Status Report Biorefinery 2007

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Abstract

Within a future sustainable society, biomass is expected to become one of the major renewable resources for the production of both food, feed, materials, chemicals, fuels, power and/or heat. To realise this vision a combined package of measures is necessary, a.o. an increase in overall energy efficiency, reduced consumption, and offering the framework to enable the large-scale transition towards a Bio-based Economy. The development and implementation of biorefinery processes – i.e. the sustainable processing of biomass into a spectrum of marketable products and energy – is an absolute necessity to meet the vision, i.e. to use the available biomass as efficiently as possible, and with the lowest environmental impact.

The goal of this Status Report Biorefinery 2007 is to present an overview of the current status and developments in the biorefinery area both from a national (Dutch), European and global point of view. The description of the current status includes: an overview of both existing biorefinery concepts and concepts that still have to be developed (a.o. Green, Whole Crop, Ligno Cellulosic Feedstock, Two Platform, Thermo Chemical, and Marine Biorefineries).

A description of pilot and demonstration initiatives, research and development projects, and network activities is a main part of this report.

A SWOT-analysis "Biorefinery from a Dutch Point-of-View" describes the strengths and weaknesses, the opportunities and threats of the potential of biorefineries for the specific situation in The Netherlands.

The report finishes with an overall discussion and some conclusions on biorefineries in general.

Samenvatting

Binnen een toekomstige duurzame maatschappij zal biomassa naar verwachting één van de belangrijke hernieuwbare grondstoffen worden voor de produktie van zowel voedsel, veevoer, materialen, chemicaliën, transportbrandstoffen, elektriciteit en/of warmte. Om deze visie te verwezenlijken is een gecombineerd pakket maatregelen noodzakelijk, o.a. een stijging van de totale energie-efficiëntie, verminderde consumptie en het aanbieden van een raamwerk om de grootschalige transitie naar een op biomassa gebaseerde economy (biobased economy) mogelijk te maken. De ontwikkeling en implementatie van bioraffinageprocessen – ofwel het duurzaam verwerken van biomassa tot een spectrum van vermarktbare producten en energie – is een absolute noodzaak om de visie te kunnen halen, n.l. om de beschikbare biomassa zo efficiënt mogelijk te gebruiken met de laagst mogelijke inwerking op het milieu .

Het doel van dit Statusrapport Bioraffinage 2007 is een overzicht te geven van de huidige stand van zaken en ontwikkelingen op het gebied van bioraffinage, zowel vanuit een nationaal (Nederlands), Europees en mondiaal perspectief. De beschrijving van de huidige status omvat een overzicht van bestaande en nog te ontwikkelen bioraffinageconcepten, o.a. groene, hele gewas, lignocelluse-grondstof, twee platform, thermo-chemische en aquatische biomassa raffinageconcepten.

Een beschrijving van i) pilot en demonstratie initiatieven, ii) onderzoek- en ontwikkelings-projecten en iii) netwerkactiviteiten vormt het belangrijkste gedeelte van dit rapport.

De SWOT-analyse "Bioraffinage vanuit een Nederlands standpunt" beschrijft de sterktes en zwaktes, en de kansen en bedreigingen van het bioraffinagepotentieel specifiek voor de Nederlandse situatie.

Het rapport sluit af met een overkoepelende discussie en enkele conclusies over bioraffinage in het algemeen.

Acknowledgements

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Keywords

Biorefinery, definition, concepts, conventional biorefineries, green biorefineries, whole crop biorefineries, ligno cellulosic feedstock biorefineries, two platform concept biorefineries, thermochemical biorefineries, marine biorefineries, pilots, demonstrations, research projects, networks, SWOT-analysis, stakeholders

Content

1 Introduction

1.1 Biorefinery concept essential to meet Dutch targets - description of research area

Within a future sustainable society, biomass is expected to become one of the major renewable resources for the production of both food, feed, materials, chemicals, fuels, power and/or heat. The global potential supply of biomass for energy use is very large. The GRAIN study (Hoogwijk et al., 2003) expects that the worldwide biomass supply can increase from a current 30 to 50 EJ up to 450 EJ per year in 2050 or 25 billion tonnes of dry biomass. However, the future global demand for biomass is expected to increase to such extent, and the global biomass availability is geographically dispersed, that the biomass available has to be converted to the required end-products with the highest possible efficiency and the lowest possible negative environmental impact. Furthermore, competition with the production of food and feed has to be avoided at any time.

In the Netherlands the Platform Biobased Raw Materials (in Dutch: Platform Groene Grondstoffen (PGG)) – an advisory committee to the Dutch government – has developed a Long-Term (LT) Vision that 30% of the fossil resources used as both raw materials and fuels (see Table 1) should be replaced by bio-based alternatives in 2030 (PGG, 2006a).

Table 1 The 30% LT Vision substitution goal specified over Dutch market sectors (PGG, 2006a).

Application	Fossil fuel substitution [%]	Fossil fuel substitution $[PJ_{th,\,affu}]$[1]	CO_2-emission reduction [Mt/a]
Chemicals & materials	25	140	11
Biofuels for transport	60	324	24
Power	25[2]	203	14
Heat	17[3]	185	10
Sum		852	59

[1] *affu = avoided fossil fuel use*
[2] *Full plant substitution necessary*
[3] *Mainly Synthetic Natural Gas (SNG)*

An important constraint of this LT Vision is that the overall energy consumption in 2030 is assumed to be comparable to that of the year 2000, viz. 3000 PJ_{th}. To realise the 2030 LT Vision a combined package of measures is necessary, a.o. an increase in overall energy efficiency, reduced consumption, and offering a framework to enable the large-scale transition towards a Bio-based Economy. The production of about 850 $PJ_{th, affu}$ will require about 1200 PJ_{th} raw biomass materials, corresponding to about 80 Mt dry base per year.

The choice between the four different options to substitute fossil based products with biomass based products, depends among others on the costs (Sanders et al., 2005). When the products are compared at the wholesale level on an energy content basis, large differences can be seen between the integral cost prices and the raw material costs (Table 2). In the opinion of PGG (2006b) priority should be given to the replacement of the most scarce fossil feedstock. That means first replacing oil, then natural gas and finally coal.

Table 2 Different applications and contributions of biomass (Sanders, et al., 2005).

Product	Integral cost prices (€/GJ end product)	Raw material cost fossil (€/GJ)	Netherlands energy consumption 3000 PJ_{th}
Average bulk chemicals	75	30 (oil)	+/- 20%
Biofuels for transport	10	8 (oil)	+/- 20%
Power (electricity)	22	6 (coal)	+/- 20%
Heat	4	3 (coal)	+/- 20%
Rest (a.o. materials)	n.a.	n.a.	+/- 20%

A first study to see if the required amount of biomass will be available, was performed for PGG by Rabou et al. (2006). The Gross Dutch biomass production ((import-export) + production) amounted 42.3 Mt or about 742 PJ_{th} in the year 2000. Only a small part of this biomass was available for non-food applications. The projection of the Dutch biomass availability for non-food applications in 2030 is: 6 Mt dry base primary by-products (100 PJ_{th}), 12 Mt dry base secondary by-products (200 PJ_{th}), and 0 – 9 Mt dry base energy crops (0 – 150 PJ_{th}), resulting in totally: 18 – 27 Mt dry base or 300 -450 PJ_{th}. From these data Rabou et al. (2006) conclude that 60 -80% of the biomass required to meet the 2030 LT Vision will have to be imported from outside the Netherlands. When aquatic biomass crops grown within The Netherlands could be used, the import demand could be reduced significantly. However, some import of raw biomass, biomass-derived intermediates and/or bio-based products will always be necessary.

A second study by PGG (2006b) concludes that imports of biomass can be reduced if the available Dutch biomass can be utilized in an optimal way.

This can be achieved by several transition paths: i) improving the efficiency of using existing biomass, including Dutch biomass that is not being used yet, ii) sustainable production of biomass and improving the yield and quality of biomass crops, iii) producing aquatic biomass. The biomass potential in 2030 is given in Table 3. However, also in this study imported biomass (option iv and part of the options i and ii) is still necessary, amounting to about 55% of the required biomass.

Table 3 Biomass potential in 2030 per transition path in avoided fossil PJ (PGG, 2006b).

Avoided fossil PJ	P/H/S 1)	Ethanol	Oil	Chemistry	Total	Import (%)
i) improving efficiency	261	70	10	70	411	50
ii) development of crops	69	78	57	36	240	75
iii) aquatic biomass	114	24	37	81	256	0
iv) imports of rest-, half- and end products	73	44	112	0	229	100
Total	517	216	216	187	1136	55
Ambition PGG	2) 388	324		140	852	

1) P = power, H = heat, S = Synthetic Natural Gas (SNG)
2) 203 PJ power + 185 PJ heat

For the Netherlands, the development and implementation of biorefinery processes is an absolute necessity to meet the 2030 LT Vision goal(s), i.e. to use the relatively cheap but low volume domestic biomass and the more expensive imported biomass as efficiently as possible, and with the lowest environmental impact. Another important reason for The Netherlands to focus on the development of efficient biorefinery processes (with e.g. lower costs) is the fact that our country is not only producing for its domestic market, but also for export markets. The amount of transport fuels is about three times the Dutch consumption and for chemicals this is a factor 2.5. So about two thirds of the production is exported again.

1.2 Goal of this report

The goal of this Status Report Biorefinery 2007 is to present an overview of the current status and developments in the biorefinery area both from a national (Dutch), European and global point of view. The information provided in this report can be used by the Dutch government to develop a strategy for supporting biorefinery-related research and demonstration activities, and to develop financial supporting mechanisms and policy measures to accelerate the market implementation of biorefinery concepts within the Dutch society.

Other stakeholders (i.e. industry, SMEs, the knowledge infrastructure, and non-governmental organisations) can use the information in this report to determine their specific position within the broad biorefinery area, and to decide if and with who they can enter this very promising area of biomass valorisation.

1.3 Brief overview of this report

In Chapter 2 a broad definition of the biorefinery concept will be given. Chapter 3 then describes the main types of biorefineries, e.g. based on the feedstock and the conversion technology used. Chapter 4 gives an overview of current initiatives regarding biorefineries. First the Dutch status is discussed, followed by the international initiatives. Chapter 5 sketches the first steps of a SWOT-analysis for the Dutch situation. However, this SWOT-analysis still needs to be finished in the Technology Roadmap project that is expected to start at the end of 2007. Finally Chapter 6 gives a discussion and some main conclusions. More details about the main stakeholders and the RTD initiatives are given in the Appendices.

1.4 Scope of this report

This report deals with biorefinery concepts, i.e. concepts for the sustainable processing of biomass into a spectrum of marketable products (more than one) and energy (see definition in 2.2). This means that concepts producing only a biofuel (for transport) and energy (a.o. the Choren initiative producing FT-diesel and energy, the Gussing initiative producing SNG, the EC RENEW project developing concepts in parallel for the production of biofuels for transport and energy) are outside the scope of this report, and therefore will not be described. The use of Biosyngas for the co-production of a portfolio of bio-based products in one integrated plant (a.o. the EC CHRISGAS project) is a form of Thermo Chemical Biorefinery, and therefore it is within the scope of this report.

2 Definition Biorefinery

2.1 Introduction

The basic principles of the traditional oil refinery and the biorefinery are schematically represented in Figure 1. An oil refinery mainly supplies transport fuels and energy, and only a relatively small fraction is used for chemistry. At a biorefinery a relatively larger amount is used for chemistry and material utilisation. According to Kamm et al. (2006) biobased industrial products can only compete with petro-chemical based products when biomass resources are processed optimally through biorefinery systems, where new value chains are developed and implemented.

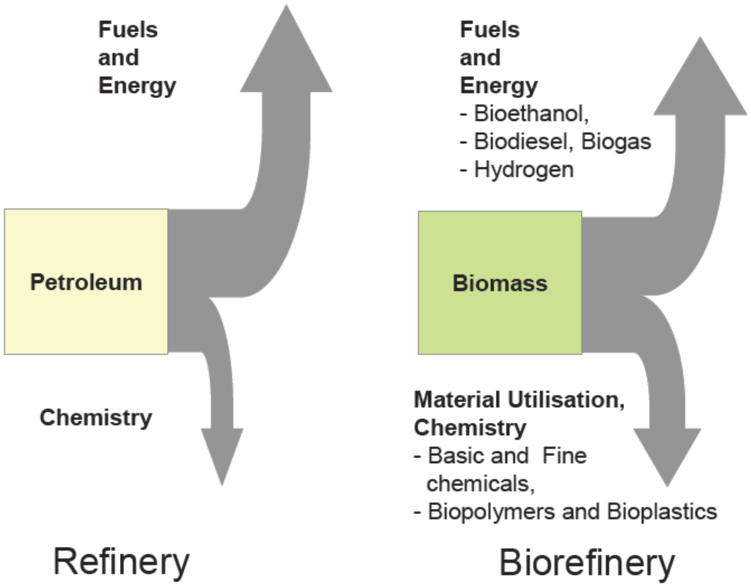

Figure 1 Oil refinery versus biorefinery (Kamm et al., 2006).

Biorefinery is a very broad field for processing of biomass into a portfolio of bio-based products (Figure 2). Biorefinery is a hot topic at the moment and within this framework a lot of activities are being performed nationally, in Europe and worldwide.

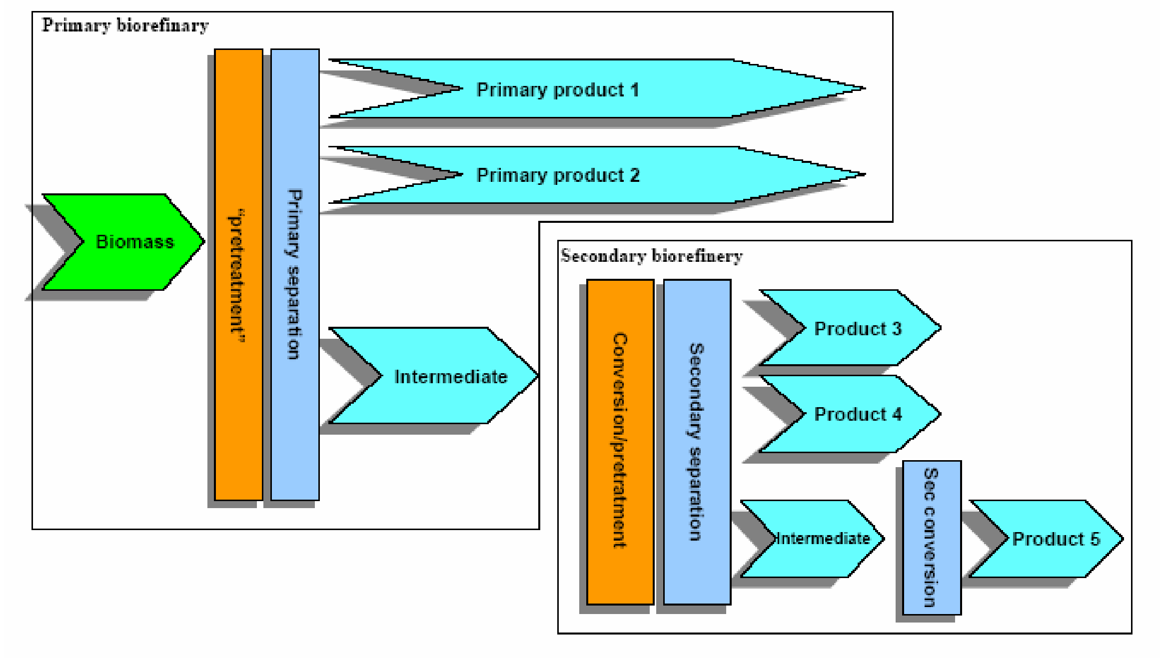

Figure 2 Schematic overview general biorefinery principle (Elbersen et al., 2003).

2.2 Definition

Depending on the type of activity and stakeholders involved, many different definitions for biorefinery are currently being used. Some examples are:

- A biorefinery is *a facility* that integrates biomass conversion processes and equipment to produce fuels, power, and value-added chemicals from biomass. The *biorefinery concept* is analogous to today's petroleum refinery, which produces multiple fuels and products from petroleum (NREL, 2007).
- A biorefinery is *a cluster of bio-based industries* producing chemicals, fuels, power, products, and materials.
- A biorefinery is *an overall concept* of a promising plant where biomass feed stocks are converted and extracted into a spectrum of valuable products (DOE, 2007).
- Biorefinery is the *separation of biomass* into distinct components which can be individually brought to the market either directly after separation, or after further (biological, thermo chemical/chemical) treatment(s) (Elbersen et al., 2003).
- The definition in Dutch: 'Bioraffinage is het fractioneren van biomassa in verschillende "producten" die al dan niet na een verdere biologische, (bio)chemische, fysische en/of thermoschemische bewerking en scheiding afzonderlijk af te zetten zijn' (EOS, 2007).
- Biorefining is the transfer of the efficiency and logic of fossil-based chemistry and substantial converting industry as well as the production of energy onto the biomass industry (Kamm et al., 2006).

- Biorefineries are integrated bio-based industries, using a variety of technologies to produce chemicals, biofuels, food and feed ingredients, biomaterials (including fibres) and power from biomass raw materials (EU Biorefinery Euroview, 2007).
- Addition of *pure plant oil* into traditional oil refineries (Shell, 2007).
- Biorefinery is *efficient use of the entire potential of raw materials and by-streams* of the forest-based sector towards a broad range of high added-value products (by co-operation in between chains) (Biorefinery Taskforce FTP, 2007).
- A biorefinery is an *integrated cluster of bio-industries*, using a variety of different technologies to produce chemicals, biofuels, food ingredients, and power from biomass raw materials (Europabio, 2007).

To streamline this wide range of definitions the following general description for biorefinery was defined within the framework of IEA Bioenergy Task 42 on Biorefineries:

Biorefinery is the sustainable processing of biomass into a spectrum of marketable products and energy[4]

This definition includes the key words:

- Biorefinery: concepts, facilities, processes, cluster of industries
- Sustainable: maximising economics, minimising environmental aspects, fossil fuel replacement, socio-economic aspects taken into account
- Processing: upstream processing, transformation, fractionation, thermo-chemical and/or biochemical conversion, extraction, separation, downstream processing
- Biomass: crops, organic residues, agroresidues, forest residues, wood, aquatic biomass
- Spectrum: more than one
- Marketable: a market (acceptable volumes & prices) already exists or is expected to become available in the near future
- Products: both intermediates and final products, i.e. food, feed, chemicals, and materials
- Energy: fuels, power, heat

<u>This IEA Bioenergy Task 42 definition is taken as framework for this report.</u>

[4] *IEA Bioenergy task 42 on Biorefineries (definition)*

2.3 Biorefinery Classification System

Based on this definition, within this report seven different biorefinery concepts are distinguished, i.e.:

- Conventional Biorefineries (CBR)
- Green Biorefineries (GBR)
- Whole Crop Biorefineries (WCBR)
- Ligno Cellulosic Feedstock Biorefineries (LCFBR)
- Two Platform Concept (TPCBR) Biorefineries
- Thermo Chemical Biorefineries (TCBR)
- Marine Biorefineries (MBR)

A description of these concepts will be given in Chapter 3.

For the time being, a clear system to classify the different biorefinery concepts is still lacking. Concepts are nowadays being classified based on a.o.:

i) raw material input (i.e. Green Biorefinery, Whole Crop Biorefinery, Ligno Cellulosic Feedstock Biorefinery, Marine Biorefinery)
ii) type of technology (i.e. Two Platform Concept, Thermo Chemical Biorefinery)
iii) status-of-technology (Conventional and Advanced Biorefineries, 1st and 2nd Generation Biorefineries)
iv) main (intermediate) product produced (Syngas Platform, Sugar Platform, Lignin Platform)

The development of a clear classification system: a) is a necessity to make the very broad biorefinery area more accessible for different stakeholders, b) will improve the overall understanding of the advantages of biorefinery processing over single-product processes, and c) therefore will accelerate the final market implementation of these concepts into national (Dutch), European and global Bio-based Economies. The development of a proper classification system is one of the main tasks for 2008 of the country representatives of IEA Bioenergy Task 42 on Biorefineries.

3 Biorefinery Concepts

3.1 Introduction

A biorefinery might, for example, produce one or several both high-volume, high-value bulkchemicals, and a low-value, high-volume liquid transportation fuel, while generating electricity and process heat for its own use, and perhaps enough to sell green electricity (Table 4). The use of biomass for the production of transportation fuels, and to a lesser extend energy, is still more costly than the use of traditional petrochemical resources. Through agricultural and market reforms more agricultural land could supposedly become available for growing alternative non-food crops.

Table 4 Key drivers for the adoption of biorefineries in different market sectors (Clark et al., 2006).

Chemical Industry	Energy industry	Agro (food/feed) industry
Legislative and consumer requirements for end-products		
Reducing the use of non-renewable fossil resources		
Cleaner and safer chemical manufacturing	Improve economics of biofuels by co-producing value-added products from residues	Improve economics of the full food product lifecycle by producing added-value products from wastes
What is waste in the agro-industry is a renewable raw material for the chemical and the energy industry !		

The idea behind the "biorefinery concept" is to further develop existing "food based" biorefineries such as sugar, vegetable oil, starch and grain processing facilities, or to develop completely new installations, which could dry and fractionate the whole biomass crop into its appropriate primary feedstock state, and further process it into sustainable bioproducts, such as materials, polymers, chemicals, fuels, and heat and power. By producing multiple outputs outside of the standard "food chain" a biorefinery is able to maximise the value derived from biomass feedstocks and optimise the cost-effectiveness of its products.

The main product groups of a biorefinery are: chemicals, biofuels, electricity & heat, materials (fibres, starch, wood), food and feed, minerals, CO_2, and H_2O. The sequence of the items in this list is arbitrary. It could also have been sorted according to the amount of biomass needed for production, according to the value of the products, according to reduced energy consumption or according to reduction of emission of greenhouse gasses.

The first product group chemicals is very interesting because they have a higher economic value (compared with most of the other products), and because production through a petro-chemical route often needs more energy than the biorefinery route. The principle is to use as many as possible valuable components that are already present in the biomass. A study commissioned by Industry Canada predicted North American markets for some high-growth chemical intermediates in 2020 (Table 5).

Table 5 Predicted North American markets for some high-growth chemical intermediates in 2020 (Towers et al., 2007).

Intermediate	Production in 2020 (in metric tonnes)
Polylactic acid	640,000
Citric acid	450,000
Propylene glycol	1,300,000
Sorbitol	400,000
Formaldehyde	7,500,000
1,4-butanediol	860,000

A recent study of Nowicki et al. (2007) has made a state-of-the-art assessment of the market for biobased products and biofuels in Europe (Table 6). It was concluded that the current level of the production of materials that are entirely or partially biobased, had a market value of about 454 billion Euros in the EU25 in 2005 (Table 7). The truly biobased part of these products is estimated to be 245 billion Euros. This share could grow rapidly to 332 billion Euros.

In the product groups biofuels and electricity/heat biomass is used as an energy carrier. The ultimate goal is to make biorefineries self-sufficient with respect to heat and when possible electricity. The product group materials often is already produced from biomass, a.o. by the paper and board industry (see also Table 6). However, this group also contains relatively new products like bioplastics that potentially will be a growth market in Europe. The UK e.g. is a pioneer in the field of replacement of packaging materials by bioplastics.

Table 6 Product families organised by production type (Nowicki et al., 2007).

Separation to materials	Separation to substances	Fragmentation to building blocks
Biomass	Biodiesel	Additives
Chemicals	Chemicals	Agrochemicals
Fabrics	Cosmetics	Base chemicals
Fibres	Glue	Bioethanol
Free sugars	Lubricants	Chemicals
Lignocellulose	Oils & fats	Cosmetics
Oils & fats	Paints & inks	Enzymes
Pharma & neutraceuticals	Pharma & neutraceuticals	Fabrics
Proteins	Polymers	Fibres
Pulp & paper	Pulp & paper	Paints & inks
Skins & leather	Solvents & detergents	Pharma & neutraceuticals
Starch		Polymers
Wood & ligneous materials		

Table 7 Overview of biobased production in 2005 for EU25 according to Eurstat (Nowicki et al., 2007).

Production type	Total value for EU25 (billions €)	Actual biobased value (billions €)	Potential biobased value (billions €)
Biomass separated to materials	250.6	187.7	211.6
Biomass separated to substance	47.9	23.1	38.6
Biomass fragmented to building blocks	155.2	34.5	81.6
Totals	453.7	245.3	331.8

In the current biorefinery definitions food and feed often are neglected. However, these definitions should be expanded, because looking at the interactions between all these different value chains is very important. Finally products like minerals should not be forgotten. The mineral balances of certain regions in the world should be treated very carefully. Mining one region, while creating a surplus in another region should be avoided, e.g. by creating return flows of minerals. The CO_2 that is produced in the processes of a biorefinery can also have an economic value, e.g. when horticultural production in glasshouses can be improved using this CO_2. The same holds for the surplus water produced in biorefineries.

In the schematic flow-chart of biomass to products (Figure 3) the main precursors are given, viz: carbohydrates, starch, hemicellulose, cellulose, lignin, lipids, oil and protein. Through different platforms these precursors are transferred into so-called building blocks that can be used to build secondary chemicals, intermediates and final products. These final products deal with almost every possible aspect of our daily life: industrial, transportation, textiles, safe food, environment, communication, housing, recreation and health.

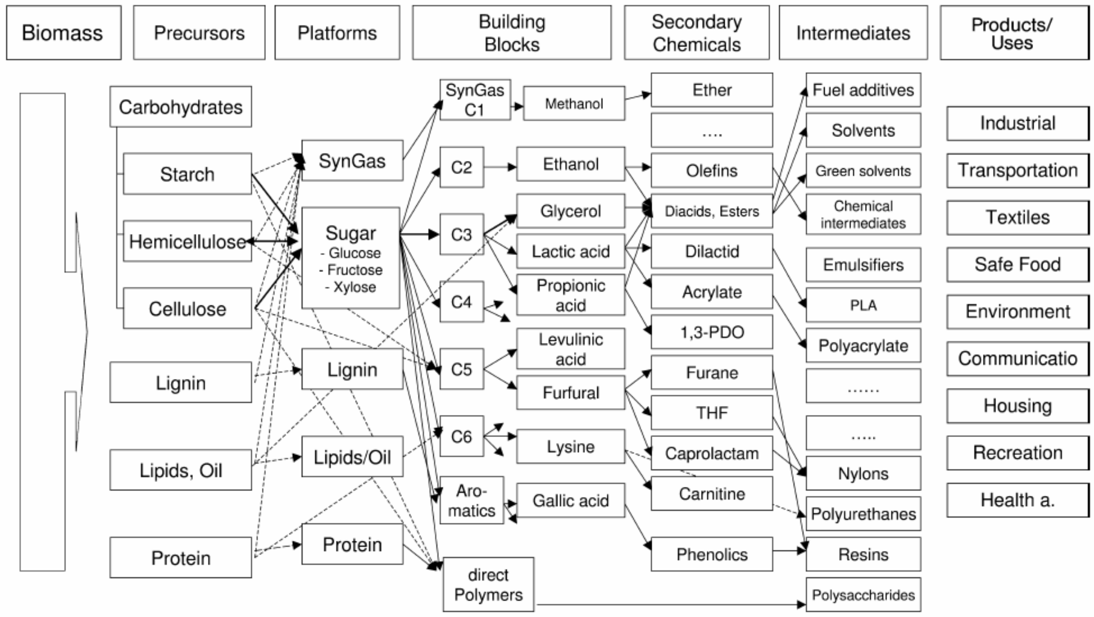

Figure 3 Schematic overview flow-chart: biomass-to-products (Kamm et al., 2006).

