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Final Deliverables D3total, D6.3.1 and D6.6

Biorefinery-based Knowledge Import

from outside the EC (D3total and D6.3.1) international co-operation (D6.6)

Agrotechnology and Food Innovations B.V. (A&F)
ABNT
VTT
Aston

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Dissemination level

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

Preface and Reading Advice

This report describes the results of the Knowledge Import activities – both from outside the EC (D3total and D6.3.1) and from International Co-operation (D6.6) – to the Bioref-Integ Project. This knowledge will be used on the one hand to provide info for upgrading of the reference-case biofuel production processes to integrated biorefinery facilities producing both fuels and bio-based products (materials, chemicals, ...), and on the other hand to give the EC an overview on the technical state-of-the-art of biorefinery facilities in and outside Europe.

Chapter 1. describes developments in Advanced Biorefinery Schemes occurring (mainly) outside the EC (Task 3.1). These developments are grouped around the following main types of biorefineries:

- Green Biorefineries – Fibre Platform
- Oil Crop Biorefineries
- Lignocellulosic Feedstock Biorefineries
    - Biochemical Pathway – Sugar Platform
    - Thermochemical Pathway – Syngas Platform
    - Lignin Platform
- Marine Biorefineries
    - Micro Algae
    - Macro Algae / Seaweeds

Chapter 2. gives an overview of Biorefinery issues dealt with within the International Energy Agency (IEA) Bioenergy Programme (Task 3.2).

In Chapter 3. the results of an internal workshop are summarized in which some key stakeholders from outside the EC (Japan, US. ....) gave their views on biorefinery developments within their specific countries (Tasks 3.3/6.3).

In Chapter 4. “International Co-operation” main data are shown on biorefinery-relevant developments within the EC, viz.: European Technology Platforms (Plants for the Future TP, Biofuels TP SUSCHEM TP, Forest-Based Sector TP) Fuel Cells and Hydrogen JTI, European Road Transport Advisory Council, European Algae Biomass Association, Network-of-Excellence (NoE) Bioenergy, and a variety of FP6 and FP7 projects.

In Chapter 5. the information gathered within chapters 1 – 4 is structured around the specific market sectors (bioethanol sector, biodiesel sector, pulp/paper sector, oil refinery sector, power production sector, food industry sector, agrosector) dealt with within this Bioref-Integ project. In this chapter project partners can find relevant info for their market specific activities. Specifically, info is shown for upgrading of their reference-case biofuel plants to integrated biorefinery facilities.

Content

1. Advanced Biorefinery Schemes (Task 3.1)

Knowledge-import from outside the EC

A&F, ABNT, VTT, Aston

1.1 Introduction and Methodology

The objective of Bioref-Integ's Task 3.1 is to conduct an analysis of the publicly available material on biorefinery activities *outside the EU*. Information has been collected from conferences, seminars, workshop proceedings, and websites. The information collected is organised for the following biorefinery concepts:

- Green Biorefinery issues
    - fibre platform
    - protein platform
- Oil Crop Biorefinery issues
- Lignocellulosic Feedstock Biorefinery issues
    - biochemical pathway / sugar platform
    - thermochemical pathway / syngas platform
    - lignin platform
- Marine Biorefinery issues
    - Microalgae
    - Macroalgae / seaweeds

Within each section, the initiatives are described in alphabetical order of the lead participant.

The dissemination of results from biomass conversion technology research and development activities in the US is done for a significant part through the channels of national and regional programs. A leading program in the US to balance the portfolio of research in biomass conversion technologies, for instance, is the Biomass Program of the US Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy (EERE). Results found through such program channels have been addressed throughout chapter 1, together with other results found for the lead participant of the activities. For additional information, a general description of the Biomass Program is presented in Appendix C, the partners have been summarized in Appendix D.

1.2 Green Biorefinery issues

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 1). 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 [1]. 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 level of the biomass raw materials as they are currently processed is still low. Simple base technologies can be used and pass a good biotechnical and chemical potential for further conversions.

[1] Van Ree, R. & Annevelink, E., Status Report Biorefinery 2007, Wageningen UR – AFSG report 847.

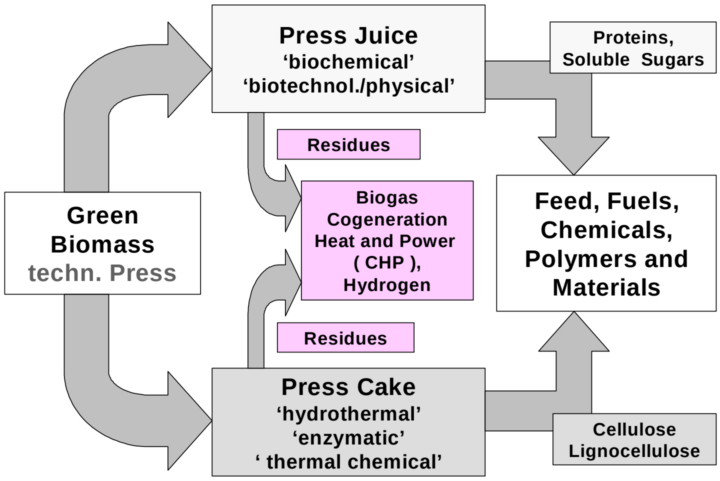

Figure 1 Green Biorefinery [2].

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 2).

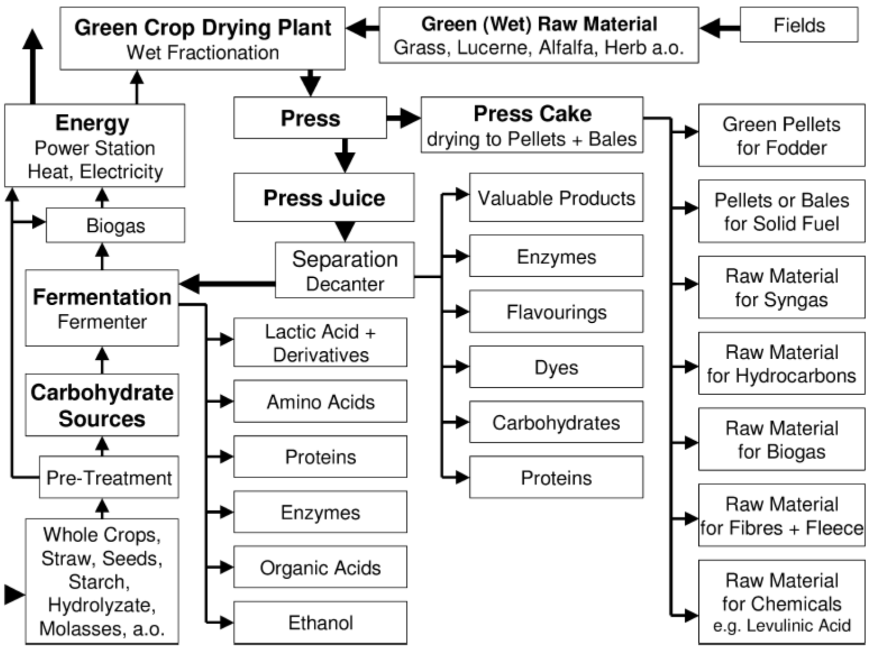

Figure 2 Potential products from a Green Biorefinery (dry milling) [3].

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[2] Kamm, B., P.R. Gruber & M. Kamm (eds), 2006. Biorefineries – Industrial Processes and Products, edited by, Wiley-VCH, ISBN: 3-527-31027-4, Weinheim, Germany.

[3] Kamm, B., P.R. Gruber & M. Kamm (eds), 2006. Biorefineries – Industrial Processes and Products, edited by, Wiley-VCH, ISBN: 3-527-31027-4, Weinheim, Germany.

Specifically within the EC (Austria, the Netherlands, Ireland, Germany, Switzerland) a lot of effort is put in the development, piloting, demonstration, and implementation of the Green Biorefinery concept for the conversion of grasses and other wet organic residues (sugar beet leaves, ...) into a spectrum of biobased products and bioenergy. Outside the EC no information has been found concerning this specific Biorefinery concept.

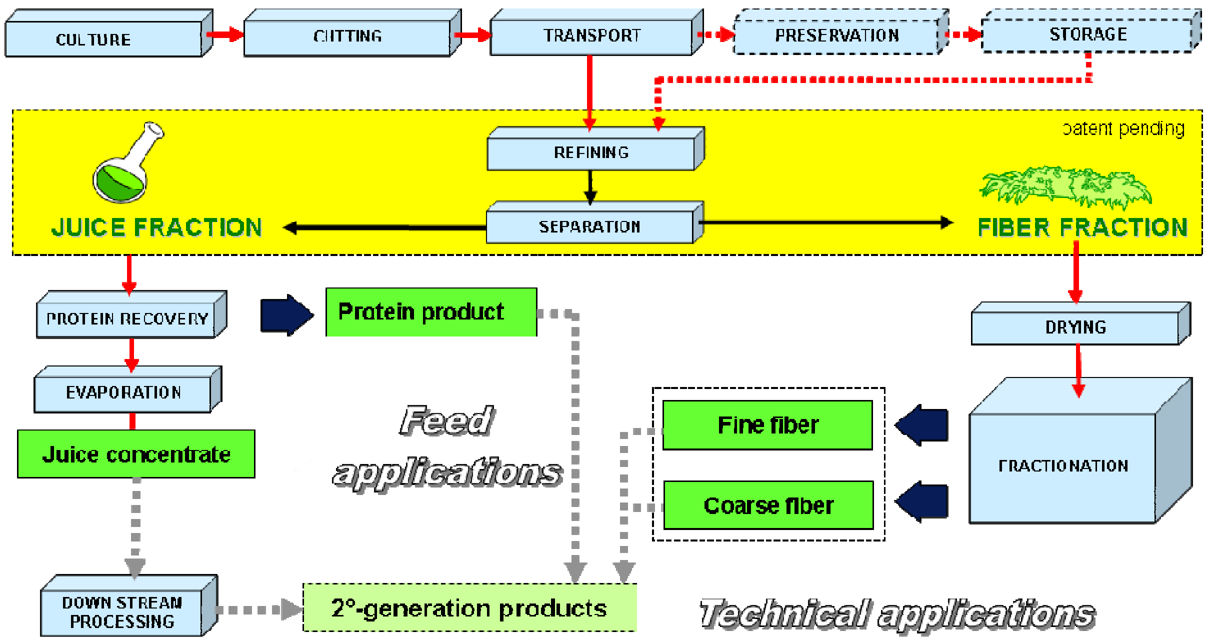

Figure 3 Green Biorefinery concept as being developed in the NL.

Table 1 Current Status Green Biorefineries in the EC.

Country	Current status	Products	Remarks
Austria	Pilot plant Utzenaich started-up in Q4 2009	Lactic acid, amino acids, biogas	LA + AA separation out of silage juice; fibres to biogas
The Netherlands	Avebe pilot-plant closed. New conventional Grassa demo-plant running. New advanced pilot-plant planned (WUR)	Proteins, ethanol, biogas, fibres for a variety of applications	Juice-derived proteins (amino acids), ethanol, biogas; Cake-derived fibres (pulp/paper, insulation material, ..)
Ireland	Demo plant	Biogas and insulation materials	Current status ?
Germany	Pilot plant in Brandenburg Demo plant "Biowert"	Lactic acid Biogas, feed , fibre	Fermentation of fresh green juice +starch hydrolysis Mainly biogas
Switzerland	Demo plant	Grass fibre insulation product, biogas and feed options	Commercial business for insulation material; biogas and feed not jet fully integrated.

1.3 Oil Crop Biorefinery issues

In conventional biodiesel production processes, oil-rich crops and/or residual plant oils animal fats are used. Oil crops are crushed producing an oil-rich fraction and a press-cake. The oil-rich fraction is catalytically converted into biodiesel with the use of methanol (transesterification); whereas the pr4ess-cake is sold as animal feed.

Free fatty acids contaminate the base catalyst that is used for conventional biodiesel production. In pure vegetable oils, only a very small fraction of free fatty acids is present. In animal fat and residual oils from for example restaurants much larger quantities are available. Ames Laboratory (Ames, IA, US)[4] has developed an acid catalyst that can convert animal fat and restaurant oils into a fatty acid free oil, which can be converted into biodiesel by transesterification using conventional biodiesel synthesis[5]. This technology is commercialized by Catilin Inc. (Ames, IA, US)[6], founded by the inventor of the material, Victor Lin. The catalyst with channels of less than 1 nm diameter can be operated at standard conditions currently used by alkaline biodiesel processes, however, it is not sensitive to free fatty acids. The catalyst is in granular form and can be used in existing plants using the same reactor configuration (Figure 44). The first stage reactor effluent, which will contain unconverted oil, products and catalyst, enters a separator where the catalyst is removed and recycled to the reactor. The catalyst free stream enters a second reactor system, where the reaction to methyl esters is completed. The second stage reactor effluent is then routed to a second stage separator section, where the catalyst is recycled, and products are separated and the biodiesel is treated in a single stage system to produce ASTM/EN specification biodiesel. Also see WO patent 2008/013551 and WP patent 2008/0021232 A1.

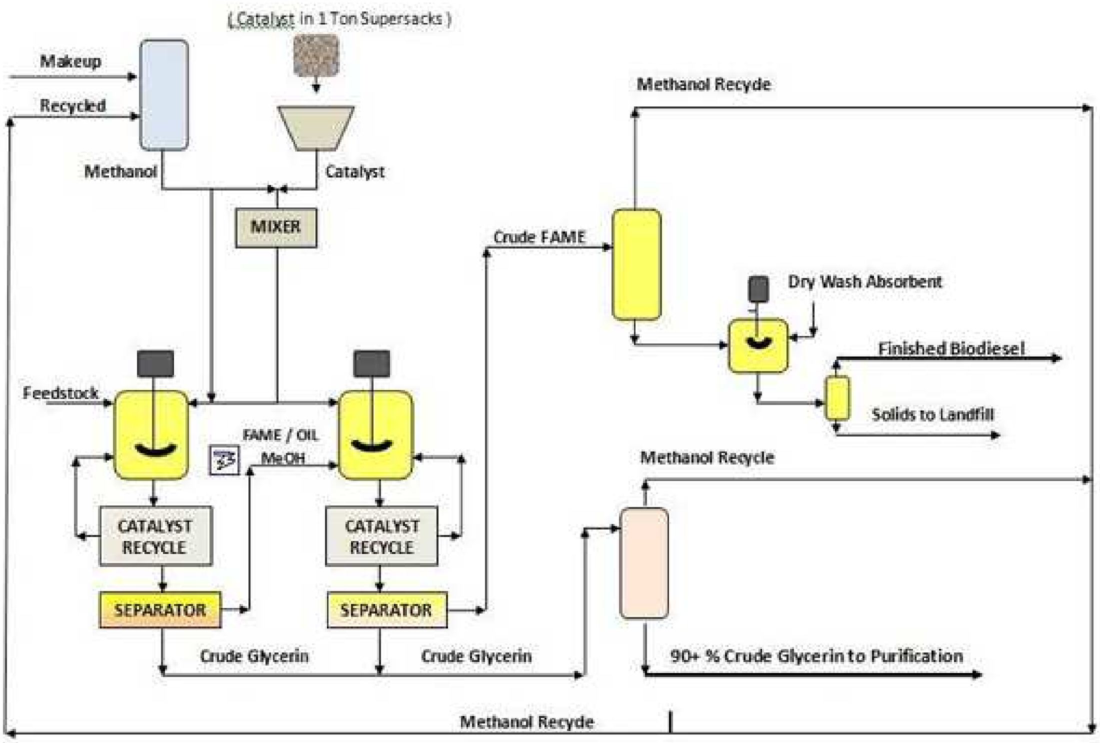

Figure 4 Typical process flow diagram using Catalin catalyst.

4 http://www.ameslab.gov/, visited 17 July 2009
5 http://www.york.ac.uk/res/gcrn/presentations/George%20Kraus%20-%20Iowa%20State%20University,%20US.pdf, visited 17 July 2009
6 http://www.catilin.com/, visited 17 July 2009

Also, Ames Laboratory has developed a process to convert glycerol, a by-product of biodiesel production, by using ionic hydrogenation in similar porous structures into 1,3-Propanol, which is used in DuPont's Sorona polymer[7].

Australian Renewable Fuels (ARF, Perth, Australia)[8] is currently producing biodiesel at two plants, one in Adelaide and one in Picton. ARF is now in its third year of operation. The technology used is the proven Energea process (Austria)[9], and each plant can produce 44.5 million litres of bio-diesel per year using low-grade tallow. By-products include 4,000 tonnes of raw glycerine and 1,200 tonnes per annum of sulphate of potash fertilizer in paste form. ARF has an exclusive five-year feedstock (fat or tallow) supply agreement with Gardner Smith[10], Australia's market leader for the delivery and storage of fats. ARF is evaluating the potential of an oilseed crop and oil production from algae.

ARF was announced to have made a 50/50 joint venture with Transpacific Industries Group (Milton, Australia)[11] to develop a 45 ML biodiesel production facility in Brisbane based on used cooking oil[12]. This initiative is not found back at their websites currently, however. Transpacifics philosophy is that all waste is a resource and aims to incorporate recovery, recycling and reuse throughout all its operations. The company has collection services, material recovery facilities, waste transfer stations and landfill sites to provide a holistic waste management solution. The company collects, treats and reuses: used cooking oils and fats, from restaurants, fast food chains, shopping centres and food manufacturing facilities.
In the same announcement, Natural Fuel Australia[13] was mentioned to have acquired a mobile biodiesel facility at engineering firm AGC [14] for its $45 million biodiesel facility in Darwin. Natural Fuel Australia was placed under administration in September 2008 however[15].

Also see BP biorefinery activities in Australia described in section 0 which uses vegetable oil, next to animal fats.

Researchers at Chiang Mai University (Chiang Mai, Vietnam) study ethanolysis of soybean oil into biodiesel using sodium hydroxide as catalyst[16].

At Clemson University (Clemson, SC, US) ethanolysis of cottonseed oil into biodiesel high in gossypol content is being studied using potasium hydroxide as catalyst[17]. Gossypol is known to have antioxidant properties that may potentially increase the shelf life of the oil and biodiesel.

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7 http://www.york.ac.uk/res/gcrn/presentations/George%20Kraus%20-%20Iowa%20State%20University,%20US.pdf, visited 17 July 2009
8 http://www.arfuels.com.au/, visited 20 July 2009
9 http://www.energea.at/en_info.html, visited 20 July 2009
10 http://www.gardnersmith.com/, visited 20 July 2009
11 http://www.transpacific.com.au/TPI/index.php, visited 20 July 2009
12 http://www.bioenergy.org.nz/documents/newsletters/2006/BANZ_issue42_Apr06.pdf, visited 20 July 2009
13 www.naturalfuel.com.au, visited 20 July 2009
14 http://www.ausclad.com.au, visited 20 July 2009
15 http://www.theaustralian.news.com.au/story/0,25197,24384032-5005200,00.html, visited 20 July 2009
16 N. Tippayawong et al., Ethanolysis of Soybean Oil into Biodiesel: Process Optimization via Central Composite Design, Journal of Mechanical Science and Technology, 19 (10), 2005, 1902-1909
17 H.Ch. Joshi, J. Toler, T. Walker, Optimization of Cottonseed Oil Ethanolysis to Produce Biodiesel High in Gossypol Content, J Am Oil Chem Soc, 85, 2008, 357-363

Dow Chemical Company (Midland, MI, US) [18], Castor Oil Inc. (Plainview, TX, US) [19], and the USDA Western Regional Research Center have performed a project on the "development of improved chemicals and plastics from oilseeds" in order to develop technology that can be applied to the production of various chemicals and plastics from seed oils[20]. The consortium has developed catalysts and processes for converting various oil seeds to monomers for use in commercial formulations of plastics, foams, and industrial coatings. Dow also has developed Renuva ™ soybean oil based polyols for polyurethane materials[21].

Gushan Environmental Energy is the largest biodiesel producer in China[22]. The Company currently operates five production facilities in Mianyang in the Sichuan province, Handan in Hebei province, Fuzhou in Fujian province, and in Beijing and Shanghai with a combined annual production capacity of 340,000 tons[23]. The company produces biodiesel primarily from vegetable oil waste and used cooking oil. The by-products include glycerine, plant asphalt, erucic acid, erucic amide, and stearic acid. Gushan sells biodiesel directly to users, such as marine vessel operators, as well as to petroleum wholesalers and individual retail gas stations. Gushan targets to increase its annual production capacity to 400,000 tons with the expansion or addition of new production facilities in Beijing, Shanghai, Hunan and Chongqing.

Iowa State University is performing research on soybean oil based resins and composites [24].

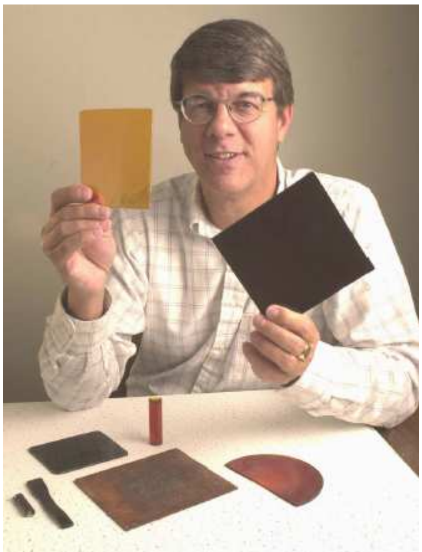


Figure 5 Researcher of Iowa State University showing samples of soybean oil based resin.

In Vietnam, the Institute of Tropical Biology has produced biodiesel from sesame oil from wild trees [25]. Sesame belongs to the Euphorbiacea family and is widely distributed in Africa, North America and the Caribbean. This perennial tree can grow up to 5 meters high and blossoms all the year round, especially in the rainy season.

18 http://www.dow.com/, visited 16 July 2009.
19 http://castoroilinc.com/, visited 16 July 2009.
20 http://www1.eere.energy.gov/biomass/program_achievements.html
21 http://www.dow.com/PublishedLiterature/dh_016b/0901b8038016bce3.pdf?filepath=renuva/pdfs/noreg/793-00007.pdf&fromPage=GetDoc, visited 16 July 2009.
22 http://www.chinagushan.com/en/ , visited 13 July 2009
23 http://www.chinagushan.com/en/archives/2009/06/15173014.htm, visited 13 July 2009
24 http://www.bioeconomyconference.org/images/Larock,%20Richard.pdf, visited 17 July 2009
25 http://www.thebioenergysite.com/news/624/vietnam-extracts-biodiesel-from-sesame, visited 13 July 2009

Oil is extracted from its seeds (containing 31-37% oil). The Institute's Cell Technology Department also has suggested that waste from the extraction process provides material to produce organic fertilizer and pesticides.

Researchers at the Universidade Federal de Alagoas (Maceió, Alagoas, Brazil) study the ethanolysis of castor and cottonseed oil into FAEE [26].

1.4 Lignocellulosic Feedstock Biorefinery issues

1.4.1 Introduction

This type of biorefinery is based on the fractionation of lignocellulosic-rich biomass sources (a.o. wood, straw) into the major intermediate output streams cellulose, hemicellulose and lignin (Figure 66), which can then be further processed into a portfolio of bio-based end-products, materials, chemicals, fuels and power and/or heat (07). These bio-based products will have a good position on both traditional petrochemical and 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 competes 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 [27].

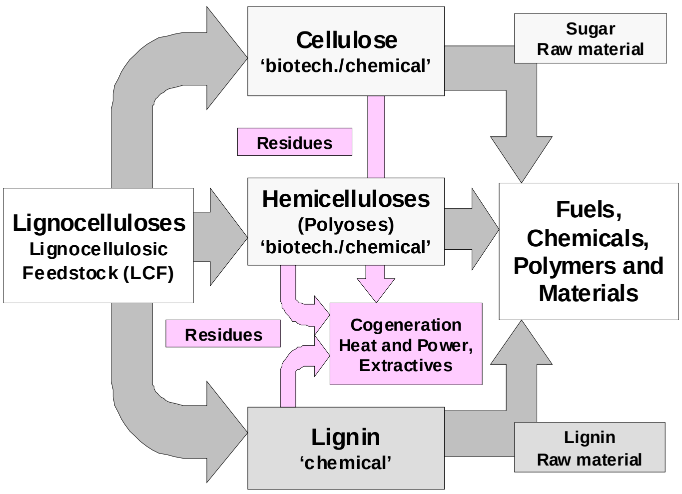
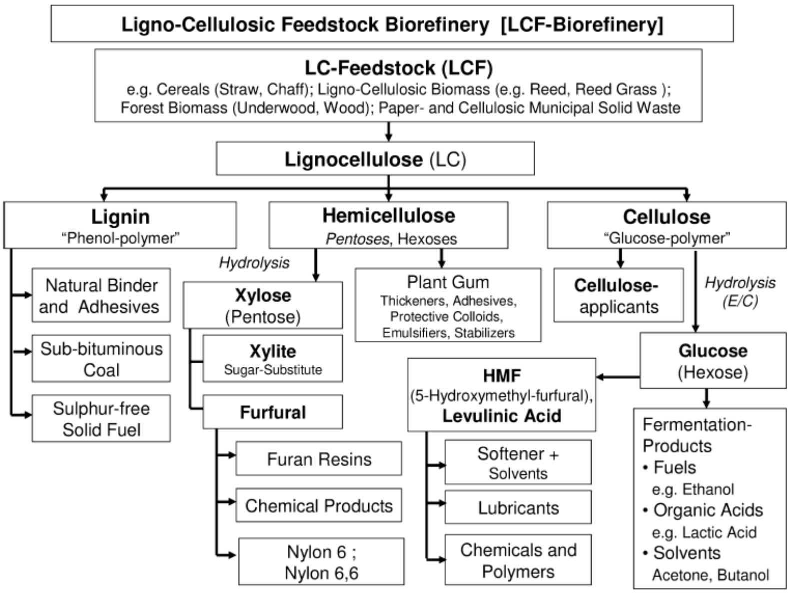


Figure 6 Lignocellulosic Feedstock Biorefinery [28].

