renewable energies has lead to landuse competition between energy recovery and material use of RRM.

After the end of the compulsory agricultural set-aside policy in Europe and the reorientation of agriculture toward a world market, the alternative uses of agricultural raw materials for food, feed, energy and materials all compete with one another over the same area. In Europe, land use competition between the material and energetic applications of RRM is quite obvious. While in countries like Germany the area for the cultivation of RRM for energy recovery could potentially have expanded in the decade by a factor of 10, the area for materially used RRM stagnated. Especially in years of high food prices and strong support of energy crops, the material use of RRM was disadvantaged – already in the acquisition of land.

The decision of farmers to cultivate certain crops (partly also directly for specific uses) is primarily based on the expected rate of return. Based on the whole of Europe, other effects like investments in certain process chains, available technology and others play a relatively minor role. The rates of returns that can be achieved with certain crops depend on world market prices and prices on local markets, but also on the political framework.

In the field of energy recovery, many EU-countries have developed strong, systematic and long-term support measures which significantly determine the rates of returns of bioenergy use and in particular of biofuels but also biogas. In Germany, up to 80% of the rate of return of some energy lines are achieved through support measures (EEG, tax reductions, quota) (Rascka et al., 2009)

Equivalent support programs for the material use of RRM have never been developed in an EU-country, merely temporary market entry programs for few lines like bio-lubricants and natural fibre insulation materials.

Following the disparity in political support between material use and energy use, which can be found in all EU-countries, there are great distortions in the potentially achievable rates of returns for certain product lines, which can reinforce considerable misallocations of raw materials. This means that agricultural and forestry raw materials are used for energy recovery, even though under ecological and macroeconomic considerations they should rather be used for material applications. This was and still is also a fundamental reason for the above described growth of acreage.

Nevertheless the potential area for material and energy use is the same, since in both cases the area is determined by what is left after the use for food and feed (incl. export). Given adequate support measures, these acreages can be either completely cultivated for energy recovery, for material uses or for a mixture of both. How this mixture will look is largely determined by politics: whether an equal framework is developed for both energy recovery and material uses (e.g. on the basis of a support for saved CO_2 per hectare) or whether one line of utilisation is preferred over the other, as it has been the case for the energy recovery so far.

6.4 Perspectives for the material use of renewable raw materials in Europe

Given adequate framework conditions, meaning in particular an equal treatment with energy recovery, the material use in the EU has a bright future. With rising oil prices and other raw materials it becomes more and more important to find alternatives for the supply of industries and consumers with materials and energy.

While in the energy sector there exist, with solar, wind and water energy, potent and sustainable alternatives to fossil in addition to biogenic energy sources, which are increasingly established in markets and that have also become increasingly economically competitive, the outlook is different for material applications. Here, the “solar raw materials” from arable land and forests are the only sustainable (and also potent) alternatives to the finite fossil and mineral raw materials.

With rising raw material prices and a stronger establishment of renewable energy sources the use of RRM will continually gain in importance. In this respect it should not be overlooked that in past decades, the material use of agricultural raw materials and timber has, both globally and in Europe, always been larger than the use for energy recovery - and this in spite of all support programs for bio-energy. Politically, a reappraisal of the material use and a reorganisation of framework conditions is due, after which the support of material and energy uses takes place according to traceable ecological and macroeconomic criteria, which will overcome the current market distortion and will rehabilitate the constructive market forces.

The concept of cascade use of RRM has gained public and political awareness in the last few years as it demonstrates a resource and energy efficiently use of raw materials. Cascade usage means a multiple use of the RRM in the way that the biomass will be used consecutive for several purposes. At the beginning the RRM is materially used and several times recycled or upcycled. After several material use cycles, the biomass is processed for energy recovery. This concept has multiple advantages. The multiple use of the raw material results in lower resource demand and higher material efficiency. Further the arable land is used more efficiently as a higher added value is gained on the same area. Economically, the cascade usage leads to lower costs for raw materials and reduced disposal fees. Through the combination of material and energy use of RRM fossil resources can be saved twice and the environmental advantages of both are connected and gained.