Potentially this whole range of products could be produced. However, the question which products will really be produced, depends on the ability to compete with existing products that are already economically viable and that originate from traditional production routes (see Table 2 in section 1.1). Furthermore, other possible barriers will play a role such as compliance with specific rules and regulations.

3.2 International developments

Figure 4 shows the biorefinery developments in the US as described by DOE (2007). In 2005 existing biorefineries were mainly based on starch: wet and dry mills. These biorefineries are mainly limited by co-products markets. Recent research projects (like EU IP Biosynergy, see section 4.3.2) aim at finding new routes for adding value to these co-products. Developing good fractionation and separation technology will be one of the key factors for the success of the biorefinery concept. Biorefinery technology differs from traditional oil based refinery technology because it will be mainly water-based. This difference certainly holds for the first part of the chain. Further down the chain perhaps traditional petrochemical technology can be re-used, e.g. by further processing Pure Plant Oil (PPO) in traditional refineries.

In 2020 DOE expects the presence of integrated industrial biorefineries in the US with multiple feedstocks that will be fractioned to many different high value products. Also in The Netherlands ideas were developed by the Prograss consortium to process potatoes and grass in the same industrial complex (Sanders, et al., 2005). However, it is still the question if highly different feedstocks will be used in practice within the same biorefinery concept. It is more likely that different biorefinery concepts will focus on relatively uniform biomass feedstocks for both technological and economic reasons.

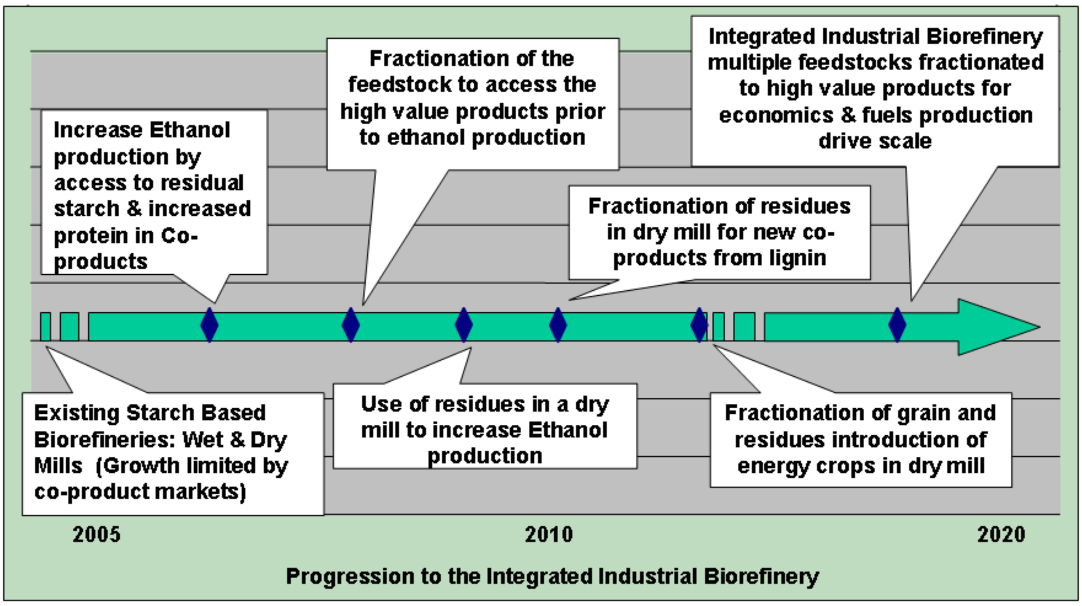

Figure 4 Biorefinery developments (DOE, 2007).

3.3 Conventional Biorefineries (CBR)

Many existing industries are in fact already a sort of conventional biorefinery:

- Sugar Industry (beet, cane)
- Starch Industry (wheat, cassave, potato)
- Vegetable Oils Industry (soy, rape seed)
- Feed Industry
- Food Industry
- Pulp and Paper (Forest) Industry
- (Petro) Chemical Industry
- Conventional Biofuel Industry (biodiesel, bioethanol, biogas)

This means that these industries use conversion and upgrading technologies to separate biomass into some main products and residual materials. Of course these industries, like the food industry, already try to add some value by supplying their by-products to other sectors, e.g. to the feed industry. However, their main emphasis is still on producing their main products, and no large efforts are made yet to produce a broad spectrum of other added-value products, like bio-chemicals or biofuels. This strategy is changing rapidly however, and this will probably lead to a change (economic and ecological upgrading) of the existing conventional biorefineries. In many cases an extension of a conventional biorefinery will form the basis for the development of one of the newer types of biorefineries, that will be described in the next sections.

3.4 Green Biorefinery (GBR)

The Green Biorefinery is based on pressurisation of wet biomass, such as green grasses and green crops (lucerne, clover), resulting in a fibre-rich press cake and a nutrient-rich press juice (Figure 5). This biorefinery concept differs from the others because fresh biomass is processed. This means that specific points of interest have to be taken into account, e.g. rapid primary processing or use of preservation methods (i.e. silage) is necessary to prevent degradation of the harvested materials.

Often the economy of bioprocesses is still a problem because in the case of bulk products, the price is highly affected by raw material costs. The advantages of the Green Biorefinery are a high biomass profit per hectare and a good link with the agricultural production; whereas the price segment of the raw materials is still low. Simple base technologies can be used and pass a good biotechnical and chemical potential for further conversions.

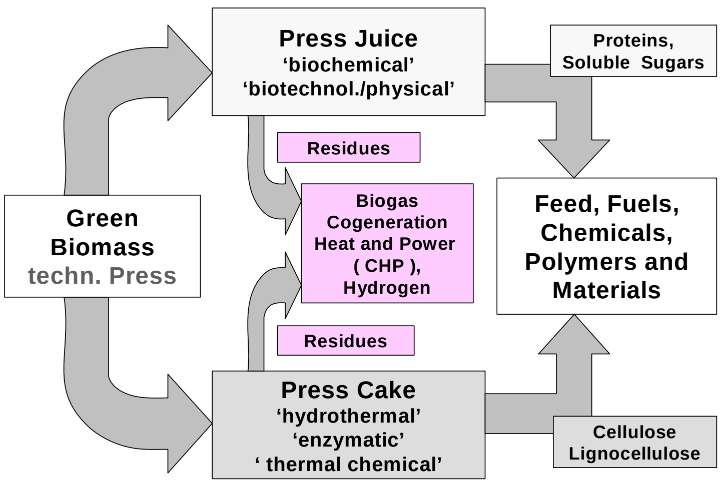

Figure 5 Green Biorefinery (Kamm et al., 2006).

A portfolio of end-products can be produced of both the fibre fraction in the press cake and the green juice fraction (containing a.o.: proteins, free amino acids, and minerals; Figure 6).

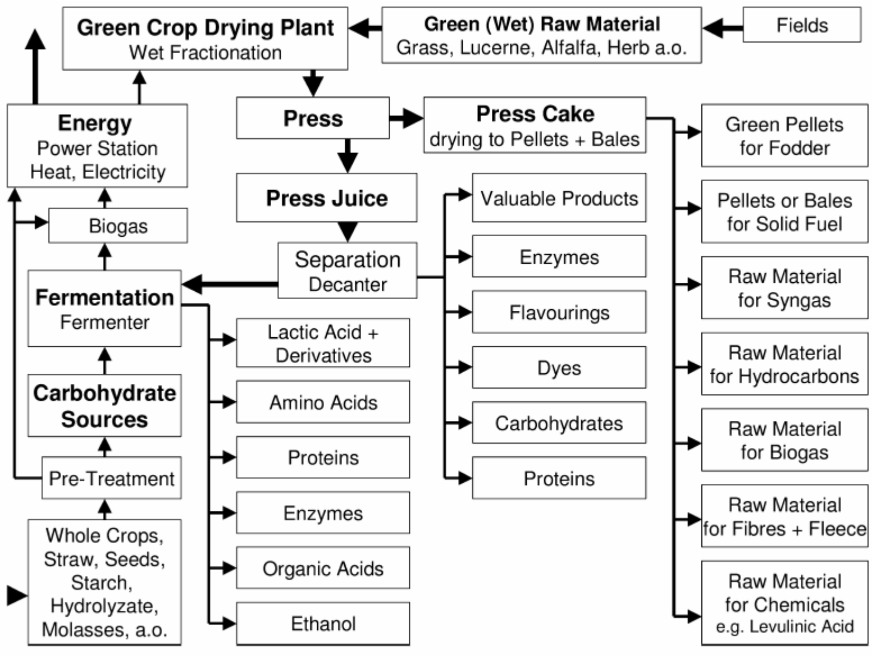

Figure 6 Potential products from a Green Biorefinery (dry milling) (Kamm et al., 2006).

3.5 Whole Crop Biorefinery (WCBR)

The Whole Crop Biorefinery is based on dry or wet milling of biomass (Figure 7). Raw materials are cereals, such as: rye, wheat, and maize. First step is the mechanical separation into a grain and straw fraction; where the portion of grain is approximately 20 wt% and the portion of straw is 80 wt%. Both streams will be further processed separately. The grain will deliver starch. The straw (a mixture of chaff, nodes, ears and leaves), represents a lignocellulosic feedstock, and may be further be processed in a LCFBR (see section 3.6).

Both fractions can be processed further to result in a portfolio of end products (Figure 8).

In case of wet milling the grain is swelled and pressed afterwards, releasing value-added products. The advantages of using a wet milling system are that natural structure elements, such as: starch, cellulose, and proteins are saved. Furthermore, known basic technologies can be used.

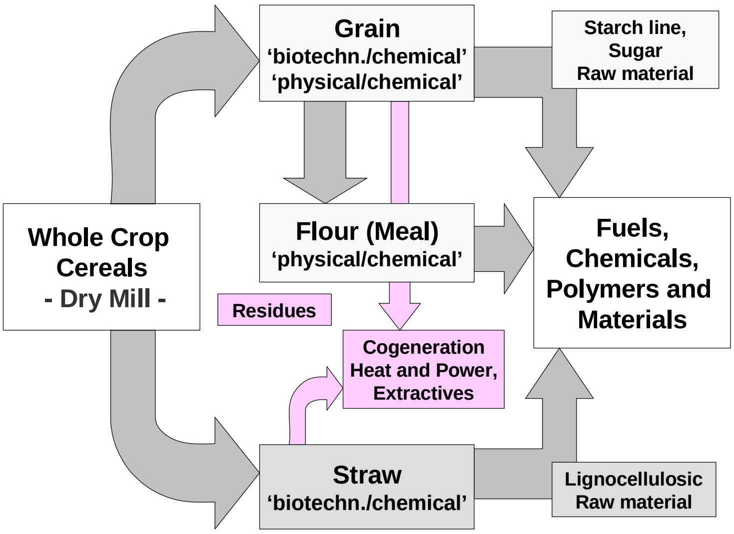

Figure 7 Whole Crop Biorefinery (dry milling) (Kamm et al., 2006).

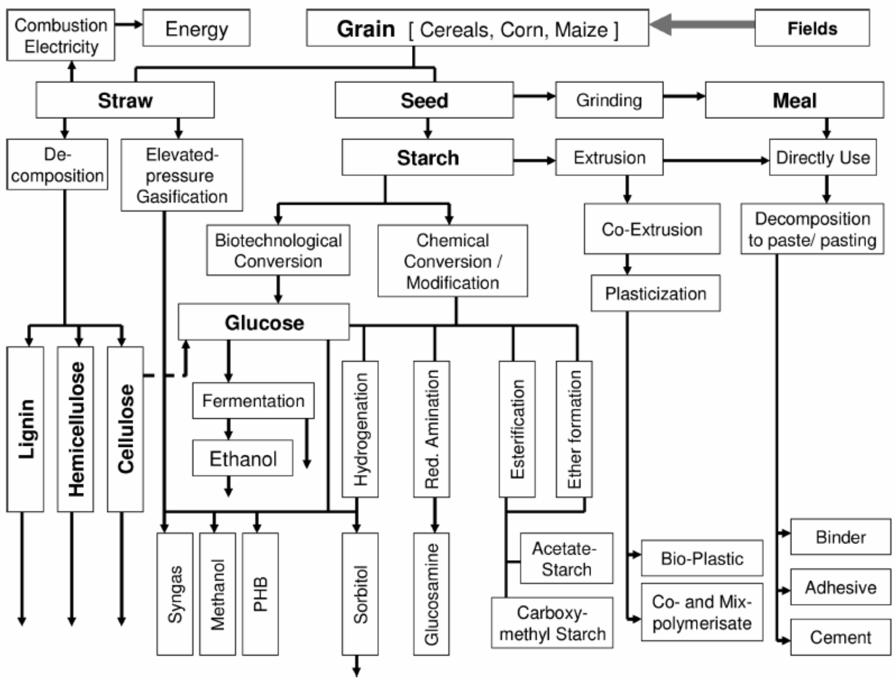

Figure 8 Potential products from a Whole Crop Biorefinery (dry milling) (Kamm et al., 2006).

Wheat straw (Figure 9) is an example of a low-value and high-volume agricultural by-product that can be used for the co-production of materials, chemicals, fuels and power/heat by an integrated biorefinery approach.

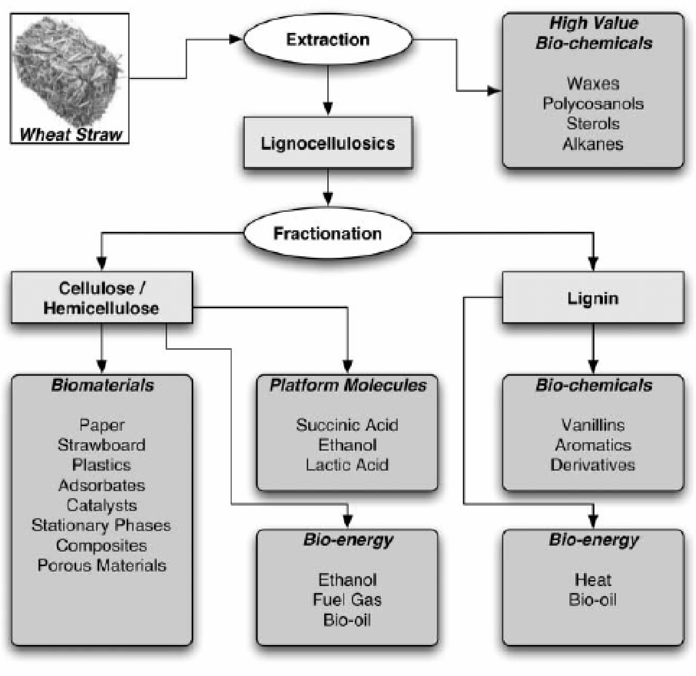

Figure 9 Wheat Straw Biorefinery Concept (Clark et al., 2006).

3.6 Ligno Cellulosic Feedstock Biorefinery (LCFBR)

The LCFBR is based on the fractionation of lignocellulosic-rich biomass sources into the intermediate output streams cellulose, hemicellulose and lignin (Figure 10), which can then be further processed into a portfolio of bio-based end-products, materials, chemicals, fuels and power and/or heat (Figure 11). These bio-based products will have a good position on both the traditional petrochemical and the expected future bio-based markets. Lignocellulosic-rich biomass is expected to become the most important biomass source of the future, because it will become widely available at moderate costs, and its cultivation and use compete less with food and feed crops. However, when lignocellulosic biomass can be processed to ethanol, it can also be used as feed. So in the future different biomass value chains (food, feed, fuels and chemicals) will be largely linked together.

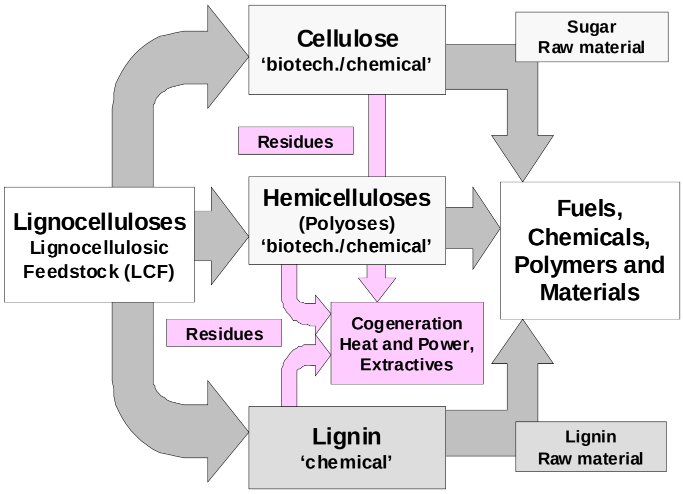

Figure 10 Lignocellulosic Feedstock Biorefinery (Kamm et al., 2006).

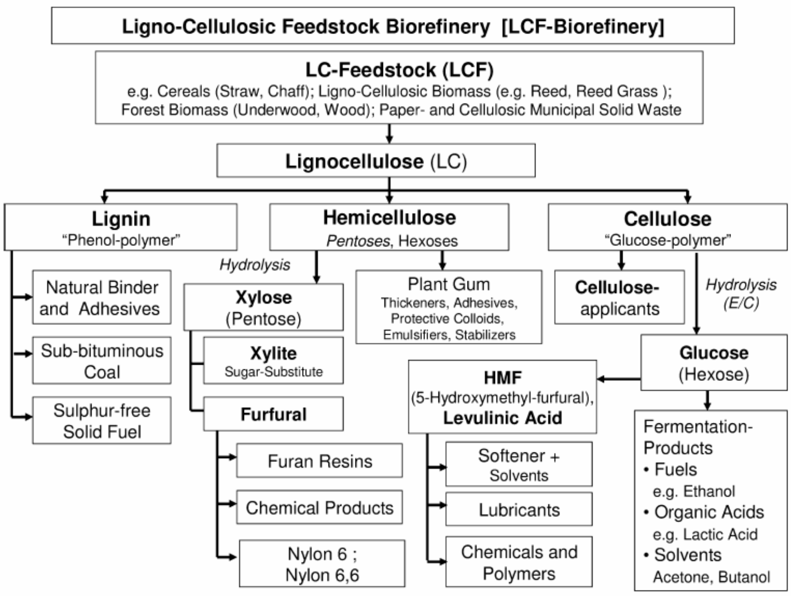

Figure 11 Potential products from a Lignocellulosic Feedstock Biorefinery (Kamm et al., 2006).

3.7 Two Platform Concept Biorefinery (TPCBR)

The TPCBR is based on fractionation of biomass into mainly a sugar (cellulose and hemicellulose) and a lignin fraction (Figure 12). The sugar fraction will be biochemically converted using a so called "sugar platform" into a portfolio of potential bio-products, such as: materials, chemicals, and fuels.

The lignin fraction (and the residues from the biochemical process) will be thermochemically converted using a so called "syngas platform" into a syngas for the potential production of a spectrum of bio-based products, including power and/or heat, to meet the internal process power and heat requirements.

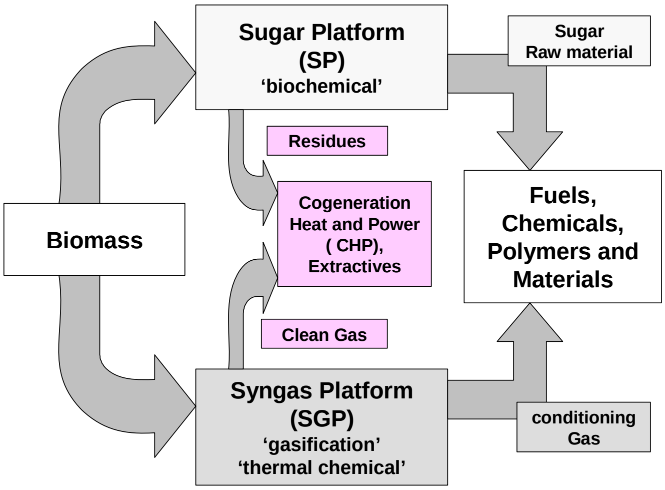

Figure 12 Two Platform Concept Biorefinery (Kamm et al., 2006).

3.8 Thermo Chemical Biorefinery (TCBR)

In a Thermo Chemical Biorefinery several technologies could be applied, such as: torrefaction, pyrolysis, gasification and/or Hydro-Thermal-Upgrading (HTU).

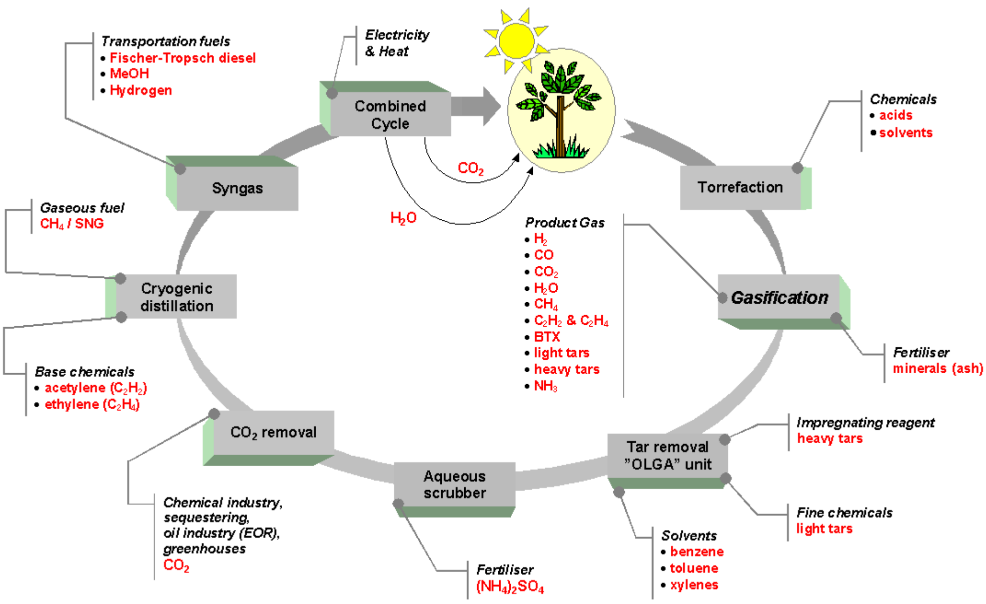

Figure 13 Thermo Chemical Biorefinery Concept (ECN, 2006).

ECN (2006) has developed the Thermo Chemical Biorefinery Concept in the Netherlands (Figure 13). In this biorefinery-concept the biomass is refined thermochemically into a portfolio of value-added products. Depending on the main business of the stakeholders involved, part of the thermochemical cycle could be used to produce the product spectrum desired.

A promising option that ECN is working on, is the co-production of value-added chemicals, mixed alcohols and Synthetic-Natural-Gas (SNG) from biomass by the development of an innovative Thermo Chemical Biorefinery Concept. This is based on low-temperature gasification, advanced gas clean-up, and innovative (intermediate product) separation and upgrading (Angelopoulou, 2007).

A specific type of Thermo Chemical Biorefinery is to make use of already existing raw oil based petrochemical infrastructure. Raw biomass and/or biomass-derived intermediates (a.o. char, pyrolysis oil, torrefaction pellets, syngas, HTU-derived biocrude) could be conditioned and then could be introduced into these existing capital intensive infrastructures, substituting fossil fuels and raw materials for the sustainable production of a spectrum of conventional petrochemical products. This kind of "green upgrading" of existing conventional infrastructures potentially will result in the realisation of the first real Thermo Chemical Biorefineries into the market.

ECN further has developed the Staged Catalytic Biorefinery Concept (Figure 14). The idea is to process biomass using a number of different technologies in sequential steps. The difference is the temperature used by the technology:

- torrefaction 180-290 °C
- pyrolysis 290-600 °C
- gasification higher than 600 °C

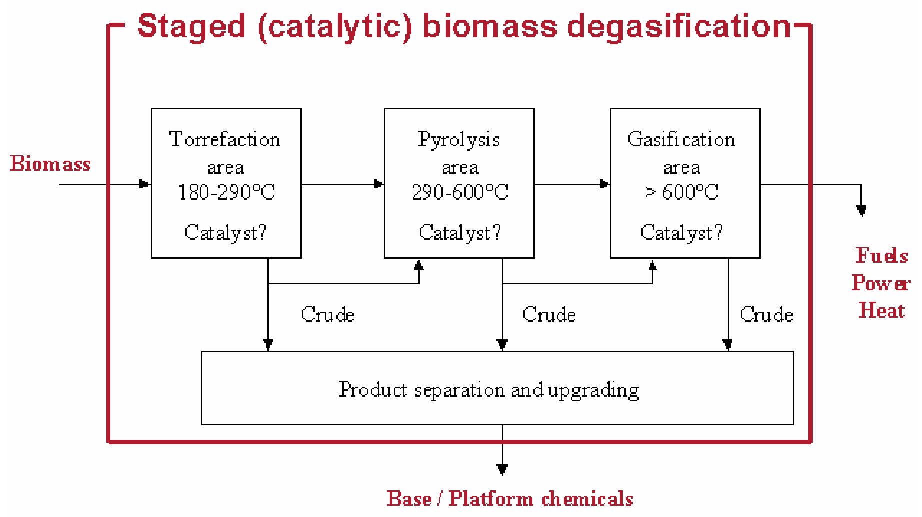

Figure 14 Staged catalytic biomass degasification (ECN, 2006).

Although the distinction between the technologies is not as strict as suggested by this list, a staged approach does offer the possibility to separate different products and chemicals at these different stages. This is an advantage when compared to producing syngas immediately through gasification. Detailing this staged approach is the topic of further research at the moment. One of the challenges is to develop suitable catalyst for different processes and technologies.

3.9 Marine Biorefinery (MBR)

Of the net global primary production of biomass, it is generally accepted that 50% is terrestrial and 50% aquatic. For the time being, policies of governments have focussed almost exclusively on the use of terrestrial biomass, with little attention on marine crops, i.e. microalgae (a.o. diatoms; green, golden, blue/green algae) and macroalgae (brown, red and green seaweeds), and their derived products (Bowles, 2007). The diatoms are the dominant life form in phytoplankton and probably represent the largest biomass potential on earth (Bowles, 2007). It is estimated that more than 100,000 species exist. Depending on the type of algea chosen and the growing conditions, marine biomass is able to accumulate significant amounts of bio-based products (a.o. oils, carbohydrates, starch, vitamins); diatoms often accumulate oils, green algae: starch and oils, and the golden algae: oils and carbohydrates.

The technical potential of marine crops for greenhouse gas abatement has been recognised for many years, given their ability to use CO_2, and the possibility of achieving higher productivities than terrestrial crops. Biofuel production from these marine crops, including overall sustainability aspects, is now an increasing topic of discussion.

Micro-algae systems

In case of *micro-algea systems*, energy production has to be combined with for example waste water treatment and/or the co-production of value-added products (food, feed, materials, chemicals) to make the overall cultivation/processing concept economically feasible (Reith, 2004). For the cultivation of microalgae both open pond systems and photobioreactors are being used/ developed. The advantage of using photobioreactors is their potentially higher production rate, a disadvantage the relatively high investment costs. The advantage of using open pond systems is their simple structure and relatively low investment costs, a disadvantage is the risk of contamination of the algae culture by bacteria or other micro-organisms. Productivities from 10-30 (open ponds) to 50-60 (photobioreactors) ton dry base/ha.yr have been reported (Bowles, 2007). Conventional processes for harvesting micro-algea are: centrifugation, foam fractionation, flocculation, membrane filtration, and ultrasonic separation. Harvesting costs may contribute 20-30% of the total algae biomass costs (Bowles, 2007).

Macro-algae systems

Macro-algea (seaweeds) cultivation for food/feed production has a long history, especially in Asia. Productivities of up to 45 ton dry base/ha.yr have been reported (Bowles, 2007).
Nowadays interesting cultivation/processing concepts are being developed in which existing off-shore infrastructures are being used as i) anchor (wind turbine parks) and ii) platform for off-shore (pre)processing (oil platforms) of the harvested materials (Reith, 2005).