[26] S.M. Plentz Meneghetti, et al., Ethanolysis of Castor and Cottonseed Oil: A systematic study using classical catalysts, JAOCS, 83 (9), 2006, 819-822

[27] Van Ree, R. & Annevelink, E., Status Report Biorefinery 2007, Wageningen UR – AFSG report 847.

[28] Kamm, B., P.R. Gruber & M. Kamm (eds), 2006. Biorefineries – Industrial Processes and Products, edited by, Wiley-VCH, ISBN: 3-527-31027-4, Weinheim, Germany.



Potential products from a Lignocellulosic Feedstock Biorefinery [29].

1.4.2 Biochemical pathway / sugar platform

Abengoa Bioenergy (Hugoton, KS, US) plans commercial scale biorefinery for production of 11.4 million gallons of ethanol annually, using 700 tons per day of corn stover, wheat straw, switchgrass, and other feedstocks [30].

Amyris Biotechnologies (Emeryville, CA, US) had developed a technology that makes it possible to alter the metabolic pathways of microorganisms such as yeasts, thus creating living factories that produce molecules with practical applications [31]. The company claims that it can now reprogramme microorganisms and test their ability to produce desired molecules in days to weeks. Its proprietary technology transforms plant-based feedstocks, such as sugarcane, into 50,000 different molecules used in a wide variety of energy, pharmaceutical, and chemical applications. The company says it uses yeast because it would be more scalable than for instance the E. coli bacteria. The science was originally validated through the development and scale-up of a much-needed anti-malaria treatment. The modified yeast can make biodiesel from sugar cane, but also from cellulosic biomass. Amyris has opened a first pilot plant in September 2008 and intends to bring the biodiesel to market in 2010, which is foreseen to take off in Brazil and the company claims it can be blended up to 50% with petroleum sourced diesel. In Brazil, Amyris is cooperating with Crystalsev Biofuels, one of Brazil's largest ethanol distributors and marketers.

The BEM Programme (Biomass—Energy—Materials) in Brazil was conceived with the objectives of maximizing the recuperation of energy from biomass, competing economically with hydroelectric and fossil fuels, and respecting all ecological requirements [32]. A critical screening indicated that prehydrolysis of biomass (digestion of hemicellulose and amorphous cellulose) fulfilled all the above items.

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29 Kamm, B., P.R. Gruber & M. Kamm (eds), 2006. Biorefineries – Industrial Processes and Products, edited by, Wiley-VCH, ISBN: 3-527-31027-4, Weinheim, Germany.
30 http://www.energy.gov/news/4827.htm
31 http://www.amyrisbiotech.com/, visited 10 July 2009
32 http://www.p2pays.org/ref/17/16274/pinatti.pdf, visited 17 July 2009

A prehydrolysis reactor was made of 10-mm high-strength low-alloy carbon steel lined with a 2-mm titanium sheet, which allowed it to be mobilized and being brought to the source of biomass and eliminating cost of transportation. At the same time, the BEM Programme eliminates the expenses of fertilisation (by returning the nutrients from the process to the field. The process is as follows: A vacuum is maintained between the steel vessel and the titanium (0.1 mm Hg) which avoids implosion and allows sporadic helium leak detection of the lining. Because of this characteristic the technology has been named a “fail-safe reactor”. The feeding device compact the biomass up to 300 kg/m3 thus allowing it to work with a liquid/solid (L/S) ratio of 2, decreasing considerably the process energy consumption. It is a batch process composed of the following steps: feeding (15 min), degassing and flooding (15 min), heating (30 min), prehydrolysis (15 min), discharge of prehydrolysate (10 min), and discharge of cellulignin (5 min).
Energy is recovered in the discharge of the prehydrolysate. The crystallinity of cellulose is maintained to allow grinding below 250 mm of particle size and drying with low energy consumption (12 kWh/t from the chimney heat lost at 125℃ in the thermoelectric plant). Two products emerge from the prehydrolysis: catalytic cellulignin and prehydrolysate. The first is used as fuel [catalytic cellulignin fuel (CCF)] and as the food energy component for animal feed. The second is used for production of chemicals from biomass (furfural, ethanol and xylitol). Water from cellulignin washing meets the internal water specification after conventional simplified water treatment. It is recycled and not discharged to the environment. In fact, the technology of the BEM Programme does not discharge any residues to the environment solid, liquid, or gaseous. One of the materials obtained from the BEM technology is submicron/nanometric inorganic powder. Pinatti et al. have shown that the ashes of organic matter of municipal solid waste exhibits higher reinforcing effects in red clay than feldspar [33].

BlueFire Ethanol Fuels Inc. (Corona, CA, US) was established to deploy a patented Concentrated Acid Hydrolysis Technology Process for the conversion of cellulosic ("Green Waste") waste materials to ethanol, and other viable alternatives to petroleum derived fuels (Figure 78) [34] [35]. The biomass that can be used includes agricultural residues (straws, corn stalks and cobs, bagasse, cotton gin trash, palm oil wastes, etc.), so called energy crops (grasses, sweet sorghum, fast growing trees, etc.), paper (recycled newspaper, paper mill sludge, sorted municipal solid waste, etc.), wood wastes (prunings, chips, sawdust, etc.), green wastes (leaves, grass clippings, vegetable and fruit wastes, etc.). The technology makes it an ideal “thermal host” for co-generation facilities. BlueFire claims to have solved the problems with the following proprietary improvements that now make the process economically viable [36]:

- efficient acid recovery and re-concentration
- high sugar concentration at high purity
- the ability to ferment C6 and C5 sugars efficiently with conventional microbes
- the ability to handle silica in biomass feedstocks
- all by-products are usable and marketable

[33] D.G. Pinatti et al., Large Scale Low Cost Production of Submicrometric Powder Through Biomass Refinery, Materials Research, 6 (3), 2003, 375-388.
[34] http://bluefireethanol.com/
[35] WO patent 94/23071
[36] http://bluefireethanol.com/technology/

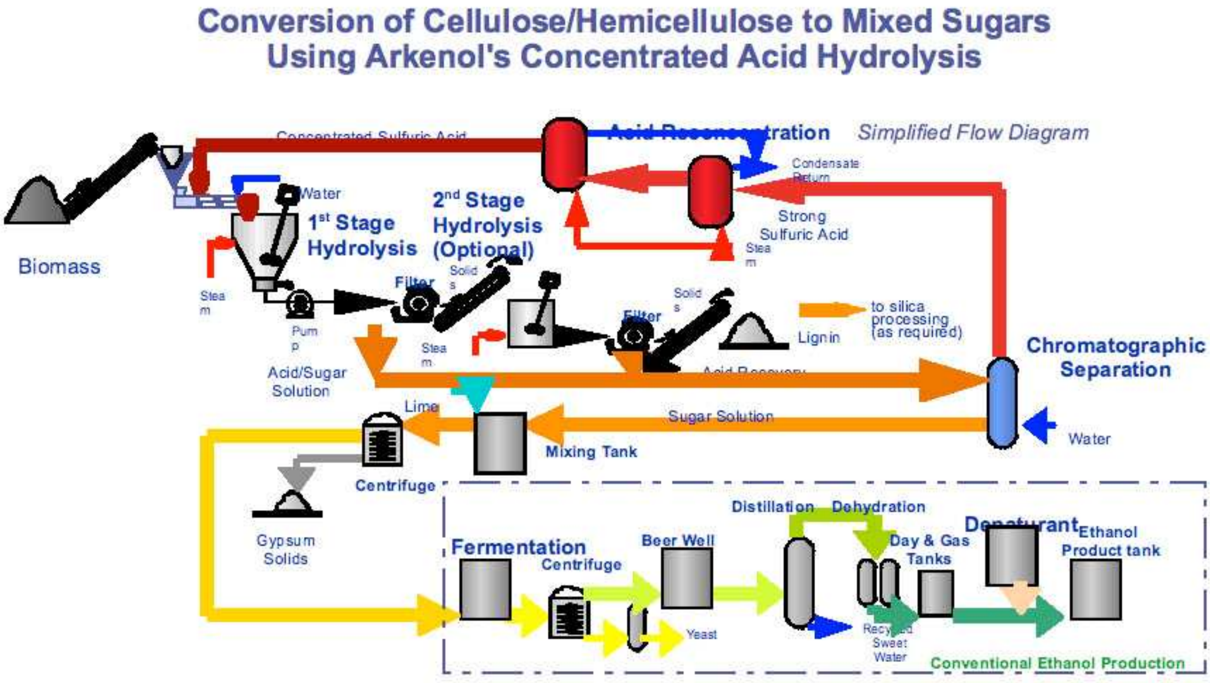

Figure 7 BlueFire process scheme for cellulosic ethanol production.

Simply put, the process separates the biomass into two main constituents: cellulose and hemicellulose (the main building blocks of plant life) and lignin (the "glue" that holds the building blocks together). Subsequently, it converts the cellulose and hemicellulose to sugars, ferments them and purifies the fermentation liquids into products.

An integrated, full-scale commercial process plant consists of six basic unit operations (Figure 7). If there is no power plant present from which to obtain steam, the production facility would use natural gas or lignin as fuel for its own boilers.

1. Feedstock preparation: Incoming biomass feedstocks are cleaned and ground to reduce the particle size for the process equipment.
2. Decrystallization/Hydrolysis: The pre-treated material is then dried to a moisture content consistent with the acid concentration requirements for decrystallization (separation of the cellulose and hemicellulose from the lignin), then hydrolyzed (degrading the chemical bonds of the cellulose) to produce hexose and pentose sugars at the high concentrations necessary for commercial fermentation.
3. Solids/Liquid filtration: Insoluble materials, principally the lignin portion of the biomass input, are separated from the hydrolysate by filtering and pressing and further processed into fuel or other beneficial uses.
4. Separation of acids and sugars: The remaining acid-sugar solution is separated into its acid and sugar components by means of chromatographic separation. The Company-developed technology that uses commercially available ion exchange resins to separate the components without diluting the sugar. The separated sulphuric acid is recirculated and reconcentrated to the level required by the decrystallization and hydrolysis steps. The small quantity of acid left in the sugar solution is neutralized with lime to make hydrated gypsum, $CaSO_4 \cdot 2H_2O$, an insoluble precipitate which is readily separated from the sugar solution and which also has beneficial use as an agricultural soil conditioner. At this point the process has produced a clean stream of mixed sugars (both C6 and C5) for fermentation.

5. Fermentation of the sugars: In an ethanol production plant, naturally-occurring yeast, which BlueFire has specifically cultured by a proprietary method to ferment the mixed sugar stream, is mixed with nutrients and added to the sugar solution where it efficiently converts both the C6 and C5 sugars to fermentation beer (an ethanol, yeast and water mixture) and carbon dioxide.
6. Product purification: The yeast culture is separated from the fermentation beer by a centrifuge and returned to the fermentation tanks for reuse. Ethanol is separated from the now clear fermentation beer by conventional distillation technology, dehydrated to 200 proof [37] with conventional molecular sieve technology, and denatured with unleaded gasoline to produce the final fuel-grade ethanol product. The still bottoms, containing principally water and unfermented pentose sugar, is returned to the process for economic water use and for further conversion of the pentose sugars.

The company has constructed and operated a pilot plant near its Southern California offices for roughly five years. Since 2003, the Technology has been successfully used by an unrelated, independent, and internationally recognized corporation to produce ethanol for the Japanese transportation fuel market. More recently, BlueFire is one of four ethanol companies awarded funding from the U.S. Department of Energy to construct a commercial scale cellulosic ethanol production facility [38]. The proposed plant will be in Corona, CA, US, at an existing landfill and produce about 19 million gallons of ethanol per year. As feedstock the plant would use 700 tons per day of sorted green waste and wood waste from landfills [39]. Other investors/participants include Waste Management Inc., JGC Corporation, MECS Inc., NAES, and PetroDiamond. BlueFire suggests that biorefineries will be located in markets with the highest demand for renewable transportation fuels thereby dramatically reducing delivery costs while simultaneously increasing the areas biofuel supply and reducing the waste streams sent to landfills.

To give some idea of what a commercial stand-alone fuel-ethanol plant configuration would be, one can assume an available feedstock supply on a 330 days per year, twenty-four hours per day basis which has an average cellulosic content of 75%, having inputs and outputs as indicated in Table 2.

[37] Alcoholic proof is a measure of how much alcohol (i.e., ethanol) is contained in an alcoholic mixture. The measure is commonly used in the United States, where it is defined as twice the percentage of alcohol by volume, so 200 proof means 100% ethanol. (http://en.wikipedia.org/wiki/Alcoholic_proof)

[38] http://www.energy-net.org/IS/EN/NUKE/DOE/FED/07228240.TXT

[39] http://www.energy.gov/news/4827.htm

Table 2 Input and output data of commercial cellulosic ethanol plant.

Inputs	
Feedstock	454 dry tonnes per day
Sulfuric Acid	18 tonnes per day
Lime	3.6 tonnes per day
Electricity	4,000 kW
Steam	55,000 kg. per hour
Outputs	
Ethanol, 200 proof	159,000 litres per day
Carbon Dioxide	121 tonnes per day
Lignin (50% moisture)	365 tonnes per day
Gypsum (40% moisture)	30 tonnes per day
Yeast (80% moisture)	55 tonnes per day

Typically, yeast would be grown at the site. Water usage would be minimal because of complete recycling of the water contained in the incoming materials. Such a plant would utilize approximately five hectares (twelve acres) for the process itself; feedstock intake, preparation and short-term storage (five days); product off-load facilities; CO_2 processing; administration and laboratory buildings. The plant is designed on a zero-discharge basis and normally uses public sewers only for sanitary purposes. A standalone plant would use lignin or natural gas to fire its boilers and therefore will require air permits for the boiler exhaust. Note that a plant sited next to a cogeneration facility and using steam from the power plant would have no combustion emissions whatsoever. Volatile organic chemical ("VOC") emissions of ethanol are readily contained by closed fermentation tanks, closed top storage tanks, and vapour recovery transfer systems. In the United States, the only other permits in addition to those for construction and general operations would be those required by the US Treasury Department for the production and storage of alcohol.

BP and Verenium have formed a 50:50 joint venture company to develop and commercialize cellulosic ethanol from non food and food feedstocks, initially focussing on grasses, energy cane (a variety of sugar cane with higher crop yields), and sugar cane [40]. The US $ 250-300 million plant will be based on Verenium's proprietary technology [41] which enables conversion of nearly all the sugars found in cellulosic biomass into ethanol and is estimated to produce about 36 million gallon of ethanol/year from 2012 [42].

BP has established a 10-year partnership with the University of California at Berkeley and the Lawrence Berkeley National Laboratory to form the Energy Biosciences Institute (EBI).

[40] http://www.bp.com/sectiongenericarticle.do?categoryId=9025113&contentId=7046637, visited 6 July 2009

[41] For details of Vereniums technology, see further on in this section.

[42] http://www.bp.com/liveassets/bp_internet/globalbp/STAGING/global_assets/e_s_assets/downloads/bp_verenium_joint_venturer_revolution_fact_sheet_final.pdf, visited 6 July 2009

Also, the University of Illinois at Urbana-Campaign (UIUC) has established a partnership with EBI. BP also collaborates with Princeton University [43].

Cargill (Minneapolis, MN, US) is active in biodiesel and ethanol production [44]. Further, the company produces specialty starches for paper making and adhesives, xanthan gum based emulsifiers for oil drilling, vegetable based oils and additives for the paint and coating industry, soy based BiOH ® polyols for polyurethane foams [45] [46].
Cargill is also developing a building block, 3-hydroxypropionic acid, a platform intermediate that can be produced at a theoretical yield of 100% from glucose [47] [48]. By integrating fermentation with chemical processing, this novel intermediate can then be cost-effectively used to make other commercially valuable chemicals such as 1,3-propanediol, acrylic acid, malonic acid, and acrylamide (Figure 89). Building on metabolic pathways developed by Cargill, Codexis and PNNL were involved to enhance the production of 3-hydroxypropionic acid from carbohydrate raw materials [49] [50]. In 2008, Cargill and enzymes producer Novozymes announced their joint development of the production technology for acrylic acid via 3-hydroxypropionic acid [51]. 1,3-Propanediol is a precursor for the production of DuPont's Sorona polymer (Figure 910).

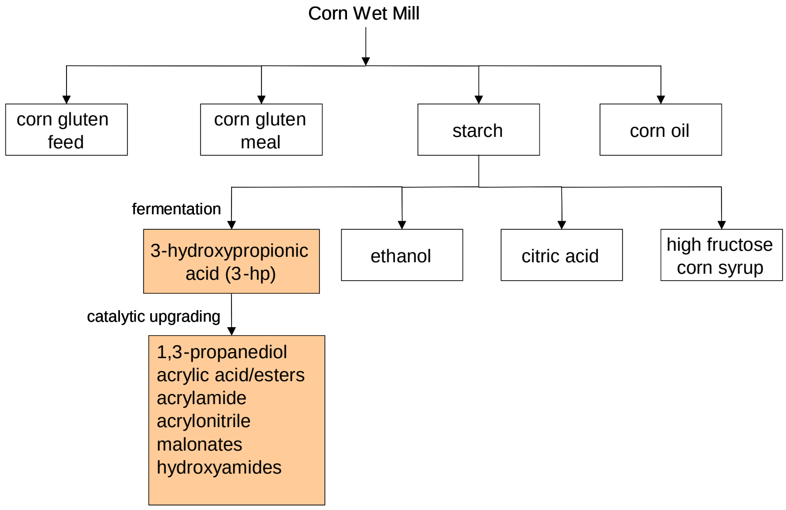

Figure 8 Scheme for production and use of 3-hydroxypropionic acid platform intermediate.

43 http://www.bp.com/genericarticle.do?categoryId=98&contentId=7048506, visited 6 July 2009
44 http://www.cargill.com/products/energy-fuels/biofuels/index.jsp, visited 20 July 2009
45 http://www.cargill.com/products/industrial/index.jsp, visited 20 July 2009
46 http://www.agwest.sk.ca/events/plantbio-oils-06/Tues-presentations/Millis.pdf, visited 20 July 2009
47 http://www.nrel.gov/ce/biotechsymp25/docs/abst5-03.doc, visited 23 July 2009
48 Cargill, WO patent 2004/076398 A1, Process for preparing 3-hydroxycarboxylic acids
49 http://www.codexis.com/wt/page/pr_1167772618, visited 23 July 2009
50 http://www.wisbiorefine.org/prod/3acid.pdf, visited 23 July 2009
51 http://www.highbeam.com/doc/1G1-174818814.html, visited 23 July 2009

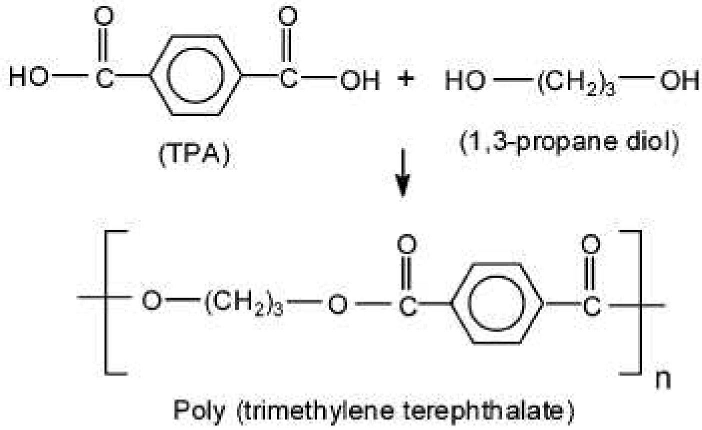

Figure 9 Reaction scheme for production of PTT (Sorona) from 1,3-propanediol.

As part of Chevron's strategy to invest in renewable energy technologies, it has formed a business unit to advance technology and pursue commercial opportunities related to the production and distribution of advanced biofuels [52]. It has formed strategic research alliances with industry, universities, national laboratories and government. These partners and efforts include:

- Georgia Institute of Technology: to pursue advanced research into viable cellulosic biofuels and hydrogen transportation fuels
- University of California at Davis: to develop transportation fuels from such renewable resources as rice straw and agricultural waste
- U.S. National Renewable Energy Laboratory (NREL): to advance the development of renewable transportation fuels
- Texas A&M University: focusing on the production and conversion of non-food crops into renewable transportation fuels.

The experience of Chevron includes molecular conversion, product engineering, advanced manufacturing and fuels distribution.

Chevron and Weyerhaeuser Co., one of the world's largest forest products companies, have formed a 50-50 joint venture, Catchlight Energy LLC [53]. Catchlight's initial focus is developing and demonstrating novel technologies for converting cellulose and lignin into economic, low-carbon biofuels. The business model is expected to involve multiple pathways based on combinations of biological, chemical and thermochemical process steps.

COFCO (Beijing, China), the largest food importer and exporter of China, has broken ground for a 400,000 ton/a fuel ethanol project in Guangxi Zhuang Autonomous Region, using cassava as raw material [54]. Cassava is cheap, the production of every ton of fuel ethanol would require about 7 tons of cassava worth RMB 2,450, versus 3.3 tons of maize worth RMB 2,970, or 17 tons of sugar beets worth RMB 2,720.

Coskata Inc. (Warrenville, IL, US) is a biology-based renewable energy company [55]. Its technology enables the low-cost production of ethanol from a wide variety of input material including municipal wastes, as well as other carbonaceous material, but preferably grasses (switchgrass, miscanthus), agricultural wastes (corn stover, bagasse) or wood chips.

52 http://www.chevron.com/deliveringenergy/biofuels/, visited 14 July 2009
53 http://www.catchlightenergy.com/, visited 15 July 2009
54 http://www.cofco.com/en/about_cofco/press_web.aspx?con_id=4604, visited 10 July 2009
55 http://www.coskata.com/, visited 13 July 2009

The company applies gasification technology, for which it collaborates with Alter NRG (http://www.alternrg.com/) and claims to have lower pre-treatment costs compared to non-gasification based technologies available today. The company uses proprietary microorganisms and patented bioreactor designs for its syngas-to-biofuel bacterial fermentation technology. Coskata claims that its proprietary microorganisms can produce predominately ethanol from syngas, what is said to be not possible via chemical catalysis. Further, the company claims that their microorganisms have demonstrated a level of tolerance to typical syngas impurities that would poison a chemical conversion approach, thus producing more than 100 gallons of ethanol per dry ton of input material. Coskata claims that its proprietary bioreactor designs mitigates the issue that a fermentor needs to be completely shut down to purge the system after it has been infected with phage (bacterial virus), a problem that would be typical for biology-based processes that use suspended cultures. While syngas fermentation leads to lower ethanol concentrations than corn fermentations, Coskata has exclusively licensed membrane separation technology to separate the ethanol from water.

DOE Great Lakes Bioenergy Research Center (GLBRC), (Madison, WI, US), is one of the 3 US bioenergy centers and focuses on identification of combinations of enzymes and pre-treatments needed to digest specific biomass types [56]. The centre is led by the University of Wisconsin and Michigan State University [57] and partners are University of Florida (Gainesville), Iowa State University (Ames), Illinois State University (Normal), Lucigen Corporation (Middleton, WI), ORNL and PNNL.

DOE Bioenergy Science Center (BESC), (Oak Ridge, TN, US) is led by ORNL and focusing on the screening of natural thermal springs to identify enzymes and microbes that effectively break down biomass at high temperature as well as trying to understand and engineer cellulosomes (multifunctional enzymes complexes for degrading cellulose). Also, BESC is setting up a 250,000 gallon/a switchgrass to ethanol demonstration plant [58]. Partners in BESC include Georgia Institute of Technology (Atlanta), NREL, University of Georgia (Athens), University of Tennessee (Knoxville), Dartmouth College (Hanover, NH), ArborGen (Summerville, SC), Verenium Corporation and Mascoma Corporation (01) [59].

DOE Joint Bioenergy Institute (JBEI), located in Berkeley, CA, US, is the third Bioenergy Center and developing biotechnologies that can be used for the production of biofuels from biomass [60]. The centre is led by the Lawrence Berkeley National Laboratory (LBNL) and focuses on connecting diverse biological parts and pathways to create entirely new organisms that produce fuels other than ethanol. Also, they engineer organisms to produce and withstand high concentrations of biofuels. Partners include Sandia National Laboratories (SNL, Albuquerque, NM, & Livermore, CA), Lawrence Livermore National Laboratory (LLNL, Livermore, CA), University of California (Berkeley & Davis), Carnegie Institution (CI, Palo Alto, CA) [61].