Instruments for the promotion of the material use of RRM should consider area-related parameters on saved primary energy and CO_2-emissions. In addition, life cycle assessment according to DIN EN ISO 14040 and 14044 are adequate instruments to assess the environmental superiority of biobased products. Therefore, extensive eco-balance sheets for RRM-based products are needed and should be provided and supported by the producing industries.

7. Summary and Conclusions

Information and data on production and use of renewable resources by industry, with special view on chemical industry has been collected and analysed. The statistics offer an overview of already existing and available data. No accurate data exists for the whole Europe; only rarely updated estimations based on expert interviews. Moreover a periodic gathering of the few existing figures does not take place leading to insufficient and inadequate data availability. Therefore, for this study it is only possible to give a general survey, but no comprehensive overview on industrial material use of RRM in Europe.

- The total area for the cultivation of renewable resources in the EU (2005) is approximately 5.1 million ha; approximately 5.2 % of agricultural land. Of this, 2.3 million ha produce RRM for material use.

- The total material use of RRM in Europe, excluding wood, is about 9 million tonnes; 6.4 million tonnes for chemical industry and 2.65 million tonnes in other industries.

- The production and use of wood is, at 240 million tonnes (in 2005), by far the largest sector of industrial material use, followed by plant oils, sugar, starch and proteins, natural fibres and others.

- A rough estimation of the economical value of biobased products allows the estimation of a total market value of the biobased or partially biobased products of 450 000 million euros in the EU-25 manufacturing sector, whereas the market value of truly biobased products is around 250 000 euros. Dominating biobased products are pulp and paper (EUR 95 700 million), wood and ligneous material (EUR 55 500 million), pharmaceuticals (EUR 28 400 million), fibres (EUR 9 400 million) and detergents and solvents (EUR 4 100 million)

- The use of RRM as a feedstock for industrial production of materials, chemicals and other biobased products can save fossil resources and reduce negative effects on the environment. Further, it can also be a main driving factor for innovations. In many cases biobased products show an advanced greenhouse gas balance over the whole life cycle and both production and disposal is normally less toxic and energy demanding compared to products based on fossil resources. But the environmental advantage of biobased products has still to be determined for many production lines. Life cycle assessment according to DIN EN ISO 14040 and 14044 are adequate instruments for this.

- RRM are the only alternative carbon source to crude oil for the production of chemical products, therefore there is a high potential for further research in the chemical industry. A high potential is seen in industrial biotechnology. The estimations of the future economic market share differ widely, as the potential of the white biotechnology depends on the further development of innovative products and production concepts.

- One of the most promising innovative biobased products are bioplastics. Four main types of biobased plastics are currently on the market. They are used mainly for food packaging, bags, fast-food packaging and tableware, hygiene products, packaging for biological waste, plant pots and biodegradable mulch films. Highly innovative usages of biobased plastics include textiles and the use in natural fibre reinforced plastics. The most common biobased plastics are those processed from starch-based polymers (nearly 60 % in 2007), followed by Polylactid Acids (PLA) with 15-20 % and cellulose-acetates with around 15 %. The market for Bioplastics in Europe is growing, even though bioplastics are -compared to the total (fossil based) synthetic market of 250 million tonnes– in relatively early phase. In 2007 between 60 000 and 70 000 tonnes of biobased plastics were consumed in western Europe, and European Bioplastic e.V. (2008) estimated the consumption to be nearly 100 000 tons for Europe as a whole, or about 1-1,5 % of the total European plastics market. In the EU the strongest markets are in Germany, Great Britain, France, Italy and the Benelux-States.

- Biobased products are already substituting fossil based materials. There is a particularly high substitution potential for products with direct contact to humans (e.g. tensides in cosmetics etc.), for which a high awareness of the environmental consequences exists (e.g. tensides for detergents and cleaners) or where the feedstock is cheaper (e.g. glycerol as platform chemical).