Dutch situation

Aquatic biomass (microalgea and macroalgae (seaweed)) offers the possibility to significantly increase the domestic biomass availability. Especially for a country as The Netherlands, which only has limited domestic biomass availability (agro residues, forest residues, energy crops), the domestic biomass production potentially could significantly be increased by the application of high-efficient fully integrated aquatic biomass cultivation – processing systems, i.e. "Marine Biorefineries" (Figure 15).

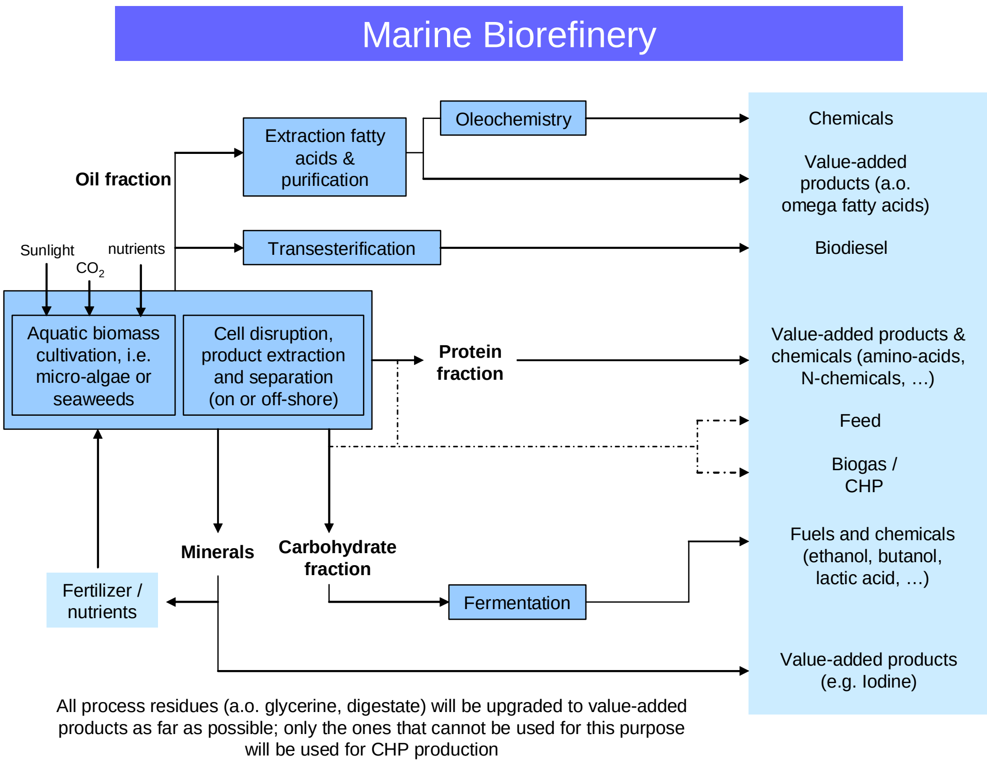

Figure 15 Marine Biorefinery.

3.10 Brief summary of different Biorefinery concepts

The new Biorefinery concepts that were described in section 3.4 – 3.9 are briefly characterized in Table 8 on the main aspects: type of feedstock, predominant technology and phase of development.

Table 8 Summary characteristics Biorefinery concepts.

Concept	Type of feedstock	Predominant technology	Phase of development
Green Biorefineries (GBR)	wet biomass: green grasses and green crops, such as lucerne and clover	pretreatment, pressing, fractionation, separation, digestion	Pilot Plant (and R&D)
Whole Crop Biorefineries (WCBR)	whole crop (including straw) cereals such as rye, wheat, and maize	dry or wet milling, biochemical conversion	Pilot Plant (and Demo)
Ligno Cellulosic Feedstock Biorefineries (LCFBR)	lignocellulosic-rich biomass: e.g. straw, chaff, reed, miscanthus, wood	pretreatment, chemical & enzymatic hydrolysis, fermentation, separation	R&D/Pilot Plant (EC), Demo (US)
Two Platform Concept (TPCBR) Biorefineries	all types of biomass	combination of sugar platform (biochemical conversion) and syngas platform (thermochemical conversion)	Pilot Plant
Thermo Chemical Biorefineries (TCBR)	all types of biomass	thermochemical conversion: torrefaction, pyrolysis, gasification, HTU, product separation, catalytic synthesis	Pilot Plant (R&D and Demo)
Marine Biorefineries (MBR)	aquatic biomass: microalgea and macroalgae (seaweed)	cell disruption, product extraction and separation	R&D (and Pilot Plant)

4 National and International Initiatives & Stakeholders

4.1 Introduction

Within this chapter the most important national and international initiatives (to the knowledge of the authors[5]) – both pilot-initiatives, demo-initiatives, other activities (a.o. networks), and running RTD-projects, – are shortly described. In the headings of the sections describing the initiatives, the abbreviation of the type of biorefinery concept concerned is shown between brackets, corresponding to the seven concepts defined in Chapter 2, and described in more detail in Chapter 3. These concepts are:

- Conventional Biorefineries (CBR)
- Green Biorefineries (GBR)
- Whole Crop Biorefineries (WCBR)
- Ligno Cellulosic Feedstock Biorefineries (LCFBR)
- Two Platform Concept (TPCBR) Biorefineries
- Thermo Chemical Biorefineries (TCBR)
- Marine Biorefineries (MBR)

The main stakeholders that are involved in these initiatives are listed in Appendix A. (National), B. (European) and C. (Rest of the world).

4.2 National Biorefinery Initiatives

An overview of some important National biorefinery initiatives is given in Table 9. The initiatives are categorized as:

- Pilot or demonstration
- Research & development
- Network

[5] *Suggestions for additions can be sent to the authors and will be taken into account in the update of the status report in 2008*

Table 9 Overview National Biorefinery Initiatives.

Name	Type	Partners	Website
Bbasic	R&D	a.o. TUD, RUG, Paques, Wageningen UR	www.b-basic.nl
Beethanol	Pilot	Agrologistiek BV, Wageningen UR, Schmitt, Actemium, Co-energy	www.beethanol.nl
Biobutanol	R&D	Wageningen UR, ECN	www.biobutanol.nl
Bio MCN	Demo/ Full scale	Bio Methanol Chemie Nederland (Bio MCN)	www.biomcn.com
Bioport	Pilot	Harbours Rotterdam/ Delfzijl/ Terneuzen	www.portofrotterdam.com
Biorefinery Cluster	R&D/ Pilot	Dutch association of paper and board industries (KVNP), Avebe, Cosun, HPA, Meneba	
BioValue	Demo	Innovantec, Delta	www.biovalue.eu
CatchBio	R&D	Netherlands Institute for Catalysis Research (NIOK), and others	www.catchbio.com
Co-refining of biomass in existing refineries (CORAF)	R&D	Twente University, BTG	www.senternovem.nl/eos
Dutch Green (grass) Biorefinery	Pilot	AVEBE, Progras consortium	
Dutch Knowledge Network on Biorefineries (Biorefinery.nl)	Network	Wageningen UR, ECN	www.biorefinery.nl
Grassrefinery – Courage	Pilot	Wageningen UR A&F, Agrologistiek BV, Bureau Ecologie en Landbouw	www.courage2025.nl
Lignocellulosic ethanol	Pilot	Royal Nedalco	www.nedalco.nl
Lignovalue	R&D	Wageningen UR A&F, and others	www.biobutanol.nl/lignovalue
Multi Fuel Power Plant Eemshaven	Demo	Nuon	www.biorefinery.nl
N-ERGY	R&D	WU-VPPC, and others	www.vpp.wur.nl
Optimal Lignocellulose Hydrolysis	R&D	Wageningen UR, HoSt BV	www.ete.wur.nl
Pectin Challenge	R&D	Royal Nedalco	www.nedalco.nl

4.2.1 Pilots and demonstrations

Beethanol (WCBR)

Agrologistiek BV has plans to install several pilot plants in the Netherlands for small-scale bio-ethanol production from arable crops (Broens, 2006; PGG, 2007a). Small-scale will be feasible by local integration. The concept was developed in the Beethanol project. The idea is to realize multiple smaller plants close to the farms. This will lower the transport costs, have zero waste and lead to easier engineering. Another characteristic is flexible use of feedstock (wheat, beet, leafs, fibres, maize and grass). By-products of the bio-ethanol are feed, biogas and CO_2. The capacity of these plants will vary between 5 and 50 million litres. The feasibility study was financed by the Province of Groningen and LTO Netherlands.

Bio MCN (TCBR)

The traditional way of producing methanol involves the use of non renewable natural gas. Bio MCN (Bio Methanol Chemie Nederland) re-opened the former Methanor production facilities in Delfzijl in 2007, and turned it into an innovative process that uses glycerin – the by-product of conventional biodiesel processes – as raw material for the production of maximally 900 kt/a 100% green bio-methanol.

Bioport

The geographical location of Netherlands, together with its available logistical (a.o. harbours of Rotterdam, Delfzijl, Amsterdam, Terneuzen), industrial, and knowledge infrastructure, makes this country potentially the Bioport of Europe. Rotterdam, for example, is one of the largest supply, process and transport areas of oil in Europe. In the harbour main companies have made important investments in the (recent) past that form a solid base for the mainport Rotterdam – an international centre in the web of national, European and intercontinental connections. This mainport links the Netherlands tightly to the rest of the world.

To meet the expected future European biomass demand to fulfil the requests from the food, feed, materials, chemicals, fuels and energy sectors, the larger amount has to be imported – both as raw materials, biomass-derived intermediates and final bio-based products, from outside the EU. The Dutch Bioport-infrastructure will allow the import of huge amounts of biomass to Europe via the Dutch harbours. In these harbours the biomass will be partly (pre-)processed to bio-based intermediates and final products in highly efficient biorefinery processes, co-producing a variety of value-added products (i.e. food, feed, biomaterials, biochemicals) together with high volumes of lower-value energy carriers (biofuels, power, heat). Main characteristic of the Bioport-concept is that the focus of biomass use will lie on the creation of maximal added-value by co-production of a portfolio of products for different market sectors, requiring the co-operation of stakeholders originally only working in their specific market sector.

The development and implementation of these high-efficient biorefinery processes is expected to take place in the short and medium term by a joint effort of industrial stakeholders, working closely together with the available knowledge infrastructure (institutes, universities). The portfolio of bio-based products produced within the Bioport-area will be used only for a small part within the Netherlands; the larger part will be exported again by ship, train and truck to other European countries.
Assessments are being made, analysing the possibilities for upgrading the existing mainports (a.o. the Rotterdam harbour area) to Bioports. Large-scale development of a Bio-Botlek area that plays an important role in the energy supply of North-West Europe, potentially could be an example of the Bioport-concept. Another example could be import of biomass in the Delfzijl and Terneuzen harbours (relatively low costs), upgrading of the raw materials at those locations, and transportation of the intermediates to Rotterdam, or other industrial complexes for further processing to final products. Currently, the Bioport-concept is being worked out in real Business Plans for the Rotterdam and Delfzijl areas.

Biorefinery Cluster (LCFBR & GBR & WCBR)
The plan for a Biorefinery Cluster is a joint initiative of forest and plant-based industries in the Netherlands. It was originally initiated within Costa Due – Concrete steps towards a sustainable Eemsmond – an Energy Valley project, but later on new partners joined the Biorefinery Cluster. The partners cooperate towards improved utilisation and energy-efficient processing of forest and agro-food-based raw materials and by-streams. At the moment this initiative is in the phase of studying the general possibilities for clustering agro-food and forest based biorefineries and identifying mutual interests and possibilities for cooperation. Business cases will be defined and then specific projects will be started aimed at developing innovative energy-efficient technology, and at creating a higher value for raw materials and by-products. No choice has been made yet for a specific biorefinery type.

BioValue (WCBR)
BioValue is an initiative of Innovantec B.V. and Delta Development and Water BV. Its main goal is setting up biodiesel plants, using vegetable oil as their raw material. BioValue also works on improving the biodiesel production process. Its activities in this field recently resulted in a new patent enabling the conversion of glycerine to a fuel and additive. The first pilot project will be realised in the Eemshaven in 2007. Compared to the products of existing biodiesel plants, BioValue is able to deliver a broad range of products:

- biodiesel according to the DIN EN 14214 standard;
- rapeseed cakes with a fat content of approx. 8%;
- artificial fertiliser;
- glycerine (minimum 80% quality);
- additives for petrol, diesel and biodiesel;
- pharmaceutical acetates.

Dutch Green Biorefinery (GBR)
The growing amount of grass surplus in the Netherlands was a reason for Avebe to study a green biorefinery concept based on grass (Hulst et al., 1999; Sanders et al., 2005). For this reason the Prograss consortium was formed with several partners: Avebe, Plant Research International, Nedalco, ABCTA, Agrifirm, NOM and Rabo. In 2000 a pilot plant was built in Foxhol (Groningen) to study the technical and economic feasibility of the concept. The main products were a grass juice concentrate, grass protein and grass fibres (Figure 16). New mechanical separation technology was developed within the project. Finding a profitable market outlet for all of these products is of great importance. This was still a problem in early 2002, when the project was finished. However, recently the economic perspective has improved, which has lead to alternative outlets, e.g. the paper industry that is now interested in producing paper based on grass fibres. Other products that could be manufactured based on these grass fibres are potting soil, construction materials and filler materials for polymer extrusion products. The grass juice concentrate can be used as feed component for pigs or to produce biofuels. Finally the grass protein can be used as feed component for pigs and poultry.

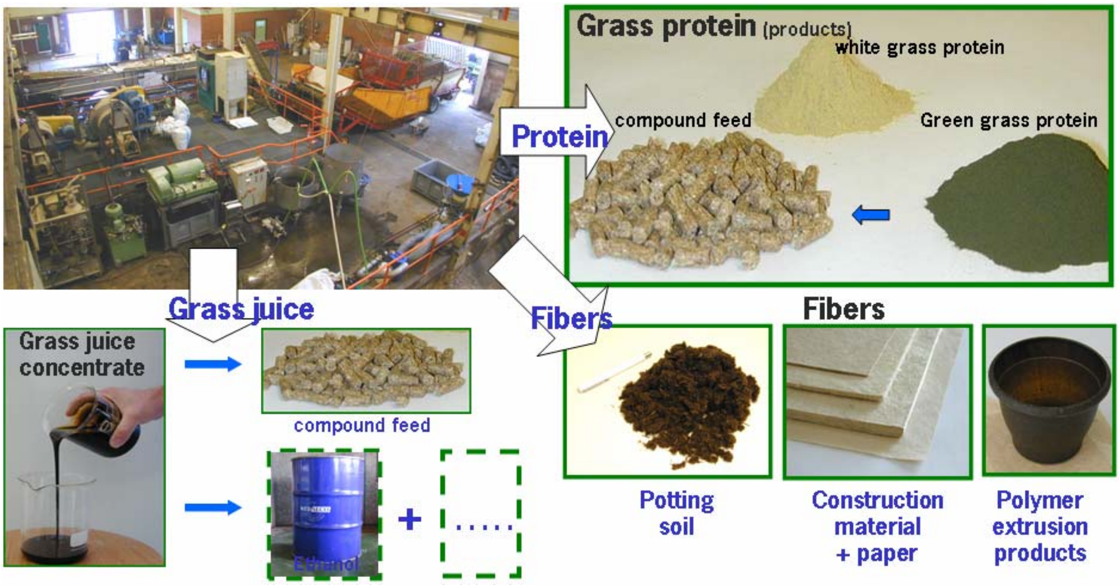

Figure 16 Pilot plant Green Biorefinery Prograss Consortium.

Grassrefinery – Courage (GBR)
Courage is a Dutch Foundation which stimulates and supports innovations for the longer term in dairy farming. One of the innovations that Courage is developing is the refining of grass (Figure 17) into a press juice and a press cake, with downstream upgrading of these fractions to value added products (a.o. proteins from the juice fraction as alternative soy feed, fibres for the fibre/paper industry from the press fraction). The remaining press juice potentially could be used as raw material for biogas-derived CHP production or fertilizer.

Refining of grass into a portfolio of value-added products and energy potentially offers a good solution for the surplus of grass nationally produced as a result of the extensivation policy. The current market price of this grass surplus is minimal and requires an innovative solution to be used in a profitable way.

The refining of grass into proteins, fibres and biogas/fertilizer is only a first step. Further refining/upgrading to amino acids (proteins), insulation materials (fibre fraction), alcohols (juice fraction) potentially could make the whole process even more profitable.

Harvesting

Pressing

Juice collection

Fibre pressing

Figure 17 Process steps in the Courage grass refinery project.

Lignocellulosic ethanol (LCFBR)

Royal Nedalco already operates a traditional first generation based bio-ethanol production plant in Sas van Gent, that uses starch as a feedstock (among others by-products obtained from the neighbouring industry Cargill). Advanced plans exist to build a pilot plant to process lignocellulosic feedstocks . For that purpose Royal Nedalco participates in research to find new second generation fermentation technology that can be applied on a relatively short-term (see also the Pectin Challenge project in Appendix D).

It is expected that companies like Nedalco that produce bio-ethanol from sugar and starch at the moment, will use second generation technology at first to increase bio-ethanol production using these current feedstocks. Then a gradual transition will be made towards lignocellulosic feedstocks.

Multi Fuel Power Plant Eemshaven (TCBR)

The Dutch power production company NUON decided in the beginning of 2007 to build a new 1200 MW_e power plant in the Eems harbour. The first plans were to build a multi-fuel power plant based on the IGCC technology. In this plant both coal, natural gas and biomass were planned to be gasified, to produce power in a high-efficiency combined-cycle (CC) process.
In September 2007 NUON decided first to start with the construction and operation (2011) of the combined-cycle part of the installation fired by natural gas, to minimize the necessary initial investment costs (the multi-fuel IGCC plant will require an initial investment of more than 1.000.000.000 €). After two years of operation, and depending on the external market at that time, the company will decide if they will build the upstream multi-fuel gasification plant for the production of clean syngas as substitute for the natural gas. This clean syngas (mainly CO and H_2) potentially could also be used for the production of a portfolio of value-added chemicals and/or transportation fuels (a.o. Fischer-Tropsch diesel, bio-methanol, hydrogen) together with the power, turning the overall plant in a highly efficient thermochemical biorefinery infrastructure.

4.2.2 Research projects

The aim of the Dutch Energy Research Subsidy programme is to expand knowledge on energy efficiency and renewable energy in the Netherlands (EOS, 2007). Biorefinery is one of the research spearheads of its Long Term (LT) subprogramme. Some running RTD-projects on Biorefineries in The Netherlands financed by the EOS-LT programme are:

- Biobutanol
- Co-refining of biomass in existing refineries (CORAF)
- Lignovalue
- N-ERGY
- Optimal Lignocellulose Hydrolysis
- Pectin Challenge

Other Dutch research programmes on biorefineries are:

- ASPECT
- BBasic
- CatchBio
- IBOS

All of these Dutch research projects have been described in more detail in Appendix D.

Unfortunately, at the moment no joint Research programme exits yet between the Energy sector and the Agricultural sector, comparable to the joint DOE-USDA initiative (BRDI, 2005) that is described in Section 4.3.2. The result is that biorefinery research projects can hardly focus on biomass feedstock issues.

4.2.3 Networks

Dutch Knowledge Network on Biorefineries (Biorefinery.nl)
Biorefinery.nl, a joint initiative of Wageningen UR and ECN, informs industry, research institutes, universities, social institutes and government about research activities, new developments and projects in the field of biorefinery (Figure 18). With the feedback of all of these groups it will also establish a biorefinery vision and formulate a roadmap for research on and development of biorefinery concepts in The Netherlands.

A close cooperation of different participants with a broad variety of disciplines within the Dutch Network on Biorefinery – Biorefinery.nl – enables research, development, demonstration and implementation of innovative biorefinery concepts. This whole route will certainly require a considerable effort of all parties involved (research institutes, government and industry). However, the final result will be a solid knowledge and market position of the Netherlands (and Europe) on the field of sustainable biomass chains.

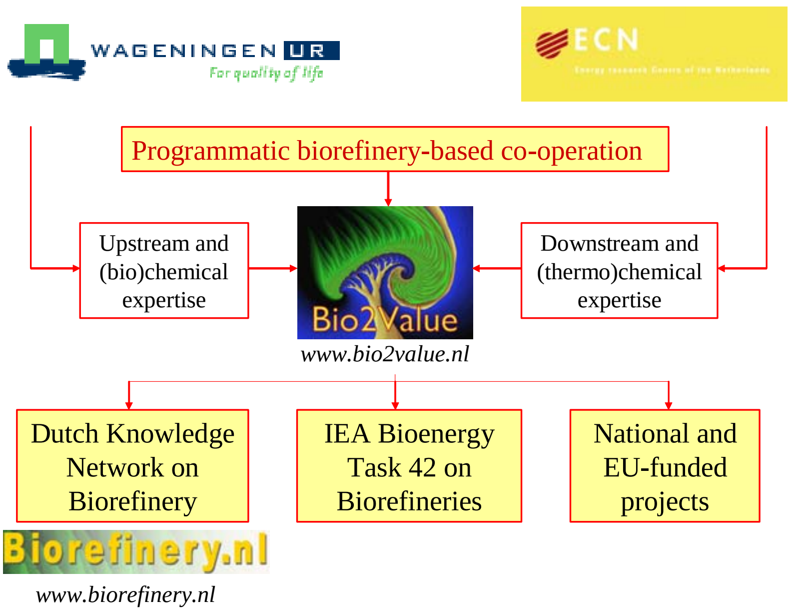

Figure 18 Dutch Knowledge Network on Biorefineries.

4.3 International Biorefinery Initiatives

An overview of some important International biorefinery initiatives[6] is given in Table 10. The initiatives are again categorized as:

- Pilot or demonstration
- Research & development
- Network

Table 10 Overview International Biorefinery Initiatives

Name	Type	Partners	Website
BIOCOUP	R&D	VTT & 17 partners, a.o. RUG	www.biocoup.eu
BioHub programme	Pilot	Roquette, Arkema, DSM, Euroovia, Metabolic Explorer, Sidel, Solvay, Tergal, Insa, and USTL	www.biohub.fr
BioGasol	Pilot	Biogasol	www.biogasol.dk
BIOPOL	R&D	Wageningen UR - AFSG, ECN, and others	www.biorefinery.nl/biopol
Biorefinery EUROVIEW	R&D	Industries and Agro-Resources Cluster, and others	www.biorefinery-euroview.eu
Biorefinery Task Force Forest-Based Technology Platform	Network		
BIOREF-INTEG	R&D	Wageningen UR – AFSG, and others	
BioSynergy	R&D	ECN, Wageningen UR – AFSG, and others	www.biosynergy.eu
Canadian Networks	Network	• Alberta Centre for Biorefining • Canadian Forest Biorefinery Network • Canadian University Forest Biorefinery Network • National Biorefining Network	

[6] *Suggestions for additions can be sent to the authors and will be taken into account in the update of the status report in 2008*

Canadian Triticale Biorefinery Initiative	R&D		
CHRISGAS	Demo	Växjö University (Sweden) a.o.	www.chrisgas.com
DOE/USDA - FY 2002 Joint solicitations on biomass R&D	R&D		www.brdisolutions.com
DOE – Six Cellulosic Biorefinery awardees	Demo	Abengoa, Alico, Blue Fire, Iogen, Poet, Range Fuels	www1.eere.energy.gov/biomass
ECOREFINE	R&D	Tecnia	www.tecnia.net
EPOBIO	R&D	Centre For Novel Agricultural Products (CNAP), and others	www.epobio.net
EUROLIGNIN	R&D	Wageningen UR – AFSG, and others	www.ili-lignin.com
FORCE Concept	R&D	STFI, VTT	
Forestry Biorefinery	Demo		
Ghent Bio-energy Valley	Demo	Ghent University, the city of Ghent, the Port of Ghent, the Provincial Development Agency for East Flanders and several industrial companies	www.gbev.org
Green Biorefinery Austria	R&D/ Pilot	Kornberg Institute, Joanneum Research, BioRefSys, Energie Institut, TUG, BOKU	www.joanneum.at
Green Biorefinery Germany	Pilot	Biorefinery.de	www.biorefinery.de
Green Biorefinery Ireland	Pilot	BiorefineryIreland	www.biorefinery.ie
IEA Bioenergy Task 42 on Biorefinery	Network	Wageningen UR - AFSG, and others	www.biorefinery.nl/iea-task-42
Joint European Technology Platform Task Force on Biorefinery	Network		
Lenzing AG	Demo	Lenzing AG	www.lenzing.com
Lignocellulosic Feedstock Biorefinery Iceland	Pilot	Biorefinery.de	www.biorefinery.de
Lignocellulosic Feedstock Biorefinery Germany	R&D	Dechema, Fraunhofer-ICT, BFAFH Hamburg, Bayer, and others	

Lignol Innovations – British Columbia	R&D	Solvent based wood fractionation to lignin and fermentable sugars	
Marine Biorefinery	Pilot	Stuttgart-Fraunhofer IGB	
NExBTL	Comm.	NesteOil	www.nesteoil.fi
Network for the implementation of biorefineries (NIB)	Network		www.bioraffinerie.at
SunPine Biorefinery	Pilot	Biodiesel and value-added products production (SWE)	
WaCheUp	R&D	STFI-Packforsk	

4.3.1 Pilots and demonstrations

BioHub Programme (WCBR)

The French BioHub-programme – led by Roquette, and supported by the French Industrial Innovation Agency – aims at the development of cereals-based chemical products to the point that they are sustainable substitutes for fossil-origin products (Figure 19). Largely available agricultural raw materials (cereals) are fed to a Whole Crop Biorefinery (WCBR) to co-produce a portfolio of platform chemicals (a.o. isosorbide) as intermediates for the production of i) biomonomers for specialty on commodity markets and ii) biopolymers. Main R&D areas are the development of new White Biotech Processes. The expected volumes and areas involved are: 1.3 million tonnes of corn (150,000 ha).