56 http://www.greatlakesbioenergy.org/wp-content/uploads/2008/02/brc2_09_2008final.pdf, visited 1 July 2009
57 http://www.science.doe.gov/News_Information/News_Room/2007/Bioenergy_Research_Centers/index.htmm, visited 1 July 2009
58 http://bioenergycenter.org/about-besc/our-partners/, visited 1 July 2009
59 http://bioenergycenter.org/interactive-map/, visited 1 July 2009
60 http://www.jbei.org, visited 1 July 2009
61 http://www.jbei.org/partners/index.shtml, visited 1 July 2009

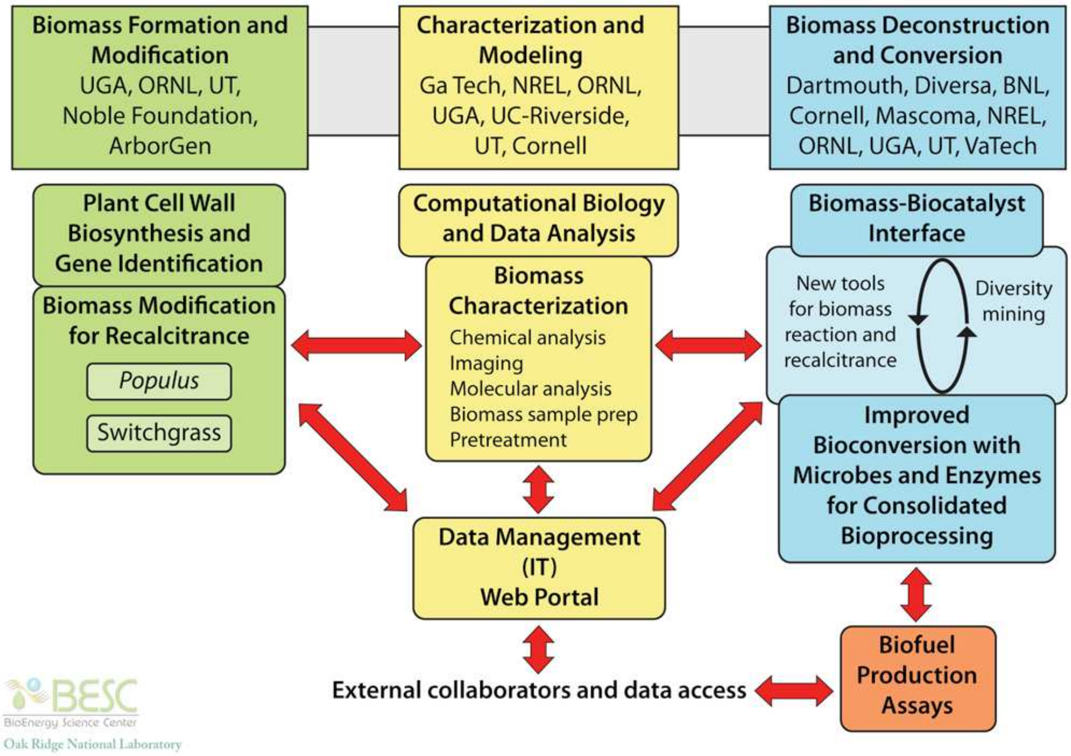

Figure 10 Organisation scheme of BESC [62].

DuPont Danisco Cellulosic Ethanol LLC (DDCE), based in Vonore (TN, US), was formed in 2008 to develop and commercialize an integrated solution for production of cellulosic ethanol (Figure 112) [63]. The joint venture combines DuPont's expertise in biorefinery design and engineering, pre-treatment chemistry, and mixed-sugar fermentation with Genencor's expertise in biomass enzymes and low-cost biocatalyst production. The company's primary product will be a technology package containing all the licenses, designs and engineering details needed to build a bioethanol-based biorefinery plant. The package will include licenses to make the bulk biocatalysts needed for production. When selecting biomass, DDCE considers accessibility of fermentable sugars for biochemical conversion, logistics, availability, etc. It is demonstrating its first biorefineries on corn cob and switchgrass, but is also interested in other biomass feedstocks such as fibre sorghum, miscanthus, sugarcane bagasse, wheat straw and others (Table 33).

The pre-treatment step opens the plant's cell wall structure, which is a lattice of crystalline polymeric sugars intertwined with lignin. DDCE applies a mild pre-treatment process to minimize inhibitors and capital expense. The first pre-treatment DDCE is commercializing is a dilute ammonia process, which is said to have a number of benefits: Ammonia is a relatively inexpensive and common industrial chemical; it can be easily recycled in the process; and it is a fermentation nutrient, which helps to keep input costs down. Because it is easily dispersed in the pre-processed biomass, it can be used at low concentrations, and at low temperature and pressure. Trials have shown excellent results with short residence time.

[62] http://bioenergycenter.org/files/themes/bioenergy_testone/images/media/flow.jpg, visited 1 July 2009
[63] http://www.ddce.com/, visited 13 July 2009

The saccharification step has been optimized with specifically designed enzyme systems for the foreseen process conditions. The system operates at greater than 25% solids loading. Enzymes are deployed in whole-broth formulation from on-site production to take advantage of complex cellulolytic activities.

DDCE has developed a mixed sugar ethanologen based on the bacterium Zymomonas mobilis (*Z. mobilis*), a naturally occurring ethanol producer used, for example, in the production of Tequila and African palm wine. DuPont has optimized a strain first acquired from the National Renewable Energy Lab and applied advanced metabolic engineering to the xylose pathway to significantly improve the organism's ability to use C5 sugars (from hemicellulose) for ethanol production from our process hydrolysate (Figure 123). *Z. mobilis* has high ethanol yield as well as high tolerance to ethanol, in excess of 100 g/l. These characteristics make this organism quite favourable compared to engineered yeast strains. As a follow up of these results, DuPont is leading a team to develop and demonstrate an economically viable, scalable Integrated Corn Biorefinery (ICBR), which converts corn grain and stover to fuel ethanol and value-added chemicals [64]. The ICBR Research Program, a US DOE funded consortium, aims at developing a biorefinery technology package that will break down entire corn plants into biofuels, such as cellulosic ethanol, and bio-based materials, such as DuPont ™ Sorona ® [65]. The partners in the program include: DuPont, Pioneer Hi-Bred, Diversa Corporation, NREL, Michigan State University, and Deere & Company.

Further, DDCE is collaborating with the University of Tennessee, through its Genera Energy foro-profit limited liability company formed in 2008 [66].

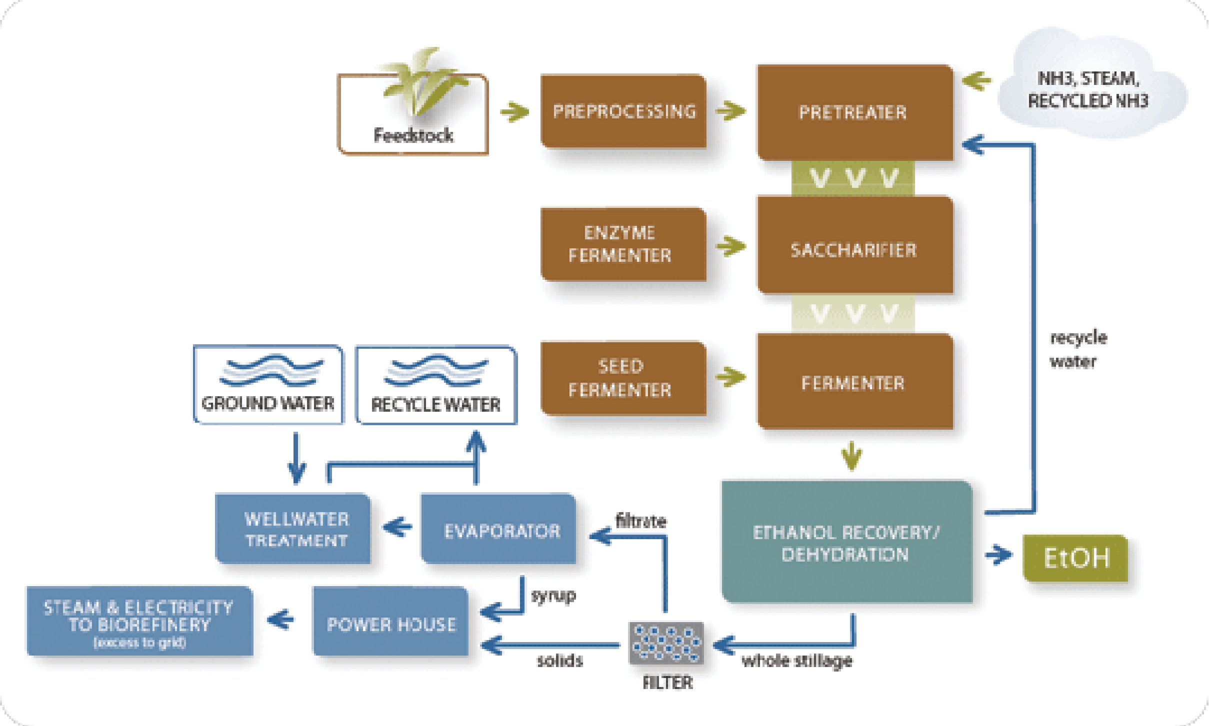

Figure 11 DuPont Danisco Cellulosic Ethanol LLC process scheme for cellulosic ethanol production.

[64] http://www1.eere.energy.gov/biomass/program_achievements.html
[65] http://www.pioneer.com/CMRoot/Pioneer/media_room/biofuels/documents/BioRefinery.doc, visited 13 July 2009
[66] http://www.danisco.com/cms/connect/corporate/media%20relations/news/archive/2008/october/pressrelease_425_en.htm, visited 13 July 2009

Table 3 Ethanol yields per feedstock, as referred to by DDCE.

Feedstock	Ethanol Yield per Dry Ton	
	Gallons	Liters
Corncob	113	428
Switchgrass	100	380
Sugar cane Bagasse	112	424
Rice Straw	110	416
Forest Thinnings	82	310
Hardwood Sawdust	101	382

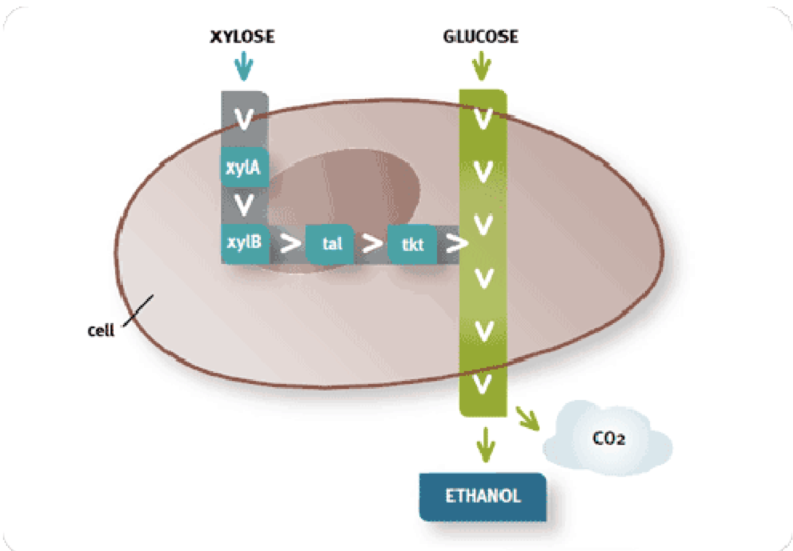

Figure 12 DuPont Danisco Cellulosic Ethanol LLC modified ethanologen based on the bacterium Zymomonas mobilis (*Z. mobilis*).

EnerGenetics Energies LLC, (Keokuk, IA, US) [67] is developing smaller-scale modular biorefinery called "Mini-BioFuel Refineries" or MBR. The company focuses on a wide variety of products from biomass: PLA, PHA, resistant starches, higher quality oils, corn protein isolate, fluffy fibre cellulose, bio-butanol.

[67] http://www.energeticsusa.com/, visited 17 July 2009

Energy Biosciences Institute (Berkeley, CA, US) [68], a partnership between BP, the University of California in Berkeley, the Lawrence Berkeley National Laboratory, and the University of Illinois, hosts a range of projects:

- Examination of ionic liquids (ILs) and ionic liquid/co-solvents with tunable properties for their ability to dissolve the cellulosic components of lignocellulosic biomass. The mild conditions employed and the possibility of recovery and recycle of ionic liquids makes them attractive alternatives to dilute acid or hydrothermolysis pre-treatments. Optimal ionic liquid composition, temperatures and biomass loadings are determined. Also the hydrolysis of cellulosics to sugars in ILs with Brønsted acid functionality is studied, in both single and biphasic systems. By addition of antisolvents such as water, cellulose can be precipitated from ionic liquids in a form readily subject to enzymatic hydrolysis. The effectiveness of cellulase systems against lignocellulosics pre-treated in ionic liquids is evaluated [69].
- Study of structure-function relation of cellulosomes for the degradation of lignocellulose into biofuels [70].
- The potential of thermophilic microorganisms to hydrolyze cellulose and hemicellulose, as well as ferment glucose, and in some instances xylose, to ethanol. Research has resulted in the isolation and characterization of three novel thermophilic bacteria with maximum growth temperatures of ~70℃. Two of the isolates, *Caldanaerobius polysaccharolyticus* and *Caldanaerobius zeae* are unique organisms that are only distantly related to the often ethanologenic genera *Thermoanaerobacterium* and *Thermoanaerobacter* at the 16S rDNA level. These bacterial isolates, however, cluster with a recently isolated bacterium from a Fijian hotspring. Also, from the same sampling site where *C. polysaccharolyticus* and *C. zeae* were isolated, a third organism *Thermoanaerobacterium bryantii* that exhibits a wide range of carbohydrate utilization was isolated. In this research, the complete genomes of *C. polysaccharolyticus* and *C. zeae,* which degrade polysaccharides to produce ethanol, will be sequenced, as well as the genome of *Thermoanaerobacterium bryantii*, which ferments diverse carbohydrates to produce butanol and ethanol as end-products. The complete genome sequences of the three thermophilic bacteria will be used as platforms in bioinformatics, microarray and proteomic studies to investigate regulation of polysaccharide hydrolysis together with pentose and hexose fermentation to biofuels, especially ethanol [71].
- Several more projects [72].

[68] http://www.energybiosciencesinstitute.org/

[69] http://www.energybiosciencesinstitute.org/index.php?option=com_content&task=view&id=151&Itemid=20, visited 16 July 2009

[70] http://www.energybiosciencesinstitute.org/index.php?option=com_content&task=view&id=152&Itemid=20, visited 16 July 2009

[71] http://www.energybiosciencesinstitute.org/index.php?option=com_content&task=view&id=154&Itemid=20, visited 16 July 2009

[72] http://www.energybiosciencesinstitute.org/index.php?option=com_content&task=blogcategory&id=22&Itemid=23, visited 16 July 2009

Green Tech America Inc. has produced a new type of yeast that the company believes will help generate cellulosic ethanol more cost-effectively [73] [74]. Nancy Ho, founder and president of Green Tech and a research professor at Purdue University's School of Chemical Engineering in the Laboratory of Renewable Resources Engineering and the Energy Center, developed a yeast to help efficiently produce ethanol from cellulosic biomass feedstocks. The yeast can co-ferment glucose and xylose. Green Tech, which is based in the Purdue Research Park, has received and optioned for an exclusive license for improvements to the new yeast. The research has been funded by a number of entities, including the U.S. DOE.

ICM Inc. (Colwich, KS, US) designs, builds and supports ethanol plants [75]. In 2008, it was among four small (10% of commercial) scale biorefinery projects selected by the U.S. Department of Energy to lead biomass-to-ethanol research efforts by utilizing numerous feedstocks and performing innovative conversion technologies to subsequently deliver online full-size, commercial-scale biorefineries [76]. Foreseen feedstocks include corn fiber, switchgrass, corn stover, and sorghum. The technology for ICM's proposed plant in St. Joseph, MO, should integrate biochemical processing and demonstrate energy recycling within the biorefinery. ICM is collaborating with Ceres, Inc., Edenspace Systems Corporation, South Dakota State University, AGCO Corporation, NREL, USDA-ARS National Center for Agricultural Utilization Research (NCAUR), Novozymes, VeraSun Energy Corporation (bankrupt in 2008 and now Valero Renewable Fuels [77]), and Qteros. According to presentation of Bruce Dale at Workshop in Osnabrück on January 29th 2009, the project has been withdrawn.

Iogen has stopped its planned development of a commercial plant in Shelley (ID, US), but continues to build one in Saskatchewan (Canada) (Figure 134) [78]. Iogen technology converts biomass into cellulosic ethanol using a combination of thermal, chemical and biochemical techniques. The yield of cellulosic ethanol is more than 340 litres per tonne of fibre [79]. The lignin in the plant fibre is used to drive the process by generating steam and electricity, thus eliminating the need for fossil sources. Iogen uses advanced microorganisms and fermentation systems that convert both C6 and C5 sugars into ethanol. The "beer" produced by fermentation is then distilled using conventional technology to produce cellulosic ethanol for fuel grade applications.

73 http://www.greentechamerica.com/, visited 1 July 2009
74 http://ethanolproducer.com/article.jsp?article_id=5714, visited 1 July 2009
75 http://www.icminc.com/
76 http://www.icminc.com/news/release/?press_release=36
77 http://www.verasun.com/Reorganization/release.cfm?ID=173
78 http://www.iogen.ca/news_events/events/2009_06_27.html, visited 23 July 2009
79 http://www.iogen.ca/cellulosic_ethanol/what_is_ethanol/process.html, visited 23 July 2009

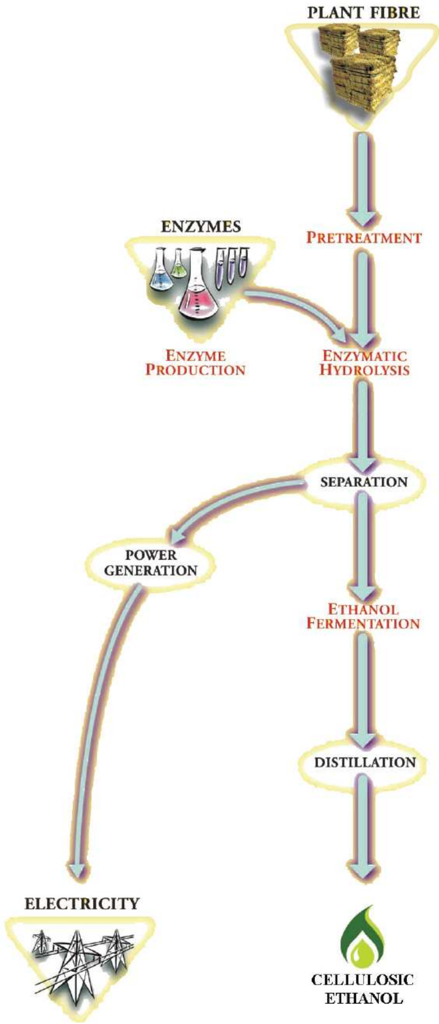

Figure 13 Schematic representation of Iogen's cellulosic ethanol production plant in Saskatchewan.

Kyushu University (Fukuoka, Japan) has presented results of an ionic liquid and a cellulase that allow enzymatic saccharification of a model cellulose substrate in 1 step [80].

Lignol (Commerce City, CO, US) small scale biorefinery (10% of commercial scale)

LS9 (South San Francisco, CA, US) [81] is engineering a wide range of DesignerMicrobes™ that are used in a proprietary 1-step fermentation process (Figure 15) to produce renewable fuels and sustainable chemicals. LS9 has developed a new means of efficiently converting fatty acid intermediates into petroleum replacement products via fermentation of renewable sugars.

[80] N. Kamiya, et al., Enzymatic in situ saccharification of cellulose in aqueous-ionic-liquid media, Biotechnol Lett, 30, 2008, 1037-1040

[81] http://www.ls9.com/, visited 22 July 2009

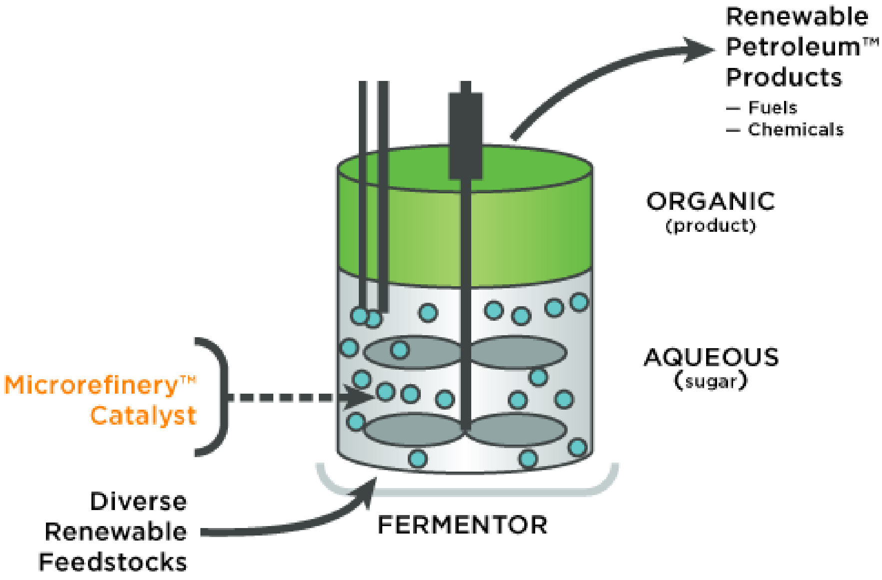

Figure 14 Representation of LS9 process scheme.

Mascoma Corporation (Lebanon, NH, US) was founded late 2005 and is developing innovative and cost effective advances in biotechnology and engineering to unlock the potential of biomass for the production of ethanol[82]. In particular, the company develops the Consolidated Bio-Processing (CBP) technology, which follows a mild pre-treatment and avoids the need for the costly production of cellulase enzymes by using engineered microorganisms that produce cellulases to hydrolyze the cellulose and ferments sugars into ethanol at high yield in a single step (Figure 156)[83].
The presentation of Bruce Dale at the Workshop in Osnabrück refers to a combination of CBP organisms with steam explosion, which can not be found at the website, however.

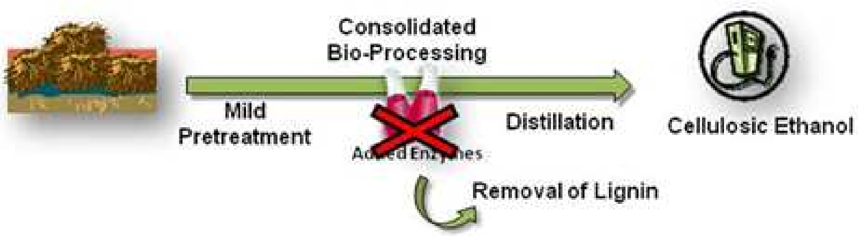

Figure 15 Mascoma process scheme for cellulosic ethanol production.

Advances have been made recently with both bacteria that grow at high temperatures, so called thermophiles, and recombinant cellulolytic yeasts. Thermophilic bacteria have recently produced nearly 6% wt/vol ethanol, an increase of 60% over what was reported just a year ago. Also an engineered metabolic of a cellulose-fermenting thermophile, *Clostridium thermocellum*, has led to a reduced production of unwanted organic acid byproducts, while selected strains of *C. thermocellum* that can rapidly consume cellulose with high conversion and no added cellulase, can grow in the presence of commercial levels of ethanol.

82 http://www.mascoma.com/
83 http://www.mascoma.com/technology/cbp.html

Recombinant cellulolytic yeast has shown a 3,000-fold increase in cellulase expression and a significant 2.5-fold reduction in the added cellulase required for conversion of pre-treated hardwood to ethanol, whereas complete elimination of added cellulase for conversion of waste paper sludge to ethanol was achieved[84].

In February 2009, Mascoma announced that its pilot facility in Rome, NY had begun producing cellulosic ethanol. The demonstration facility has the flexibility to run on numerous biomass feedstocks including wood chips, tall grasses, corn stover, and sugar cane bagasse[85].

Mascoma is co-operating with Michigan State University.

Metabolix Inc. (Cambridge, MA, US) is developing proprietary technology platforms for the co-production of biobased plastics, chemicals, and energy in non-food crops, such as switchgrass [86] [87]. Key is the development of catalysts, which allow the formation of building block monomers and their subsequent polymerization with high selectivity. Metabolix has incorporated nature's catalysts, enzymes, into microbial and plant bio-factories, to produce a broad, versatile family of useful polymers — called Mirel (chemically related to polyesters) (Figure 167). They discovered that certain soil microbes evolved with the ability to store energy in the form of polymers, which accumulate as discrete, inert granules inside the cells showed that nature had provided the means to produce potentially useful plastics. Further, Metabolix' technical capabilities can be applied to produce a number of important commercial chemicals and chemical intermediates through biological conversion of sustainable feedstocks such as sugars. Metabolix is developing proprietary technology that can produce energy from switchgrass, oilseeds, sugarcane and other crops.