From an environmental point of view, life cycle assessments should be undertaken on products based on RRM to ensure that those RRM are used in the most efficient way. With respect to the increasing world´s population and the decreasing fossil and natural resources, biomass production for food, feed, fuel or fibre will have to increase to meet the worlds´ augmenting demand. This increases the demand for agricultural land, which is already becoming scarcer, and increases the likelihood of land-use conflicts in future. The necessary biomass increase may be achieved by higher yields by intensifying agricultural production and/or by taking additional land under agricultural cultivation. A substantial rise in the use of biomass from agriculture, forestry and waste will put additional pressure on farmland and forest biodiversity as well as on soil and water resources. Moreover, landuse change and indirect landuse change can have strong environmental and social implications. It is a driver of biodiversity loss and of greenhouse gas emissions. When assessing the use of RRM as a feedstock for the industrial production of materials, chemicals or other biobased products, it is important to take account of these global implications. To limit these complex implications of biomass production a global solution approach has to be found.

From a macroeconomic point of view, the material use of RRM has clear advantages an over energy recovery in employment effects and value added. More positive macroeconomic effects would result from material use of RRM, especially as the establishment of use cascades, where several material applications are followed by energy recovery. In this way, an increase in the material use of RRM, would not necessarily prevent the use of biomass for energy recovery, but simply temporary elongate the supply chain. A more efficient use of agricultural biomass contributes towards saving greenhouse gas emissions which makes agricultural land use in general more efficient and more sustainable.

In conclusion, the present study gives a general overview on the industrial material use of RRM in Europe and a first assessment of the environmental aspects of RRM. The environmental impacts of RRM are highly complex and affect global, national and regional levels. Therefore, further research on the environmental implications of RRM is needed to provide a more sophisticated basis for political decision makers.

8. Literature

AAF (Association des Amidonniers et Féculiers, the trade association of the European Starch industry) 2009: Information on the website http://www.aac-eu.org (downloaded 2009-06-23)

Andrews, J. 2008: *personal communication to the use of natural rubber in the tire industry*, Weber & Schaer.

Arthur D. Little Limited 2008: *Market analysis of key renewable materials and product sectors.* Main Report and Appendices. Report to the National Non-Food Crops Centre, UK, August 2008.

Balkenhohl, F. 2006: *Weiße Biotechnologie: Biotech meets Chemistry.* In Dubbert, W.; Heine, T. (Eds.): Weiße Biotechnolgie – Ökonomische und ökologische Chancen. Umweltbundesamt, Dessau. 41-53

Barjol, J.-L. 2008: *Sugar for the Chemical Industry.* Brussels 22. May 2008.

Beier, W., 2009: *Biologisch Abbaubare Kunststoffe*, Umweltbundesamt Dessau-Roßlau, August 2009

Benson, S. 2007: *From Loose Fill to Solid Solution Composting Corn-Based Peanuts.* Package Design Magazine (2007/11)

Beucker, S.; Marscheider-Weidemann, F.; Carus, M. 2007: *Zukunftsmarkt Biokunststoffe.* Umwelt, Innovation, Beschäftigung 08/07, Umweltbundesamt & Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, Dessau

Bewa, H. 2007.: *Etude du marché actuel des bioproduits industriels et de biocarburants & evolutions prévisibles à 2015/2030.* Study conducted for the Agence de l`Environment et de la Maltrise de l'Enerie (Ademe), France, April 2007.

Bio-Polym Blog 2009: *NatureWorks increase PLA production to 140 metric tonsper year.* Taken from the website: http://biopol.free.fr/?p=755. Downloaded August 2009

Bitter, W.-G.; Dümmer, R.; Schade, V. 2008: *ZMP-Marktbilanz Forst und Holz 2008 Deutschland.* Hrsg. Zentrale Markt- und Preisberichtsstelle GmbH, Bonn.

Brellochs, A.; Schmolke, A.; Wolff, H. 2001: *Substitution chemisch-technischer Prozesse durch biotechnische Verfahren am Beispiel ausgewählter Grund- und Feinchemikalien*. Texte 16/01.Umweltbundesamt, Dessau

Bremmer, B.J.; Plonsker, L. 2008: *Bio-based lubricants – A market opportunity study update.* Prepared fort he United Soybean Board November 2008.