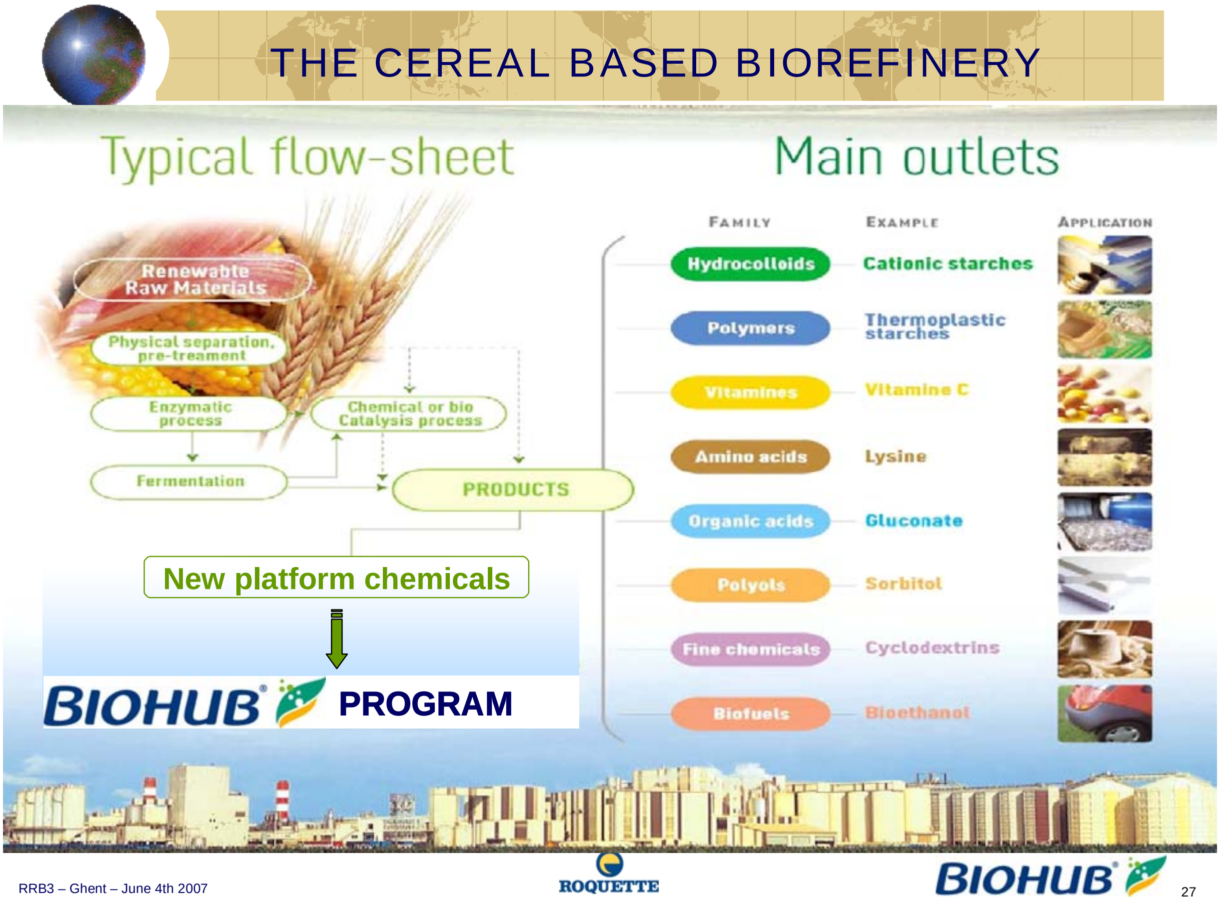

Figure 19 Cereal-based Biorefinery (Roquette, 2007).

<u>BioGasol (WCBR)</u>
BioGasol is a Danish engineering and technology company developing and designing technologies needed for second generation bioethanol production. BioGasol´s process technology is innovative and offers a cost effective production of biofuels such as bioethanol, hydrogen, methane and other valuable byproducts.
BioGasol builds Denmarks first second generation bioethanol demonstration plant on the island of Bornholm in the Baltic sea. The plant will convert 100,000 tonnes waste, grass and agricultural residues into bioethanol and other energy products. The plant will produce 10 million litres bioethanol, approximately 10.000 tonnes of solid fuel (fuel pills), and 4 million m^3 biogas.

<u>DOE 2007 – Six Cellulosic Biorefinery awardees (LCFBR)</u>
Six companies were selected in February 2007 by the US department of Energy (DOE) to construct demonstration biorefineries that will produce cellulosic ethanol and energy from biomass (Koukoulas, 2007). The total grants will amount $US 385 million and the private sector will finance the other 60%, so the total investments will be nearly $US 1 billion. The development of three conversion technologies is supported: acid hydrolysis (dilute and

concentrated), enzymatic hydrolysis and gasification (Table 11). The knowledge needed to build these demonstration biorefineries was partly generated in DOE/USDA research projects that were started in 2002/2003 (see next Section: 4.3.2). The projects will investigate how well these processes will work, and what they will cost. Several lignocellulosic feedstocks will be tested like corn stover, citrus waste, construction waste, wheat straw and wood residues.

Table 11 Six biorefinery awardees (Koukoulas, 2007).

Company	Conversion Technology	Principle Feedstock	Start Up date
Abengoa	Dilute acid hydrolysis, gasification	Corn stover	2010
Alico	Gasification, fermentation	Citrus waste	2010
Blue Fire	Concentrated acid hydrolysis	Construction waste	2009
Iogen	Enzymatic hydrolysis	Wheat straw	2010
Poet	Enzymatic hydrolysis	Corn stover	2009-2010
Range Fuels	Gasification, catalysis	Wood residues	2011

FORCE-Concept (LCFBR)

In this concept woody biomass and forest residues are separated into cellulosic fibres and value-added products (Figure 20).

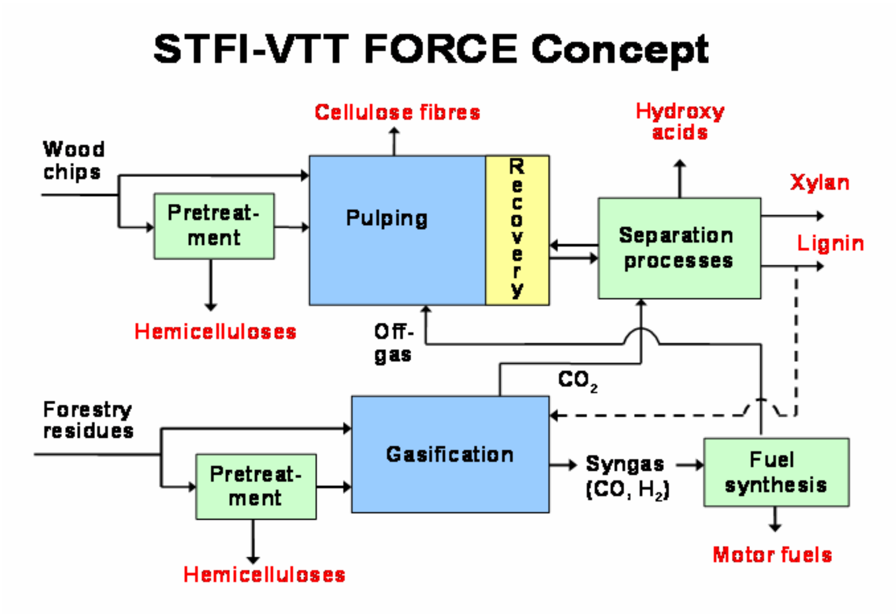

Figure 20 FORCE-concept of STFI and VTT (Swedish Country Report, 2007).

The Forestry Biorefinery (LCFBR)
In the US the Forestry Biorefinery concept is found in combination with traditional pulp and paper mills. It is based on gasification of residual wood fractions (Thorp, 2004; Figure 21). The syngas can be used to produce liquid fuels and chemicals like acetic acid. One of the main drivers for the Forestry Biorefinery is a reduction of energy costs of the industries own production processes, and ultimately even to become a net energy producer. The main advantage of the Forest Biorefinery concept is a long experience with processing large input streams of biomass (wood). Therefore the extra biomass feedstock logistics and storage can be incorporated within the traditional forestry chain relatively easy.

In Finland another forestry based initiative can be found (Figure 22) to produce value-added chemicals from wood, e.g. products from the bark (suberine extractives) and from tall oil (fatty acids). Furthermore, products from pulping liquor are investigated (like carbohydrates, phenolics and methanol). The Finnish approach to a Forest-based Biorefinery is shown in Figure 23.

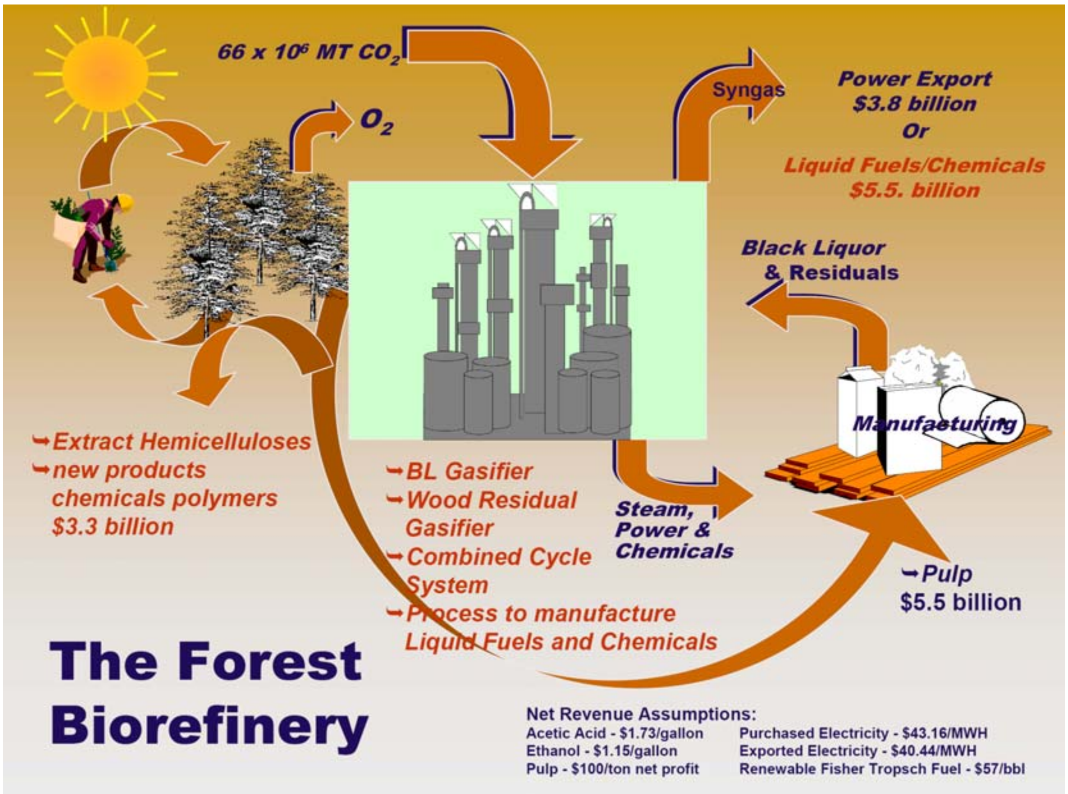

Figure 21 The Forest Biorefinery in the US (Thorp, 2004).

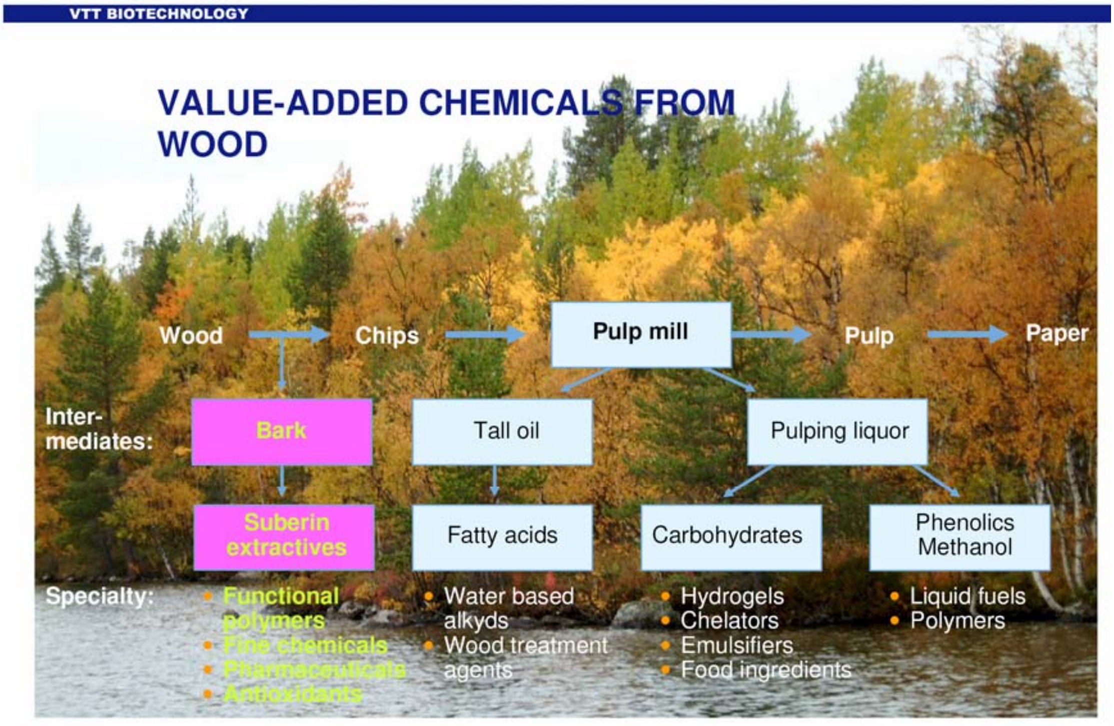

Figure 22 Value-added chemicals from wood (VTT, 2006).

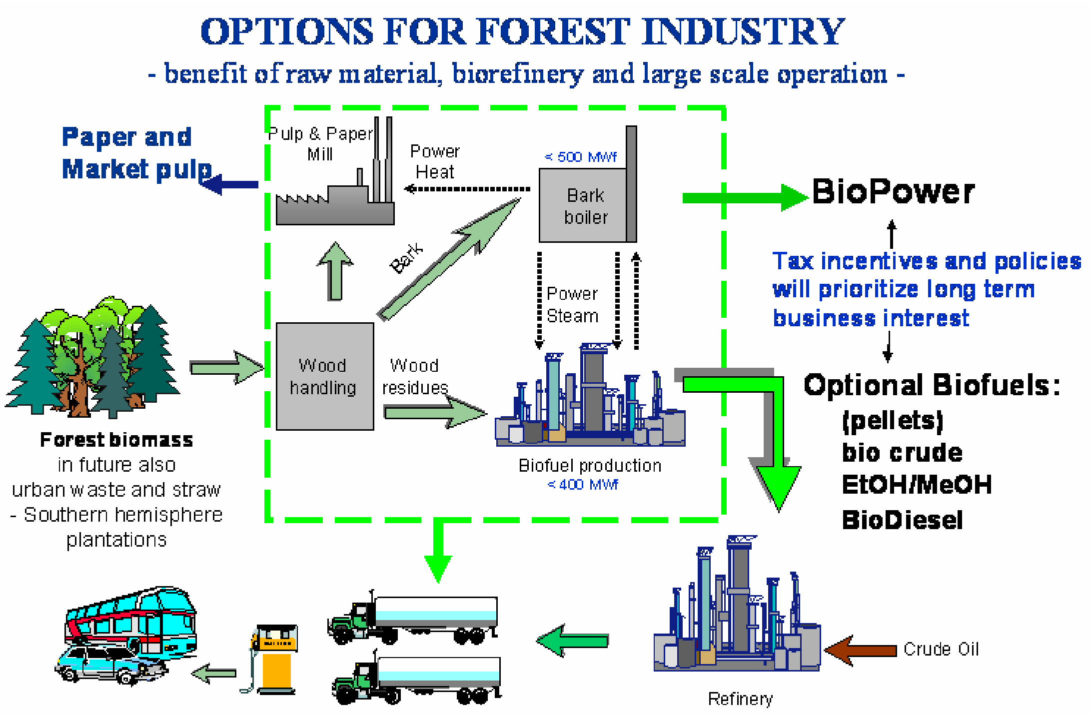

Figure 23 Finnish approach to a Forest-based Biorefinery (Makinen, 2007).

Ghent Bio-energy Valley

Ghent Bio-Energy Valley is a public private partnership supporting the development of sustainable bioenergy activities and resulting economic growth in the region of Ghent (Belgium). It is a joint initiative of Ghent University, the city of Ghent, the Port of Ghent, the Provincial Development Agency for East Flanders and several industrial companies (a.o. Alco Biofuel, Bioro, Oleon Biodiesel, Cargill, SPE, Electrabel, Fabricom GTI, Organic Waste Systems, Oiltanking, Lalement, Axtoll, Sea-Invest, Genencor, Desmet-Ballestra) from the Ghent region that are active in the fields of bioenergy production, generation, storage and use. Ghent Bio-Energy Valley promotes the development of bioenergy through collaborative programmes, initiatives, and synergy between the partners in the fields of research & development, structural measures and policy aspects, logistics, and communication towards the general public. Currently initiatives are displayed within the field of bioethanol, biodiesel, vegetable oils, biogas, biohydrogen, solid biofuels, and biopower.

Green Biorefinery Austria (GBR)

The Austrian Green Biorefinery concept (Figure 24) is based on the processing of green biomass from silage into a range of bulk and fine chemicals (a.o. lactic acid, amino acids), fibre-derived products (animal feed, boards, insulation materials, cardboard and paper), and CHP from biogas. The Austrian concept differs from other initiatives (a.o. Brandenburg Germany, Switzerland, Denmark) by using silage instead of fresh grass, so that the plant can be operated full year round. In Utzenaich (upper Austria) optimisation of the Green Biorefinery process is taking place for the production of amino acids, lactic acid and biogas from grass silage.

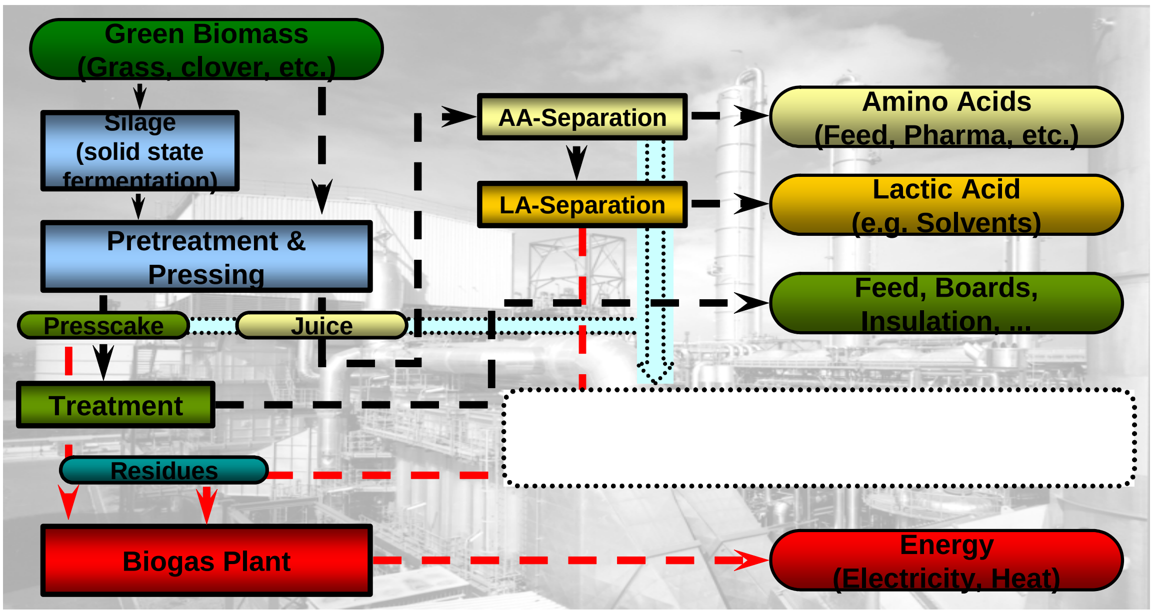

Figure 24 Austrian Green Biorefinery (Schwarz & Schnitzer, 2007).

Green Biorefinery (GBR)

The demonstration Green Biorefinery plant in Brandenburg Germany (Figure 25) will use 24,000 fresh t/a alfalfa, Lucerne and wild grass. It will use mechanical separation (pressing) and fermentation technology. The main products are press cake for fodder and fuels, proteins for industry and cosmetics and heat and electricity. The primary biorefinery is combined with a green crop drying plant. Chemical and biotechnical product lines are situated in a Chemistry Park nearby. The first step of construction will be in 2008.

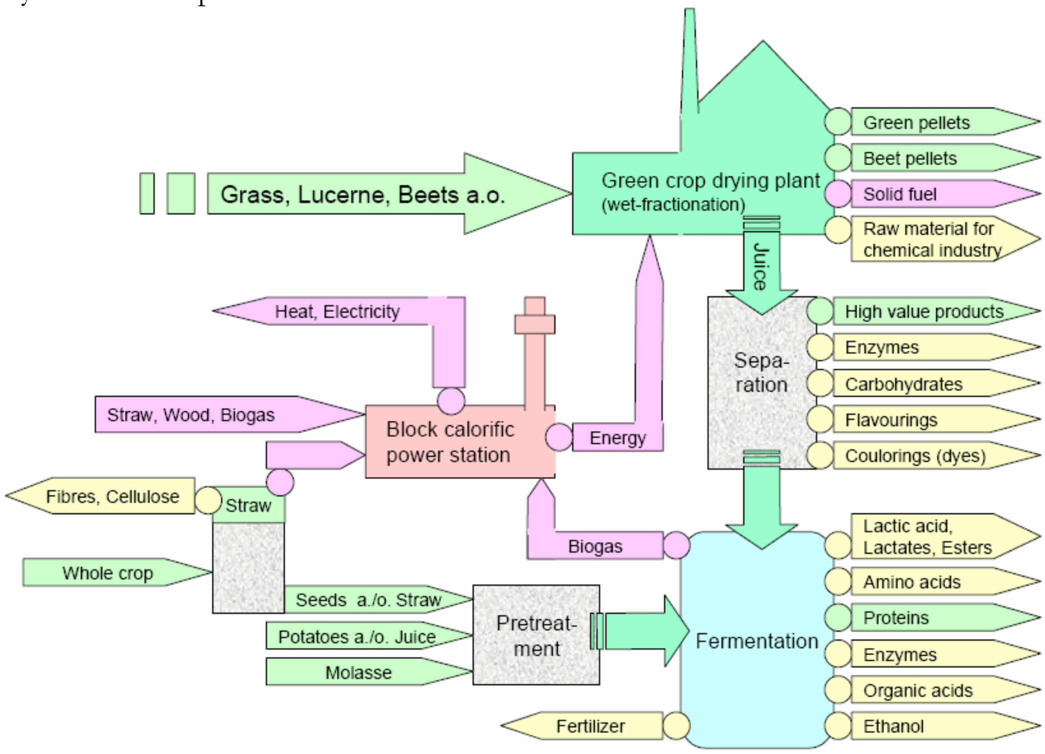

Figure 25 The Green Biorefinery Brandenburg (Kamm & Kamm, 2005).

Also a Green Biorefinery pilot-plant at the Leibniz Institute for Agricultural Engineering Potsdam-Bornin (ATB) is available, for the continuous production of lactic acid (Willke, 2007). Location: Potsdam-Bornim in Brandenburg; operation since 10/2006; capacity: 10 t/a; feedstock: sugar/starch; investment costs: 3.2 M€.

Green Biorefinery Ireland (GBR)

In Ireland, as well as elsewhere in the EU, agriculture is facing many challenges, one of which is characterised by the overcapacity production of low cost biomass such as grass as animal feedstuff. To cope with this overproduction of green biomass, concepts and technologies for its alternative sustainable utilisation have to be developed. Biorefining is one such technology. The immediate objective of Biorefinery Ireland is to design, construct and operate a commercial green biorefinery in Ireland using herbaceous biomass such as grass, immature cereals, legumes and sugar beet as feedstock; and produce energy, biofuels and high value biochemicals with food, feed and industrial applications. The initial objective is to establish a green biorefinery using fresh grass/grass silage.

Lenzing AG (LCFBR)

Lenzing AG in upper Austria separates a variety of chemicals as a co-product of its fibre and paper process. Co-products produced are: furfural, acetic acid, sodium sulfate and potassium-lignin-sulfate (Jungmeier, 2007).

Lignocellulosic Feedstock Biorefinery Iceland (LCFBR)

The demonstration Lignocellulosic Feedstock Biorefinery Plant in Mývatn, Iceland (Figure 26) uses 20,000 tons lignocellulosic biomass (mix). The main technologies used are acid hydrolysis and sugar fermentation. Process energy is supplied by geothermic steam. The main product is bio-ethanol. This small scale LCFBR, using energy-intensive processes is profitable in the Icelandic situation mainly because of the availability of very efficient and low price geothermic energy.

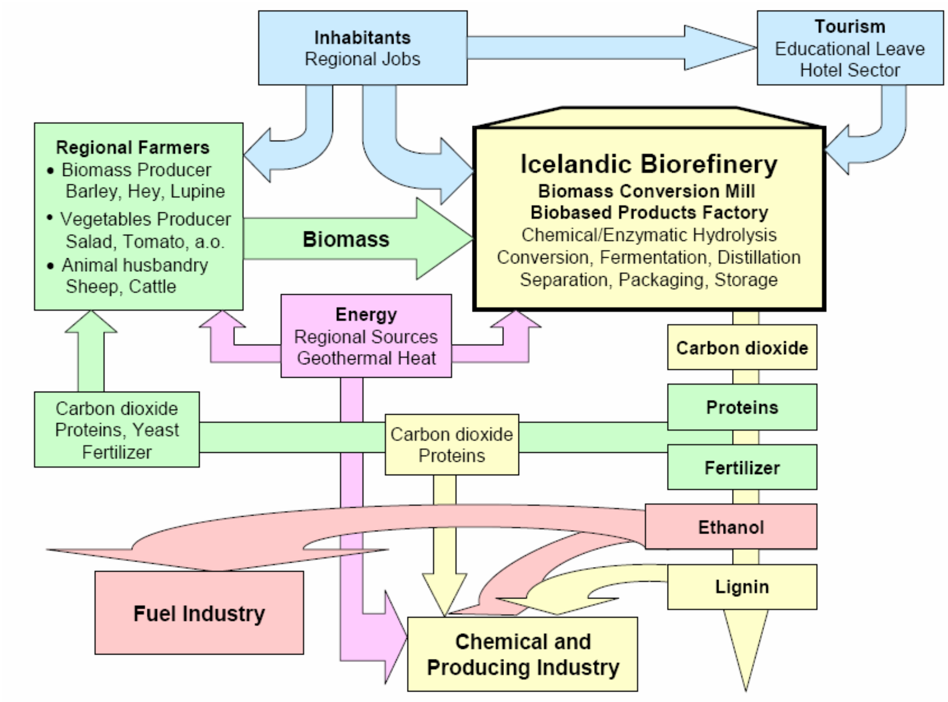

Figure 26 The Green Biorefinery Iceland (Kamm & Kamm, 2005).

Lignocellulosic Feedstock Biorefinery Germany (LCFBR)

This is a 1.9 M€, 16 partners, RTD-project on cellulose, glucose, hemicellulose, xylose and lignin preparation using ionic liquids and new enzymes for hydrolysis; as well as testing of carbohydrates for fermentation processes (Willke, 2007).

Marine Biorefinery Germany (MBR)
In Germany a pilot-plant for the cultivation of microalgae for the production of high-value products for feed, food, pharmacy and cosmetics was built (Willke, 2007). The location is Stuttgart-Vaihingen and it is in operation since August 2007. The scale is 5,000 – 10,000 l (400 m^2). The feedstock is polluted water and CO_2 and the costs are about 600,000 €.

NExBTL (TCBR)
NesteOil in Finland has developed the NExBTL-process for the production of a second generation biodiesel fuel (NExBTL) from vegetable oils and animal fats (Figure 27). The NExBTL-process is integrated with conventional oil refinery processes to be able to: i) use the necessary H_2, ii) blend the biodiesel into bio-/fossil diesel blends, and iii) make use of existing logistical infrastructures and economy-of-scale.