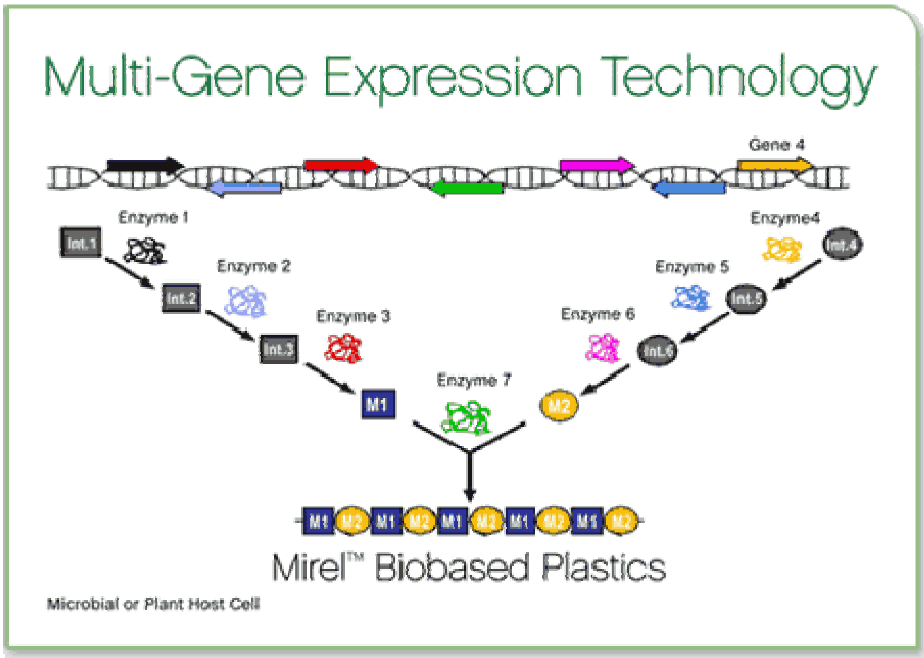

Figure 16 Schematic representation of Metabolix' biocatalysis approach for the production of plastics.

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84 http://www.mascoma.com/news/pdf/Technology%20AdvancesRelease%20-%20050709%20FINAL.pdf, visited 1 July 2009

85 http://www.mascoma.com/news/pdf/Technology%20AdvancesRelease%20-%20050709%20FINAL.pdf, visited 1 July 2009

86 http://www.metabolix.com, visited 16 July 2009

87 http://files.shareholder.com/downloads/MBLX/682254629x0x221748/7e2b170f-e359-42e3-a4a4-291deb4e3bb8/MBLX_News_2008_8_11_General_Releases.pdf, visited 16 July 2009.

Mississippi State University (Swalm, MS, US)[88] performs research on oleaginous yeast *Rhodotorula glutinis*, which has the ability to produce up to 70% of its weight as oil in the form of triacylglycerol (TAG), which can be a feedstock for biodiesel production. Feedstock for the yeast can be glucose and glycerol, a key by-product of same biodiesel production.

National Renewable Energy Laboratory (NREL) (Golden, CO, US)[89] is one of the key partners in the US DOE Biomass Program and leads the DOE National Bioenergy Center. The institute pioneered the Zymomonas mobilis work [90] (Also see DDCE). In general, NREL's biomass projects focus on developing, integrating, and demonstrating biochemical and thermochemical conversion technologies, and renewable diesel technologies[91]. Focus within NREL's biochemical conversion technologies is on pre-treatment, cellulose enzymes, catalysts for products from sugars, sugar platform integration and corn ethanol production improvement. Also see NREL's activities in sections 1.4.3 and 1.5.1.

NewPage (Wisconsin Rapids, WI, US) small scale biorefinery (10% of commercial scale).

Oak Ridge National Laboratory (ORNL)[92] is one of the key partners in the US DOE Biomass Program.

Pacific Ethanol (Boardman, OR, US) small scale biorefinery (10% of commercial scale)

Pacific Northwest National Laboratory (PNNL) (Richland, WA, US)[93] is one of the key partners in the US DOE Biomass Program. Among other studies, the institute works on decrystallization of cellulose in triflouroacetic acid at 0℃, resulting in hydrolysis reactivity close to corn starch [94].

POET (Sioux Falls, SD, US, formerly known as Broin), the world largest corn ethanol producer, operates a 20,000 gallons of cellulosic ethanol per year facility in Scotland (SD, US), and plans to build a commercial scale 25 million gallons biorefinery plant, baptized the LIBERTY project, in Emmetsburg (IA, US) to convert agrofibre waste into ethanol using a biochemical technology by 2011[95].

At its 105 million gallons per year corn ethanol plant in Chancellor (SD, US), POET uses two alternative energy sources to offset a large portion of its fossil fuel needs[96]. A solid waste fuel boiler burns several hundred tons of wood chips each day (Figure 178). The boiler also captures and burns methane gas, brought to the facility through a 10-mile low-pressure pipeline from the nearby Sioux Falls Regional Sanitary Landfill. The two sources together now offset as much as 90 percent of the plant's process steam needs.
According to the Environmental Protection Agency, the annual environmental benefits from using this gas for power is equal to removing emissions from more than 27,000 passenger vehicles or removing carbon dioxide emissions from more than 344,000 barrels of oil.

[88] E.R. Easterling, W.T. French, R. Hernandez and M. Licha, The effect of glycerol as a sole and secondary substrate on the growth and fatty acid composition of *Rhodotorula glutinis*, Bioresource Technology, 100 (1), 2009, 356-361
[89] http://www.nrel.gov/biomass/, visited 23 July 2009
[90] http://www.nrel.gov/biomass/pdfs/40742.pdf, visited 23 July 2009
[91] http://www.nrel.gov/biomass/projects.html, visited 1 July 2009
[92] http://bioenergy.ornl.gov/main.aspx, visited 23 July 2009
[93] http://www.pnl.gov/biobased/, visited 23 July 2009
[94] http://aiche.confex.com/aiche/2006/techprogram/P74488.HTM, visited, 23 July 2009
[95] www.poetenergy.com/news/showRelease.asp?id=167
[96] http://www.poetenergy.com/sustainability/wastepower.asp, visited 10 July 2009

At its Scotland, South Dakota, based cellulosic ethanol pilot plant, POET has started up an anaerobic digester which uses the liquid waste created in the process of converting corn cobs into ethanol for the production of methane gas, which is used to offset natural gas usage at the plant [97]. The anaerobic digester was designed and built by Biothane [98].

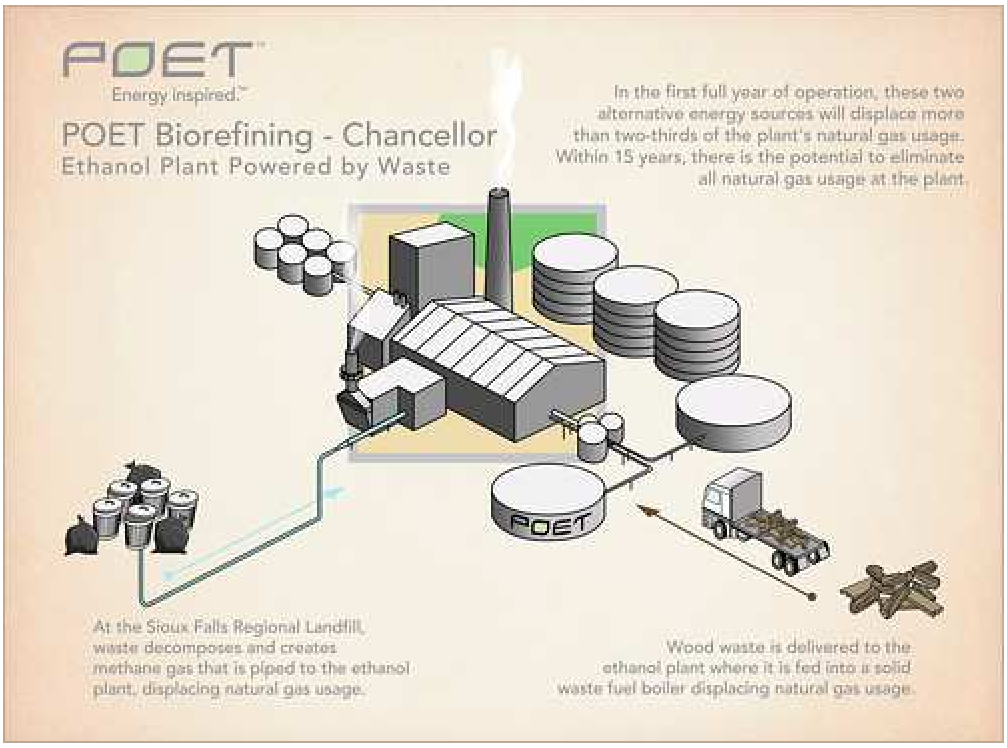

Figure 17 Scheme of POET's corn based ethanol plant in Chancellor, 90% of its energy input is derived from waste fuel boilers burning wood chips and methane coming from a nearby landfill site.

Purdue University is an active player in various renewable energy systems, wind, solar and biomass based[99]. Regarding biomass utilization, it is in particular active in topics related to ethanol production[100] and also livestock manure anaerobic digestion[101].

The Laboratory of Renewable Resources Engineering (LORRE) at Purdue University has developed a so called Tactical Garbage to Ethanol Refinery (TGER - pronounced "tiger"), a hybrid gasification and fermentation biorefinery that converts food, paper, cardboard, and plastics into biofuels[102]. The food is converted to ethanol by way of enzymes and yeast. The other organic materials are converted to producer gas (low molecular weight hydrocarbons) by way of gasification. Both biofuels power a modified diesel generator. The whole biorefinery is built to slide into a standard shipping container for movement anywhere a truck or plane can haul it. When in place, the TGER slides out and auxiliary equipment for processing the incoming waste is set up alongside. Each day, the TGER processes 2,000 pounds of waste while continuously generating 60 kW of electricity.

97 http://www.poetenergy.com/news/showRelease.asp?id=169, visited 10 July 2009
98 http://www.biothane.com, visited 10 July 2009
99 http://extension.purdue.edu/renewable-energy/index.shtml
100 http://www.extension.purdue.edu/extmedia/ID/ID-335.pdf
101 http://extension.purdue.edu/renewable-energy/bioenergy.shtml#publications-liquid
102 http://cobweb.ecn.purdue.edu/~lorre/16/research/index.shtml, visited 1 July 2009

About 30% of the electricity produced is used to process the waste, while the rest is available for any other use. Partners in this project were Defense Life Sciences LLC and Community Power Corporation.

PureVision (Fort Lupton, CO, US) claims that its biomass fractionation technology converts wood, energy crops and agricultural residues into biomaterials that can be used to produce practically anything made with fossil-based feedstocks, including: biofuels, bio-based chemicals, composites, pulp and paper products and energy[103 104]. PureVision claims that its technology efficiently separates (fractionates) the primary constituents of cellulosic biomass within one pressurized reaction chamber into three streams: hemi-cellulose, lignin, and cellulose (Figure 189)[105]. The cellulosic biomass is purchased and size-reduced and fed into a pressurized reaction chamber designed for counter-current processing. The technology can be accomplished in a single stage or in multi-stages, depending upon the desired products. The counter-current extraction removes and recovers the hemicellulose and lignin fractions in two liquid streams, resulting in a solid fraction containing a relatively pure cellulose or fibre. This patented biomass fractionation process occurs within approximately 10 minutes. A scientific paper by employees of PureVision suggests that the process involves an extruder with dynamic plugs[106]. The cellulose, lignin and fermentable (hemi-cellulose) sugars are sold by PureVision for further processing.

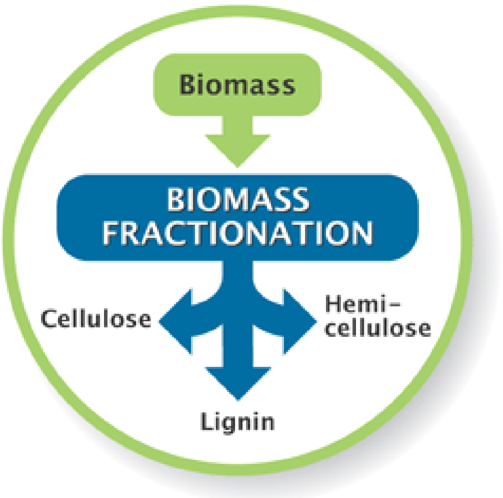

Figure 18 Schematic representation of PureVision's fractionation technology.

In a two-stage setup, the target within the reaction chamber is to first wash out most of the hemicellulose in the form of hemicellulose sugars while keeping as much of the lignin and cellulose intact in a solid form. After the solids enter the second half of the reaction chamber, the pH, temperature and pressure are adjusted to wash and remove as much lignin as possible. These two washing stages yield (1) the xylose-rich liquor fraction, (2) the lignin-rich liquor fraction and (3) the remaining solid and relatively pure cellulose fraction.

In the first stage most of the solid hemicellulose can be converted into hemicellulose sugars. These sugars can then be fermented to produce products such as ethanol, xylitol or furfural or can be processed into a purified xylose stream. The first wash liquor fraction also contains smaller portions of the lignin, cellulose, protein, and ash components of the biomass, most of which can be recovered.

103 Patent WO 2008/019228 A2
104 http://www.purevisiontechnology.com/index.html, visited 8 July 2009
105 http://www.purevisiontechnology.com/technology.html, visited 8 July 2009
106 K.L. Kadam. C.Y. Chin, L.W. Brwon, Flexible biorefinery for producing fermentation sugars, lignin and pulp from corn stover, J. Ind Microbiol Biotechnol, 35, 2008, 331-341.

After the counter-flow washing of the hemicellulose occurs, most of the lignin and possibly the remaining hemicellulose are washed out in a second stage. This second stage wash liquor fraction contains most of the lignin and any targeted amount of the remaining hemicellulose sugars. This lignin-rich fraction is then further processed to produce a high quality, low-molecular weight lignin that can be sold as an industrial raw material to produce industrial and consumer products. The lignin can also be used as a bio-fuel to provide energy for making electricity and steam to run the biorefinery.

The remaining cellulose fraction is between 90% to 97% cellulose, as most of the lignin, hemicellulose and extractives have been stripped off in the wash liquor fractions. Because of the high purity of the cellulose fraction, it can be sold as a pulp or enzymatically hydrolyzed into glucose. PureVision claims that the obtained cellulose requires far less enzymes to produce glucose compared to competing technologies.

The processing variables can be chosen so as to optimize the process for the desired main product, e.g. pulp for making paper products or dissolving pulps or cellulose acetate, sugars for making ethanol or other industrial chemicals or bio-plastics (Figure 1920).

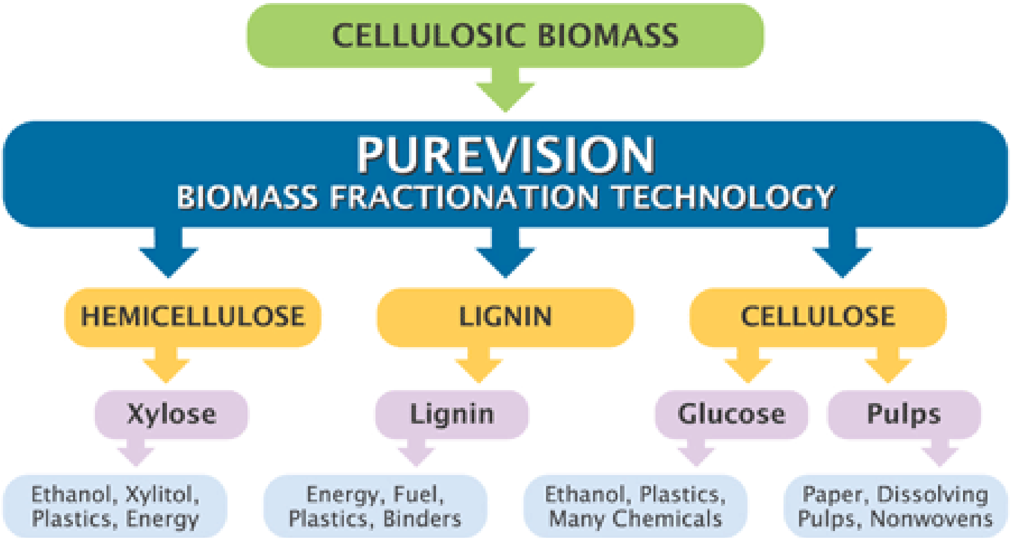

Figure 19 Schematic representation of PureVisions' technology to refine biomass into products.

PureVision is studying fractionation using γ-alumina ceramic tubular membranes (Figure 2020)[107]. Parameters evaluated are permeance decline and measures to restore permeance, total organic carbon (TOC) and sodium recovery, and the molecular mass of the fractionated organic species.

107 K.R. Colyar et al., Fractionation of Pre-Hydrolysis Products from Lignocellulosic Biomass by an Ultrafiltration Ceramic Tubular Membrane, Separation Science and Technology, 43, 2008, 447-476

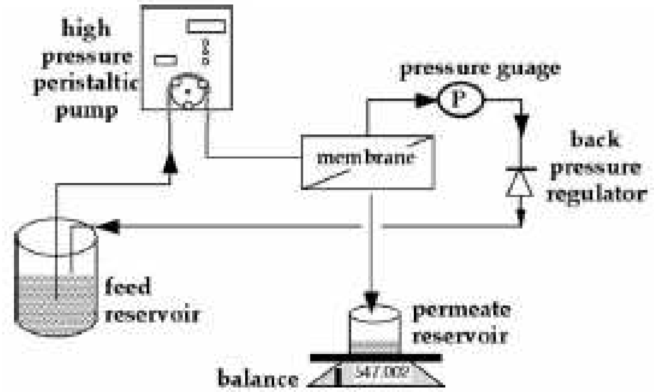

Figure 20 Filtration scheme used with γ-alumina, 5 nm, ceramic tubular membrane.

The Rohm & Haas Company[108] (Philadelphia, PA, US) is researching and developing a biorefinery technology platform for adhesives, elastomers and foams. Together with Ceres Inc.[109], an energy crop company headquarted in Thousand Oaks (CA, US), Rohm and Haas, a leading manufacturer of specialty materials like acrylate and methacrylate, will determine if energy crops planted for cellulosic ethanol could simultaneously produce methacrylate monomers, a key raw material used in the manufacture of many products including paint and coatings, building materials, and acrylic sheet and resins[110]. Some plants naturally produce compounds similar to methacrylate monomers, but do not necessarily accumulate them in extractable forms or quantities. The companies try to alter the way plants produce these compounds so that they can be extracted from the dried stalks, stems and leaves before these are fed into biorefineries producing ethanol from cellulose. The Biomass Program website refers to substantial progress made toward developing new flexible laminating and assembly adhesive products and foam and elastomer prototypes[111].

Shell, Codexis Inc. (Redwood City, CA, US)[112], an industrial biocatalysts producer, and Iogen Energy Corp. cooperate to enhance the efficiency of enzymes used in the Iogen cellulosic ethanol production process[113] [114].

Syntroleum (Tulsa, OK, US)[115] has developed a proprietary Bio-Synfining™ process to transform a wide variety of renewable feedstocks such as vegetable oils, fats, and greases into synthetic diesel and jet fuel. The company has announced the establishment of Dynamic Fuels (Geismar, LA, US) [116], a 50/50 venture formed with Tyson Foods, the world's largest processor and marketer of chicken, beef, and pork.

108 http://www.rohmhaas.com, visited 16 July 2009
109 http://www.ceres.net, visited 16 July 2009
110 http://www.businesswire.com/portal/site/rohmhaas/?ndmViewId=news_view&newsId=20071112006122&newsLang=en, visited 16 July 2009
111 http://www1.eere.energy.gov/biomass/program_achievements.html
112 http://www.codexis.com, visited 17 July 2009
113 http://www.shell.com/home/content/media/news_and_library/press_releases/2007/biofuels_codexis_06112007.html, visited 17 July 2009
114 Renewables Energy Focus, May/June 2009, page 19. http://e-ditionsby-fry.com/ActiveMagazine/getBook.asp?Path=RRF/2009/05/01&BookCollection=RRF&ReaderStyle=Gray&browserWindowWidth=1270&browserWindowHeight=974&ScreenRes=2, vis. 17 July 2009
115 http://www.syntroleum.com/Main.aspx, visited 22 July 2009
116 http://www.dynamicfuelsllc.com/, visited 22 July 2009

Utilizing fats and oils feedstock from Tyson, coupled with Syntroleum's Bio-Synfining™ technology, Dynamic Fuels' first plant will be designed to produce 75 million gallons per year of renewable synthetic fuels, starting in 2010. At longer-term, Syntroleum plans to employ its proven Fischer-Tropsch capabilities to produce ultra-clean renewable synthetic fuels from our nation's extensive supply of biomass.

The Texas A&M University (College Station, TX, US) has developed the MixAlco process[117] (02), a method for producing fuels from biomass, such as municipal waste, agricultural residues, sewage sludge, and manure. The biomass is treated with lime and air to enhance digestibility. This material is fed to a mixture-culture of microorganisms that produce carboxylic acids, which are transformed into salts by addition of $CaCO_3$. After drying, the salts are thermally converted into ketones. Finally, the ketones are hydrogenated to alcohols.

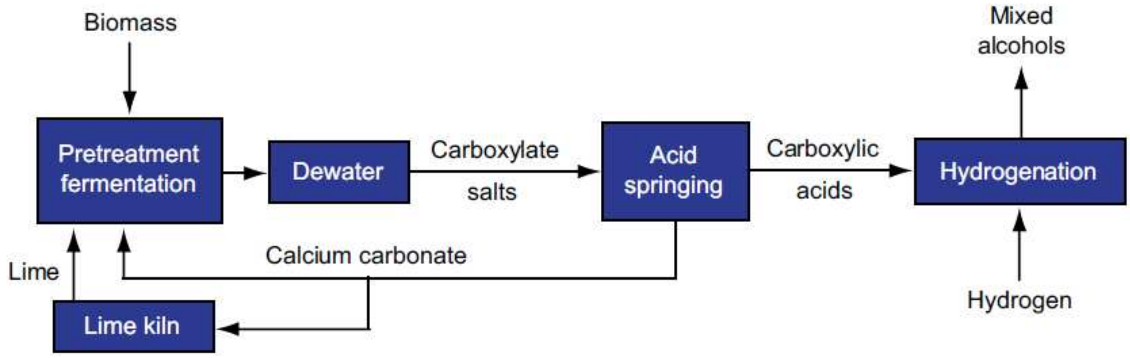

Figure 21 MixAlco process scheme.

Tianguan Group, (Nanyang City, Henan province, China), including its subsidiary Tian Zhiguan Renewable Fuels Co. seems to be an important bio-fuel player in China[118]. With a 300,000 ton/year ethanol producing line, it is one of the four fuel ethanol suppliers in China, and it claims to be the biofuel developing centre in China, and the Recyclable economic Demonstration Base of China.

Further, in Shanghai, a 600 tons of cellulosic ethanol-per-year plant has been built using acid and enzymatic hydrolysis processing. The feedstocks tested are saw dust and rice straw[119]. The same presentation by Y. Zhenhong refers to a 400 ton/a thermal pyrolysis pilot system, biodiesel plant based on *Pistachia Chinesis* and *Jatropha Curcas* in the provinces of Sichuan, Henan, Hunan, Yunnan and Hebei with a total of 30,000 tons/a, a 3,000 ton/a ethanol plant based on sweet sorghum in Shandong and Heilongjiang, and a laboratory scale gasification and Fischer-Tropsch synthesis biodiesel unit at Guangzhou Institute of Energy Conversion (CAS).

A team of researchers from the University of Akureyri (Borgir Nordurslod, Iceland), Tampere University of Technology (Finland), and Chia University (Taichung, Taiwan), have found new strains of bacteria with the potential of producing hydrogen or ethanol fuels from wastewater now discharged from factories that process sugar beets, potatoes and other plant material [120] [121].

[117] http://www.eri.ucr.edu/ISAFXVCD/ISAFXVPP/RcAMAP.pdf, visited 23 July 2009
[118] http://www.tianguan.com.cn/english/SCIENCE.asp
[119] http://www.martinot.info/Yuan_WBS2006.pdf, visited 10 July 2009
[120] http://www.greencarcongress.com/2007/12/researchers-ide.html, posted 3 December 2007, visited 2 December 2009
[121] Koskinen, Perttu E. P.; Lay, Chyi-How; Beck, Steinar R.; Tolvanen, Katariina E. S.; Kaksonen, Anna H.; Örlygsson, Jóhann; Lin, Chiu-Yue; and Puhakka, Jaakko A. "Bioprospecting Thermo-

The used organisms were hydrogen and ethanol producing thermophilic microorganisms derived from hot spring environments in Iceland that could withstand temperatures over a temperature range of 50–78℃. One of the enrichments (33HL) produced 2.1 mol of hydrogen per mol of glucose at 59 ℃. Another enrichment (9HG), dominated by bacteria closely affiliated with *Thermoanaerobacter thermohydrosulfuricus*, produced 0.68 mol of hydrogen per mol of glucose, and 1.21 mol of ethanol per mol of glucose at 78 ℃. Hydrogen and ethanol production by 9HG was characterized further in a continuous-flow bioreactor at 74℃. The highest hydrogen and ethanol yields of 9HG were obtained at pH 6.8 ± 0.3. Lactate production decreased the hydrogen and ethanol yields in the continuous-flow bioreactor, and the yields were lower than those obtained in the batch fermentations.