Carus, M.; Vogt, D.; Breuer, T. 2008: *Studie zur Markt- und Konkurrenzsituation bei Naturfasern und Naturfaser-Werkstoffen (Deutschland und EU).* Gülzower Fachgespräche Band 26. Erstellt durch: nova-Institut GmbH, Hürth. Hrsg. FNR e.V., Gülzow.

Carus, M.; Pauls, A.; Hau, A. 2008b: *Fossile und nachwachsende Rohstoffe für Verpackungen: Marktentwicklung und Preistrends.* Vortrag zum Deutschen Verpackungskongress 2008, 12.Juni 2008, Berlin

Carus, M.; Müssig, J.; Gahle, Ch. 2008c: *Naturfaserverstärkte Kunststoffe.* FNR e.V., Gülzow

Carus, M.; Raschka, A.; Piotrowski, S.; Haufe, J.; Herrmann B. 2009: *Entwicklung von Förderinstrumenten für die stoffliche Nutzung von Nachwachsenden Rohstoffen in Deutschland. Ergebnisse der Module 3 und 4.* Nova-Institut GmbH, 2009 (unpublished)

Christensen, C.H.; Rass-Hansen, J.; Marsden, C.C.; Taarning, E.; Egeblad, K. 2008: The Renewable Chemicals Industry. In: ChemSusChem 4/2008, Wiley-VCH Verlag GmbH&CoKaA, Weinheim. S. 284-289.

CEI-Bois 2009: *European Wood Factsheets: 1. Forestry and 2. The woodworking industry.*

CEPI (Confederation of European Paper Industries) 2008: *Key Statistics 2007. European Pulp and Paper Industry.* July 2008

Confederation of European Paper Industries (CEPI) 2009: *Preliminary Statistics 2008. European Pulp and Paper Industry*. February 2009

Deimling, S.; Goyman, M.; Baitz, M.; Rehl, T. 2007: *Auswertung von Studien zur ökologischen Betrachtung von nachwachsenden Rohstoffen bei einer stofflichen Nutzung*. Erstellt durch: PE International im Auftrag der Fachagentur nachwachsende Rohstoffe e.V.

Dubbert, W.; Heine, T. (Eds.) 2006: Weiße Biotechnolgie – Ökonomische und ökologische Chancen. Umweltbundesamt, Dessau.

Ebert, J. 2007: *Discovering new uses for Glycerin.* Biodiesel Magazine, September 2007. Grand Forks

Enzing, C.; van der Giessen, A.; van Groenestijn, J.; van Dongen, M. 2008: *Biobased economy - Exploring the opportunities for The Netherlandsss. Bijlage 3: Public policy instruments to support a bio-based economy.* Study for the Ministerie van Landbouw, Natuur en Voedselkwaliteit, September 2008.

European Commission 2007: *A lead Market initiative for Europe (COM(2007) 860 final).* Available on http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2007:0860:FIN:en:PDF

European Commission 2009, Agricultural and Rural Development: „Agriculture in the European Union - Statistical and economic information 2007“. Available on http://ec.europa.eu/agriculture/agrista/2007/table_en/index.htm

European Bioplastics e.V. 2008: *Bioplastics – Frequently Asked Question*. June 2008, Berlin

FAO (Food and Agriculture Organization of the United Nations) 2006: *Global Forest* Resources Assement 2005. FAO Forestry Paper 147, Rome

FEDIOL 2009: *Statistical data on production, trade and consumption of oilseeds and plant oils.* Taken from the website http://www.fediol.be at June 2009.

FEFAC (European Feed Manufacture's Federation) 2009: *Feed & Food – Statistical Yearbook 2007.* Available on http://www.fefac.org/file.pdf?FileID=17088.

FNR (Fachagentur Nachwachsende Rohstoffe e.V.) 2007: *Daten und Fakten zu nachwachsenden Rohstoffen*. Hrsg. FNR e.V., Gülzow.