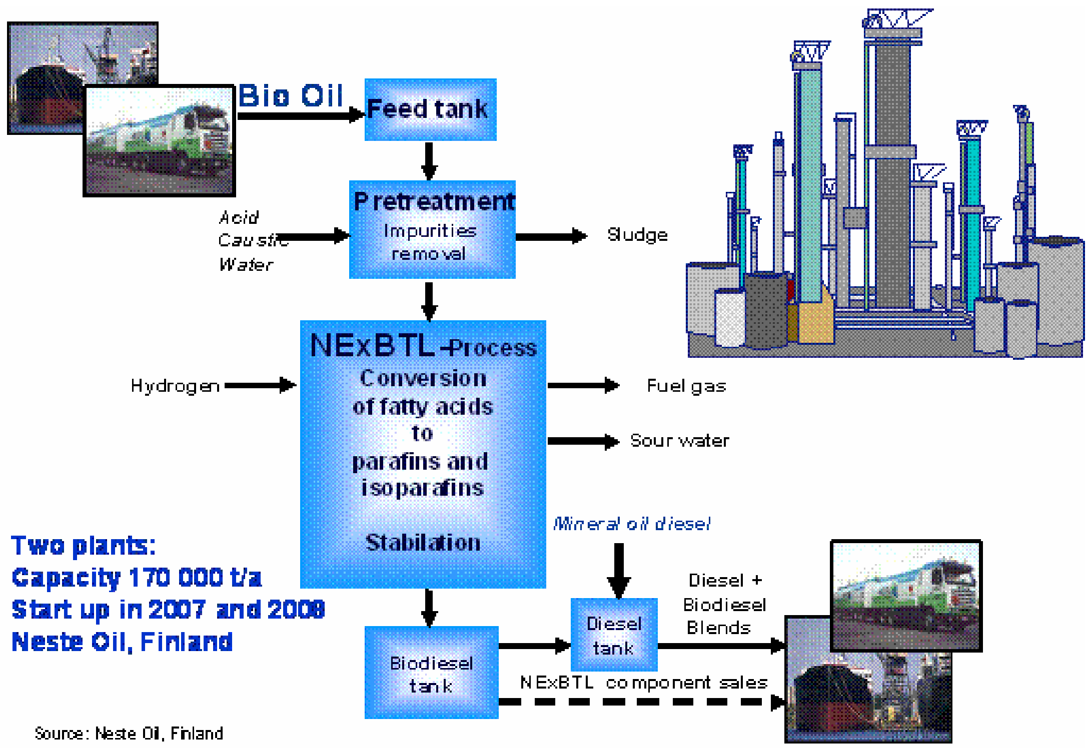

Figure 27 NExBTL-process for the production of 2^{nd}-generation biodiesel – NExBTL (Makinen, 2007).

4.3.2 Running and recently finished research projects

Europe

Some running and recently finished international RTD-projects on Biorefineries financed by the EC are:

- Biocoup
- Biopol
- Biorefinery Euroview
- Bioref-Integ
- Biosynergy
- Chrisgas
- Ecorefine
- Epobio
- Eurolignin
- Green Biorefinery
- WaCheUp

These European research projects are described in more detail in Appendix E.

United States

In the US several research projects on biorefinery concepts were started in 2002/2003 coordinated by the Biomass Research and Development Initiative (BRDI, 2005). This is a multi-agency effort of the U.S. Department of Energy (DOE) and the U.S. Department of Agriculture (USDA) to coordinate and accelerate all Federal biobased products and bioenergy research and development. It has delivered several projects in the field of biorefinery, that are summarized in Table 12. The results of some of these projects were input for the DOE 2007 – Six Cellulosic Biorefinery awardees (see previous section: 4.3.1). Some of the accomplished results of these projects (see corresponding project numbers in Table 12) are (quoted from BRDI, 2005):

1. "the use of corn bran in a bench-scale fermentation to demonstrate increased ethanol production, a completed retrofit of the fractionation facility, and the permits obtained to install the pilot-scale fermentation facility;
2. the selection of a suitable strand; the identification of reactor configuration, catalyst, and operating conditions; the successful development of the enzyme assay and the demonstration of enzyme production; and the improvement of the key enzyme in the 3-HP pathway;
3. the completion of economic feasibility modelling and development of initial process flow diagrams; the development of improved strains; assessment of the strain baseline and the development of advanced experimental tools, resulting in superior strains compared to the latest published in literature studies; construction of the fermentation system and the beginning of fermentation; and the completion of the second-generation strain
4. the completion of an economic study to show the production of PDO in an integrated biorefinery had a significantly higher return on investment than the biological production in a non-integrated facility and from a petroleum refinery; the formation of a joint

venture between DuPont and Tate & Lyle to produce PDO biologically from wet mill-derived glucose; the completion of a benchmark ASPEN model for both production of a value-added chemical from corn grain and ethanol from corn stover; and the completion of the subcloning of endoglucanases and the characterization of 70 percent of the subclones;

5. troubleshooting and base line runs for the dry mill portion of the pilot plant; the completion of over a dozen milestones and deliverables in the first quarter of FY 2005; and the demonstration of a reduction in residual starch and an increase in the overall yield of ethanol through bench-scale pre-treatment and fermentation processing;
6. the decision to continue with pilot-scale testing and the project's leading to a secondary project that could potentially result in a major breakthrough in biodiesel production;
7. the identification of the best strain and the beginning of the genetic engineering of the strain;
8. the modification of the PNNL continuous reactor; the assessment of the viability of the PNNL process; and the completed study of various solid acids in the reactor."

Table 12 DOE/USDA - Joint solicitations on biomass R&D (BRDI, 2005).

Name	Partners	Start year	Goal
1. A second generation dry mill biorefinery	Broin and Associates Inc., NREL, and South Dakota State University	2003	To improve the economics of existing dry mills by adding additional co-products and increasing ethanol yields
2. New biorefinery platform intermediate project	Cargill Inc., Codexis, Inc., and Pacific Northwest National Laboratory (PNNL)	2003	To develop a new bio-based platform technology that produces an array of products based on 3-HP produced by the fermentation of carbohydrates
3. Making the Industrial Biorefinery Happen	Nature Works LLC, Genencor, and Iogen	2003	To develop and validate process technology for use with sustainable agricultural systems that economically produce sugars and chemicals such as lactic acid and ethanol
4. Integrated Corn-Based Biorefinery Project (ICBR)	DuPont, Diversa, NREL, and Michigan State University	2003	To develop the integrated corn-based biorefinery for the parallel production of fuel ethanol and 1,3 propanediol (PDO)
5. Advanced Biorefining of Distiller's Grain and Corn Stover Blends	Abengoa Bioenergy LLC, NREL, Novozymes NA, Inc., and VTT	2003	To develop a novel biomass-derived process technology that utilizes advanced biorefined distiller's grains and corn stover blends to achieve higher ethanol yields in a dry mill

6. Separation of Corn Fiber and Conversion to Fuels and Chemicals	National Corn Growers Association (NCGA), PNNL, and Archer Daniels Midland, Co.	2002	To economically derive high-value chemicals and oils from corn fiber
7. Value-Added Products from Hemicellulose Utilization in Dry Mill Ethanol Plants	Iowa Corn Promotion Board, Minnesota Corn Research and Promotion Council, Ohio Corn Marketing Program, PNNL, and the Idaho National Engineering and Environmental Laboratory (INEEL)	2003	To integrate enzymatic hydrolysis, fermentation and aqueous phase catalysis that produce high-value components from hemicellulose
8. Continuous Isosorbide Production from Sorbitol Using Solid Acid Catalysis	Iowa Corn Promotion Board in partnership with PNNL and Archer Daniels Midland, Co.	2003	To establish the conceptual process flow diagrams, material and energy balances, capital estimates and operating costs for the conversion of sorbitol to isosorbide via pilot plant operations

Canada

Canada sees Biorefinery opportunities for the Canadian pulp and paper industry (Towers,et al., 2007). Three important research topics are: feedstocks, conversion and separation technologies and markets for products. A list of proposed research activities mainly on the LCFBR type of biorefinery in connection with the traditional pulp & paper industry is given in Table 13.

Table 13 Proposed research activities in Canada (Towers, et al., 2007).

Title	Description
Product opportunity analysis	Market analysis; high value vs high volume products
Availability of forest feedstocks	Available biomass (forest, sawmill, pulp mill, agricultural or other residues): costs, logistics, etc.
Thermochemical pathways	Gasification and pyrolysis pathways to novel products
Bioproducts from effluent and solid wastes	Bio-degradable plastics; products from anaerobic treatment systems; value-added uses of sludges
Products from hemicellulose	Extract fuels and specialty chemicals while maintaining pulp properties
Products from lignin	Extraction of lignin from Kraft black liquor, and its use in novel products
Products from extractives	Synthetic diesel and other products from crude tall oil
Products from condensates	Methanol extraction, purification, and transformation processes
Phytochemicals	Novel high value, low volume products from bark, branches and foliage
Integrating novel products with existing product lines	Maintaining pulp and paper properties while modifying existing mills for novel products
Conversion of uncompetitive mills	Identifying new uses for idled Kraft production lines, in particular batch pulping systems
Integration with other industries	Identify synergies with commercial, industrial or domestic neighbours

Canadian Triticale Biorefinery Initiative

An R&D Network focussed on developing triticale, a high yielding non-food cereal crop, as a biorefinery feedstock for the manufacture of fuels, chemicals, and materials (Phillips, 2007).

Canadian Forest Biorefineries

A forest biorefinery will use multiple feedstocks, including harvesting residues, extracts from effluents, and fractions of pulping liquors, to produce fibre, energy, chemicals, and materials. In 2006, a Technology Roadmap for Canadian Forest Biorefineries was developed (MSS, 2006).

4.3.3 Networks

Biorefinery Task Force Forest-Based Technology Platform

The Forest-based sector Technology Platform set up a Task Force on Biorefinery in June 2006 (Biorefinery Taskforce FTP, 2007). The aim was to create a network of leading forest-based sector experts within the Biorefinery subject, focusing on Europe. In the FTP Biorefinery Task Force's Vision, biorefinery aims to create more value from the raw material provided by the forest-based sector. These added-values can be in the form of current and new products, chemicals and energy (Figure 28).

Their definition is: Biorefinery is efficient use of the entire potential of raw materials and by-streams of the forest-based sector towards a broad range of high added-value products (by co-operation en in between chains).

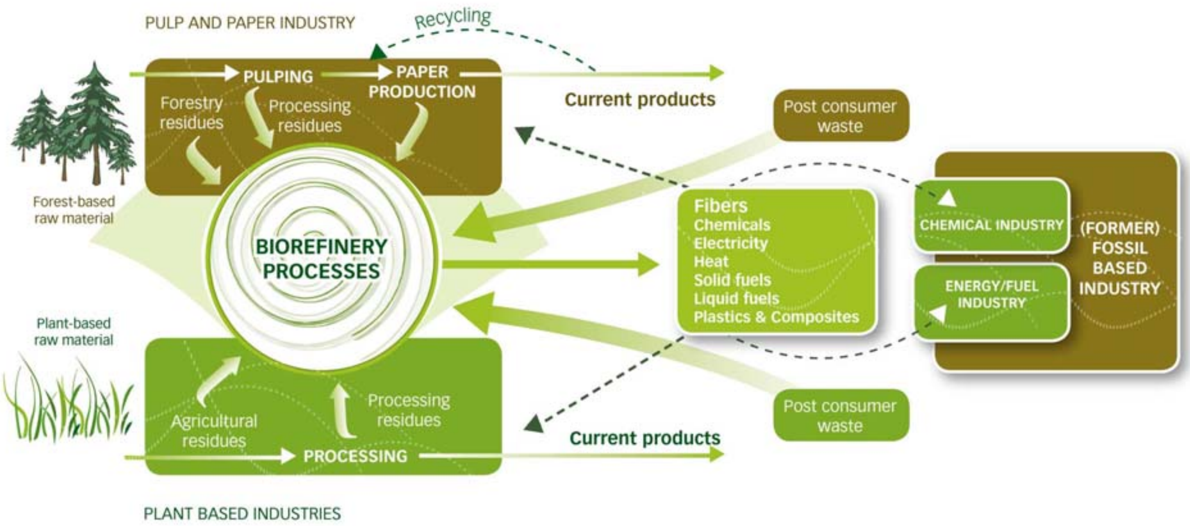

Figure 28 Pulp and paper based biorefinery concept (Biorefinery Taskforce FTP, 2007).

The Biorefinery Taskforce has the ambition to define the direction of the key activities that need to take place in the field of biorefinery, and which will increase the competitiveness of the forest-based sector in the coming decades. They advice how funds earmarked for biorefinery RTD-issues in the EU FP7 programme should preferably be allocated.

Some clear remarks as given in the final Biorefinery Task Force FTP (2007) report are:

- Increases in oil prices have drawn the attention of other manufacturing sectors – outside the energy sector – such as the chemical sector, towards bio-based materials as raw material.
- Biorefinery is at the heart of the research focus within the EU FP7 programme on bioenergy.
- Biorefinery should make energy production much more efficient, fulfilling policy goals that are being set.
- The bioenergy share in the European pulp and paper industry should be raised to 56% in 2010 (current contribution: 49.5%).
- Existing technology in pulp making can already be called a biorefinery. Besides pulp, different chemical by-products and energy carriers are produced.
- Potential new biorefinery-based options in the paper/pulp industry are: black liquor gasification, lignin production from black liquor, using by-products and residues in the paper recycling loop.
- The forest-based sector is one of the few sectors in the world that have the potential to become carbon neutral as a whole.
- The forest-based sector has to develop a new model for co-operation and integration with other industrial sectors in the bio-based economy.
- In case of paper produced from chemical pulp, only half of all the pulpwood is used as paper. The remainder of the organic material (mainly lignin and hemicelluloses) is dissolved and in most cases used as fuel.
- Combining chemicals and biofuel production from forestry and processing residues may represent the best economical opportunity for the forest-based sector.
- The ultimate ambition is to achieve a zero-waste paper mill.
- Cross-sectorial clustering of biorefinery activities will enhance the overall efficiency and economics of increased use of bio-based raw materials.
- Biorefinery can provide sustainable and accepted products within a sustainability-conscious society.
- In order to promote the advanced zero-waste and wood-based biorefinery concept, five research directions are pointed out:
    - efficient separation and conversion processes;
    - biorefinery as source for wood-based solid and liquid biofuels;
    - recycled fibre biorefinery, optimising fibre cascading in the pulp/paper chain;
    - above-sector synergies with the agricultural and chemical sector;
    - socio-economic impact of biorefinery development; optimising to the highest added-value and employment from the raw materials.

Canadian Biorefinery Networks
In Canada several networks exist in the field of Biorefinery:

- Alberta Centre for Biorefining
- Canadian Forest Biorefinery Network
- Canadian University Forest Biorefinery Network
- National Biorefining Network

These networks focus mainly on the LCFBR type, due to the main available feedstock: (residual) wood from the forestry sector.

IEA Bioenergy Task 42 on Biorefinery
The IEA Task 42 Biorefineries covers a new and very broad biomass-related field with a very large application potential. To open up the biorefinery-related potential, international system and technology development together with industry is a necessity. Joint international priorities and RD&D-programmes between industry, research institutes, universities, governmental bodies and NGOs are necessary; whereas identification of market introduction strategies together with industry will be inevitable for the creation of a proper RD&D-framework.

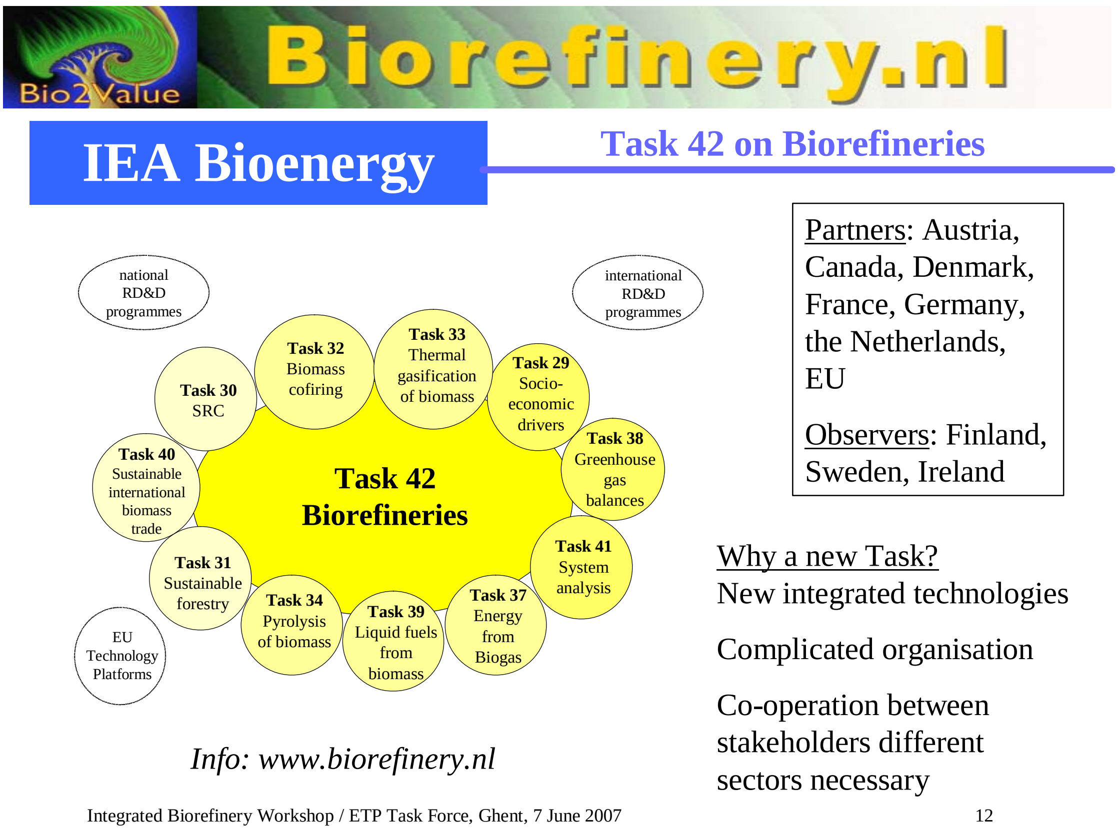

Figure 29 IEA Task 42 on Biorefineries.

In contrast to most of the other IEA Bioenergy Tasks (Figure 29), the proposed Biorefineries Task will cover i) a variety of market sectors (a.o. transport sector, chemical sector, power sector, agricultural sector) with a lot of interested stakeholders, and ii) a variety of biomass conversion technologies and, more important, integrated concepts of both (bio)chemical and thermochemical conversion technologies.
Concerned integrated biorefinery concepts convert a variety of feedstocks, including residues, into a portfolio of products with improved energetic chain efficiency, economy and environmental effects, compared to stand-alone processes often producing only one or two products.
The major objective of this IEA Task for the first three years is to asses the worldwide position and potential of the biorefinery field and to gather new insights that will indicate the possibilities to come to new breakthrough, competitive, sustainable, safe and eco-efficient processing routes for the simultaneous manufacture of transportation fuels, added-value chemicals, (CH)power, and materials, the so-called Biorefineries.

Joint European Technology Platform Task Force on Biorefinery
The Joint European Technology Platform Task Force on Biorefinery brings together biorefinery experts/representatives of the different European Technology Platforms, i.e.: Biofuels, Forest-based, Suschem, Plants for the Future; to discuss common biorefinery-related activities (a.o. necessary R&D-activities, pilot and demo initiatives).

The aims of the first meeting of this Joint ETP Task Force Biorefinery – held in Ghent (Belgium) on 7 June 2007 – were:
i) to define what kind of biorefinery types are needed in Europe;
ii) to identify what type of biorefinery pilot/demonstration plants are needed in Europe, and;
iii) to analyse the financial needs – incl. barriers and possible solutions – of biorefinery pilot and demo-plants.
The recommendations coming out of this meeting will be discussed with the European Commission.

i) What kind of biorefinery types are needed in Europe?
There cannot be defined any general biorefinery plants for piloting because the biorefinery area is far too broad. Pilot and demonstration plants will be necessary in a variety of technological areas: see paragraph 3.3.

ii) What kind of biorefinery pilot and demonstration plants is needed in Europe?
First of all, it has to be clear what pilot and demonstration plants are, and which role they play in the full RTD-trajectory: idea/hypothesis – lab/bench-scale R&D – pilot-scale R&D – pre-commercial demonstration RTD – commercial production (see Table 14).

Table 14 Specifications & Status of pilot-scale R&D plants and Pre-commercial demonstration-scale RTD.

Type	Specifications	Status
Pilot-scale R&D plants	• Aim: Scaling-up of a specific process. • Multi-purpose equipment that mimic industrial equipment. • Mainly publicly financed (equipment can be donated by local companies). • Multi-purpose facilities that can be rented. • Owned by universities and R&D institutes. • Output: functionality with industrially applicable equipment, proof-of-concept (PoC), scaling-up, economic feasibility.	• Different pilot-plants are already existing, but mapping of what is available in Europe is needed (where, which technologies, …) -> EU-projects Euroview, Biopol, IEA Bioenergy Task 42 on Biorefineries. • What are the future (technological) needs and gaps. • There is a need for better co-ordination, improving the access (sharing) and use of pilot-plants. • More funding needed for SMEs for pilot initiatives (Proof-of-Concept). • Funding of new pilot-plants is already possible (regional, MS, structural funds, EIB, …).
Pre-commercial demonstration-scale RTD	• Aim: pre-commercial demonstration of an integrated production process (on a smaller scale). • Dedicated plants – using equipment identical to the real factory – that have to be build. • Multi-process and/or multi-company. • Total costs often > 10 M€. • Owned by private companies (often with public financial support). • Output: data for factory planning and final investment decision.	• (Partial) funding is possible in the EU, but very fragmented. • Access to such funding should be co-ordinated and facilitated. • Industry should define their needs; identify the most promising technological developments that are at demonstration phase in the EU, and see what is needed for public support; then …?

iii) What are the financial needs (incl. bottle-necks and possible solutions) of biorefinery pilot and demo-plants?
In Europe possible subsidies for pilot-plants are very fragmented. Examples are:

- European Investment bank (EIB): financing of large European research infrastructures.
- Risk Sharing Finance Facility (RSFF): a joint EU/EIB facility for the financing of private and public research activities (risk sharing with public stakeholders).
- European Regional Development Fund (ERDF): co-financing productive investments leading to the creation or maintenance of jobs, infrastructures, local development initiatives, and business activities of small and medium enterprises.
- FP7 Research Infrastructures (DG Research): a) optimising of the use and development of the best research infrastructures currently existing in Europe, and b) contributing to the construction of new research infrastructures of pan-European interest in all fields of science and technology.

Network for the implementation of biorefineries (NIB)
The Austrian organisation NIB is the Network for the Implementation of Biorefineries. Members are scientists, entrepreneurs, farmers and other stakeholders. It is a platform for interdisciplinary co-operation and exchange of information on biorefinery topics.

5 SWOT Analysis: Biorefinery from a Dutch Point-of-View

5.1 Introduction

In this chapter a SWOT-analysis is presented on Biorefinery from a Dutch point-of- view. The results of this SWOT-analysis give a (first) overview of the Strengths, Weaknesses, Opportunities and Threats of the application potential of biorefineries in The Netherlands.

The procedure that was used for this SWOT-analysis contains three steps (Kuiper, 2006):

1. Assessment of the internal (Strengths and Weaknesses) and external (Opportunities and Threats) factors concerning the application potential of Biorefineries in the Netherlands.
2. Set-up of a confrontation matrix in which the most important internal and external factors are related to each other.
3. Formulation of concrete actions to arrive at the desired results.

5.2 Assessment of internal and external factors

Strengths can be seen as competences available in the Netherlands related to biorefinery concepts that are stronger than those of our competitors, and that can be used to utilize opportunities and to defend ourselves against threats. *Weaknesses* are shortcomings or limitations that block possibilities to achieve the same or a better performance compared to our competitors. *Opportunities* are events or trends that show potential routes to new competitive advantages. And finally *threats* point to external developments that erode the current competitive advantages or that worsen the possibilities to further develop the current distinguishing competences.

The internal (Strengths and Weaknesses) and external (Opportunities and Threats) factors concerning the application potential of Biorefineries in the Netherlands are given in Table 15. This matrix and the judgement of the main factors still has to be discussed and fine-tuned with the stakeholders involved.

The sources for this matrix are among others the National Governmental Vision on the Biobased Economy, the results of two workshops that were organised in 2006 by the Dutch Knowledge Network on Biorefineries (Biorefinery.nl) and a brainstorm with experts of Wageningen UR.

Table 15 SWOT analysis Biorefinery from a Dutch point-of-view.

Strengths (internal)	**Weaknesses (internal)**
S1. Strong agrocluster, chemical sector & energy sector available, situated relatively close to each other S2. Advantageous geographical position in European market and logistical infrastructure (a.o. harbours in/export) S3. Food industry is already experienced with biorefinery processes S4. Good Knowledge Infra Structure (KIS, universities and institutes) S5. Position in White Biotechnology S6. Position in catalysis S7. Interest of chemical industry to use more biobased feedstocks S8. National R&D funding programmes (a.o. EOS LT) S9. Large biomass flux is common already (import) S10. National stakeholder platform (biorefynery.nl) available S11. International stakeholder platforms (IEA Bioenergy Task 42, EU TPs) available S12. Focus on zero-waste production processes – sustainable use process residues	W1. Insufficient co-operation between stakeholders of agro, chemical and energy sectors W2. Governmental departments do not work together closely enough W3. Key technologies partly still in R&D-phase W4. Most optimal biomass – product chains still not identified W5. Studying instead of implementing W6. Investment capital for pilot and demo initiatives difficult to find W7. Full chains often not yet market competitive due to relatively cheap fossil fuels W8. R&D funding programmes often fragmentised concerning budget and content W9. A common vision and roadmap is still lacking W10. Insufficient co-operation within the KIS W11. Funding instruments not tuned yet for co-production processes W12. Domestic terrestrial biomass potential limited even when optimal utilization is achieved
Opportunities (external)	**Threats (external)**
O1. Biorefinery central on national and European policy agendas O2. Challenging national and European policy goals for bioenergy (fuels, energy) lead to high demand and trade of biomass O3. Biorefinery is a necessity to meet the biofuel-related policy goals O4. Strengthening of the economic position of the agro, chemical and energy sectors O5. Preferential position in Europe still vacant O6. Interdepartmental approach potentially results in an integrated policy framework O7. Co-operation between stakeholders can boost the development and implementation of biorefinery concepts O8. Much regional interest to contribute O9. Potential energy savings and improved process economics O10. Optimal use of domestic biomass (e.g. insufficiently used agro residues) O11. Short-time implementation conventional biorefineries by upgrading residues O12. Development advanced biorefineries to prevent competition with food/feed O13. Development multi-purpose biorefineries in a framework of scarce raw materials and energy O14. Sustainability criteria in biofuels for transport will make biorefinery alternatives more attractive O15. Large sea surface available for biomass production O16. NL can use export power - producing more biofuels (3x) and bulkchemicals (2.5x) than our own consumption	T1. The biorefinery area is very broad, fashionable, and complex T2. US (and EU) are ahead on implementation T3. External costs fossil-based products still not taken into account T4. Fluctuating (long-term) governmental policies delay company investments T5. No policy goals for biomaterials and biochemicals yet T6. Focus on single products like biofuels and electricity only (no chemicals yet) and not on multiple products T7. Markets for complete product portfolio are a necessity for success T8. Existing industrial infrastructure is not depreciated yet T9. High initial investment costs for pilots and demos T10. Decreasing oil price will lower the urgency and economic feasibility of the biobased economy T11. Discussion food/feed/fuels and biomass sustainability T12. No level-playing-field for end-products T13. Companies using traditional production processes can slow down new developments T14. Lock-in effect of conventional biofuels caused by agricultural interests T15. Difficult biomass contractibility and sustainability T16. Uniform EU and worldwide sustainability criteria still missing T17. Insufficient sense of urgency T18. NL is depending on export (see O16)

5.3 Set-up of a confrontation matrix to find strategic points-of-attention

A so-called confrontation matrix is set-up in which the most important internal and external factors are being related to each other to find strategic points-of-attention (Table 16). The confrontation matrix shows four possible strategies to deal with these strategic point-of-attention:

- Attack
- Defend
- Maintain
- Back-off

Table 16 The setup of a confrontation matrix.