At the University of Georgia (US), the faculty of engineering is developing integrated systems for the conversion of biomass to chemicals, fuels, and bio-products (Figure 223)[122]. The evaluated technologies include: pre-treatment of biomass for fermentation, anaerobic digestion, bio-ethanol and biodiesel production. Also see section 1.4.3.

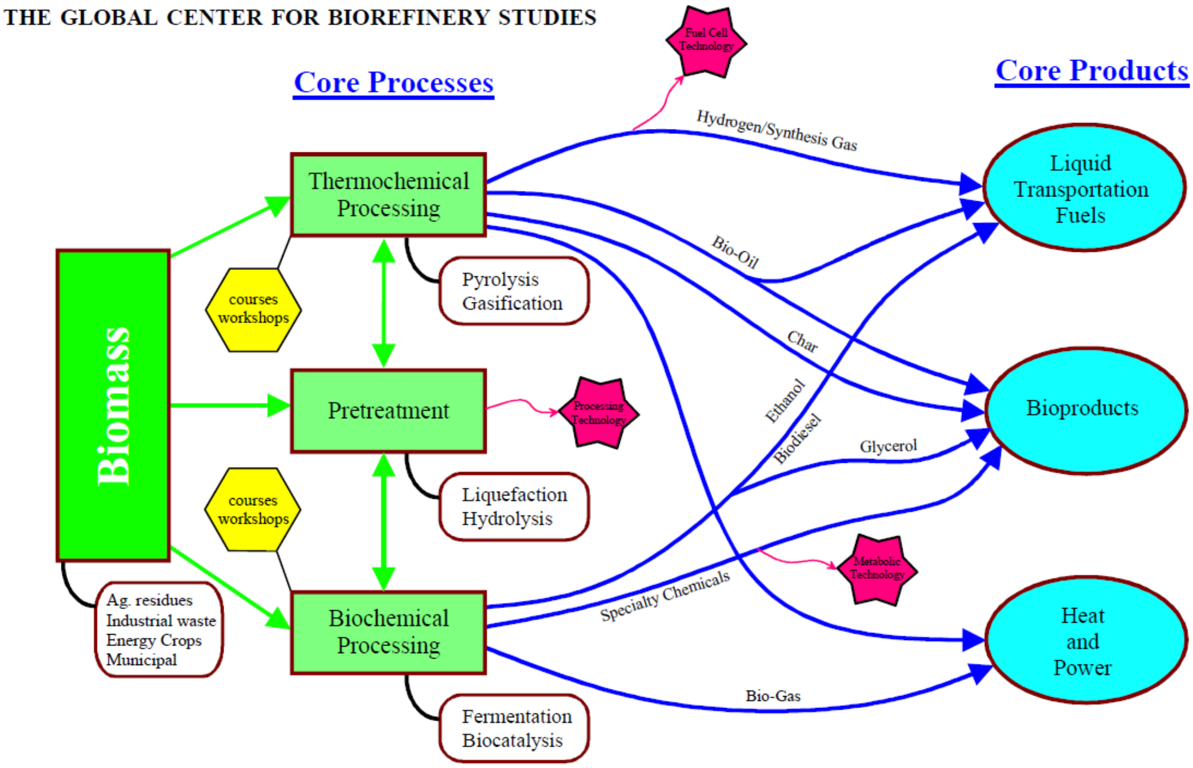

Figure 22 Positioning of biorefinery activities by University of Georgia.

Verenium Corporation is the result of a merger of two companies formerly known as Celunol and Diversa early 2007[123]. It acquired its current name half a year later. The company has established a 1.4 million gallon per year demonstration plant in Jennings, LA, US, for the production of bioethanol from cellulosic biomass (04)[124]. The feedstock is sugarcane bagasse, switchgrass, wood products, and dedicated energy crops.

philic Microorganisms from Icelandic Hot Springs for Hydrogen and Ethanol Production", *Energy Fuels 22 (1)*, 2008, p. 134-140

122 www.gtsav.gatech.edu/outreach/workshop/presentations/kdas.pdf, visited 30 June 2009

123 http://cleantech.com/news/1355/diversa-and-celunol-become-verenium

124 http://www.verenium.com/pdf/Jennings_factsh.pdf, visited 1 July 2009

The key element of the technology developed by Verenium is genetically engineered *Escherichia coli* bacteria that can ferment both C6 (hexose) and C5 (pentose) sugars present in cellulosic biomass[125].

Verenium plans a US $350 million cellulosic ethanol plant which can produce 36 million gallons of ethanol from 400,000 tonne of dried feedstock per year in Highlands County, FL, US[126].

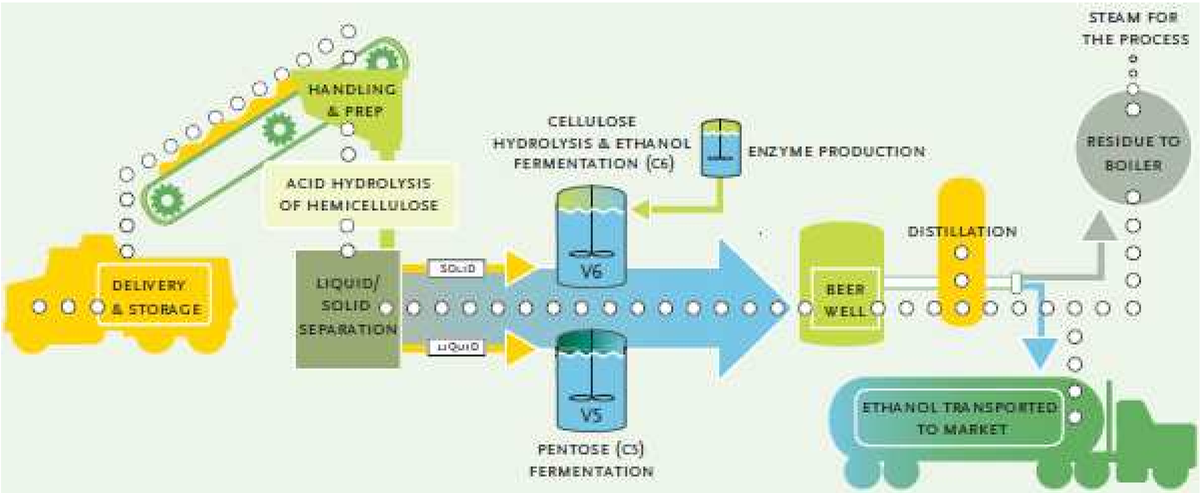

Figure 23 Verenium process for cellulosic ethanol production.

In addition, Verenium technology has been licensed by Tokyo-based Marubeni Corp. and Tsukishima Kikai Co., LTD [127] and has been incorporated into BioEthanol Japan's 1.4 million liter-per-year cellulosic ethanol plant in Osaka, Japan. The feedstock is wood construction waste[128]. Tsukishima Kikai is also thinking about producing non-fuel products from wood (05). The consortium has planned to open a 3 million liter-per-year plant in Saraburi, Thailand[129]. This plant will use the sugarcane-bagasse from a nearby facility that will produce ethanol from sugar-cane derived sucrose.

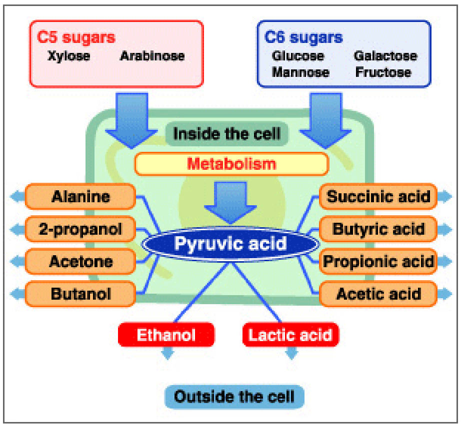

Figure 24 Non-fuel products from wood envisaged by Tsukishima Kikai.

125 http://www.greencarcongress.com/2007/01/bioethanol_japa.html
126 http://domesticfuel.com/category/cellulosic/page/7/
127 http://www.tsk-g.co.jp/en/tech/industry/bio.html, visited 22 July 2009
128 http://www.verenium.com/cellulosic-ethanol_facilites.asp, 1 July 2009
129 http://prnwire.com/cgi-bin/stories.pl?ACCT=104&STORY=/www/story/07-15-2008/0004849620&EDATE=

Verenium is also collaborating with New Zealand Crown Research Institutes Scion and AgResearch with focus on biofuel production[130].

Virginia Polytechnic Institute and State University has presented a hemicellulose utilization tree (06)[131].

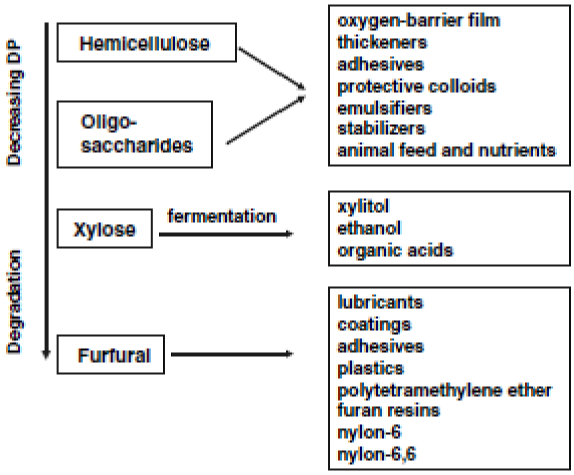

Figure 25 Hemicellulose utilization tree.

The Wisconsin Biorefining Development Initiative™ intends to help Wisconsin expanding biorefining activities by introducing new opportunities for refining multiple, higher-value products from biomass materials and waste streams[132]. Project funding sponsors are the US DOE – Chicago Regional Office, and the State of Wisconsin Department of Administration – Division of Energy. The initiative involves contributions from a wide range of organizations and programs, including: Energy Center of Wisconsin, University of Wisconsin-Madison, CleanTech Partners Inc. (formerly Center for Technology Transfer), Oak Ridge National Laboratory, National Renewable Energy Laboratory, Pacific Northwest National Laboratory, USDA, Forest Products Laboratory, DOE Biomass Program,

The technologies addressed in the Initiative include: biomass gasification, black liquor gasification, biomass combustion, dry and wet mill corn processing, thermochemical liquefaction, fast or flash pyrolysis, aqueous-phase reforming, lipid extraction, (trans)esterification, and fermentation of lignocellulosic biomass.

Qteros of Marlborough, MA, US, (formerly SunEthanol), a spin off from the University of Massachusetts, is optimizing a naturally occurring microbe, which the company calls the Q Microbe, to make ethanol[133]. The microbe was discovered by Susan Leschine, University of Massachusetts professor of microbiology and company adviser, in the woods/wetlands area near the Quabbin Reservoir in western Massachusetts.

In the Qterus proprietary Complete Cellulosic Conversion (C3) process, the Q Microbe (*Clostridium phytofermentans*) simultaneously decomposes and ferments cellulosic biomass to ethanol (Figure 267). It converts both cellulose (C6 sugars) and hemicellulosic (C5 sugars) plant material, and Qterus claims that the C3 process broadens the pre-treatment options and has higher yields than other bioconversion processes.

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130 http://www.verenium.com/specialty-enzymes_products_fuelzyme-cx.asp

131 Y.-H. Percival Zhang, Reviving the carbohydrate economy via multi-product lignocellulosic biorefineries, J. Ind. Microbiol. Biotechnol., 35, 2008, 367-375.

132 http://www.wisbiorefine.org/, visited 9 July 2009

133 http://www.qteros.com/

The Q Microbe breaks down a wide variety of plant materials, including corn residues, cane bagasse, woody biomass, cellulose waste, grasses, and more, and can be engineered to optimize ethanol output from a specific plant material.

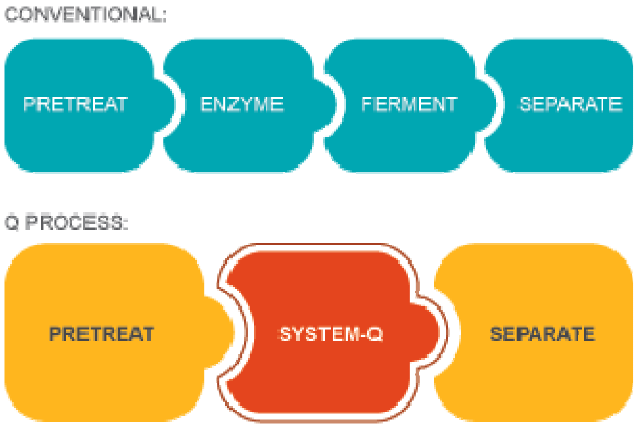

Figure 26 Qterus C3-process versus conventional cellulosic ethanol production process.

ZeaChem (Lakewood, CO, US) is pioneering biorefinery cellulosic ethanol technology using a hybrid combination of biochemical and thermochemical processing steps (Figure 278)[134]. After chemically fractionating the biomass, the sugar stream (both xylose [C_5] and glucose [C_6]) are sent to fermentation where an acetogenic process is utilized to ferment the sugars to acetic acid without CO_2 as a by-product. In comparison, traditional yeast fermentation creates one molecule of CO_2 for every molecule of ethanol. Thus the carbon efficiency of the ZeaChem fermentation process is nearly 100% vs. 67% for yeast. A particular aspect of the fermentation is that it uses microbes from a termite stomach[135]. The acetic acid is converted to an ester which can then be reacted with hydrogen to make ethanol. To get the hydrogen necessary to convert the ester to ethanol, ZeaChem takes the lignin residue from the fractionation process and gasifies it to create a hydrogen-rich syngas stream. The hydrogen is separated from the syngas and used for ester hydrogenation and the remainder of the syngas is burned to create steam and power for the process. The net effect of combining the two processes is that about 2/3 of the energy in the ethanol comes from the sugar stream and 1/3 comes from the lignin steam in the form of hydrogen. At an expected Nth plant yield of 135 gallons per bone dry ton, the process is nearly balanced with the necessary steam and power generated from the non-hydrogen portion of the syngas stream. ZeaChem plans the construction of plant producing 1.5 million gallons of ethanol per year from non-food feedstock, such as wood chips and grasses[136].

[134] http://www.zeachem.com/technology/overview.php, visited 9 July 2009
[135] http://news.cnet.com/greentech/?keyword=biotech
[136] http://news.cnet.com/greentech/?keyword=biotech

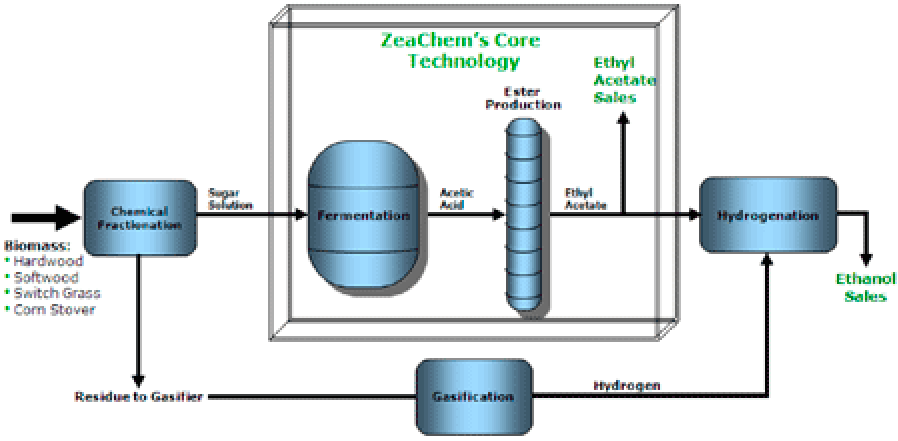

Figure 27 ZeaChem process for cellulosic ethanol production.

1.4.3 Thermochemical pathway / syngas platform

Abengoa Bioenergy
Abengoa Bioenergy is studying various routes for the thermochemical conversion of the biomass with the goal of selecting the technology with the most promising technical and economical attributes, and therefore it is pursuing a few projects for development and implementation of biomass thermochemical conversion. As part of Abengoa's concept of Integrated Biorefinery, a gasification system will convert biomass to syngas, which is then used for steam generation. In the short term, the steam will provide the heat requirements for the entire biomass plant, including the biomass enzymatic hydrolysis to ethanol part, and for an adjacent starch to ethanol plant. The longer term goal is to use syngas for catalytic synthesis of ethanol. In order to enable this, Abengoa Bioenergy is working on or will start a few projects developing the necessary technology. Laboratory catalysis research is being applied to develop and improve the catalysts for ethanol synthesis. In a joint project, a demonstration plant will be erected in 2010 and used to study the syngas cleaning and conditioning and its use for alcohol synthesis.

In the 1990s, the so called BIG-GT project (Brazil) has been established. The biomass integrated gasification-gas turbine (BIG-GT) technology aimed at producing power from biomass[137]. The project suffered from delays and partners left the consortium[138]. In this study, no dedicated active website has been found.

The Central Research Institute of Electric Power Industry (CRIEPI) in Abiko, Japan, is working on innovative thermal power generation technologies, such as biomass gasification and coal-based Integrated Gasification Combined Cycle (IGCC, Figure 289)[139]. In collaboration with Kansai Electric Power Co., CRIEPI is developing a carbonizing-gasification gas engine power generating system which can use a mixture of wood and waste biomass as fuel.

[137] E. Carpentieri and N. Macedo, The introduction of BIG-GT technology – possible future uses in Northeast Brazil, Energy for Sustainable Development, IV (3), October 2000, 8-13.
[138] http://www.p2pays.org/ref/17/16274/pinatti.pdf, visited 17 July 2009
[139] http://criepi.denken.or.jp/en/activities/project/environmental.html, visited 7 July 2009

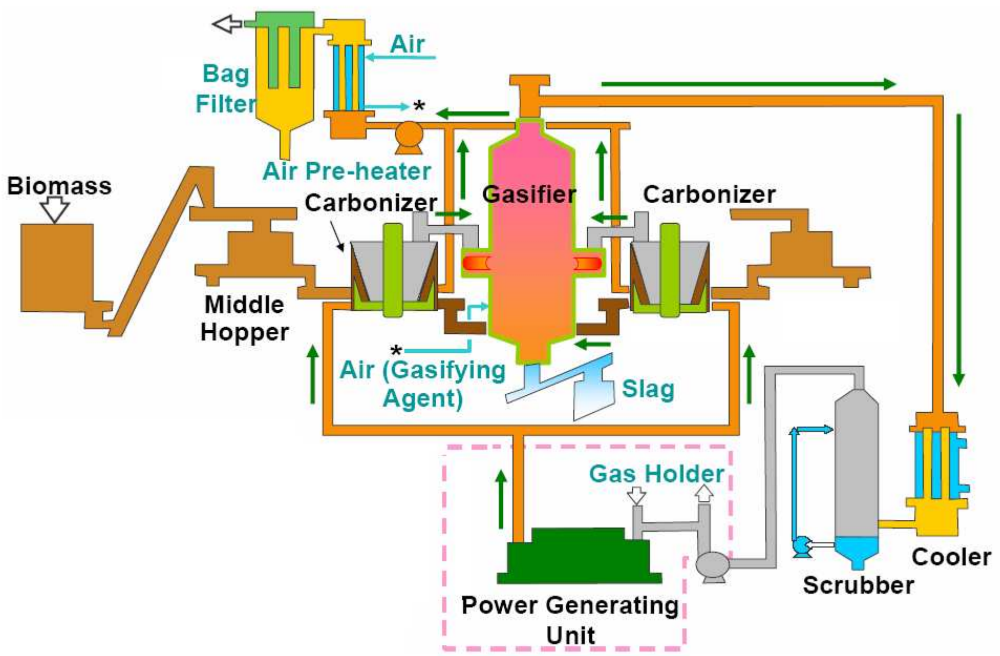

Figure 28 CRIEPI scheme of biomass gasification and coal-based IGCC.

China Biomass Development Center is working on thermal pyrolysis, including gasification, liquefaction and carbonization, for treating crop and/or forest residues, industry organic wastes to produce fuel gas, bio-diesel and coke fuel (030)[140 141].

In recent years, the gasification technology has made great progress in China. Three processes have been developed for treating different materials and different usage. First one is the up-draught fixed bed gasifier. Its gasifying efficiency is 75% and maximum energy output is about 1,400 MJ/h.

The system can convert crop residues into gas fuel and one system can provide 800 m^3 of gas fuel to 90 rural families daily by a gas supply net. Second one is the downdraught fixed bed gasifier. Its gasifying efficiency is over 75% and maximum energy output is 620 MJ/h. The system is mainly used for treating wood wastes and supplying 2,600 m^3 of gas fuel to wood drying process in a factory. Third one is down draught recycle fluid bed gasifier. Its gasifying efficiency also is 75% but its maximum energy output is up to 2,900 MJ/h. The system has been operated successfully for treating wood powder and providing gas fuel in a factory.

[140] http://ec.europa.eu/research/energy/pdf/03_yuan_zhenhong_biofuels_china_en.pdf
[141] http://www.unescap.org/esd/energy/information/promotion/biomass_seminar/ChinaBiomass.pdf

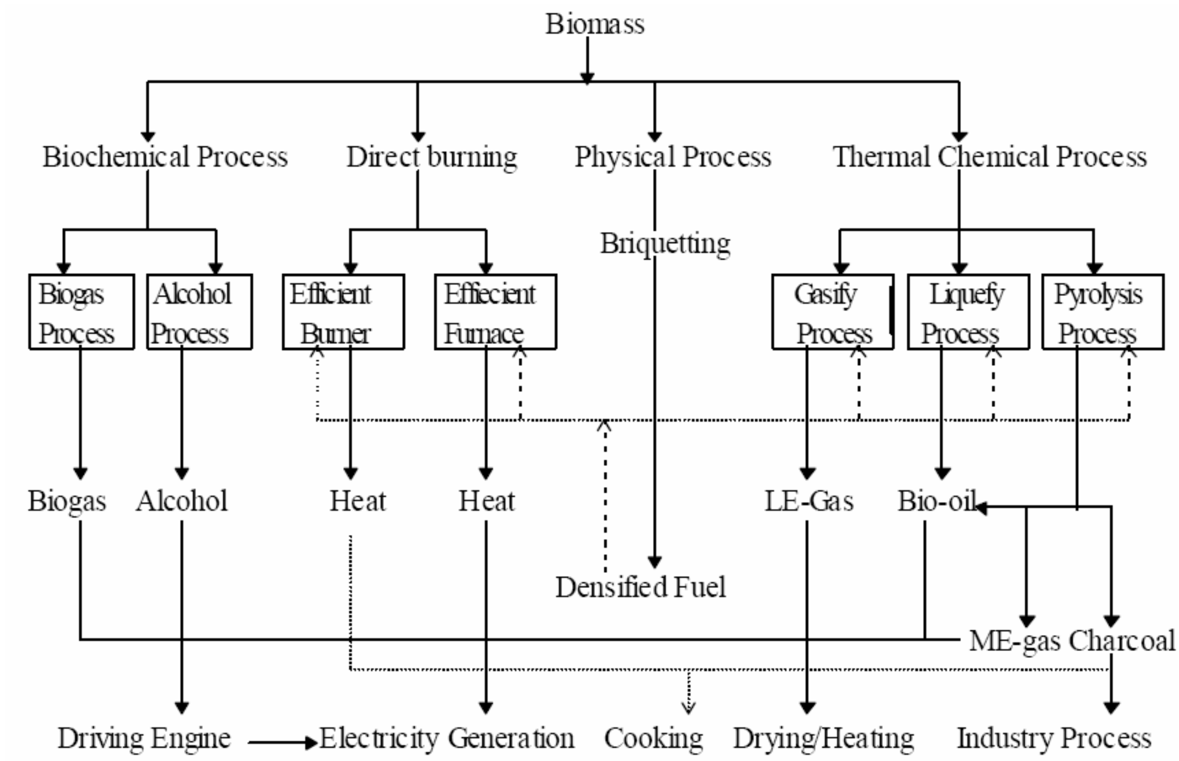

Figure 29 Activities of China Biomass Development Center.

Being undertaken a pyrolysis process, many kinds of biomass materials can be converted into three kinds of energy products: fuel gas, charcoal and bio-oil. By controlling reaction conditions, such as temperature, pressure and detained time in the reactor, we can change the proportion between the three products. In a typed process, 200~250 m^3 of gas fuel, 250 ~600 kg of charcoal and 200~300 kg of bio-oil can be produced respectively.

Several research groups in China have researched some new technologies, such as biomass liquefaction by thermal-chemical processes and alcohol from sugar or cellulose materials. These technologies are still at a research stage.

By 1998, a great achievement has been made by China on biomass as energy, specially on biogas technology[142]. The application result is so good that the total energy production has arrived at 1.15 million TOE, providing 0.24% of the total rural energy. The second is the technology of improved stove and heat bed, about 0.525 million TOE saved yearly. Some new technologies have been developed in recent years and have resulted into small scale applications.

142 http://www.unescap.org/esd/energy/information/promotion/biomass_seminar/ChinaBiomass.pdf

For example, about 700 sets of gasifiers have been operated for cooking by independent users or by centralized gas supply nets, wood drying processes and electricity generations; and about 800 sets of briquetting machines have been stalled for treating rice husks or stalks in the country. The total biomass energy output by these new technologies has been up to 1.77 million TOE.