Freedonia Group 2008: *Freedonia study presents trends for the rise on biodegradable plastic in the U.S.A.* Pressemitteilung vom 22. August 2008.

Fritsche, U; Fehrenbach, H.; Hennenberg, K. 2009: *GBEP Workshop on Indirect Land Use Change (ILUC): Status of and Perspectives on Science-Based Policies.* Briefing Paper. Available on http://www.ipieca.org/activities/fuels/workshops/nov_09.php

Gahle, C. 2008: Persönliche Abschätzungen von Christian Gahle, nova-Institut GmbH.

GME (Gelatine Manufacturers of Europe) 2008: Information on the website http://www.gelatine.de (downloaded 2008-09-18)

Graf von Armansperg, M.; Patel, M. K. 2007: *Weiße Biotechnologie*. In: Marktanalyse Teil II - Nachwachsende Rohstoffe. Prepared by meó Consulting Team, Institut für Energetik und Umwelt GmbH, Faserinstitut Bremen, nova-Institut GmbH and Copernicus Institute. Published by Fachagentur Nachwachsende Rohstoffe e. V. (FNR), Gülzow

Heyland, K.-U.; Hanus, H.; Keller, E.R. 2006: *Ölfrüchte, Faserpflanzen, Arzneipflanzen und Sonderkulturen. Handbuch des Pflanzenbaus Band 4.* Eugen Ulmer KG, Stuttgart.

Hill, K. 2008: *Vegetable oils as raw materials for industrial applications.* Vortrag im Rahmen des Kongresses 'Rohstoffwende', Dezember 2008.

Holmes, C. A. 2005: *IENICA – Interactive European Network for Industrial Crops and their Applications. Summary Report fort he European Union 2000-2005.* Taken from the website http://www.ienica.org at June 2009.

Hoppenheidt, K.; Mücke, W.; Peche, R.; Tronecker, D.; Roth, U.; Würdinger, E.; Hottenroth, S.; Rommel, W. 2005: *Entlastungseffekte für die Umwelt durch Substitution konventioneller chemisch-technischer Prozesse und Produkte durch biotechnische Verfahren.* Texte 07/05. Umweltbundesamt, Dessau

Hüsing, B.; Angerer, G.; Gaisser, S.; Marscheider-Weidemann, F. 2003: *Biotechnologische Herstellung von Wertstoffen unter besonderer Berücksichtigung von Energieträgern und Biopolymeren.* Texte 64/03. Umweltbundesamt, Dessau

IVC Industrievereinigung Chemiefaser e.V.) 2007: *Die Chemiefaser-Industrie in der Bundesrepublink Deutschland e.V.*

IVC (Industrievereinigung Chemiefaser e.V.) 2008: Information on the website http://www.ivc-ev.de (downloaded 2008-07-23)

International Rubber Study Group 2008: Information on the website http://www.rubberstudy.com (downloaded 2008-07-27)

Kamm, B.; Kamm, M. 2004a: *Principles of biorefineries.* Appl. Microbiol. Biotechnol. (64), 137-145.

Kamm, B.; Kamm, M. 2004b: *Biorefinery-Systems.* Chem. Biochem. Eng. Q. (18/1), 1-6.

Kamm, B.; Gruber, P.R.; Kamm, M. 2006: *Biorefineries - Industrial Processes and Products; Status Quo and Future Directions, Volume 1 and 2*. Wiley-VCH, Weinheim.

Kibat, K. 2008: Persönliche Mitteilung von Dr. Klaus Kibat, VDP

Lörcks, J. 2005: *Biokunststoffe.* FNR e.V., Gülzow

Lünnemann, O 2007: *Quo vadis Glycerin? Große Mengen fallen bei der Herstellung von Biodiesel an - und müssen Verwendung finden.* Pressemitteilung. Universität Dortmund (Bezug: Forschungsarbeit Arno Behr, Fachbereich Bio- und Chemieingenieurwesen).

Luther, R. 2009: *Lubricants based on renewable raw materials.* Vortrag im Rahmen des Kongresses 'Biorefinica 2009', Februar 2009.