		Opportunities Oi Oj Ok	Threats Ti Tj Tk
Strengths	Si Sj Sk	**Attack**	**Defend**
Weaknesses	Wi Wj Wk	**Maintain**	**Back-off**

A first suggestion for a selection of important factors of the SWOT matrix is given in Table 17. However, agreement about this selection still has to be reached with the main stakeholders involved. That should be part of the process of establishing a common Dutch Technology Roadmap on biorefinery. Within this report only a brief example will be given on the suggested method and approach. The next sub-sections will give some examples of strategic points-of-attention that could be dealt with. Probably the most interesting strategy for the Netherlands would be an attack strategy. However, also that choice should be made while developing the Dutch Technology Roadmap together with the stakeholders. In the simple examples in the next subsections, each time only one internal factor (strength or weakness) is confronted with only one external factor (opportunity or threat). Of course, in reality several internal factors will interact with several external factors. This should be taken into account when this analysis will be performed in more detail during the Roadmap process.

Table 17 Some important factors of the SWOT matrix that are transferred to the confrontation matrices.

Strengths (internal)	Weaknesses (internal)
S1. Strong agrocluster, chemical sector & energy sector available, situated relatively close to each other S2. Advantageous geographical position in European market and logistical infrastructure (a.o. harbours in/export) S4. Good Knowledge Infra Structure (KIS, universities and institutes)	W1. Insufficient co-operation between stakeholders agro, chemical and energy sectors W3. Key Technologies partly still in R&D-phase W9. A common vision and roadmap is lacking
Opportunities (external) O4. Strengthening of the economic position of the agro, chemical and energy sectors O5. Preferential position in Europe still vacant O13. Development multi-purpose biorefineries in a framework of scarce raw materials and energy	**Threats (external)** T1. Area is very broad, fashionable, and complex T9. High initial investment costs for pilots and demos T15. Biomass contractibility and sustainability

5.3.1 Point of attention for an attack strategy

The main strategic points of attention for an attack strategy are (Table 18):

A1. How can the strength of the Dutch agro, chemical and energy sectors be used to strengthen the economic position of these sectors?

A2. How can the geographical position of the Netherlands in a European market and the available logistical infrastructure (a.o. harbours in/export) be used to achieve a preferential position on biorefinery in Europe?

A3. How can the strong Dutch Knowledge Infra Structure (KIS, universities and institutes) be used to develop multi-purpose biorefineries in a framework of scarce raw materials and energy?

Table 18 Relation Strengths (internal) and Opportunities (external). How can we best use our strengths to make use of the opportunities?

Attack	**Opportunities**		
Strengths	O4.	O5.	O13.
S1.	A1		
S2.		A2	
S4.			A3

5.3.2 Point of attention for a defend strategy

The main strategic points-of-attention for a <u>defend strategy</u> are (Table 19):

D1. How can the strength of the Dutch agro, chemical and energy sectors be used to better define and to focus within the very broad, fashionable, and complex biorefinery area?

D2. How can the geographical position of the Netherlands in a European market and the available logistical infrastructure (a.o. harbours in/export) be used to contract enough biomass in a sustainable way to fulfil the future market demand?

D3. How can the strong Dutch Knowledge Infra Structure (KIS, universities and institutes) be used to lower the high initial investment costs of necessary biorefinery pilot and demo plants?

Table 19 Relation Strengths (internal) and Threats (external). How can we best use our strengths to avert the threats?

Defend	**Threats**		
Strengths	T1.	T9.	T15.
S1.	D1		
S2.			D2
S4.		D3	

5.3.3 Point of attention for a maintain strategy

The main strategic points-of attention for a <u>maintain strategy</u> are (Table 20):

M1. How can the insufficient co-operation between stakeholders in the agro, chemical and energy sectors be improved to maintain the strong economic position of these sectors?

M2. How can the fact that the key technologies are still in the R&D-phase be combined with the development of multi-purpose biorefineries in a framework of scarce raw materials and energy?

M3. How can a lacking common vision and roadmap be overcome to achieve a preferential position in Europe on biorefinery?

Table 20 Relation between Weaknesses (internal) and Opportunities (external). How can we best strengthen our weaknesses to take advantage of opportunities?

Maintain	**Opportunities**		
Weaknesses	O4.	O5.	O13.
W1.	M1		
W3.			M2
W9.		M3	

5.3.4 Point of attention for a back-off strategy

The main strategic points-of-attention for a back-off strategy are (Table 21):

B1. How can we deal with the insufficient co-operation between stakeholders in the agro, chemical and energy sectors to answer to the fact that necessary pilot and demo facilities require high initial investment costs?

B2. How can the fact that the key technologies are still in the R&D-phase be used to deal with the very broad, fashionable and complex biorefinery area?

B3. How can a lacking common vision and roadmap be used to deal with the biomass contractibility and sustainability discussion?

Table 21 Relation between Weaknesses (internal) and Threats (external). How can we best deal with our weaknesses within the framework of the threats?

Back-off	**Threats**		
Weaknesses	T1.	T9.	T15.
W1.		B1	
W3.	B2		
W9.			B3

5.4 Implementation strategy

The strategic points-of-attention (questions) form the basis for the formulation of a strategy (answers to the questions) concerning the biorefinery concept implementation in The Netherlands. Potential answers are given in Table 22.

A complete set of answers has to be provided by the major stakeholders involved, as part of the development of an Action Plan (Technology Roadmap) Biorefinery, including a Strategic Research Agenda and a Technology Deployment Plan.

Table 22 Potential answers to strategic point-of-attention

Question	Answer
A1.	Co-operation between the sectors, a.o. by developing and implementation of integrated biorefinery concepts, using each other residues (materials, energy, water, …), and by jointly co-producing a portfolio of added-value bio-products.
A2.	The Netherlands should become the "Port-of-Europe" for the import of raw biomass materials, biomass-derived intermediates and bio-based products making use of both the available logistical infrastructure (a.o. harbours), the (petro)chemical infrastructure, and the agrofood industry.
A3.	The Dutch KIS should work closely together (universities: Proof-of-Principle activities, research institutes: Proof-of-Concept activities) with industry (Proof-of-Feasibility activities and market implementation) to develop and implement highly innovative biorefinery concepts.
D1.	The Biorefinery area is very broad and fashionable. The strong economic sectors in the Netherlands (agro, chemical and energy sectors) should set the framework (market pull) for a focussed development and implementation of biorefinery concepts within the Netherlands.
D2.	…
…	
B3.	…

6 Discussion & conclusions

6.1 Discussion

Biorefinery, i.e. the sustainable processing of biomass into a spectrum of marketable products and energy, is an ***absolute necessity to meet the national (Dutch), European and global policy goals*** within the fields of greenhouse gas emission reduction and diversification of raw materials.

Biorefinery can ***build on a long experience***, as it has already been applied for decades in existing industries, such as a.o.: the sugar and starch industry, the vegetable oils industry, the feed and food industry, the pulp and paper (forest) industry, the (petro)chemical industry, and the conventional biofuel (biodiesel, bioethanol, biogas) industry. However, the main emphasis of these processes lies on the production of one main valuable product, whereas process residues are often used only as feed or for the production of power and/or heat. To economically compete with fossil resources, the high-efficient co-production of a portfolio of bio-based products, to maximise overall process economics, and to minimise the negative environmental impact, is essential, and is in most cases still outside of the core-business of the stakeholders involved. However, their strategy is changing rapidly, and this will probably result in the short-term (up to 2013) market implementation of the first real biorefinery concepts (i.e. ***upgraded existing industrial infrastructures***).

Besides the short-term market implementation into existing (industrial) infrastructures, ***new biorefinery concepts*** are being developed to process specific bio-based raw materials. Some promising concepts are: Green Biorefineries, Whole Crop Biorefineries, Ligno Cellulosic Feedstock Biorefineries, Two Platform Concept Biorefineries, Thermo Chemical Biorefineries and Marine Biorefineries. For the ***specific Dutch situation***, taking into account the available national strengths (agricultural and chemical sectors, harbours and other infrastructure, knowledge infrastructure) especially the development and implementation of the following new biorefinery concepts offer huge possibilities: Green and Whole Crop Biorefineries (use of agroresidues, crops and grass), Ligno Cellulosic Feedstock, Two Platform and Thermo Chemical Biorefineries (conversion of imported lignocellulosic raw materials and intermediates in harbour areas), and the Marine Biorefinery (conversion of domestic aquatic biomass resources).

The new biorefinery concepts are all composed of ***process unit operations*** that are ***integrated*** in a highly efficient way concerning heat use and the re-use of secondary process residues. Generally, the following types of process unit operations will be part of integrated biorefinery concepts: biomass pre-treatment equipment (drying, size reduction), primary refinery equipment (a.o. pressing, decomposition/hydrolysis, torrefaction, pyrolysis, hydro-thermal-processing, digestion), secondary biorefinery equipment (a.o. fermentation, gasification), energy production equipment (digestion/combustion and CHP production from process residues), product separation equipment, and (catalytic) intermediates and final products upgrading equipment (a.o. catalytic syngas conversion, catalytic synthesis marketable products from platform chemicals).

For a successful market implementation of an integrated biorefinery concept all composing process unit operations must be technically mature. Furthermore, these process unit operations must be optimally integrated to make synergistic full use of each other, resulting in an overall concept with maximal profitability and minimal ecological impact. Depending on the technological state-of-the-art of composing process unit operations and full integrated concepts different kinds of ***financial governmental support***, i.e. R&D-support and support for the realization and operation of pilot and demonstration facilities, will be necessary before real market implementation could take place. Because of the variety in Biorefinery concepts, and the variety in maturity of the composing subprocesses, no general national financial governmental support framework can be presented. This national financial framework in general should contain budget for both R&D activities, pilot plant activities and demonstrations. The national budgets potentially could be multiplied to a certain extent in case activities are being performed in EU framework (7^{th} framework programme).

The market implementation of an integrated biorefinery concept is not only depending on technological aspects. Also ***full chain economic and ecological aspects*** (i.e. biomass production to conversion to end-use) are very important. Except in cases where organic residues are used as raw materials to feed the biorefinery concepts, ***biomass cultivation technology*** always should be part of the development and implementation of integrated biorefinery concepts. Specific biomass crops should be developed to produce a maximum amount of products required. Examples: i) when the main objective of an initiative is to produce a high quality biodiesel, oil-rich crops could be developed to co-produce the required quality of fatty acids and value-added chemicals in an optimal way, and ii) co-production of a portfolio of value-added products and energy carriers from aquatic biomass (micro and macro algae), increasing the availability of raw biomass materials within both the national (Dutch) and European context, deceasing the import dependency.

Full technical, economic and ecological chain assessments will also give an answer concerning the ***scale of implementation*** of the different biorefinery concepts. Conventional oil refineries are operated at very large-scale because of economy-of-scale advantages improving both overall process efficiencies and economics. Biorefineries potentially could also be applied on small regional scale. Mobile decentral biomass pre-treatment/primary refinery units potentially could be used to pre-process agricultural products at the place of production. During pre-processing intermediate products will be produced that will be transported to a regional/central secondary biorefinery facility to produce marketable end-products; whereas pre-processing residues (a.o. minerals) will be given back the farm land to keep the nutrient balance.

Biorefinery concepts are able to produce a spectrum of bio-based products and energy in a sustainable way. Depending on the specific interests of the ***industrial stakeholders*** involved a selection of desired products has to be made. Because biorefinery concepts by definition will produce more than one product and energy, often more than one industrial stakeholder will be involved in the development and implementation of the integrated biorefinery concept. Specific attention has to be paid on how the costs, revenues, IP-positions of the biorefinery concept has to be divided among these stakeholders. Also the industrial stakeholders necessary for the implementation of the full biorefinery concept often do not know each other yet, because they normally are operating in separate market segments. Consultation activities by means of a biorefinery stakeholder platform potentially will solve this problem.

6.2 Conclusions

1. Biorefinery in itself is not new because it is already applied in a variety of industrial sectors. However, the sustainable production of a spectrum of bio-based products and energy (definition biorefinery in this report) to maximise the profitability and minimise the environmental impact of the raw materials used is new, and has the potential to introduce biomass competitively at a large-scale in national (Dutch), European and global economies to meet environmental policy goals.

2. Biorefineries are expected to be introduced in a variety of market sectors in the short-term (up to 2013) by upgrading of existing industrial infrastructures.

3. New high-efficient biorefinery concepts are expected to be implemented into the market at the medium-term (2013 – 2020). Before implementation can take place, a start has to be made with the development of relevant composing process unit operations as soon as possible. Therefore both public (governmental) and industrial budget should become available for the building and operation of necessary full pilot and demonstration facilities.

4. Currently there exists no proper system for the classification of different biorefinery concepts.

5. Separation and catalytic upgrading processes will be essential process unit operations in all different biorefinery concepts. Therefore, specific attention should be given to the development of these processes.

6. Development and implementation of biorefinery concepts should cover both biomass cultivation, biomass conversion, and final product application. Full technical, economic and ecological chain aspects, including scale and logistical aspects, should be taken into account in designing the most optimal biorefinery concepts.

7. Development and implementation of biorefinery concepts will require co-operation of (industrial) stakeholders that are traditionally not working together yet (like the agro, chemical, and energy sector).

8. Producing and importing knowledge and disseminating it is very important to inform the stakeholders involved so that they can make the right decisions based on up-to-date information.

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Appendix A. National Stakeholders

Name	Area of interest /Expertise / Type
Industry	
ADM	
Akzo Nobel	Biomass-derived chemicals
Albemarle Catalysts	Catalyst development
Argos Oil	Transport fuels
Avantium Catalysts	Catalyst development
Avebe	Potato & starch production
AVR - Van Gansewinkel	Biomass handling
BIOeCon B.V.	
BTG	Thermochemical biorefinery – fast pyrolysis
Cargill	Food production
CCL bv	
CHV	Feed production
Cosun	Sugar industry
Delta	Energy production
DOW Europe	Biomass-derived chemicals
DSM	BioHUB Programme (WCB) – White Biotechnology
Dyadic Nederland BV	
Electrabel	Energy production
ENC	
Eneco	Energy production
E-On	Energy production
Essent	Energy production
Groningen Seaports	Transport & logistics
Loders	Food production
Meneba	Feed production
NOM	Regional development organisation
Nuon	Energy production
Nutreco	Feed & Food production
Paques	
Port of Amsterdam	Transport & logistics
Port of Rotterdam	Transport & logistics
Port of Terneuzen	Transport & logistics
Purac	Lactic acid production; www.purac.com
Rodenburg Biopolymers	Biopolymer production

Royal Nedalco	Bioethanol production
Sabic Europe	Biomass-derived chemicals
Shell Global Solutions	Transport fuels
Sonac bv	Animal residue conversion
Ten Kate Vetten	
Unilever	Food production
VOPAK	Storage facilities
Research Institutes	
Energy research Centre of the Netherlands (ECN)	Thermochemical biorefinery (staged gasification, syngas production/conversion, FT-diesel production)
TNO	
Wageningen UR - Agrotechnology and Food Sciences Group (WUR-AFSG)	Biorefinery concept development, (bio)chemical subtechnology development, full biomass – end products chain expertise
Universities	
Technical University of Delft (TUD)	Thermochemical biorefinery, white biotechnology, separation technology
Technical University of Eindhoven (TUE)	
University of Groningen (RUG)	
University of Leiden	
University of Twente (UT)	
University of Utrecht (UU) – Copernicus Institute	Biomass availability, contractibility and trading, integrated chain assessment
Wageningen University and Researchcentre– Valorisation Plant Production Chains (WUR-VPPC)	Biorefinery concept development, (bio)chemical subtechnology development, full biomass – end products chain expertise
Others	
Energy Valley	Regional development organisation
EZ	Ministry
Greenpeace	NGO
HPA	Commodity board for arable crops
Kennis Centrum Papier & karton (KCPK)	Forest-based Biorefinery Taskforce
LTO	National Farmer's organisation
LTO-Noord	Northern Farmer's organisation

LNV	Ministry
MVO	Product Board for Margarine, oils and fats sector
Natuur & Milieu	NGO
PGG	Platform organisation
PHG	Platform organisation
Rabobank	Bank
SenterNovem	Governamental organisation
SHV	
VNPI	Representative petrochemical sector
WWF	NGO
ZLTO	Southern Farmer's organisation

Appendix B. European Stakeholders

Name	Area of interest / Expertise / Type	Country
Industry		
Abengoa/Greencell	Cellulosic/Bio-ethanol production	Spain
Agrana	Bioethanol	Austria
Agroferm A/S	Lysin production for animal feed	Denmark
Akzo	Chemical company	Sweden
Andritz	Pulp and paper	Austria
Arkema	Whole Crop Biorefinery (BioHUB)	
BASF	Chemical industry	Germany
Bayer Bioscience		Germany
Biofine		Ireland
BioGasol		Denmark
Biorefinery Ireland Ltd	Green Biorefinery	Ireland
Biorefinery.de	Biorefinery implementation	Germany
BIORO	Biodiesel producer	Belgium
BP Chemicals		UK
British Sugar	Sugar Industry	UK
Cargill Europe		Belgium
Cepsa	Oil Refinery / Petrochemicals	Spain
Chimar Hellas	Bio-materials	Greece
CP Kelko	Pectins and carregeenan from fruits and seaweed	Denmark
Daka	Biodiesel from animal waste	Denmark
Dechema		Germany
Degussa GmbH	Chemical industry	Germany
Domsjo	Paper company	Sweden
DONG Energy	Energy industry	Denmark
Energie AG	Energy industry	Austria
Fortum	Energy industry	Sweden
Foster Wheeler	Equipment supplier	Finland
Genencor Danisco	Enzymes for modification and hydrolysis of plant fibres and polysacharides	Danmark
Ghent Bioenergy Valley		Belgium
Haldor Topsoe	Catalysts, processes	Denmark
Henkel	Chemical industry	Germany
Landmannen	Agri-industry	Sweden
Lenzing AG	Pulp and paper production	Austria

Linde	Plant manufacturer	Germany
Neste Oil	Oil industry	Finland
Novozymes A/S	Enzymes for modification and hydrolysis of plant fibres and polysacharides	Denmark
OMV	Oil refinery	Austria
Perstorp	Chemical company	Sweden
Port of Ghent		Belgium
Repotec	Biomass gasification	Austria
Roquette	Whole Crop Biorefinery (BioHUB)	France
Sodra	Paper company	Sweden
Solvay	Whole Crop Biorefinery (BioHUB)	Belgium
Sud-Chemie AG		Germany
Südzucker	Sugar Industry	Germany
Total		France
Uhde	Plant manufacturer	Germany
UPM	Forest industry	Finland
Value for Technology	Technology Deployment	Belgium
Vapo	Biomass supplier	Finland
Vattenfall	Energy industry	Sweden
Vogelbusch	Sugar/starch based ethanol	Austria
Research Institutes		
AFOCEL/CTP	Forest-based Biorefinery	France
Alternative Energy Systems		Ukraine
ARD	(Bio)chemical synthesis	France
BioPos e.V.	Biorefinery concepts	Germany
CPI	Nat. Ind. Biotechnology Facility	UK
CRES	Biomass availability	Greece
EC-BREC	Biomass availability	Poland
ETC (Solander)	Biorefinery concepts	Sweden
Frauenhofer Institute	a.o. monomers from renewables	Germany
FAL	Chemicals, oil-derived products, biotechnology	Germany
GIG	Product separation	Poland
Institute Industrial Ecology	Ecology	Austria
IFP	Conventional/thermochemical refinery	France
INRA		France
Institute of Catalysis	Catalyst development	Russia
Joanneum Research	Grass biorefinery, thermochemical conversion	Austria
KCL	Forest-based Biorefinery	Finland
Leibniz-Institutes	Green Biorefinery	Germany

Metla	Forest Research Institute	Finland
MTT	Agrifood Research	Finland
STFI-Packforsk	Forest-based Biorefinery	Sweden
UPM-Kymmene	Forest-based Biorefinery	Finland
VTT Technical Research Centre of Finland	Forest-based biorefinery concept development, (bio)chemical subtechnology development, full biomass – end products chain expertise	Finland
Universities		
Aarhus University	Agricultural Sciences	Denmark
Aston University	Thermochemical refinery	UK
TU Athens	Scenario-analysis	Greece
University of Bologna		Italy
Chalmers Un. of Techn.		Sweden
University of Copenhagen		Denmark
Technical University of Denmark (DTU/Riso)		Denmark
Ghent University	Biorefinery concept development, (bio)chemical subtechnology development, full biomass – end products chain expertise	Belgium
University of Graz	Thermochemical refinery	Austria
Helsinki University (of Technology)		Finland
Imperial College	Full TEE chain assessments	UK
University of Limerick		Ireland
TU Lodz		Poland
Lund University	Socio-economics on biorefineries	Sweden
University of Manche Ster		UK
University of Natural Resources	Applied life sciences	Austria
Petroleum and Gas University		Romania
IER University Stuttgart	Forest-based Biorefinery Taskforce	Germany
UNI Weihenstephan	Non-food crops research	Germany
University Of York	Green chemistry, Extraction and synthesis processes	UK
Vaxjo University		Sweden

Others		
Europabio	European biotechnology sector	Belgium
Finish Bioenergy Association		Finland
Finish Forest Industry Federation		Finland

Appendix C. Stakeholders rest of World

Name	Country
Industry	
ADM	US
Cargill	US
CEA Inc.	US
Dupont	US
Exxon Mobile	US
Genencor International	US
Mitsubishi chemical	Japan
Nature Works LLC	US
Novozymes Biotech Inc	US
Outlast Technologies Inc.	US
Winrock International	US
Research Institutes	
BioTechnology Institute	US
Centre for Sustainable Environmental Technologies	US
Centro de Tecnologia Canavieira Fazenda	BRA
Natural Resources Canada	Canada
NRC	Quebec, Canada
NREL	US
Oak Ridge National Laboratory	US
Pacific Northwest National Laboratory	US
Renewable Products Development Laboratories	US
Universities	
University of Arkansas	US
Cornel University	US
Iowa State University	US
Michigan State University	US
University of Missouri	US
Universidade Federal de Sao Carlos	BRA
University of Tennessee	US
Others	
Biobased Industrial Products Consulting	US
Biotechnology Industry Organization (BIO)	US
Department of Energy (DOE)	US
National Bioenergy Centre	US

Appendix D. Running Dutch RTD-projects

ASPECT

Title	Advanced Sustainable Processes by Engaging Catalytic Technologies
Contractor	The program is open to all Dutch universities and some research institutes under the standard ACTS-NWO rules
Contact person	
Phone no.	
E-mail	
Website	www.nwo.nl
Partners	ASPECT is financially supported by the Ministry of Economic Affairs, by the Netherlands Organization for Scientific Research (NWO), as well as by a number of industries: Albemarle Catalysts, Dow Benelux, DSM, Engelhard, Exxon Mobil, Johnson Matthey, SABIC, and Shell.
Term	2004 – 2011
Programme	NWO – ASPECT
Project no.	
Abstract	

The ASPECT programme concentrates on commodity chemicals and catalysis with the aim of increasing sustainability. The goals as formulated in the program are largely based on the Report 'Catalysis, key to sustainability' of the Technology Roadmap Catalysis. They aim for long-term changes, requiring a concerted effort of industry, academia and other research institutes. The ASPECT programme has the following research themes:

- Short- to medium-term research activities, focusing on the present slate of products and their manufacturing processes, as they are expected to change only marginally in the next 5 to 10 years. Projects in this part of the programme focus on the utilization of current feedstocks and their conversion processes, aiming for significant improvements in selectivity and yield, as well as integration of several process steps.
- Activities focusing on long-term changes, to accomplish a significant transition to more sustainable or renewable feedstocks. Methane and lower alkanes will be screened as feed for new routes to existing products. Today these feedstocks are often incinerated at production sites. The challenge is to develop new, very efficient oxidation catalysts employing air or oxygen as reagent. Renewable feedstocks will ultimately close the C-cycle in the production of bulk chemicals. Main challenges here are the use of renewable feedstocks in existing processes and infrastructures, the development of bio-catalytic and fully biosynthetic processes for bulk chemicals, and the integration of chemo-catalysis and bio-catalysis.
- Enabling tools should be developed as an integral part of these programmes and projects, like 'high-throughput' techniques, and various in situ spectroscopic techniques. This will enable a significant reduction of the development time for bulk chemical processes.

BBasic

Title	Bio-BAsed Sustainable Industrial Chemistry
Contractor	Delft University of Technology
Contact persons	Prof.dr.ir. Luuk van der Wielen (science), Dr. Gerda Lourens (business)
Phone no.	+31-15- 2786654 (Drs. M. Blomjous)
E-mail	m.blomjous@tnw.tudelft.nl
Website	www.b-basic.nl; info@b-basic.nl
Partners	WUR - AFSG , Groningen University, Leiden University, TNO-MEP, Paques, Shell Global Solutions, Akzo Nobel, DSM
Term	2004 – 2009
Programme	NWO – ACTS
Project no.	

Abstract

B-Basic is a consortium of universities, research institutions and industry. Research in the B-Basic optimally benefits from the latest breakthroughs in genomics research by using the new insights to develop processes that can convert biomass into chemicals using biocatalysts as micro-organisms and enzymes. The B-Basic mission is to provide the chemical industry with an advanced set of tools and concepts by approaching Bio-based Sustainable Industrial Chemistry in a fully integrated manner, combining functional genomics, intensified bioprocess technology and feedstock scenarios. The multidisciplinary B-Basic programme is performed in 5 thematic subprogrammes, viz.: bulk monomers, fine chemicals, performance materials, novel feedstocks, and Life Science & Technology Training Centre. The ambition level of B-Basic is high. The on-going genomics revolution will be exploited in the B-Basic initiative, leading to major shifts in typical performance parameters for the chemical industry, such as outlined in the Figure below, to create a cleaner world, where high quality materials are produced in clean and efficient bio-based processes. The integrated and focused research and training programme of B-Basic will form an essential basis for these shifts to innovations for 2020 and beyond.

BIOBUTANOL

Title	Biobutanol: A new process for the full conversion of lignocellulosic biomass into CO_2-neutral biofuels for transport, energy and chemicals
Contractor	Agrotechnology and Food Innovations B.V. (part of Wageningen –UR)
Contact person	Rob Bakker / Anna Lopez Contreras
Phone no.	+31-317-477569 / +31-317-478572
E-mail	robert.bakker@wur.nl / ana.lopez-contreras@wur.nl
Website	www.biobutanol.nl; www.biorefinery.nl
Partners	Energy research Centre of the Netherlands (ECN)
Term	1 October 2005 – 30 September 2008
Programme	Long Term Energy Research Strategy (EOS-LT)
Project no.	EOSLT02036

Abstract

Due to new developments in biotechnology and the higher oil price, there has been renewed interest in fermentative production of butanol, a platform chemical and alternative biofuel. To date, high substrate costs and low volumetric productivity remain significant bottlenecks that preclude large-scale application of ABE (acetone, butanol, ethanol) fermentation. By using our combined experience in biomass pre-treatment, fermentation, separation technology and energy system design, we are developing new concepts for conversion of cellulosic biomass into butanol. The ultimate goal is to design a new, efficient and economically viable bioprocess for the conversion of low-cost cellulosic feedstocks into butanol.