Clemson University (Clemson, SC, US) is performing research on heterogeneous Mg-Al hydrotalcite base catalysts for the conversion of poultry lipids to biodiesel [143].

ConocoPhillips (Houston, Texas, US), the third-largest integrated energy company in the United States, has established a several million US $ cooperation with Iowa State University (ISU) since 2007[144]. The research projects include studies of various biofuel production technologies, technical and economic analyses of different types of biorefineries, production of crops for conversion to biofuels, sustainable growing of crops and biomass, the harvest, storage and transportation of biomass, and the combustion performance of biofuels in engines.

A specific subject is the development of a method to make synthetic cellulosomes, enzymes found in termites and the first stomachs of cows that excel at breaking down cellulose from plants. Another study evaluates how heat, water and chemicals move through the soil and how various biomass crop systems affect water quality beneath the soil, the carbon content of the soil and carbon dioxide emissions from the soil.
Also, in December 2007, the U.S. Department of Energy selected an Iowa State-ConocoPhillips research project for an award that will allow to design and build a biomass gasification system that produces synthetic diesel fuel.

ConocoPhillips and Archer Daniels Midland Company (ADM) are collaborating in the field of conversion of biomass from crops, wood or switchgrass into 'biocrude' (pyrolysis oil, bio-oil)[145]. The idea is to pyrolyse biomass close to where it can be found, and then to ship the bio-oil and char to a central gasification plant, where the syngas is transformed into liquid biofuels.

Dynamotive Energy Systems Corporation (Vancouver, Canada) had developed a fast pyrolysis technology that uses medium temperatures and oxygen-free conditions to turn dry waste biomass and energy crops into BioOil® for power and heat generation. BioOil® can be further converted into vehicle fuels and chemicals [146].
Prepared feedstock (<10% moisture and 1-2 mm particle size) is fed into the bubbling fluid-bed reactor, which is heated to 450–500 ℃ in the absence of oxygen. This is lower than conventional pyrolysis systems and, therefore, has the benefit of higher overall energy conversion efficiency. The feedstock flashes and vaporizes like throwing droplets of water onto a hot frying pan. The resulting gases pass into a cyclone where solid particles, char, are extracted. The gases enter a quench tower where they are quickly cooled using BioOil already made in the process. The BioOil condenses and falls into the product tank, while non-condensable gases are returned to the reactor to maintain process heating. The entire reaction from injection to quenching takes only two seconds. 100% of the feedstock is utilized in the process to produce BioOil and char. As the non-condensable gases are used as energy to run the process, nothing is wasted and no waste is produced.

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[143] Y. Liu et al, Transesterification of poultry fat with methanol using Mg-Al hydrotalcite derived catalysts, Applied Catalysis A, 331, 2007, 138-148
[144] http://www.conocophillips.com/newsroom/news_releases/2008news/05-01-2008.htm, visited 15 July 2009
[145] http://news.mongabay.com/bioenergy/2007/09/conocophillips-and-archer-daniels.html
[146] http://www.dynamotive.com/

The uncondensed, flammable gases are re-circulated to fuel approximately 75% of the energy needed by the pyrolysis process. Three products are produced: BioOil (60-75% by weight), char (15-20% wt.) and non-condensable gases (10-20% wt.). Yields vary depending on the feedstock composition. BioOil and char are commercial products and non-condensable gases are recycled and supply a major part of the energy required by the process. No waste is produced in the Dynamotive process.
In April 2009, Dynamotive announced the plans for a 200 tonnes/day BioOil plant in Arkansas (US)[147].

Ensyn (Ottawa, Ontario, Canada)[148] is commercializing a proprietary biomass to liquid technology, Rapid Thermal Process (RTP)™. Ensyn claims to provide the world's only rapid pyrolysis process that has operated on a long-term commercial basis. Ensyn has designed, built, and commissioned seven commercial RTP™ plants in the United States and Canada; the largest, located in Renfrew, Ontario has the capacity to process 100 tonnes of dry residual wood per day. RTP™ is a fast thermal process whereby biomass is introduced into a vessel and rapidly heated to 500ºC by a tornado of hot sand and then rapidly cooled within seconds. The process generates a relatively high yield (i.e., approx 75 wt%) of pourable, liquid "bio-oil" from residual forestry or agricultural biomass). The actual conversion takes less than 2 seconds. The process also produces by-product char and non-condensable gas, both of which can be efficiently used to provide process energy, which can then be used in the re-heater to maintain the RTP™ process and/or in the dryer to condition the biomass. If the moisture content of the incoming feedstock is less than 45%, there are opportunities to use surplus energy for other purposes, such as steam production and process and space heating.

Eprida (Earth, People, Research, Innovation, Development, Acknowledgement) of Athens (Georgia, US) is a technology development company which has developed a pyrolysis technology to convert agricultural waste biomass into hydrogen and enriched carbon, organic slow-release sequestering (ECOSS™) fertilizer (Figure 3031 and 32)[149]. This process has been developed in collaboration with National Renewable Energy Laboratory (NREL) and Oak Ridge National Laboratory (ORNL)[150]. The production of ECOSS uses CO_2, SO_x and NOx release from fossil fuel plants. In tropical or depleted soils, ECOSS fertilizer sustainably improves soil fertility, water holding and plant yield far beyond what is possible with nitrogen fertilizers alone. The hydrogen produced from the biomass can be used to make ethanol, or a Fischer-Tropsch gas-to-liquids diesel (BTL diesel), as well as the ammonia used to enrich the carbon to make the ECOSS fertilizer. The company claims that, unlike other biomass gasification technologies, the Eprida process can operate at small scale, converting waste biomass into fuel and fertilizer. The company is currently pursuing additional development and deployment.

147 http://www.dynamotive.com/?s=plant
148 http://www.ensyn.com/index.htm, visited 20 July 2009
149 www.eprida.com, Visited 30 June 2009
150 www.eprida.com/hydro, visited 30 June 2009

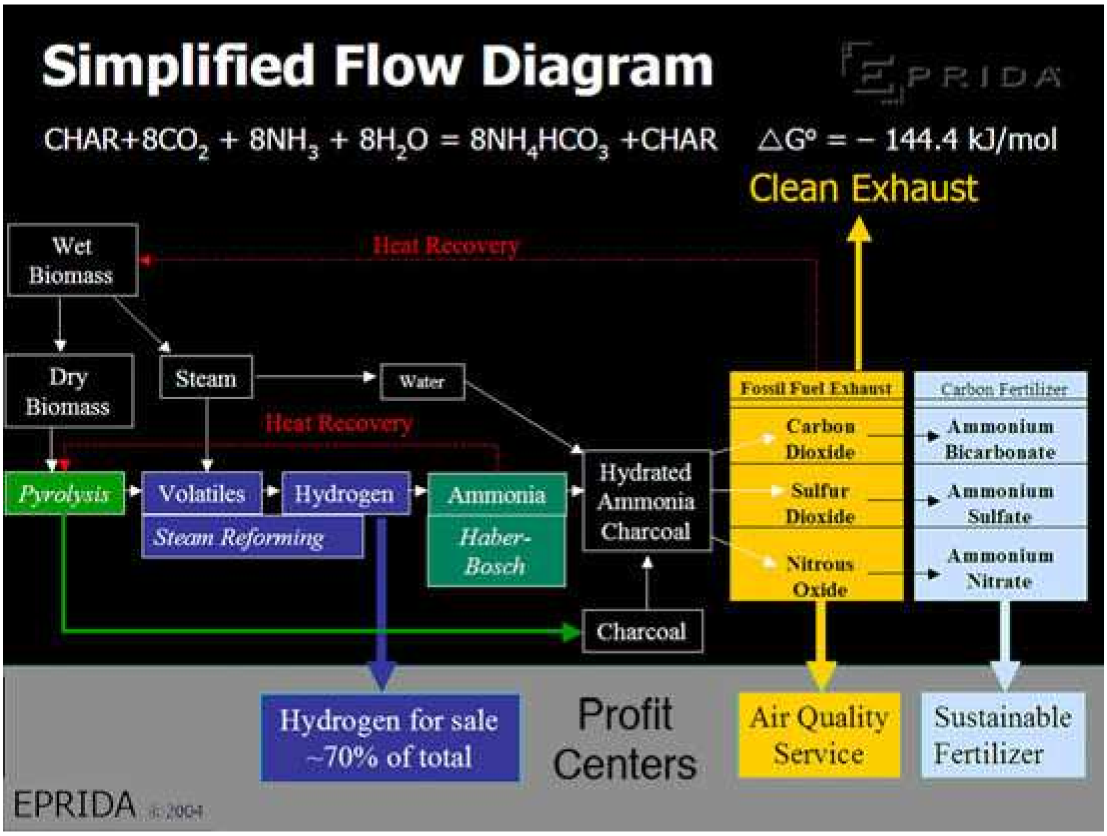

Figure 30 Biorefinery process scheme of Eprida ™ technology to produce hydrogen and ECOSS fertilizer.

Figure 31 Eprida ™ pilot line.

Iowa State University - Center for Sustainable Environmental Technologies has established a syngas fermentation program that explores hybrid thermochemical/biological processing of biomass[151]. The gaseous mixture resulting from the gasification of carbonaceous feedstocks can be fermented to various products including carboxylic acids, alcohols, esters, and hydrogen. In benchtop (10 L) trials, syngas has been converted to polyhydroxy alkanoate (PHA) biopolymers in batch fermentations using *Rhodospirillum rubrum*, a photosynthetic purple non-sulfur bacterium.
In particular, the university evaluates several types of pyrolysis systems[152]:

- Fluidized bed for fast hydrolysis, pyrolysis in less than a second (Figure 323)
- Auger reactor, as an alternative for the fluidized bed reactor which is a proven yet ‘expensive’ process because the need for an inert carrier gas like N_2
- Free Fall reactor, as an alternative for the fluidized bed reactor (Figure 334)

Together with Iowa Energy Center [153], Iowa State University has developed a thermally ballasted gasifier that uses a single reactor for both combustion and pyrolysis of switchgrass into hydrogen-rich gas. Instead of spatially separating these processes, they are temporarily isolated. The producer gas is neither diluted with nitrogen or the produces of combustion. The heat released during combustion at 850°C is sto red as latent heat in the form of molten salt sealed in tubes immersed in the fluidized bed[154].

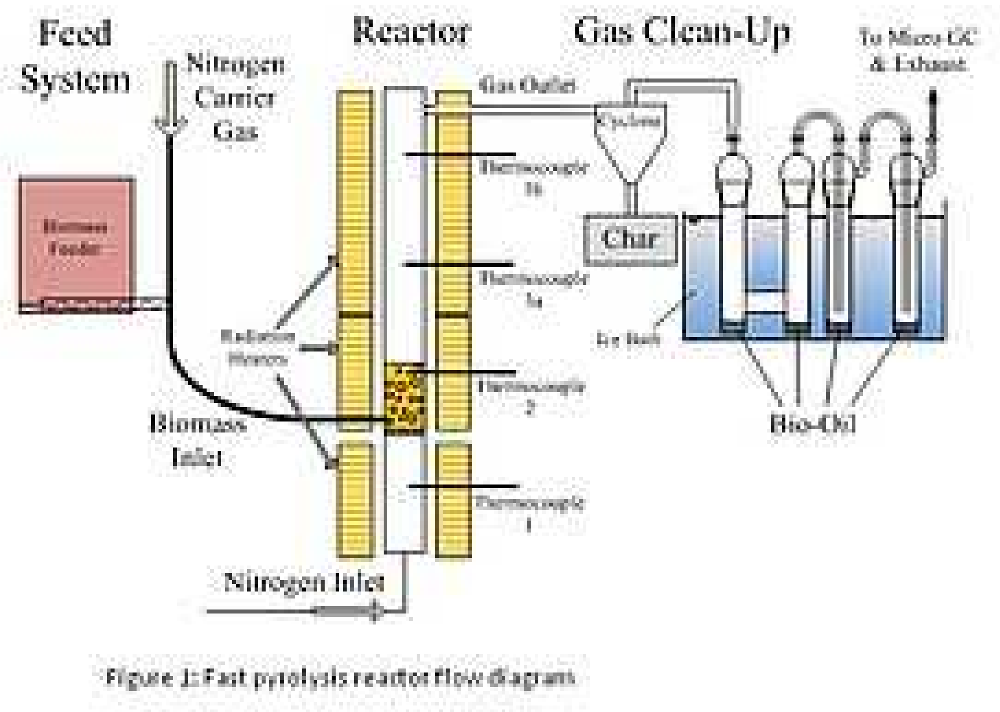

Figure 32   Scheme of fluidized bed pyrolysis reactor at Iowa State University.

[151] http://www.cset.iastate.edu/index.php?id=5817 , visited 15 July 2009
[152] http://www.cset.iastate.edu/research-projects/technoeconomics-research-summary.html, vis. 15 July 2009
[153] http://www.energy.iastate.edu/becon/ , visited 15 July 2009
[154] http://www.cset.iastate.edu/research-projects/hydrogen-from-gasification.html , visited 15 July 2009

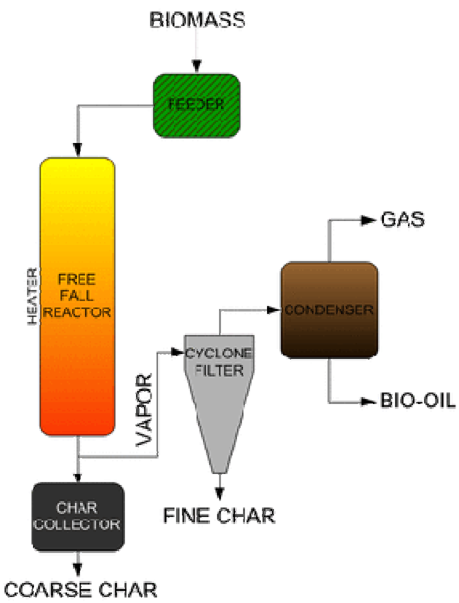

Figure 33 Scheme of Free Fall reactor at Iowa State University.

Iowa State University, in partnership with ConocoPhillips Company, will test an integrated biomass-to-liquids system that uses gas cooling through oil scrubbing rather than water scrubbing in order to minimize waste water treatment[155]. Switchgrass will be the biomass feedstock fed into the gasifier. The gas-oil scrubbing liquid will then be sent to a coker in existing petroleum refining operations to be used as a feedstock.

Iowa State University is developing an integrated system of thermochemical and catalytic technologies to efficiently produce ethanol from plant biomass[156]. Plant biomass such as corn stalks and switchgrass would be broken down by fast pyrolysis, and converted into a bio-oil, which is subsequently gasified with steam and/or oxygen into synthesis gas. The hydrogen and carbon monoxide in the synthesis gas would be reacted with a nanotechnology-based catalyst to produce ethanol fuel. The researchers use a new kind of catalyst which is based on solid nanospheres just 250 billionths of a meter in diameter that have honeycomb channels running through them. These channels can be loaded with a metallic catalyst and other species that can promote higher reactivity and product selectivity. The new technology, because of the nanoporous structure and the unique spatial arrangement of the catalytic components, solves some of the selectivity and control problems of the old chemistry. A patent application has been filed.

Iowa State University performs research on enzymatically modified soy protein adhesives[157].

Also, at Iowa State University, in 2006, a study has been financed which aimed at treating fuel ethanol with ozone and activated carbon can economically remove impurities so the alcohol can be used by the beverage industry[158].

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155 http://energy.ihs.com/News/biofuels/2007/doe-invests-biofuels-120707.htm
156 http://www.public.iastate.edu/~nscentral/news/2008/mar/syngas.shtml
157 http://74.125.77.132/search?q=cache:qUvANINbiPwJ:www.reeis.usda.gov/web/crisprojectpages/204284.html+%22Lawrence+A+Johnson%22+soy+protein+adhesives&cd=1&hl=en&ct=clnk&gl=nl, visited 23 July 2009
158 http://www.ccur.iastate.edu/newsletters/summer06/summer06.htm, visited 7 July 2009

In their only coal fired power plant, Kansai Electric Power Co, Osaka, Japan, is using up to 3% biomass pellets (Figure 345)[159]. The pellets are coming from Canada. Kansai is considering a second multi-fuel combustion system in 2010.

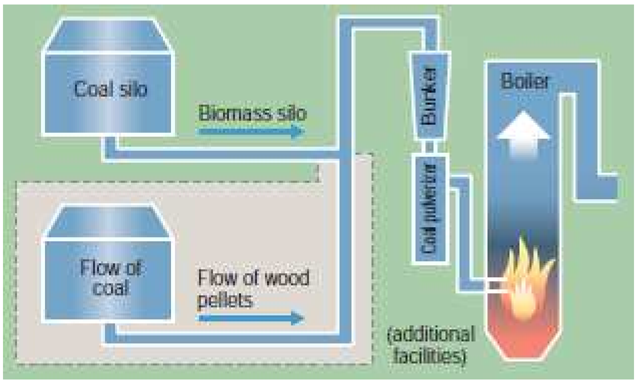

Figure 34 Scheme of co-firing of biomass in Kansai's only coal-fired plant.

At Kansas State University, research is being performed on the catalytic deoxygenation of fatty acids into alkanes and alkenes, using ZnO, alumina and zeolite ZSM-5 [160].

KL Energy Corp. (Rapid City, SD, US)[161] claims to be a world leader in biofuels technology, specializing in cellulose ethanol. The company designs plants and has their own cellulosic ethanol facilities. Input material is wood waste. The company claims to use a thermal-mechanical and enzymatic hydrolysis process, making use of virtually no acids. KL Energy is isolating the lignin from woodchips to produce high energy fuel pellets[162]. The KL process also produces a liquid co-product that contains high nutritional value for livestock, much like the syrup product from a corn ethanol plant. The liquid co-product can be used as a feed supplement for livestock in areas where corn or syrup from corn is not available.

National Renewable Energy Laboratory (NREL) (Golden, CO, US)[163] is, next to being active on the biochemical routes to convert biomass in useful products (see section 1.4.2), also developing thermochemical conversion routes (Figure 356), because the lignin-rich parts – constituting about one third of biomass weight– cannot be easily converted biochemically[164]. Focus within NREL's thermochemical conversion technologies is on syngas production and utilization, gasifier system development, and rural energy systems.

159 http://www.kepco.co.jp/english/action/pdf2008/e2008.pdf, visited 7 July 2009
160 http://aiche.confex.com/aiche/2006/preliminaryprogram/abstract_74985.htm, visited 23 July 2009
161 http://www.klprocess.com, visited 16 July 2009
162 http://www.klprocess.com/documents/energy-with-vision_000.pdf, visited 16 July 2009
163 http://www.nrel.gov/biomass/, visited 23 July 2009
164 http://www.nrel.gov/biomass/pdfs/40742.pdf, visited 23 July 2009

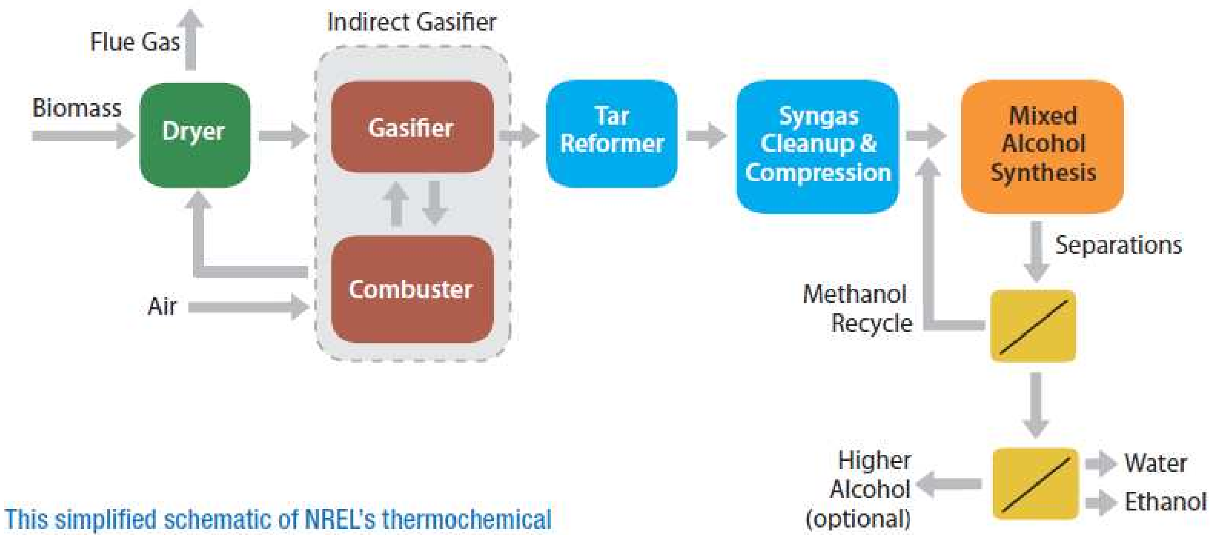

Figure 35 Simplified scheme of NRELs thermochemical conversion model.

New Planet Energy LLC was already involved in the Alico commercial scale bioethanol plant in LaBelle, Florida, US, and has taken over the lead (Alico has quit the development 2 June 2008). The intended Alico plant would produce 13.9 million gallons of ethanol per year, 6.255 kW electric power, and 8.8 tons of hydrogen and 50 tons of ammonia per day[165].
The company's website is not updated to date, however[166].

Range Fuels (Broomfield, CO, US) has invented a two-step thermo-chemical process to produce low carbon biofuels, such as cellulosic ethanol and methanol, and clean renewable energy[167]. In the first step, a broad range of biomass (including wood, grasses, and corn stover, which may be of various size and moisture content) is fed to a devolitizing unit and heat and pressure are applied to convert the biomass into gas. Energy recovered during this step and subsequent steps is used to generate power. The gas is reformed with steam into syngas, which is cleaned before entering the second step. The cleaned syngas is passed over a proprietary catalyst and transformed into cellulosic biofuels. These cellulosic biofuels can then be separated and processed to yield a variety of low carbon biofuels, such as cellulosic ethanol and methanol, which can be used to displace gasoline or diesel transportation fuels. See http://www.rangefuels.com/conversion-process.html for an animation of the process scheme. The company plans to build a commercial scale ethanol plant in Soperton (GA, US) which aims to produce 20 million gallons per year from wood and dedicated energy crops[168] [169].

At the University of Georgia (US), the faculty of engineering is developing integrated systems for the conversion of biomass to chemicals, fuels, and bio-products (Figure 223)[170]. The evaluated technologies include: pyrolysis, in particular its kinetics (07), gasification, carbon sequestering fertilizer (ECOSS, also see at Eprida in this section), and direct or co-firing with coal.

165 http://www.energy.gov/news/4827.htm
166 http://www.newplanetenergy.com/, visited 15 July 2009
167 http://www.rangefuels.com/, visited 10 July 2009
168 http://www.rangefuels.com/groundbreaking-georgia.html
169 http://domesticfuel.com/category/cellulosic/page/7/
170 www.gtsav.gatech.edu/outreach/workshop/presentations/kdas.pdf, visited 30 June 2009

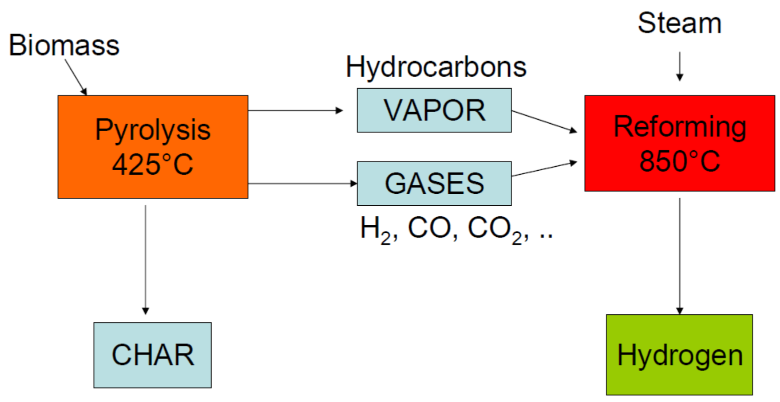

Figure 36 Scheme of pyrolysis process at University of Georgia (US).

The University of Iowa (Iowa City, IA, US)[171] is working on transformation of biomass into sugars and other compounds using subcritical and supercritical water conditions. Compounds mentioned are glucose, fructose, erythrose. Work has also started on organic acid esterfication in supercritical alcohols.

The University of Tokyo is working on the isolation of furfural from rice husk, using a membrane reactor under hydrothermal conditions[172]. Background is that under the conditions at which furfural is obtained from pentoses, also undesired secondary decomposition of the furfural occurs. The formed furfural is directly removed from the reactor by pervaporation.

1.4.4 Lignocellulosic Feedstock Biorefinery issues: Lignin platform

DOE Joint Bioenergy Institute (JBEI), one of the 3 Bioenergy Centers and located in Berkeley, CA, US, performs research to derive useful chemical products from lignin[173].

Iowa State University evaluates possibilities to convert lignin from the pyrolytic bio-oil process into valuable products. It could be separated and used as a direct precursor of gasoline-like products. The remaining water-rich carbohydrate fraction can be steam reformed over a catalyst to generate hydrogen, which could be used to catalytically upgrade the lignin products to fuels in the same centralized facility[174].