Mantau, U. 2007: *Aufkommen und Verwendung von Holzrohstoffen 2007.* Übermittelt durch K.-D. Kibat (VDP); Hamburg 2007

Mantau, U. 2008: *Wood availability in Europe under the special aspects of the wood-based panel industry demands.* Presentation at 6thEuropean Wood-Based Panel Symposium, October 2008

Münch, J. 2008: *Nachhaltig nutzbares Getreidestroh in Deutschland, Positionspapier.* Erstellt durch: Institut für Energie- und Umweltforschung Heidelberg GmbH, Juli 2008.

NNFCC 2008: *Biochemical Opportunities in the United Kingdom. NNFCC project 08-008.* Study funded by Defra, project managed by NNFCC and conducted by Nexant ChemSystems. September 2008.

Nova-Institut 2008: *Globale Marktsituation der Biokunststoffe – Ergebnisse aus Studie des nova-Instituts für Reifenhäuser.* Biowerkstoff-Report Juni/Juli 2008. 29-31

Nowicki, P.; Banse, M.; Bolck, C.; Bos, H.; Scott, E.: Biobased economy. State-of-the-art assessment. Study from the Agricultural Economics Research Institute (LEI), Le Hague, February 2008.

OECD 1998: *Biotechnology for Clean Industrial Products and Processes: Towards Industrial Sustainability.* OECD, Paris

OECD 2001: *The Application of Biotechnology to Industrial Sustainability.* OECD, Paris

OECD (Editor) 2004: *Biomass and Agriculture – Sustainability, Markets and Policies.* OECD, Paris

Oertel, D. 2007: *Industrielle stoffliche Nutzung nachwachsender Rohstoffe – Sachstandsbericht zum Monitoring „Nachwachsende Rohstoffe“.* Arbeitsbericht Nr. 114 des Büros für Technikfolgen-Abschätzung beim Deutschen Bundestag (TAB).

Patel, M.; Crank, M.; Dornburg, V.; Hermann, B.; Roes, L.; Hüsing, B.; Overbeek, L.; Terragni, F.; Recchia, E. 2006: *The BREW-Project: Medium and long-term Opportunities and Risks of the Biotechnological Production of Bulk Chemicals from Renewable Resources - The Potential of White Biotechnology.* Abschlussbericht September 2006.

Pereira, A. 2008: *Cork - from a traditional product to a modern building material for industry.* Vortrag im Rahmen des Kongresses 'Rohstoffwende & Biowerkstoffe', Dezember 2008

Peters, D. 2006: *Nachwachsende Rohstoffe in der Industrie*. FNR e.V., Gülzow.

Pude, R.; Wenig, B. 2005: *Pflanzen für die Industrie*. 4. Auflage. FNR e.V., Gülzow.

Raschka, A.; Carus, M.; Piotrowski, S.; Scholz, L. 2009a: *Industrial material use of renewable resources in Europe.* Nova-Institut GmbH, 2009 (unpublished)

Raschka, A.; Carus, M.; März, U.; Korte, H.; Huber, T. 2009b: *Entwicklung von Förderinstrumenten für die stoffliche Nutzung von Nachwachsenden Rohstoffen in Deutschland. Ergebnisse der Module 1 und 2.* Nova-Institut GmbH, 2009 (unpublished)

Rothermel, J. 2008: *Stoffliche Nutzung nachwachsender Rohstoffe - Zwischenbilanz und Ausblick.* In: Brickwede, F.; Erb, R.; Hempel, E.; Schwake, M. 2008: *Nachhaltigkeit in der Chemie. 13. Internationale Sommerakademie St. Marienthal.* Erich Schmidt Verlag, Berlin.

Sauerwein, P. 2008: Persönliche Mitteilung von Dr. Peter Sauerwein, VHI

Schmitz, B. 2008: *For the four Themes concerned of the Cooperation Specific Programme.* Info Day & Brokerage Event Biorefinery Joint Call Brussels, September 2008

Suddell, B.C. 2009: *Industrial fibres: recent and current developments.* In: Proceedings of the Symposium on Natural Fibres. Common Fund of Commodities, 20.October 2008, Rome. S. 71-82

Theissen, H. 2006: *Die Marktsituation biologisch abbaubarer und biogener Schmierstoffe in Deutschland 2006.* Erstellt durch: Institut für fluidtechnische Antriebe und Steuerungen (IFAS), Aachen.