The objectives of this project are:

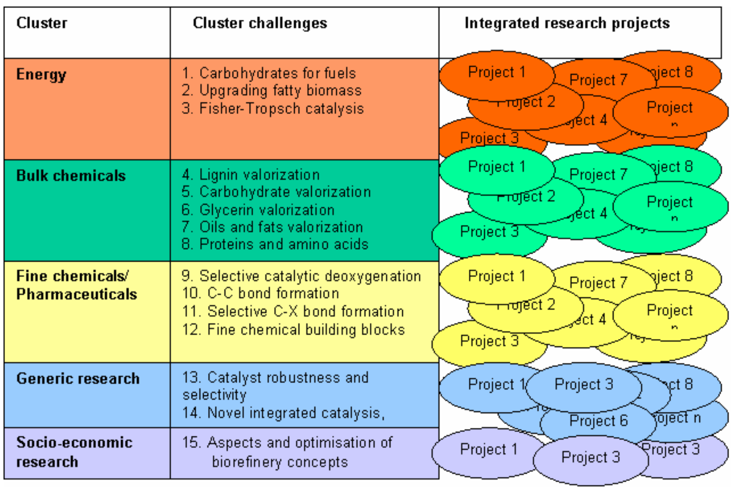
- to reduce substrate costs for ABE fermentation by using lignocellulosic biomass feedstocks;
- to improve productivity of ABE by applying high-cell density fermentation and innovative separation techniques, and
- to develop an efficient and sustainable conversion system for cellulosic biomass into butanol based on integration of biomass pre-treatment with fermentation, in-situ butanol recovery, and energy recovery from non-fermentable co-products

CatchBio

Title	Catalysis for Sustainable Chemicals from Biomass
Contractor	Netherlands Institute for Catalysis Research (NIOK)
Contact person	Prof.dr.ir. B.M. Weckhuysen
Phone no.	+31-30-2534328
E-mail	b.m.wechuysen@chem.uu.nl
Website	www.catchbio.com
Partners	Utrecht University, Agrotechnology and Food Innovations BV, Energy research Centre of the Netherlands, NV Organon, Albemarle Catalysts BV, Dow Benelux BV, DSM Pharmaceutical Products, DSM Research BV, Engelhard de Meern BV, Sasol Technology Ltd, Shell Global Solutions BV, Avantium Technologies, BIOeCON BV, Hybrid Catalysis, VibSpec
Term	2007 – 2015
Programme	SmartMix
Project no.	

Abstract

This 28.4 M€ SmartMix R&D Programme focuses, integrates, and strengthens Dutch research into chemo-catalysis that will enable Dutch energy and chemical industries to successfully switch from oil-based to biomass-based sustainable production routes for fuels, chemicals and pharmaceuticals. The overall Work Programme is subdivided into 15 subprogrammes in which a variety of specific integrated R&D-projects will be specified, submitted and performed.



12 out of the 15 subprogrammes are directly biorefinery-related. Therefore, within this Dutch SmartMix Programme the main biorefinery-related items within a catalytic framework will be addressed.

CORAF

Title	Co-refining of biomass in existing refineries
Contractor	Twente University
Contact person	Sacha Kersten
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Website	
Partners	Biomass Technology Group (BTG)
Term	1 June 2006 – 1 June 2010
Programme	Long Term Energy Research Strategy (EOS-LT)
Project no.	EOSLT04018
Abstract	

At the present time generating fuel from biomass is still an expensive process. The partners in this project will examine the possibilities to pre-process biomass in such a way so that it could be processed in the regular process installations in oil refineries, apart or together with petroleum. Another possibility for employing biomass for energy provisioning is by converting it into bio-fuels. This for example is an aim set by a 2003 European directive that determined that throughout Europe part of petrol and diesel for transportation purposes will be replaced by bio-fuels: 2% by 2005 and 5.75% by 2010. However, in most cases the production of bio-fuel in Europe is so expensive that the bio-fuels can be introduced into the market only with subsidies and tax exemptions. In the past, options were examined from a perspective of large-scale gasification as a new production method, whereby biomass, bio-liquid or bio-grout was converted into a CO/H2 synthesis gas. Afterwards this gas is cleaned and converted into the desired bio-fuel in a catalysing process. In the meantime it is well known that such Syngas solutions are also expensive and are only economically feasible on a large scale.

A relatively new idea is to refine biomass in the same installation as petroleum. This could mean enormous cost saving because the process uses existing infrastructure and markets. However, the biomass must first be upgraded. The refining that follows could be either mixed with petroleum or could be processed in a separate feeding line. The principle is called co-refining.

The partners in the project will first study the refining processes in the petrochemical industry more in-depth and will conduct discussions with the petrochemical industry about the possibility to establish the outlined set-up and the required quality specifications. Subsequently, they will examine under lab conditions how bio-liquids have to be upgraded. Finally, a small installation will be build to demonstrate the operation of the upgrading process.

The intention of the project is to make a start with and to provide a direction to the necessary trajectory for a fundamental research study that will be carried out in the coming 10 years. The project is closely linked to the EU bio-refinery project 'Biocoup' of a large consortium of European industries and research institutes.

IBOS

Title	Integration of Biosynthesis and Organic Synthesis
Contractor	
Contact person	Mark Schmets
Phone no.	+31-70-3440 537
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Website	www.nwo.nl
Partners	
Term	2003 – 2010
Programme	
Project no.	
Abstract	

Fine chemicals contribute considerably to the quality of life (e.g. food and pharma). As the desired products tend to become more and more complex as a result of industrial and societal requirements (higher development speed, efficiency and sustainability of production processes), a drastic and radical change of strategy in synthetic chemistry is needed. Time has come to better use the learning opportunities offered by nature, as most of the biochemical processes that occur in living beings easily outperform the 'best practices' of conventional synthesis methods.
The IBOS Programme (Integration of Biosynthesis & Organic Synthesis) embodies this strategy change by integrating the diversity of today's (bio)chemistry with the subtlety of modern molecular biology. Biotechnology integrated into chemical synthesis will enable a new future for synthesis, meeting the increasing demands of the strongly science-dependent health care, materials and other industries.

The programme focuses along three research lines:

- Molecular Biology & Biosynthesis
- Bio-transformations
- Bio-inspired Organic Synthesis

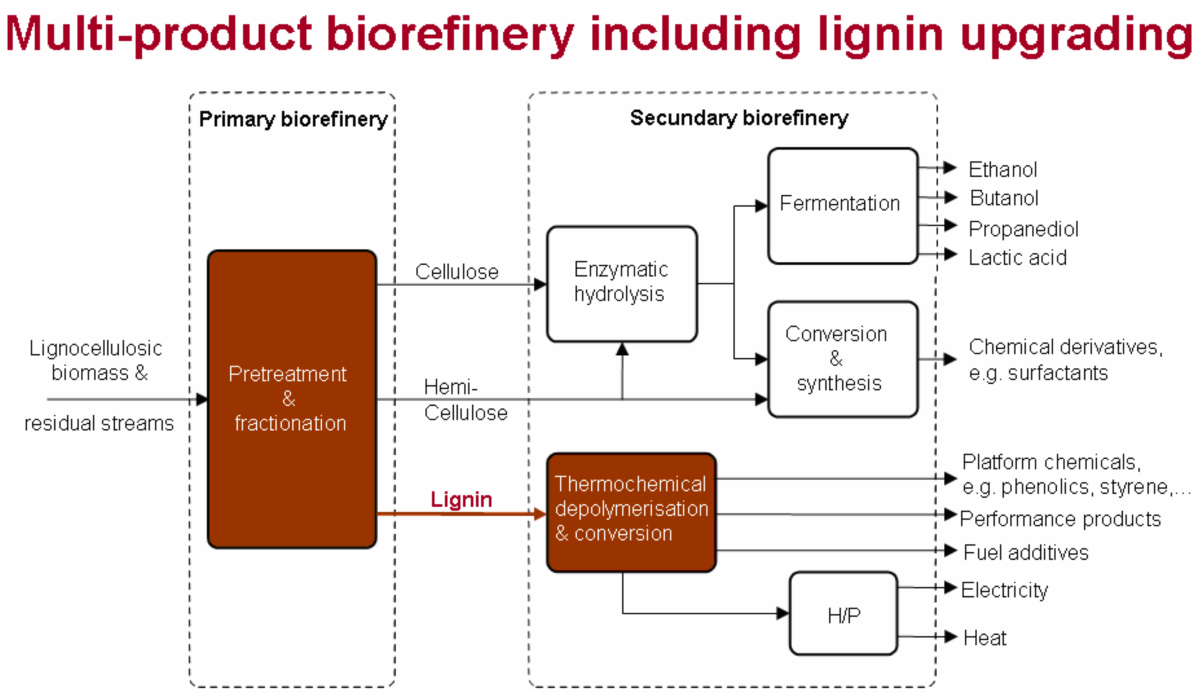
For the long term, full integration will be the goal. For the next 5-10 years the objectives are:

- New catalytic methods for organic syntheses in which a number of atomic bonds are formed simultaneously
- Protective group chemistry, elaborate isolations and purifications will become obsolete
- Fermentation will reach a much wider scope including non-natural products ranging from simple bulk-molecules to complex medicines
- New hybrid syntheses integrating molecular biology and chemistry
  Processes for simple and complex molecules with molecular weights up to 1000 should become available through IBOS, allowing straightforward development and sustainable commercialization in industry.

LignoValue

Title	High Grade Valorisation of Lignin for Optimal Biorefinery of LignoCellulose to Energy Carriers and Products
Contractor	Agrotechnology and Food Innovations B.V. (A&F, part of Wageningen UR)
Contact person	Richard Gosselink
Phone no.	+31-317-475210
E-mail	richard.gosselink@wur.nl
Website	www.biobutanol.nl/lignovalue; www.biobasedproducts.nl; www.biorefinery.nl;
Partners	Wageningen University - Department of Valorization of Plant Production Chains (WU-VPPC), University of Groningen (RUG), Energy research Centre of the Netherlands (ECN)
Term	1 January 2007 – 31 December 2010
Programme	Long Term Energy Research Strategy (EOS-LT)
Project no.	EOSLT05011
Abstract	

The main goal of this biorefinery project called "LignoValue" is to valorize the lignin fraction via the production of phenols, performance products and fuel additives.



This R&D project focuses on:

- Primary biorefinery technology for production of high quality streams of cellulose, hemicellulose and lignin facilitating further production of products and energy carriers for all biomass fractions
- Secondary biorefinery technology for the production of phenols, performance products like resins, fuel additives, electricity and heat out of the lignin fraction
- Development of an integral biorefinery concept in which the developed technologies have been optimally integrated and all biomass fractions consist of an optimal quality for further refinery and valorisation.

Valorization of lignin will be the key issue in the further development of biofuels production from lignocellulose. Conversion of lignin to chemical feedstocks will positively influence the economic feasibility resulting in a substantial decrease of the production costs of bio-ethanol.

Conversion of lignin to chemicals will be studied via two thermochemical routes e.g. pyrolysis and depolymerisation under supercritical conditions.

This project is financially supported by a grant from the EOS-LT (Energy Research Subsidy) programme of the Dutch Ministry of Economic Affairs, the Hague.

N-ERGY

Title	N-ergy: micro-biological co-production of N-chemicals and ethanol from biomass fractions
Contractor	Wageningen University, Chair of Valorisation of Plant Production Chains (WU-VPPC)
Contact person	Johan Sanders
Phone no.	+31-317-475163
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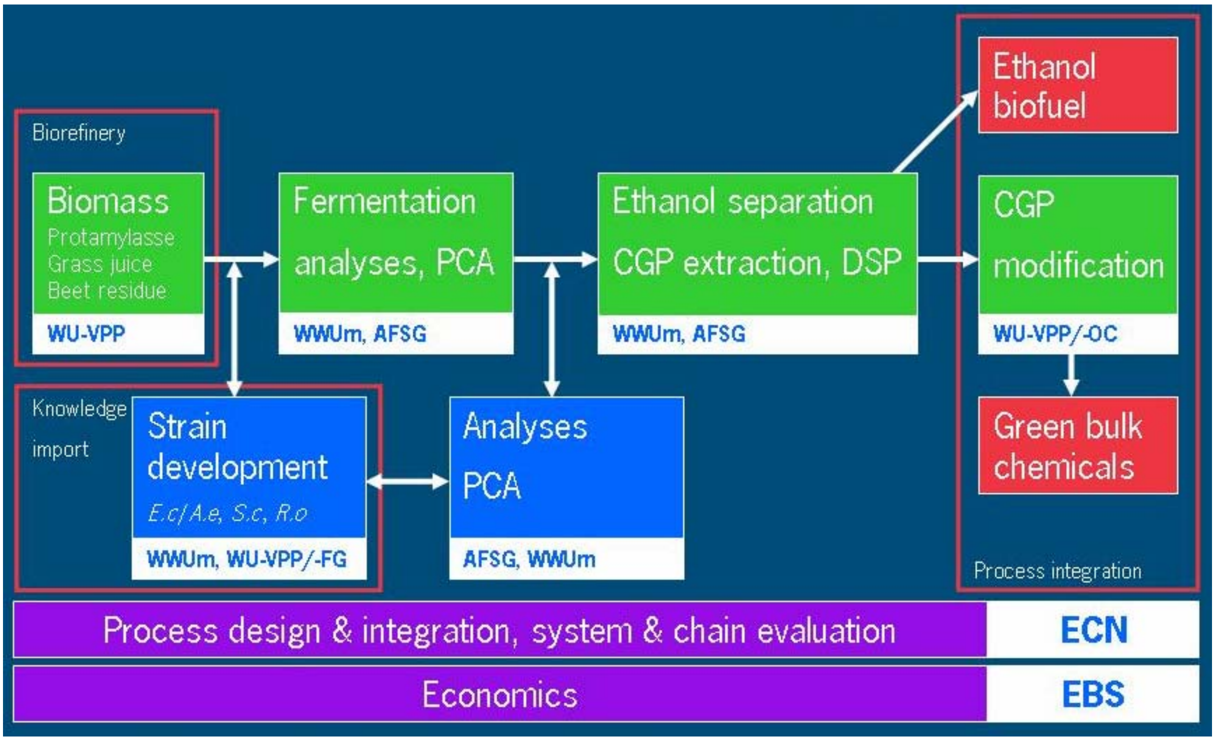
Website	www.vpp.wur.nl
Partners	Wageningen University and Research Centre (WUR-A&F), Energy research Centre of the Netherlands (ECN), University of Münster (Westfälische Wilhelms Universität Münster, WWUm), Easthouse Business Solutions B.V. (EBS)
Term	1 January 2006 – 31 December 2009
Programme	Long Term Energy Research Strategy (EOS-LT)
Project no.	EOSLT02034
Abstract	

Objective - The production of functionalised bulk chemicals containing a.o. nitrogen is very energy-intensive because not only the naphtha feed stock but also different chemicals are needed such as chlorine and ammonia. The production of these chemicals itself already requires much energy in the form of electricity and natural gas. The exploitation of biomass fractions that resemble these bulk chemicals in structure makes the application as feed stock for the chemistry 2-4 times more efficient with respect to energy consumption as the use of the same biomass as feed stock for the generation of electricity or transportation fuel. Of course this energy-efficiency has also economic implications through cost reductions that include less expensive investments. However, it is a matter of research which technology should be developed on a large scale for the biorefinery route and which will be the costs.

In the current project a starting point will be a fermentation process in which a yeast or fungus variety will be developed which will be capable to accumulate a water-insoluble biopolymer that belongs to the group of non-ribosomal peptides (poly[amino acid], cyanophycine, CGP) and simultaneously to produce ethanol, when growing on diluted or concentrated fractions deriving from the biorefinery process of e.g. grass, potatoes or beets. The CGP already available from bacteria can be used for the investigations regarding the production of derived bulk chemicals. For this purpose different enzymatic conversions will be required which are known from literature and which will serve for the development of an operational process.

Technique - For the simultaneous production of ethanol and CGP (a polymer existing of aspartic acid and arginine) from dilute or concentrated biorefinery juice fractions a yeast and/or a fungal strain will be developed (*S. cerevisae* and/or *R. oryzae*, respectively) that accumulates CGP and simultaneously (or in the same fermentation run) produces ethanol (Process integration). CGP, with the derivatives polyaspartic acid and arginine, can be used as the starting material for the production of bulk chemicals such as butane-diamine, urea, acrylonitril. Polyaspartic acid may be used to replace polyacrylic acid.



Innovative aspects - Circumventing a number of petrochemical synthesis steps and the need for petroleum as a feed stock, chlorine and ammonia will lead to a significant increase in energy value of biomass fractions. The intended approach using an anaerobic production process, in which the sugars present can be converted to ethanol, may yield a very efficient process. The intended simultaneous production of a (*biofuel*) energy carrier and precursor for bulk chemicals is a unique form of process integration, which even with the conventional production organism *S. cerevisiae* has not been attempted for an economically sound process before.

Importance for a reliable and affordable energy housekeeping - No use of petroleum, chlorine or ammonia and a high energy-efficiency of the biomass used and the broad availability of cheap starting materials will contribute to the total energy housekeeping.

Optimal Lignocellulose Hydrolysis

Title	Maximising the bioenergy potential of lignocellulose biomass; mitigating the effect of humic and fulvic acids
Contractor	Wageningen UR
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Website	www.ete.wur.nl
Partners	HoSt BV
Term	1 January 2006 – 1 January 2010
Programme	Long Term Energy Research Strategy (EOS-LT)
Project no.	EOSLT05006
Abstract	

Due to the limited processing options for lignocellulosic material, biomass (waste) flows are more than abundant and relatively cheap. Optimising the hydrolysis of lignocelluloses material can increase the energy production from biomass enormously. Optimising the hydrolysis is also vital for other high-grade application other than bio-methane, for example the production of bio-ethanol. During hydrolysis polymers (celluloses) are split into dimers and monomers (sugars). Unfortunately, the hydrolysis – the speed-limiting step – is slowed down by the presence of humic and fulvic acids. These acids, which form inevitably, bond with the enzymes that are responsible for the hydrolysis.

First of all this project will study the relationship between the presence and the percentage of these acids and the hydrolysing speed. The acids are studied according to their composition and origin (vegetable waste product or animal manure). In order to decrease the slow-down effect on the useful enzymes, the researchers will examine which functional groups are responsible for bringing about the bonding between the acids and enzymes and how this bonding can be prevented. Earlier studies have shown that calcium is an appropriate candidate for this. The research study will also take a close look at the bonding capacity of humic and fulvic acids for hydrolysing enzymes.

Later on in the project the researchers will optimise the process conditions in an anaerobic reactor and they will contemplate and implement measures for improving hydrolysis. Following laboratory research, a test of the optimisation will be conducted in an existing biogas installation. In order to predict the progress of the process and the energy yields (bio-methane) far better, additional existing computer models will be adapted.

With the results of this study, fibrous residual products such as straw and manure could be converted into methane with greater efficiency. According to expectations, the technology can be implemented relatively fast.

Pectin Challenge

Title	Towards bioethanol from sugar beet pulp: the pectin challenge
Contractor	Royal Nedalco
Contact person	Jan de Bont
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E-mail	j.debont@nedalco.nl
Website	www.nedalco.nl
Partners	DYADIC Nederland BV, Wageningen University, Technical University of Delft, Energy research Centre of the Netherlands
Term	1 January 2007 – 31 December 2010
Programme	Long Term Energy Research Strategy (EOS-LT)
Project no.	EOSLT05019

Abstract

Biomass released as waste product during industrial processes is potentially an important source of sustainable energy. In this context, pulp from sugar beet processing could present an attractive type of waste flow for the Netherlands. Presently this method has a net value of almost zero while it concerns huge amounts that are found in only a limited number of locations. The high concentration of carbohydrates makes the sugar beet pulp exceptionally attractive as an ingredient for the production of bio-ethanol.

Sugar beet pulp consists of three categories of carbohydrate polymers: cellulose, hemi cellulose and pectin. The relative large proportion of pectin creates a big problem because there are no enzymatic processes that can hydrolyse this substance on a large scale and in an economically competitive manner. Furthermore, there are no yeasts available as yet that can ferment the galacturonic acid, which is created in the case of hydrolysis, into ethanol. This project will tackle both problems using molecular biotechnology.

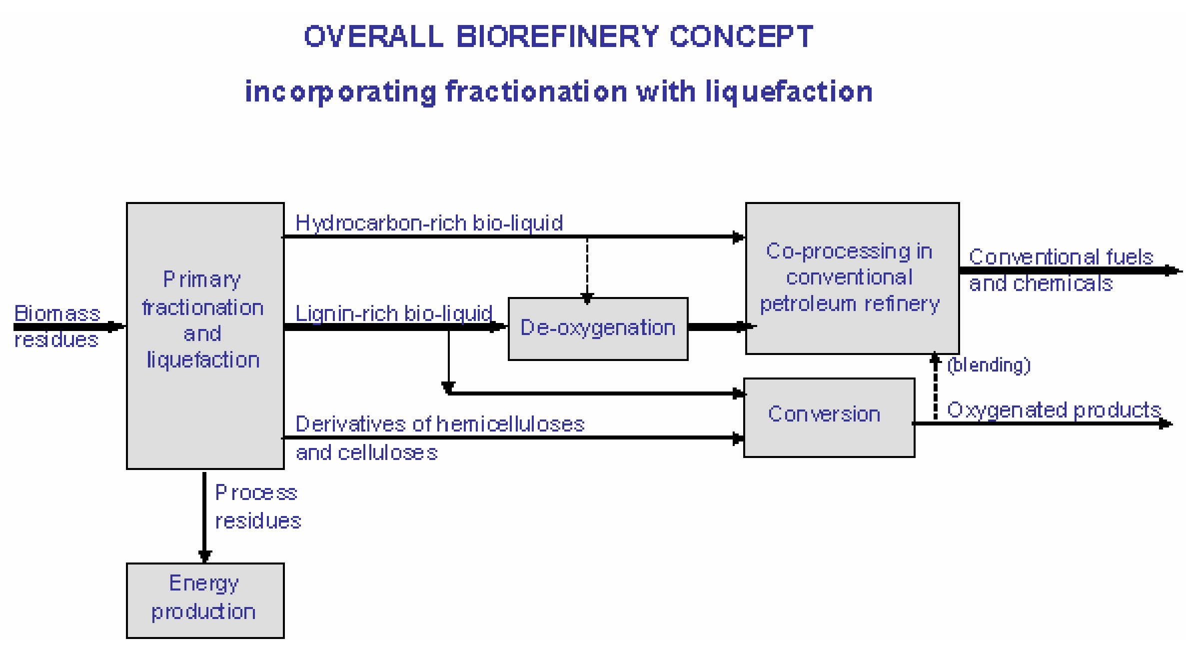
DYADIC Nederland will develop enzymes that could carry out the specific and active processes that are necessary for hydrolysing pectin. Wageningen University will assist DYADIC in this project by constantly determining the precise effects of the developed enzymes and by helping devise applications and new development directions. Based on its specific knowledge about yeast, the Delft University of Technology will create yeast that can ferment galacturonic acid into bio-ethanol. Based on the results, the Energy Research Centre of the Netherlands (Dutch: ECN) will design a complete conversion process. Ethanol manufacturer Nedalco is the project coordinator and will test the process in practice. This way sugar beet pulp could become an attractive new source for ethanol production.

Appendix E. Running and recently completed International RTD-projects

BIOCOUP

Title	Co-processing of upgraded bio-liquids in standard refinery units (BIOCOUP)
Contractor	Technical Research Centre of Finland VTT, Finland
Contact person	Yrjö Solantausta
Phone no.	+ 358 20 72 25 517
E-mail	yrjo.solantausta@vtt.fi
Website	www.biocoup.eu
Partners	17 partners from 7 countries
Term	May 2006 – April 2011
Programme	EU-FP6-IP
Project no.	518312
Abstract	

Bio-energy, bio-fuels and valuable bio-chemicals will be produced on a single petrochemical site, in existing standard refinery units.



The overall objective of this research is to upgrade biomass-derived liquids in order to make them suitable for co-processing.

- As a secondary objective, the separation of valuable chemicals from biomass and biomass–derived liquids is considered, prior to the upgrading for co-processing in the refinery.
- The main aim of the BIOCOUP project is to co-process upgraded bio-liquids in conventional refinery co-processing units. To achieve this, the consortium will integrate their competencies to achieve the following scientific and technical objectives:
- To develop processes of primary fractionation and biomass liquefaction to produce quality-controlled bio-oils;
- To develop bio-liquid upgrading technology such as deoxygenation including development of specific catalysts and to scale it up to PDU-scale;
- To study co-processing opportunities of biomass derived components in archetypal refinery units;
- To produce discrete oxygenated target chemicals;
- To evaluate the most promising optimised biomass-refinery chains (biomass feedstock → final products) through scenario analysis based on estimates of the technical, economical and LCA (life-cycle analysis) performances of the chains.

The project has six sub-projects, each of which deals with critical areas of the proposed biomass utilization chain. The overall objectives in each sub-project are:

1. Biomass liquefaction and energy production: To reduce bio-oil production costs;
2. Upgrading technologies: To develop de-oxygenation technology and scale it up to process development unit-scale;
3. Evaluation of upgraded bio-liquids in standard refinery units: To assess the viability of upgraded bio-liquids co-processing in a standard refinery;
4. Conversion to chemicals: To identify optimal recovery and fractionation strategies and technologies for the production of discrete target compounds from bio-liquids;
5. Scenario and life cycle analysis: To outline a low-risk, low-cost development path for the most promising bio refinery chains, a path based on stage-wise validation, demonstration and implementation;
6. Transversal activities: To optimise the impact of the project by a structured management and the efficient coordination of transversal activities (standardisation, exploitation and dissemination)

BIOPOL

Title	Assessment of **BIO**refinery concepts and the implications for agricultural and forestry **POL**icy (BIOPOL)
Contractor	WUR - Agrotechnology and Food Sciences Group
Contact person	Bert Annevelink
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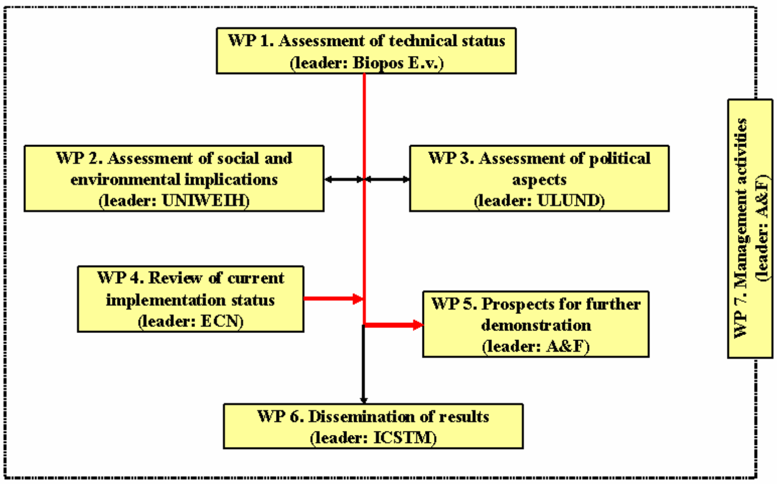
E-mail	bert.annevelink@wur.nl
Website	www.biorefinery.nl/biopol
Partners	Research Institute Biopos e.V., Imperial College of Science Technology and Medicine, Lund University, Institute for Fuels and Renewable Energy, Energy research Centre of the Netherlands (ECN), University of Applied Sciences of Weihenstephan, Institute of Communication and Computer systems Athens
Term	1 March 2007 - 28 February 2009
Programme	FP6-2005-SPP-5A
Project no.	44336

Abstract

The overall goal of the SSA project BIOPOL is to assess the status (technical, social, environmental, political, and implementation) of innovative BIOrefinery concepts and the implications for agricultural and forestry POLicy. Biorefinery concepts are aimed at relevant market-competitive and environmental-friendly synthesis of bio-products – chemicals and/or materials – together with the production of secondary energy carriers – transportation fuels, power and/or CHP. BIOPOL will result in a scenario grounded assessment of sustainable solutions that impact several European key industries, and will generate valuable knowledge to fill in part of the research agenda of the recent Biomass Action Plan of the European Commission.