Supercritical methanol treatment by Shiro Saka (Kyoto University), which breaks down lignin into a variety of dimeric compounds.

171 http://www.energy.iastate.edu/Renewable/biomass/cs/supercriticalwater.htm, visited 23 July 2009
172 http://aiche.confex.com/aiche/2005/techprogram/P26361.HTM, visited 23 July 2009
173 http://www.jbei.org/feedstocks/people.shtml, and http://www.jbei.org/assets/docs/JBEI_Brochure_0209.pdf, visited 1 July 2009
174 http://www.cset.iastate.edu/research-projects/bio-oil-upgrading-to-hydrogen-via-steam-reforming.html, visited 15 July 2009

Virginia Polytechnic Institute and State University has presented a lignin utilization tree (08)[175].

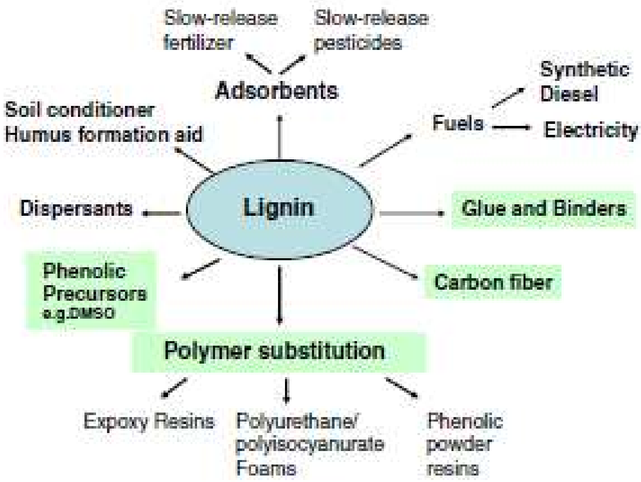

Figure 37 Lignin utilization tree.

1.5 Marine Biorefinery issues

1.5.1 Microalgae

Australian Renewable Fuels (ARF, Perth, Australia)[176] is evaluating the potential of oil production from algae, next to its running biodiesel production activities at two plants with a total of 89 million litres capacity based on used cooking oil and tallow.

Biolsystems Co Ltd (Seoul, Korea) has signed a memorandum of understanding (MoU) with the province of Bohol (Philippines) regarding a bioethanol project [177]. According to the MoU, the province of Bohol would give Biolsystems Co Ltd: 3 ha of land for aquaculture testing, 500 ha to seedling plantations and at least, and 25,000-100,000 ha to aquaculture property. Biolsystems Co Ltd would be given this over a 50 year period which may then extend for a further 25 years. The aquaculture plantation will be more of a community than an aquaculture farm and 60 ha of the total land will be made available for housing, the farm will also provide over 300 jobs for ethanol extraction with a total investment of US $100 million. Training will also be provided to locals to increase awareness and to teach the techniques of farming and drying of algae.

Catilin Inc. (Ames, IA, US)[178] claims to have developed a catalytic technique to efficiently extract algal oils without killing the organisms. A porous honeycomb system absorbs the oil and leaves the organisms. The intention is that the system will be ultimately integrated with Catilin's biodiesel catalyst[179].

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175 Y.-H. Percival Zhang, Reviving the carbohydrate economy via multi-product lignocellulosic biorefineries, J. Ind. Microbiol. Biotechnol., 35, 2008, 367-375.

176 http://www.arfuels.com.au/, visited 20 July 2009

177 http://aquaticbiofuel.com/category/2nd-generation-biofuels/, posted 18 September 2009, visited 2 December 2009

178 http://www.catilin.com/, visited 17 July 2009

179 http://www.catilin.com/news/Biodiesel_Magazine_Article_July_2009.pdf, visited 17 July 2009

National Renewable Energy Laboratory (NREL)[180] is one of the key partners in the US DOE Biomass Program and a pioneer in the area of biodiesel from algae (09)[181]. NREL focuses on cultivation and harvesting, and oil production. One of its projects aims to engineer cyanobacteria (a form of prokaryotic algae) to divert biosynthetic pathways away from glycogen synthesis and toward lipid synthesis. Cyanobacteria are not currently considered to be good candidates for high density biofuel production because they typically produce carbohydrates as storage products rather than lipids[182].
Even after a few decades of R&D work, end of 2008, DOE in collaboration with NREL and Sandia National Laboratories have organized an Algal Biofuels Workshop to identify and prioritize R&D needs for commercialization.

The workshop was to lay the framework for a roadmap by drawing upon the expertise of a carefully balanced group of invited experts in the various required disciplines: e.g., biology, systems and process engineering, modeling and analysis, algae cultivation, algal oil extraction and conversion, algal-based co-products, water and land use, and policy and regulatory issues.

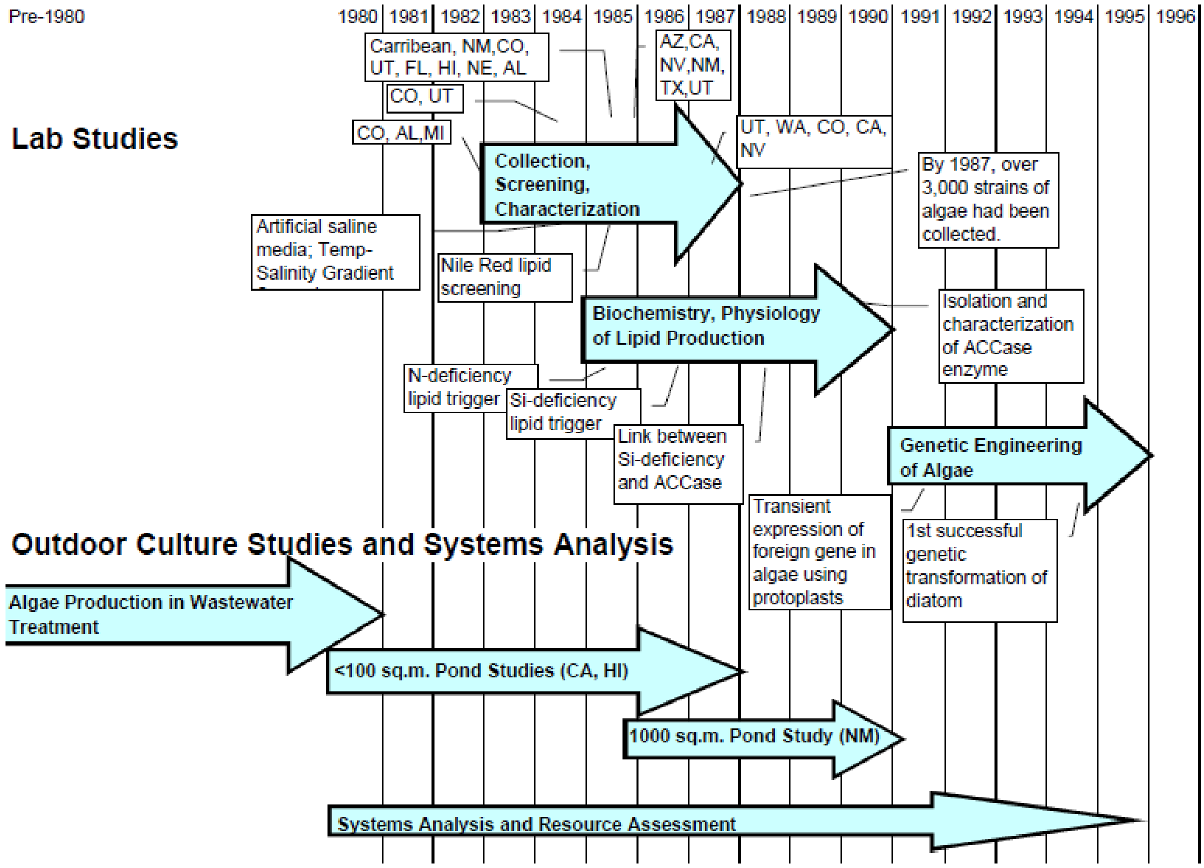

Figure 38 Algae research in the US in the period 1980-1996.

[180] http://www.nrel.gov/biomass/, visited 23 July 2009
[181] http://www.nrel.gov/docs/legosti/fy98/24190.pdf, visited 23 July 2009
[182] http://www.nrel.gov/biomass/proj_microalgae.html, visited 27 August 2009

Royal Dutch Shell and HR Biopetroleum have announced the construction of a pilot facility in Hawaii to grow marine algae and produce vegetable oil for conversion into biodiesel [183]. The companies have formed a joint venture company, called Cellana, to develop this project on the Kona coast of Hawaii Island. The site, leased from the Natural Energy Laboratory of Hawaii Authority, is planned near existing commercial algae enterprises, primarily serving the pharmaceutical and nutrition industries. The facility aims to grow only non-modified, marine microalgae species in open-air ponds using proprietary technology. Once the algae are harvested, the vegetable oil will be extracted. The facility's small production volumes will be used for testing. The companies claim that the algae can produce at least 15 times more oil per hectare than alternatives such as rape, palm, soya or jatropha. The Cellana demonstration will use bottled CO_2 to explore the potential of capturing waste CO_2 from industrial plants such as power plants.

Solazyme Inc. (Palo Alto, CA, US) focuses on marine microbes to create clean and scalable solutions for the renewable energy, industrial chemical, and specialty ingredient markets[184]. Solazyme develops microbial biofactories. Its growing patent portfolio comprises a number of patent applications in varying stages of prosecution. The applications are directed to novel genetic engineering methods, assays, and gene and protein sequences to evolve microbes to perform desired biochemical functions.

Solazyme claims to be the leader in algal synthetic biology. Solazyme's unique microbial conversion technology process allows algae to produce oil in standard industrial facilities quickly, efficiently and at large scale. These oils are tailored not only for advanced biofuel production, but also as replacements for fossil petroleum and plant oils in a diverse range of products running from green household cleaning supplies to cosmetics and foods.

The U.S. Department of Energy (DOE) has announced plans to invest up to US$4.4 million, in 2 algae projects [185]. Montana State University (Bozeman, MT, US) will partner with Utah State University to evaluate the oil content of algae cultures and identify populations that naturally have higher rates of oil production. In this project, they will test the oil producing microalgae in existing open ponds for growth characteristics and oil production and determine the optimal algae type and most efficient biorefinery design.

University of Georgia (Athens, GA, US) plans to develop novel approaches to supply nutrients to oil-producing algal systems resulting in cost-effective algae-biofuel production systems. The project aims to take advantage of the abundance of litter from the poultry industry as a source of low cost nutrients, and develop a nutrient delivery system to grow algae sustainably. Additionally, this project aims to develop process methods for the harvesting of algae from open ponds and subsequent processing to biofuels and other value added products from algae.

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183 http://www.shell.us/home/content/usa/aboutshell/media_center/news_and_press_releases/archive/2007/hawaii_cellana_121107.html, posted 11 December 2007, visited 8 December 2009.

184 http://solazyme.com/, visited 15 July 2009

185 http://www.environmental-expert.com/resulteachpressrelease.aspx?cid=29287&codi=37012, posted 11 September 2008, visited 8 December 2009

1.5.2 Macroalgae / Seaweeds

The Bio Architecture Lab (BAL, Seattle, WA, US) [186], and DuPont have secured a $9 million grant from the DOE's Advanced Research Projects Agency-Energy (ARPA-E) to examine the potential of macroalgae as feedstock for the production of biobutanol [187].

Also, Bio Architecture Lab has founded BAL Chile, and will develop a 100 ha pilot seaweed farm on the island of Chiloé. The $5 million project will include a pilot ethanol production facility that will be located in Los Lagos. BAL has developed microorganisms that ferment the algae into ethanol, and has partnered with local Chilean companies and universities on the project. The project is expected to increase to a 10,000 ha harvest area spanning the entire coastline of the country, that will produce 165 million litres of ethanol, enough to replace 5 percent of Chilean gasoline consumption [188].

Korea Institute of Industrial Technology (KITECH) has signed an agreement with the Indonesian Maritime Affairs and Fisheries Ministry to develop a biofuel derived from the abundant seaweed resource in Indonesia [189]. The agreement aims at encouraging partnerships and exchange of information and technologies among researchers and experts. Best cultivation areas are currently being looked at and these include: West Nusa Tenggara, South Sulawesi and Bangka-Belitung. For South Korea this project will contribute to the overall aim of increasing market share for renewable energies to 11 percent of its total domestic energy market by 2030.
http://www.nsti.org/Nanotech2007/sponsors.html?id=149

Pacific Norhtwest National Laboratory (PNNL, Richland, WA, US) has performed an extensive study towards the Techno-Economic Feasibility of Offshore Seaweed Farming for Bioenergy and Biobased Products [190]. The report reviews current seaweed industry, possible biobased products from seaweed, past attempts on offshore seaweed farming, seaweed biotechnology, and includes a techno-economic feasibility of offshore seaweed production and a science and technology roadmap. Foreseen production systems comprise the integrated of seaweed production in other offshore activities, like fish and wind farms (0).

Tokyo University (Marine Science and Technology), Mitsubishi Research Institute, Mitsubishi Heavy Industries and other firms (Japan) [191] have announced to envision a 10,000 square kilometre Sargasso seaweed farm at Yamototai in the middle of the Sea of Japan [192].

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186 http://www.ba-lab.com
187 http://www.biofuelsdigest.com/blog2/2009/11/26/dupont-bio-architecture-lab-secure-9-million-from-arpa-e-for-macroalgal-biofuels-rd/, posted 26 November 2009, visited 2 December 2009
188 http://en.mercopress.com/2009/11/25/future-algae-bio-fuel-production-confirmed-in-southern-chile, posted 25 November 2009, visited 2 December 2009
189 http://aquaticbiofuel.com/2009/03/12/seaweed-biofuel-in-s-korea/, posted 12 March 2009, visited 2 December 2009
190 Roesijadi G., Copping A.E., Huesemann M.H., Forster J., Benemann J.R., 'Techno-Economic Feasibility Anaysis of Offshore Seaweed Farming for Bioenergy and Biobased Products', Independent Research and Development Report, IR number PNWD-3931, Battelle Pacific Northwest Division, 31 March 2008. Sponsors: Battelle Pacific Northwest Division & Aquacopia Ventures LLC.
191 NEC Toshiba Space Systems, Mitsubishi Electric, IHI, Sumitomo Electric Industries, Shimizu Corporations, Toa Corporation, Kanto Natural Gas Development Co. Ltd., and the Japan Agency for Marine-Earth Science and Technology (JAMSTEC)
192 http://www.blogonsmog.com/motor-monday/seaweed-farms-hold-promise-for-biofuel-production.html, posted 15 June 2009, visited 2 December 2009

Seaweed is claimed to grow 10 times as fast as sugar cane. Some species are claimed to contain significant amounts of oil. The farm is estimated to produce about 20 billion litres of bioethanol per year, being one third of Japanese fuel consumption. Enzymes are used to break down the main components of the seaweed in floating reactors. An enzyme for breaking down fucoidan into sugars has been discovered already, an enzyme to break down alginic acid is still being looked for.

The conversion into ethanol will be performed at sea as well. The researchers claim to produce 10 % of ethanol from sea lettuce and 16 % from water hyacinth on dry matter basis [193].

Also the project aims at genetically modifying the algae. As an additional benefit, the researchers claim to remove some of the excess nutrient salts that flow into the sea from surrounding land masses.

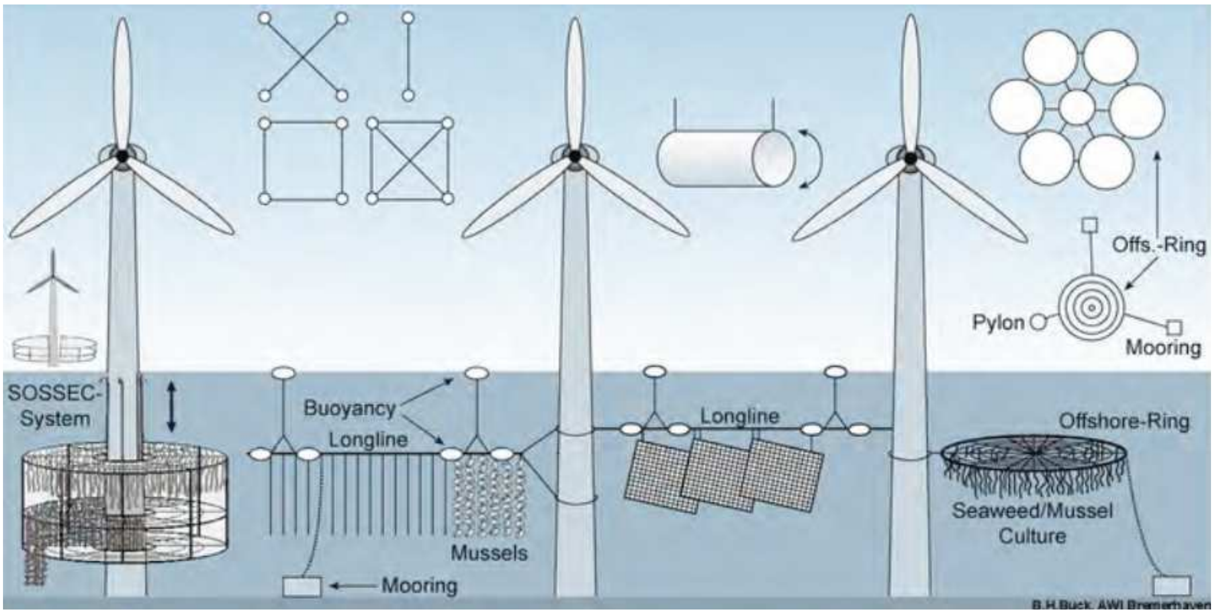

Figure 39 Scheme of integrated offshore farm (copied from Roesijadi et al., original from Buck B.H., Smetacek V., Aquafarm Roter Sand, Vol. 2007 Alfred-Wegener-Institut für Polar- und Meeresforschung, 2006).

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Bioclear (NL), Technologie-Centrum Noord-Nederland (TCCN, NL), Oosterhof Holman Milieutechniek (NL), Hogeschool Van Hall Larenstein, MaRenate (D) and D.G.A. Die Gründeragentur (D) have submitted a proposal to start research aiming at the production of compounds and energy from seaweed in the Eems Dollard region [194].

The University of Bari, Department of Chemistry and CIRCC (Italy), is evaluating the extraction of biofuels from macroalgae using supercritical CO_2 [195].

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[193] http://www.japanfs.org/en/pages/027116.html, posted 17 August 2008, visited 2 December 2009

[194] Mischa Brendel, Grondstoffen en energie uit zeewier (in Dutch), Technisch Weekblad 40 (35/36), 5 September 2009, p. 1.

[195] http://www.anl.gov/PCS/acsfuel/preprint%20archive/Files/49_1_Anaheim_03-04_0855.pdf, and http://www.anl.gov/PCS/acsfuel/preprint%20archive/Files/48_1_New%20Orleans__03-03_0469.pdf, visited 2 December 2009

The project ‘Conversion of Macro Algae to ethanol through fermentation’ considers the composition and fermentability of selected macroalgae (seaweeds) for their use as a future source of biomass for bioethanol production. This project is a collaboration between universities and research institutes throughout Great Britain and Ireland.

1.6 Other

Biosphere Technologies (Ponoka, Alberta, Canada, http://www.biorefinex.com/) has developed their patented so called BioRefinex technology, a thermal hydrolysis process for biorefining organic waste and residual materials, including animal carcasses and food waste, transforming them into safe, value-added organic fertilizers and nutrient feedstocks for anaerobic digestor biogas and green energy production. The company has built a facility that operates at 180℃ and 12 bar and can process 16,000 tonnes of waste per year [196]. The technology breaks down complex protein into amino acids and peptides and claims to inactivate prions. The potential outputs from the BioRefinex process are feedstock for anaerobic digesters, fuel for the production of syngas, feedstock for the manufacturing of organic fertilizers and safe landfill. Biosphere claims that the Bio-Refinex process is approved by several International Health & Environmental Agencies for high risk disease programs.

BP has developed a process to convert biological oils into a vehicle fuel known as 'renewable diesel' at its Bulwer Island refinery near Brisbane in Queensland, Australia [197]. To make renewable diesel, material such as animal fats rendered into tallow, or vegetable oil, are mixed with distilled crude oil prior to the mixture being heated, treated with hydrogen, and passed over a catalyst in a reactor at high temperature and pressure. Triglycerides, glycerol and fatty acids present in the biological feedstock are converted to water, propane and alkanes, respectively. The alkanes are the same as those found in conventional diesel derived from crude oil, making the renewable diesel indistinguishable from its petroleum-derived counterpart. The renewable diesel can be burned in normal diesel engines without the blending limitations experienced with biodiesel, and delivers the same performance as conventional diesel. BP intends to manufacture renewable diesel at Bulwer refinery, initially using up to 120,000 tonnes per annum of tallow rendered from beef and sheep fat. This will be blended in proportions of up to five per cent by volume with hydrocarbons distilled from crude oil, to produce the feedstock for hydrotreatment.

The Canadian Triticale Biorefinery Initiative (CTBI)[198] is a 10-year R&D program to develop triticale as a dedicated industrial biorefining crop for Canada. CBTI’s 2015 vision has significant triticale acreage grown in western Canada supplying locally established, world-scale biorefineries producing a range of products and co-products including renewable energy, platform chemicals, bio-materials and bio-composites.

30 R&D projects with six strategic priorities for triticale:

1. Competitiveness of triticale biorefining
2. Biorefining modern triticale varieties (primary manufacturing)
3. Platform chemicals (secondary manufacturing)
4. Polymers and advanced materials (tertiary manufacturing)
5. Future competitiveness of triticale crop production
6. Enabling biotechnology

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196 http://www.iafbc.ca/funding_available/programs/livestock/documents/LWTI-11_Anaerobic%20Report.pdf

197 http://www.bp.com/sectiongenericarticle.do?categoryId=9021004&contentId=7038907, visited 13 July 2009

198 http://www.ctbi.ca/, visited 17 July 2009

China Biomass Development Center is working on anaerobic digestion, including a household digester and industrial anaerobic system, for treating animal manure and waste water to produce biogas[199] [200]. No particular new developments are mentioned. The report of the first footnote refers to a 10,000 m^3/day biogas facility running on pig manure.

Highmark Renewables (Vegreville, Alberta, Canada) and Alberta Research Counsel (ARC) have developed an integrated manure utilization system (IMUS) (Figure 409)[201]. IMUS technology utilizes biogas production. This is achieved through anaerobic digestion, with adjustments to temperature, pH and the solid/liquid ratio to create optimal thermophilic bacterial growth. The IMUS process results in a shortened hydraulic retention time, over 99 % destruction of pathogens and maximization of biogas production. The process includes a power generation unit and a heat exchanger system. The system delivers waste heat to fuel the pre-digestion steps, the digester and the fertilizer production system.
The two parties are also establishing a pilot plant in China [202].

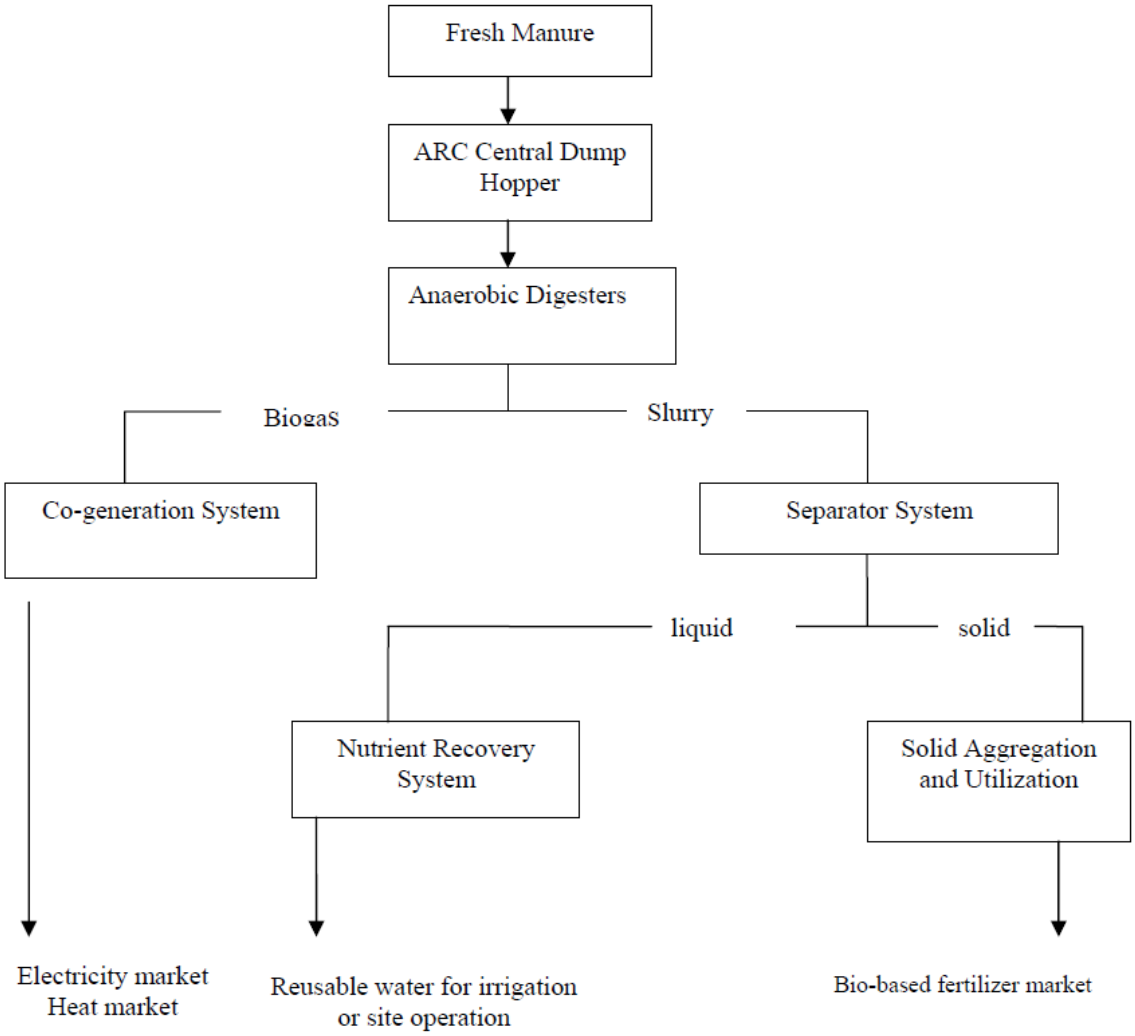

Figure 40 IMUS process scheme of Highmark[203].