Thrän, D.; Weber, M.; Scheuermann, A,; Fröhlich, N., Zeddies, J., Henze, A.; Thoroe, C.; Schweinle, J.; Fritsche, U.; Jenseit, W.; Rausch, L.; Schmidt, K. 2006: *Sustainable Strategies for Biomass Use in the European Context. Analysis in the charged debate on national guidelines and the competition between solid, liquid and gaseous biofuels.* IE - Institut für Energetik und Umwelt, Leipzig 2006

van Dongen, M.; Bossenbroek, J.; Piera, T.; van Groenestijn, J.; Enzing, C. 2008: *Biobased economy - Exploring the opportunities for The Netherlandsss. Bijlage 2: Market potential of chemical applications for The Netherlandsss.* Studie für das Ministerie van Landbouw, Natuur en Voedselkwaliteit, 30. September 2008.

van Groenestijn, J.; Enzing, C.; van Dongen, M.; Bossenbroek, J. 2008: *Biobased economy - Exploring the opportunities for The Netherlandsss. Bijlage 1: Overview of high value added applications of biomass and biorefinery.* Studie für das Ministerie van Landbouw, Natuur en Voedselkwaliteit, 30. September 2008.

VDP (Verband Deutscher Papierfabriken e.V.) 2008: *Kennzahlen deutscher Zellstoff- und Papierfabriken*. Hrsg. VDP, Bonn.

VHI (Verband der deutschen Holzwerkstoffindustrie e.V.) 2008: Daten und Fakten der Holzwerkstoffindustrie in Deutschland. Persönliche Mitteilung des VHI auf Anfrage.

VHI (Verband der deutschen Holzwerkstoffindustrie) 2009: Information on the website www.vhi.de (downloaded 2009-06-21)

Vogt, D.; Karus, M.; Ortmann, S.; Schmidt, Ch.; Gahle, Ch. 2006: *Wood-Plastic-Composites (WPC)- Märkte in Nordamerika, Japan und Europa mit Schwerpunkt Deutschland.* Studie des nova-Institut, Hürth

Walz, R.; Ostertag, K.; Doll, C.; Eichhammer, W.; Frietsch, R.; Helfrich, N.; Marscheider-Weidemann, F.; Sartorius, C.; Fichter, K.; Beucker, S.; Schug, H.; Eickenbusch, H.; Zweck, A.; Grimm, V.; Luther, W. 2008: *Innovationsdynamik und Wettbewerbsfähigkeit Deutschlands in grünen Zukunftsmärkten.* Umwelt, Innovation, Beschäftigung 03/08, Umweltbundesamt & Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, Dessau

WBGU (Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen/German Advisory Council on Global Change) 2009: *World in Transition-Future Bioenergy and Sustainable Land Use.* Earthscan, London

WDK (Wirtschaftsverband der deutschen Kautschukindustrie e.V.) 2007: *Die Kautschukindustrie 2006*

WDK (Wirtschaftsverband der deutschen Kautschukindustrie e.V.) 2008: *Die Kautschukindustrie 2007*

Wenig, B. 2007: *Nachwachsende Rohstoffe – Spitzentechnologie ohne Ende.* FNR e.V. (Hrsg), Gülzow

Weisz, H.; Keausmann, F.; Amann, C.; Eisenmenger, N.; Erb, K.-H., Hubacek, K.; Fischer-Kowalski, M. 2005: *Development of Material Use in the European Union 1970-2001. Material consumption, cross-country comparision, and material flow indicators.* Eurostat, Office for Official Publications of the European Communities, Luxembourg

Wirtschaftliche Vereinigung Zucker e.V. 2009: Information on the website http://www.zuckerverbaende.de/2_3_2.html (downloaded on 2008-06-21)

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