Biorefinery EUROVIEW

Title	Current situation and potential of the biorefinery concept in the EU: strategic framework and guidelines for its development
Contractor	Industries and Agro-Resources Cluster
Contact person	Marc Chopplet
Phone no.	+33-3 22 97 89 28
E-mail	marc.chopplet@alternatech.org
Website	www.biorefinery-euroview.eu
Partners	Agrobiopôle Wallon, Confederation of European Paper Industry (CEPI), European Association on Biotechnology (Europabio), Europol'Agro, Ghent University, Regional Development Agency of the North Great Plain Hungary, Technical Research Centre of Finland (VTT)
Term	1 March 2007 - 28 February 2009
Programme	FP6-2005-SPP-5A
Project no.	44275

Abstract

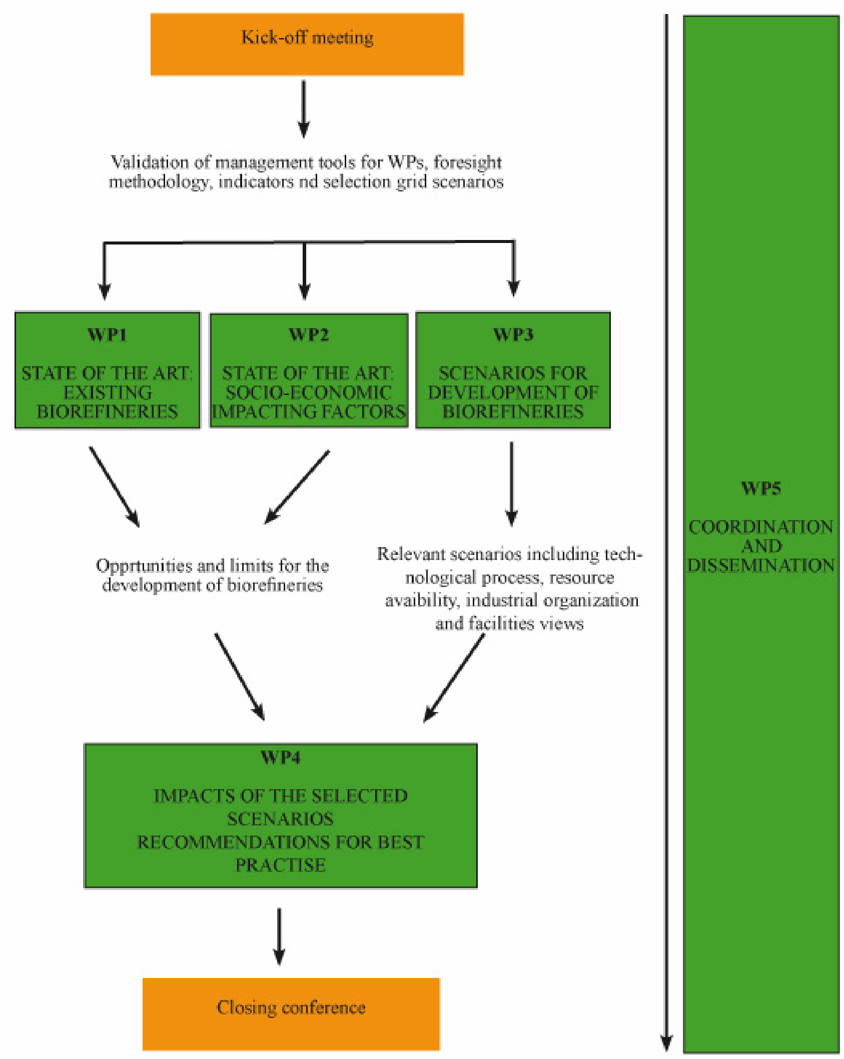
Three approaches have been combined in the BIOREFINERY EUROVIEW project. The first concerns the study of existing or planned European biorefineries. The goal is to understand the diversity of designs and to identify the implemented technologies, the invested resources and the expected outputs, whilst taking into account the different facets of their economic, social and environmental impact. A comparison will be performed with case studies of biorefinery development models outside Europe.

The second approach focuses its attention on socio-economic factors and regulatory aspects. It seeks to identify the obstacles to development of the biorefinery concept, as well as existing regional, national and European incentives. The data will be gathered via i) a survey of prime contractors and decision-makers and ii) an analysis of the various policies and regulations implemented in European countries.

The goal of the third approach is to build a range of theoretical scenarios for biorefinery development in Europe at the 2020 horizon, on the basis of expert opinions on technological development, resource availability, trends in regulatory and fiscal policies, industrial development strategies and customer and societal perception of these new industrial configurations and the resulting products. These scenarios will be compared with those conceived in non-European countries (the USA, in particular).

By implementing a dynamic, collaborative process based on the scientific and technological skills of the organisations involved and their strategic expertise in building activities in this domain (Network of Excellence, Technology Platform, Competitiveness Hub, R&D clusters, etc.), the

BIOREFINERY EUROVIEW project will meet the set objectives in terms of defining the criteria for selecting the concepts and the operational policies for the future development of biorefineries, by dealing with each approach as a function of its constituent technologies, resources and outputs.



A link will be organized between the BIOREFINERY EUROVIEW project and the BIOPOL project (that has common points) through a permanent contact between coordinators of both projects. Exchange of information and common activities are planned

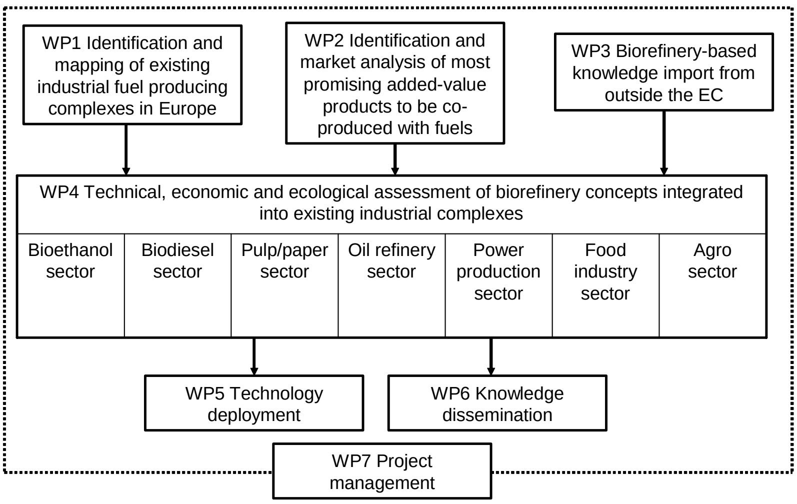
BIOREF-INTEG

Title	Development of advanced **BIOREF**inery schemes to be **INTEG**rated into existing industrial fuel producing complexes
Contractor	WUR - Agrotechnology and Food Sciences Group
Contact person	René van Ree
Phone no.	+31-317-476593
E-mail	Rene.vanree@wur.nl
Website	www.afsg.nl; www.biorefinery.nl
Partners	Greencell S.A. (Es),Ghent Un. (Be), Bioro N.V. (Be), STFI –Packforsk AB (S), ETC (S), VTT (Fin), ECN (Nl), Aston Un. (Uk), Ten Kate B.V. (Nl), ENC (Nl), VFT (Be), Cehave (Nl)
Term	01-01-2008 – 31-12-2009
Programme	FP7-ENERGY-2007-1-RTD
Project no.	

Abstract

The overall aim of BIOREF-INTEG is to develop advanced biorefinery schemes to be integrated into existing fuel producing complexes. S&T-objectives of the project are: to make the production of biofuels more competitive, to identify and develop the optimal integrated biorefinery schemes for the production of best suited "building blocks" in terms of processes and bioproducts, and to identify opportunities of various biomass sectors to produce fuels while increasing their market competitiveness by co-producing added-value products. Sectors dealt with are: sugar/starch (bioethanol), biodiesel, pulp/paper, conventional oil refinery, power production, food industry, and the agrosector. The project is performed by 7 separate but strongly interrelated WPs.

Graphical presentation of the WPs showing their interdependencies (Pert diagram)



BIOSYNERGY

Title	**BIO**mass for the market competitive and environmental friendly **SYN**thesis of bio-products (chemicals and/or materials) together with the production of secondary en**ERGY** carriers (transportation fuels, power and/or CHP) through the biorefinery approach, combining both biochemical and thermochemical pathways, and process development from lab-scale to demonstration at pilot-scale.
Contractor	Energy research Centre of the Netherlands (ECN)
Contact person	Hans Reith
Phone no.	+31-224-564371
E-mail	reith@ecn.nl
Website	www.biosynergy.eu
Partners	Greencell (Es), Cepsa (Es), Dow (Nl), VTT (Fin), Aston Un. (Uk), WUR-A&F (Nl), ARD (F), IFP (F), CRES (Gr), BTG (Nl), Joanneum (At), Biorefinery.de (D), Glowny Inst. (Pol), JRC (Be), Chimar (Gr), Delft University (Nl)
Term	1 January 2007 - 31 December 2010
Programme	EU-FP6-IP
Project no.	038994 – (SES6)
Abstract	

Sustainable management of Europe's natural resources and their integration with human activities, specifically in the bioenergy, fuels and chemical industry, motivate the research proposed for this IP. BIOSYNERGY aims to use biomass for synthesis processes (transportation fuels, platform chemicals) and energy production (power, CHP) by application of innovative fully integrated, synergetic biorefinery concepts, using advanced fractionation and conversion processes, and combining biochemical and thermochemical pathways. The use of biomass for the production of transportation fuels, and to a lesser extend energy, is still more costly than the use of traditional petrochemical resources. The aim of BIOSYNERGY is to achieve sound techno-economic process development of integrated production of chemicals, transportation fuels and energy, from lab-scale to pilot plant. This project will be instrumental in the foreseen establishment of facilities for integrated production of bulk quantities of chemicals, fuels and energy from a wide range of biomass feedstocks.

BIOSYNERGY will create great potential impact as it will set-up pilot plants of the most promising technologies for a "bioethanol side-streams" biorefinery, in close collaboration with the "lignocellulose-to-bioethanol" pilot-plant of Greencell, currently under construction in Salamanca, Spain.

The use of biomass for the production of transportation fuels, and to a lesser extent energy, is still more costly than the use of traditional petrochemical resources. The overall aim of BIOSYNERGY is to achieve sound techno-economic process development of integrated co-

production of chemicals, transportation fuels and energy, from lab-scale to pilot plant.
This project will be instrumental in the foreseen establishment of facilities for integrated co-production of bulk quantities of chemicals, fuels and energy from a range of biomass feedstocks.

BCyL bioethanol pilot-plant of Greencell in Babilafuente (Salamanca, Spain)

Technical approach – major innovations

- Advanced technologies for the physical/chemical fractionation of various biomass feedstocks (pre-treated barley straw and DDGS from the pilot-plant, and straw and clean wood as representatives of major European biomass streams) into their composing components for further downstream processing.
- Innovative technologies for the thermo-chemical/biochemical conversion of feedstocks into biomass-derived intermediate products (e.g. butanol, phenolic oils, furfural).
- Downstream processing of biomass-derived intermediates into value-added chemicals and energy carriers, based on integral biomass-to-products chain design, analysis and optimisation.

Expected achievements (selection)

- Technical, socio-economic and ecological European perspective of integrated refinery processes for the co-production of chemicals, transportation fuels and energy from biomass by performing integral biomass-to-products chain design, analysis and optimisation.
- Lab-scale development and pilot-scale demonstration of biorefinery-based composing sub-processes, i.e.: physical/chemical fractionation processes, thermo-chemical conversion processes, biochemical conversion processes, and chemical conversion and synthesis processes.
- Basic Design of an innovative cellulose ethanol based biorefinery process in which the residues are upgraded to added-value products (chemicals, power, CHP).

CHRISGAS

Title	Clean Hydrogen-rich Synthesis Gas
Contractor	Vaxjo University (Sweden)
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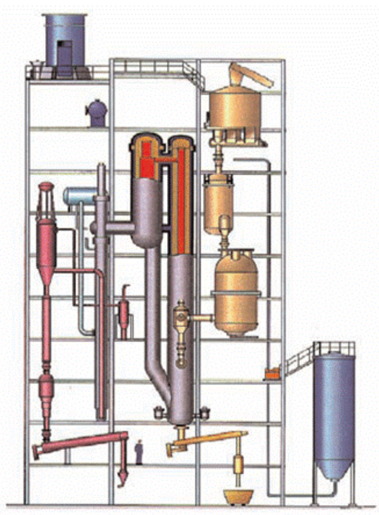
Website	www.chrisgas.com
Partners	Catator AB (SWE), Ciemat (ES), Forschungszentrum Jullich (D), Helector SA (GR), KS Ducente AB (SWE), KTH (SWE), Linde AG (SWE), Pall Schumacher (D), SEP (SWE), TKE (DK), TPS (SWE), TUD (NL), University Bologna (IT), Valutec AB (FIN), Vaxjo Energy AB (SWE), Vaxjo Varnamo Biomass gasification Centre AB (SWE)
Term	09/2004 – 09/2009
Programme	EC FP6
Project no.	SES6-CT-2004-502587

Abstract

The aim of the Chrisgas-project is to demonstrate, within a 5 year period, the production of hydrogen-rich synthesis gas from biomass. The existing Varnamo gasification demo-plant will be used and modified for this purpose. This will be based on steam/oxygen-blown gasification of biomass, followed by hot gas clean-up to remove particulates, and steam reforming of tar and light hydrocarbons to further enhance the hydrogen yield. The hydrogen-rich syngas will be upgraded to liquid fuels, such as: DME, methanol, and FT-diesel. The success of Chrisgas therefore will pave the way for the next challenging stage – the demonstration of vehicle fuel production.



The Gasification Plant at Värnamo

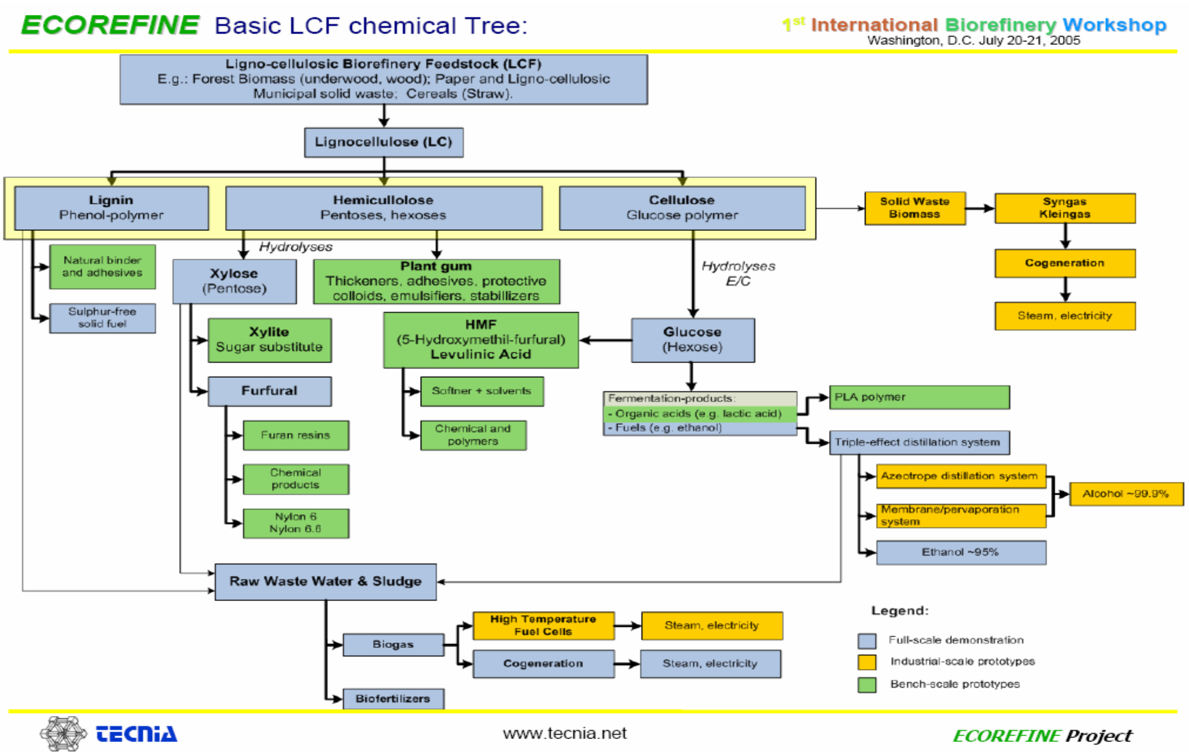
Ecorefine

Title	A European Integrated Biorefining Project for the use of Lignocellulosic feedstock (LCF) into the whole chain of downstream processes
Contractor	Tecnia
Contact person	António Ferreira
Phone no.	+351 261 912 470
E-mail	amcmf@tecnia.net
Website	www.tecnia.net
Partners	26 partners: industry, associations, research institutes and universities
Term	November 2004 -
Programme	EU
Project no.	Status unclear
Abstract	

The main objectives of the project are to:

- demonstrate innovative technologies to apply in industrial biorefining;
- build two or more complete industrial demonstration biorefineries (capacity from 10,000 – 30,000 tons LCF/year.

Additional objectives are: demonstrate the viability to deliver to the market; advanced energy recovery and uses; environmental sustainable industry; develop new agricultural opportunities.



EPOBIO

Title	EPOBIO - Realising the economic potential of sustainable resources - bioproducts from non-food crops
Contractor	Centre For Novel Agricultural Products (CNAP), Department of Biology
Contact person	Dianna BOWLES
Phone no.	+ 44 1904 328 770
E-mail	djb32@york.ac.uk
Website	www.epobio.net; www.biomatnet.org/secure/FP6/S1811.htm
Partners	British Sugar plc, United Kingdom; CPL Press, UK; Hamburg University, Germany; Max Planck Society for the Advancement of Research, Germany; Metabolic Explorer, France; National Helenic Research Foundation, Greece; Novamont SPA, Italy; Plant Research International, The Netherlands; Swedish University of Agricultural Sciences, Sweden; University of Lusanne, Switzerland; Plant Gene Expression Center, ARS-USDA, California; United States Department of Agriculture, ARS, Louisiana
Term	1 November 2005 - 31 October 2007
Programme	FP6-SSPE-CT-2005
Project no.	022681
Abstract	

EPOBIO is an international project funded through the European Union's Sixth Framework Programme (FP6) to realise the economic potential of plant-derived raw materials. The EPOBIO objective is to design new generations of bio-based products derived from plant raw materials that will reach the market place 10-15 years from now.

An integrated analysis of technical and non-technical barriers facing non-food applications was performed so that further RTD effort is not wasted, but is focused on those areas with a high possibility of success, with social, economic and environmental benefits and contributing to mitigation of greenhouse gases. The integrated multidisciplinary analysis has reviewed scientific and technical challenges in the context of societal expectations and economic, environmental legislative and regulatory parameters. It will result in recommendations of key activities (Flagship Programmes) that are most likely to result in development of products/ applications that can be developed from agriculture and forestry and provide tangible societal benefit by 2020.

EUROLIGNIN

Title	Co-ordination network for lignin-standardisation, production and applications adapted to market requirements (EUROLIGNIN)
Contractor	WUR - Agrotechnology and Food Sciences Group
Contact person	Richard Gosselink
Phone no.	+ 31 317 475347
E-mail	Richard.gosselink@wur.nl
Website	www.ili-lignin.com
Partners	26 partners, including lignin producers, research centres, universities and lignin end users from 16 European Countries
Term	August 2002 – July 2005
Programme	EU-FP5
Project no.	G1RT-CT-2002-05088

Abstract

The major goal of this project was to accelerate the introduction of sustainable, high-value, lignin-based raw materials derived form leftovers in pulp and paper, and biomass processes to industry and consumers (Gosselink, et al., 2004). Extensive state-of-the-art information on lignin production, characterisation and utilisation has been assessed and reports and a bibliography are available through The International Lignin Institute (ILI). The market demand for natural, non-toxic, multifunctional materials as lignin is increasing due to environmental concerns, specific structural properties, interest in transportation biofuels and high oil prices. Results from this network showed that lignin has potential in identified added-value applications. For example as chemical resource, in adhesives and as food or polymer additive. Critical points have been addressed for these applications like the need for improved reactivity and more extensive structural-property characterisation of technical lignins.

Lignin characterisation is one of the issues that needed standardisation for lignin to become adapted as a future resource for a broader range of applications. Within EUROLIGNIN a number of protocols have been identified and 10 have been evaluated in more detail by 3 organised Round Robins. Established protocols and standard lignins for reference purposes are available now and can be supplied by ILI. ILI will further coordinate future activities for improvement and standardisation of a larger number of protocols (norms).

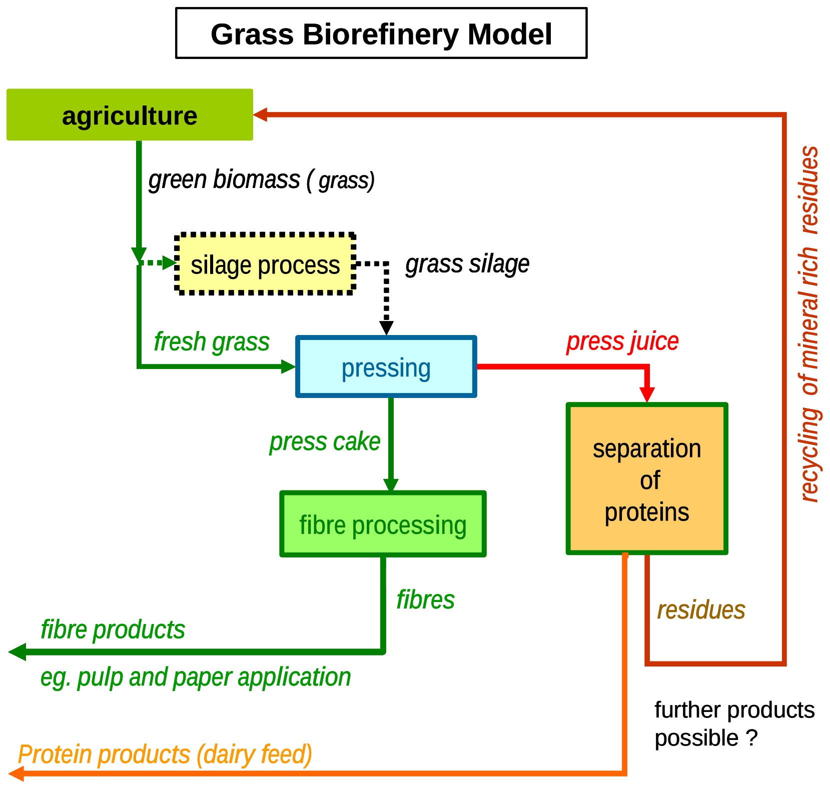
Network partners concluded that continuation of this network is necessary in order to make lignin one of the future resources world-wide. In a second network participation of more industrial partners representing the whole chain from supply to end-use is strongly advised.

Green Biorefinery

Title	Green Biorefinery: Technical, economic and ecological optimisation of value chains by the introduction and efficient use of sustainable raw materials
Contractor	Joanneum Research Forschungsges mbH (AT)
Contact person	Michael Mandl
Phone no.	+43-316-876-2953
E-mail	Michael.mandl@joanneum.at
Website	www.joanneum.at; www.bumaga.nl; www.afsg.nl
Partners	Okoplan Energiedienstleistungen GmbH (AT), OO Bioraffinerie GmbH (AT), Okoenergie Utzenaich (AT), Bumaga B.V. (NL), Agrotechnology and Food Innovations B.V. (NL)
Term	January 2008 – December 2009
Programme	EC SUSPRISE
Project no.	

Abstract

This project focuses on the development of an integrated Whole Crop Biorefinery concept for the conversion of fresh grass, silage, maize, and agricultural residues (a.o. sugar beet leaves) into a portfolio of value-added bio-based products. A schematic presentation of the grass case is shown below.



WaCheUp

Title	WaCheUp - New concepts for upgrading pulp mill waste streams to value-added chemicals
Contractor	STFI –Packforsk
Contact person	Peter Axegard
Phone no.	+ 46- 8 6767 221
E-mail	peter.axegard@stfi.se
Website	www.ili-lignin.com
Partners	VTT, Abo Akademi, University Aveiro, Lund University, Chalmers University, Amorin Florestal S.A.
Term	2005 – 2008
Programme	EU-FP6
Project no.	STREP – 13896
Abstract	

The objective of this 2.8 M€ project (2.0 M€ grant) is to upgrade low-value residual products from kraft pulp and cork manufacture into valorised green chemicals, with methods that can be efficiently integrated with the pulp/cork mills. Considerable residual streams become low-value heat at the mills with no practical use. This is a sub-utilisation of the potential of the chemicals in the residuals. Their broad spectrum of organic compounds could be processed to value-added chemical products, utilising the energy surplus of the wood/cork mills for the manufacture.

Expected innovations:

- New technologies for valorisation of pulp and cork mill waste without impairing overall energy economy or quality of the primary products.
- New value-added products from current low-value energy streams.
- Valorisation of polysaccharides in the black liquor through a new method that preserves the structure of the material for valorisation into paper additives, thickeners, food additives, emulsifiers and adsorbents.
- Chemical and biotechnical valorisation of bark/cork suberin (a natural polyester) and extractives hitherto undeveloped natural resources into green polymers, composites and specialty chemicals.

The whole value-chain is covered: Advanced methods for fractionation and purification of the raw materials, biotechnical and chemical valorisation and application potential. The sustainability of the industries is improved through better utilisation of the wood material, and decreased fossil fuel dependency and emissions of CO_2 may become possible.

Appendix F. Example Technology Roadmap Biorefinery Ingredients - Biofuels related

Source: the EU Technology Platform Biofuels (2007)

i) Short term (up to year 2013)

- Market analysis on current and future types, volumes and prices of value-added materials and/or chemicals to be co-produced with biofuels to increase their market competitiveness
- Identification and lab-scale production of most promising platform and functionalised bio-based chemicals that can be applied in the existing petrochemical infrastructure
- Optimisation current biofuel production processes by full integration of composing processes (a.o. fermentation, digestion and thermochemical conversion processes)
- Valorisation of by-products of conventional biofuels (biodiesel and bioethanol)
- Alternative lignin applications
- Lab-scale development of innovative biomass pre-treatment processes for the upstream separation of value-added products (primary biorefinery)
- Lab-scale development of advanced (catalytic) biochemical and thermochemical conversion processes (a.o. fermentation, pyrolysis, staged gasification, hydro thermal conversion, …)
- Lab-scale development and integration of innovative high-efficient and low cost product separation and upgrading processes
- Lab-scale development bio-based catalytic processes
- Proof-of-Concept (PoC) of upgraded industrial infrastructures (a.o. Oil Biorefineries)
- Proof-of-Principle (PoP) new biorefinery concepts with focus on: i) large-scale central biorefinery processes using domestic and imported crops, ii) small-scale decentral biorefinery processes using organic residues and/or crops, and ii) combinations of small-scale decentral primary biorefinery with large-scale central secondary biorefineries.
- Development and application of LCA methodology for integrated biorefineries
- Full chain assessment of integrated biorefinery concepts to identify: i) most promising chains and ii) white spots requiring additional RTD, and to show the advantage of the biorefinery approach over production processes concentrating on the production of a single product
- Analysis and development of full biomass supply chains, i.e. biomass production till product end-use, incl. logistical aspects

ii) Medium term (2013 – 2020)

- Development of new land and marine crops specially applicable for biorefinery purposes (concentration of desired components)
- Identification and lab-scale production of most promising platform and functionalised bio-based chemicals on which a new bio-based chemical sector could be build (sugar chemistry, oleochemistry, amino acid chemistry, …)
- Development new synthesis pathways to convert platform and functionalised chemicals into marketable end-products
- Proof-of-Concept (PoC) of new biorefinery concepts (building and running of pilot-plants)
- Proof-of-Feasibility (PoF) and commercial implementation upgraded industrial infrastructures

iii) Long term (2020 – 2030)

- Proof-of-Feasibility (PoF) and implementation new biorefinery concepts (building and running of demonstration plants) followed by commercial market implementation