[199] http://www.unescap.org/esd/energy/information/promotion/biomass_seminar/ChinaBiomass.pdf
[200] http://frankhaugwitz.com/doks/bio/2008_07_China_Biogas_USA.pdf, visited 17 July 2009
[201] http://www.aic.ca/conferences/pdf/2005/Mike_Kotelko_ENG.pdf
[202] http://www.bioscienceworld.ca/Albertaahometoinnovationandentrepreneurialspirit, visited 17 July 2009
[203] http://www.climatechangecentral.com/files/attachments/IMUS.pdf, visited 17 July 2009

Joule Biotechnologies Inc (Cambridge, MA, US) [204] claims to have developed a proprietary "platform" organism which, through photosynthesis, catalyzes the direct conversion of sunlight and CO_2 to useful fuels and chemicals. The so called Direct-to-Product™ process requires no agricultural land, crops, or fresh water. The patent-pending process, known as Helioculture™ technology, is claimed to ultimately enable multiple products, beginning with SolarEthanol™ fuel. The company claims that potentially more than 20,000 gallons of ethanol fuel and more than 13,000 gallons of diesel fuel per acre per year can be produced (187,000 litres ethanol and 121,000 litres diesel per year, respectively). The entire process, called SolarConverter™, is integrated in one system: optimizing conditions for the organisms, capturing sunlight, and converting and initially separating the product into specification fuel (Figure 41). The company claims that the modular photo-bioreactor design can easily upscaled from lab scale to wide-scale production. Interconnected assemblies can be multiplied to virtually any size based on land, CO_2 availability and desired output.

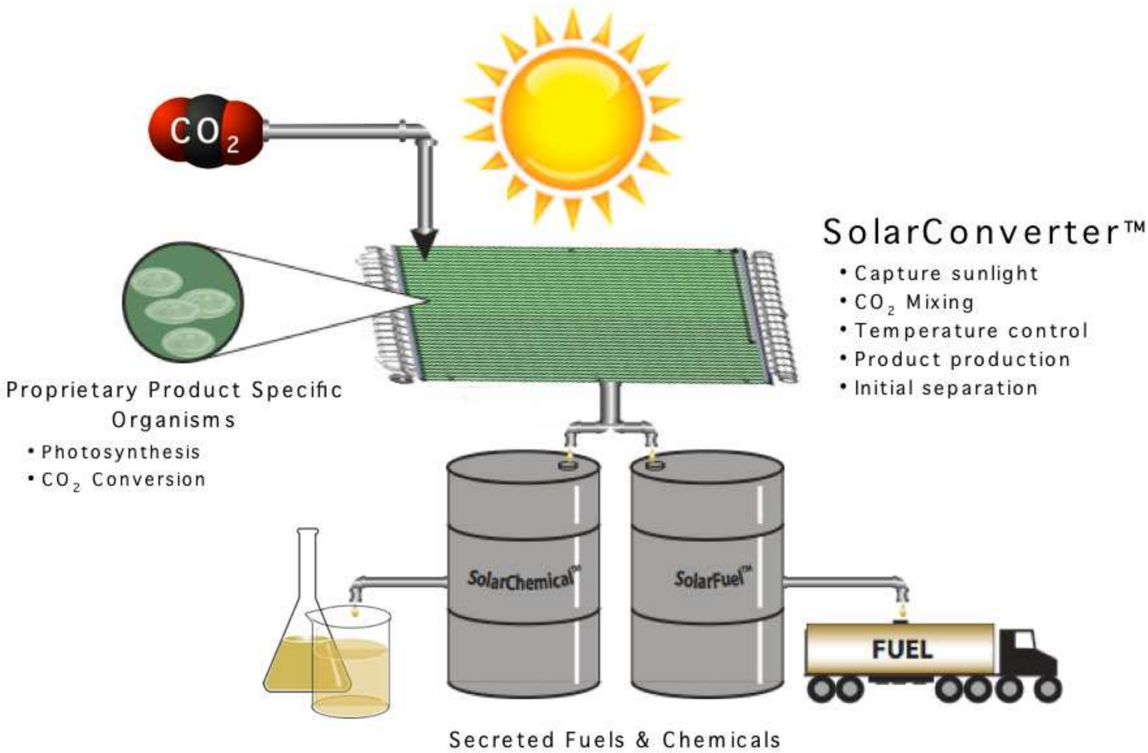

Figure 41 SolarConverter™ process scheme of Joule Biotechnologies [205].

In New Zealand, end 2008 a project has started to look at the potential to turn pig manure into energy[206]. The Pork Industry (NZPork), the Ministry of Agriculture and Forestry (MAF) and the Energy Efficiency and Conservation Authority (EECA) have joined together to launch the eight month project which will evaluate using manure in different biogas systems on farms. The project will assess up to 10 individual farm biogas systems across various regions and farm sizes and the results will be used to inform the industry of the most effective opportunities for their farms.

204 http://www.joulebio.com/contact, visited 1 September 2009
205 http://www.joulebio.com/why-solar-fuel/how-it-works, visited 1 September 2009
206 http://www.thebioenergysite.com/news/2449/nz-pork-industry-to-turn-waste-into-biogas, visited 17 July 2009

Singtex Industrial Co. (Taiwan)[207] has developed a process to make fabric out of coffee grounds, in a way which is similar to viscose production from bamboo[208]. The resulting fabric is claimed to be soft, flexible, breathable. The fibres are impregnated with activated carbon from coconut, which makes it UV-stable, wicks water away and binds sweat to eliminate unpleasant odour.

South Dakota State University evaluates the use of Ultrasound, Microwave, and ‘clean fractionation’ techniques to pre-treat biomass for biofuel production[209].

VTT Technical Research Centre of Finland[210] and Hiep Thanh Seafood JSC (Vietnam)[211] have launched ENERFISH, a three-year project concerned with producing biodiesel from the waste generated at a fish processing plant in Vietnam. To ensure the viability and rapid commercialisation of the technology, the partners are constructing a biodiesel production plant next to the Vietnamese fish processing plant Hiep Thanh Seafood JSC. The company produces 120,000 kg of fish processing waste daily. At the moment it is sold for feed industry. The other Vietnam based organisations involved in the project are ECC - Energy Conservation Center for Ho Chi Minh City, RCEE Energy and Environment JSC and AFI-Industry JSC.

A number of jatropha-biodiesel plants have been announced for implementation in India, Nigeria, and Ghana. US technology company Thar Technologies Inc has announced to establish a biodiesel plant in Rajasthan, India[212]. The main source of the biodiesel - jatropha and karanj - is extensively grown in Rajasthan. The company has recently received a $1.9 million US federal Advanced Technology Programme (ATP) grant for development of a biodiesel production process in southwestern Pennsylvania.
Food for All International (FFAI) and Center for Jatropha Promotion and Biofuels have joined forces to produce biofuels from Jatropha in Nigeria[213].
Norwegian biofuels firm ScanFuel has established a project to produce 5,000 barrels per day of crude oil equivalent of biodiesel by 2015 in Ghana early in 2009 [214]. ScanFuel's operation, based outside Ghana's second largest city of Kumasi, will initially see 10,000 hectares planted with the high oil-yielding jatropha plant, with another 10,000 hectares reserved for food production, according to a report in The Guardian.

Malaysian energy company Tenaga National Bhd (TNB) is to take part in a 10MW Jengka biomass power project in Pahang under the small renewable energy power programme (SREP) launched by the Government to promote the use of renewable energy in power generation[215]. The project aims to use palm oil empty fruit bunches as main source of fuel. The company has joined forces with Felda Palm Industries Sdn Bhd (FPI) and Electric Power Development Co. constructs the power plant. TNB will have 24.5 per cent of the JV Company, while FPI and Electric Power Development will have for 51 per cent and 24.5 per cent respectively.

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207 http://www.singtex.com/competition-04.aspx?pid=P_00000001&pname=S.Café%20tm, visited 1 September 2009
208 http://www.guardian.co.uk/lifeandstyle/2009/jul/27/clothes-coffee, visited 1 September 2009
209 http://biorefinery.fh-flensburg.de/fileadmin/dokumente/Julson.pdf, visited 23 July 2009
210 http://www.vtt.fi/uutta/2008/25112008_enerfish.jsp?lang=en, visited 17 July 2009
211 http://www.hiepthanhgroup.com/index.php
212 http://www.thebioenergysite.com/news/2443/us-company-to-set-up-biodiesel-plant-in-india, visited 27 August 2009
213 http://www.thebioenergysite.com/news/2441/biofuel-deal-in-nigeria, visited 27 August 2009
214 http://africanagriculture.blogspot.com/2008/11/norwegian-biofuels-firm-to-start.html, visited 27 August 2009
215 http://www.thebioenergysite.com/news/2436/10mw-jengka-biomass-project-planned, visited 27 August 2009

Some initiatives in EUROPE:

BioMCN (Delfzijl, NL) transforms glycerine into methanol[216].

BTG Bioliquids (Hengelo, NL) plans the construction of a 5 ton/h biomass pyrolysis facility, which is claimed to become the largest in the world[217]. The temperature in the low oxygen reactor will be around 550℃. The energy content of the produced oil is 60 – 70% of the input biomass energy.

Eindhoven University of Technology (NL) has transformed used frying oil into biodiesel. Using methanol and supercritical process conditions at 300℃ and 150 bar pressure, transesterification occurs within about 10 minutes. The biodiesel is claimed to be 99.9% methylesther, whereas the byproduct glycerol is claimed to have 96.4% purity[218].

Naturgas Energia (Bilbao, Spain) has announced a project to remove CO_2 from biogas by flowing it through a basin for algae production[219]. Ingrepro (NL) is involved in this project for providing know how related to algae production, GtS (Bergambacht, NL) provides a cryogenic gas treatment system for this project.

Waste2Tricity (London, UK) intends to treat MSW with plasma in order to optimize energy recovery[220].

Wageningen University and Research centre (WUR, Wageningen, NL) together with the Energy research Centre of the Netherlands (ECN, Petten, NL), and a variety of national (industrial) stakeholders, in 2009 prepared a Dutch Biorefinery Roadmap, including major issues on biorefinery-related R&D, pilot plant research, and demonstrations, necessary to bring biorefineries, including biofuel-driven biorefineries, to the market, based on the specific strengths available in the Netherlands[221].

[216] Technisch Weekblad, 40 (12), page 3, 21 March 2009 & http://www.biomcn.eu
[217] De Ingenieur, 7, page 12, 1 May 2009 & http://www.btg-btl.com/about.html
[218] Technisch Weekblad, 40 (11), page 5, 14 March 2009
[219] Technisch Weekblad, 40 (30), page 3, 25 July 2009
[220] Technisch Weekblad, 40 (26), page 3, 27 June 2009 & http://waste2tricity.com
[221] Http://www.senternovem.nl/mmfiles/Dutch%20Roadmap%20Biorefinery_tcm24-319385.pdf

2. Biorefinery Info from IEA Bioenergy – Task 3.2

2.1 Introduction on IEA and IEA Bioenergy

The International Energy Agency (IEA) was established in November 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. It carries out a comprehensive programme of energy cooperation among OECD member countries. Its aims include to promote: systems for coping with oil supply disruptions, rational energy policies, an oil market information system, improved energy supply and demand structures, and integrated environmental and energy policies. In recent years we have seen the first steps into the transition towards a Bio-based Economy. Multiple drivers, some policy and geographically dependent, are steering an economy where material wastes are minimized, new bioproducts are replacing their fossil counterparts, Green House Gas (GHG) emissions are reduced; while economic perspectives are developed supported by innovative policies. The recent extreme volatilities in prices (fossil oil, biomass raw materials) and strongly fluctuating demand ask for robust systems to be competitive in the long run. An economy based on innovative and cost-efficient use of biomass for the production of food, feed, bioenergy and bio-based products should be driven by well developed integrated biorefining systems.

IEA Bioenergy was set up in 1978 by the International Energy Agency (IEA) with the aim of improving cooperation and information exchange between countries implementing programmes for bioenergy research, development and deployment. Presently there are 13 Tasks operating under the IEA Bioenergy umbrella covering all major aspects of the bioenergy field.

The relevance of biorefinery in a successful bioenergy research policy has been acknowledged by the establishment of a specific IEA Bioenergy Task 42 on biorefineries, co-producing transportation fuels, power, heat, added-value chemicals and materials from biomass. The major objective of this Task is to assess the worldwide position and potential of the biorefinery concept, and to gather new insights that will indicate the possibilities for new competitive, sustainable, safe and eco-efficient processing routes for the simultaneous manufacture of transportation fuels, added value chemicals, new materials and heat and power from biomass. This Task covers an exciting field which can have a large impact both in environmental and technological innovation policies and practices. To open up the biorefinery related potential, system and technology development is required. RD&D programmes can link industry, research institutes, universities, governmental bodies and NGOs, while market introduction strategies need to be developed.

2.2 IEA Bioenergy Task42 on Biorefinery

In its first triennium (2007 – 2009) the following countries were participating in Task42:

- Founding members: Austria, Canada, Denmark, EU, France, Germany, Ireland, the Netherlands (coord.) (8)
- Others: Australia, Italy (2)

In the second triennium (2010 – 2012) also the following countries decided to join this Task: United Kingdom, USA, Turkey, bringing the total amount of participating countries to 13; whereas Belgium still has to decide to participate or not.

2.2.1 Major Outputs First Triennium (2007 – 2009)

Major outputs of Task 42 in its first triennium (2007-2009) are:

1. Biorefinery definition and biorefinery classification system
2. Country reports describing and mapping current processing potential of existing biorefineries in the participating countries, and assessment of biorefinery-related RD&D programmes to help national governments defining their national biorefinery policy goals and related programmes.
3. Bringing together key stakeholders (industry, policy, NGOs, research) normally operating in different market sectors (e.g., transportation fuels, chemicals, energy, etc.) in multi-disciplinary partnerships to discuss common biorefinery-related topics, to foster necessary RD&D trajectories, and to accelerate the deployment of developed technologies.

Since its onset, Task 42 has been focusing on defining biorefinery technology while assessing its potential contribution to a more sustainable and profitable production, bringing together actors in the field of science, policy and industry. A number of meetings have been held and platforms were established. Further, to inform the public and enhance national inventories and research and implementation programmes, workshops on biorefinery have been held in Austria, Canada, Ireland and the Netherlands.

The aim of IEA Bioenergy Task 42 is to initiate and actively promote the information exchange on all features of the biorefinery concept. The information exchange and cross fertilization will concern any aspect of the biomass feedstock, the conversion and fractionation technologies, the integration of processes and use of side-streams, the products, the energy efficiency; the economic, socio-economic and environmental performance as well as other sustainability issues (impacts on food production schemes, impact on water use and quality, changes in land-use, access to resources, impact on biodiversity, and the net balance of greenhouse gases). This exchange of information should minimize fragmentation in this multidisciplinary field. It will also result in cross-thematic synergies, identifying gaps and overlaps, defining research priority needs and infrastructure.

<u>1.1 Definition</u>
Biorefining is the sustainable processing of biomass into a spectrum of bio-based products (food, feed, chemicals, materials) and bioenergy (biofuels, power and/or heat).

Both **product-driven biorefineries** and **energy-driven biorefineries** are distinguished. In product-driven biorefineries the biomass is fractionised into a portfolio of bio-based products with maximal added-value and minimal ecological impact, after which the process residues are used for power and/or heat production, for both internal use and selling of the surplus to national grids. In energy-driven biorefineries the biomass is primarily used for the production of secondary energy carriers (biofuels, power and/or heat); process residues are sold as feed (current situation), or even better are upgraded to added-value bio-based products, to optimize economics and ecologics of the full biomass supply chain.

<u>1.2 Classification System</u>
At present, biorefineries are classified based on, technological (implementation) status, type of raw materials used or main type of conversion processes applied. A proper and clear classification is still lacking for the moment.

A search of the literature revealed a variety of terms describing biorefineries:

- Conventional Biorefineries
- Advanced Biorefineries
- First, Second, and Third Generation Biorefineries
- Green Biorefineries
- Whole Crop Biorefineries
- Ligno Cellulosic Feedstock Biorefineries
- Two Platform Concept Biorefineries
- Thermo Chemical Biorefineries
- Marine Biorefineries

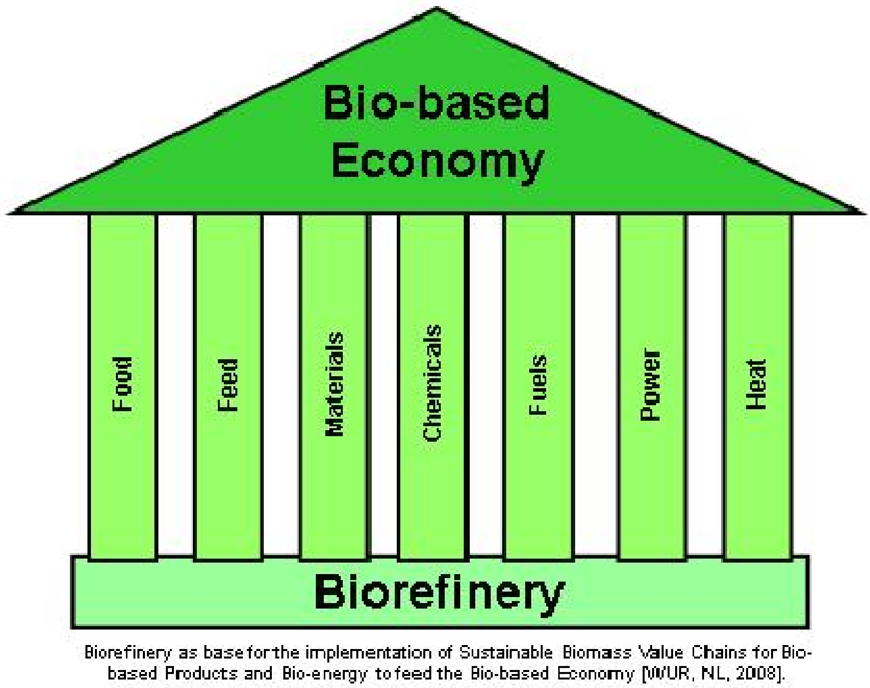


Figure 42 Biorefinery Base for a Future Bio-based Economy.

Task 42 has developed a more appropriate biorefinery classification system. This classification system is based on a schematic representation of full biomass to end products chains. The distinguishing features of the biorefinery are based upon, raw materials, primary conversion processes, main biomass constituents (carbohydrates, lignin, proteins, fats), secondary conversion processes, platform intermediates (C5-sugars, C6-sugars, syngas, oil), conversion processes, and end-products. The biorefinery processes/concepts can be classified utilising an example system (Figure 43).

The current main driver in biorefinery development, i.e. efficient and cost effective production of transportation biofuels, is to increase the biofuel share in the transportation sector, while the co-produced bio-based products provide additional economic and environmental benefits. IEA Task 42's approach to biorefinery classification considers four main features which are able to identify, classify and describe the different biorefinery systems, viz: platforms, products, feedstocks, and conversion processes. The platforms (e.g. C5/C6 sugars, syngas, biogas, etc.) are intermediates which are able to connect different biorefinery systems and their processes. The number of involved platforms is an indication of the system complexity. The two biorefinery product groups are energy products (e.g. bioethanol, biodiesel, and synthetic biofuels) and material products (e.g. chemicals, materials, food and feed). Feedstocks can be grouped as either energy crops from agriculture (e.g. starch crops, short rotation forestry) or biomass residues from agriculture, forestry, trade and industry (e.g. straw, bark, used cooking oils, waste streams from biomass processing). Concerning conversion processes, the classification system identifies four main groups, including: biochemical (e.g. fermentation, enzymatic conversion), thermo-chemical (e.g. gasification, pyrolysis), chemical (e.g. acid hydrolysis, synthesis, esterification) and mechanical processes (e.g. fractionation, pressing, size reduction). The biorefinery systems are classified by quoting the involved platforms, products, feedstocks and – if necessary – the processes. Some examples of classifications are:

- ´C6 sugar platform biorefinery for bioethanol and animal feed from starch crops´
- ´Syngas platform biorefinery for FT-diesel and phenols from straw´
- ´C6 & C5 sugar and syngas platform biorefinery for bioethanol, FT-diesel and furfural from saw mill residues´

An overview of current platforms, products, feedstocks and conversion processes is given in Figure 43. This system is expected to evolve as new technologies are developed, and additional platforms are defined.

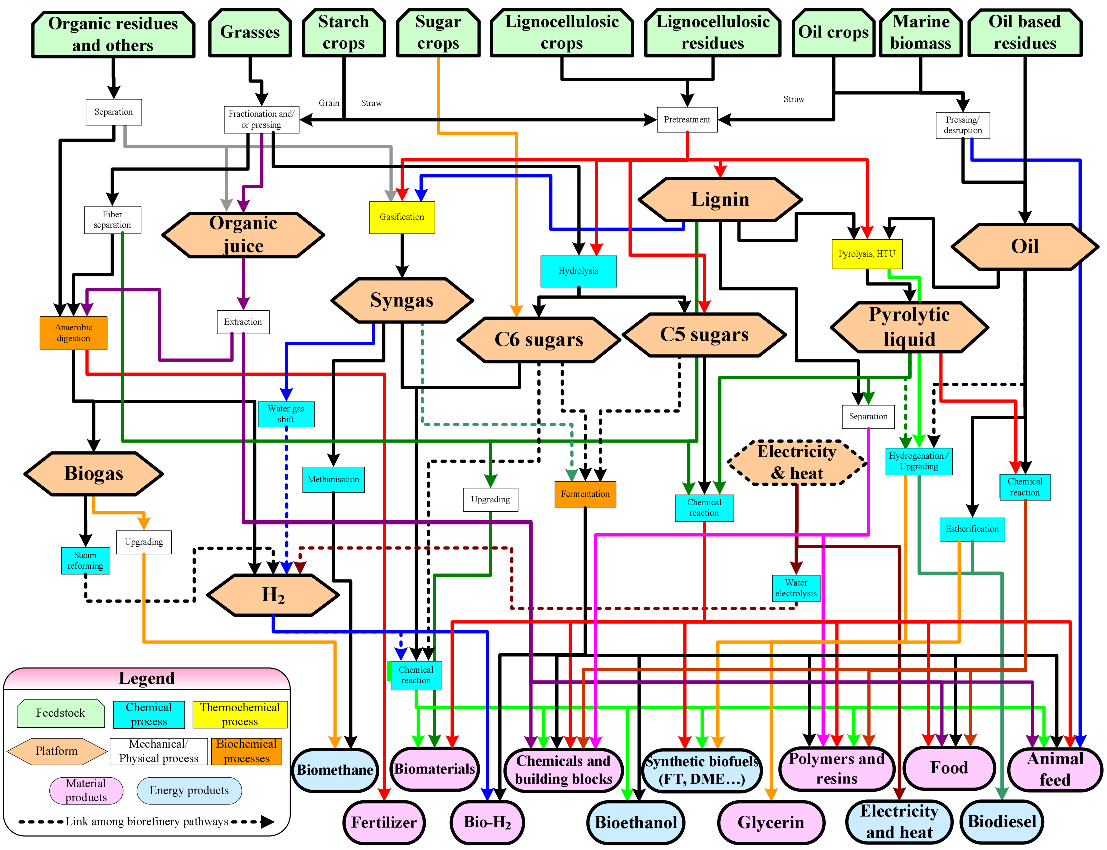


Figure 43 Network where the individual biorefinery systems are combined.

2. Country Reports

For the Task founding countries Austria, Canada, Denmark, France, Germany, Ireland, and the Netherlands so called “Country Reports” have been prepared with the following content per country:

- National biomass energy use
- Non energy national biomass use
- Biomass related national policy goals
- National oil refineries
- Bioethanol, biodiesel and biogas: production and capacity
- Existing biorefinery industries
- Pilot and demonstration plants
- Activities of research and development (national projects and stakeholders)
- National Task Leaders

The country reports are integrated in one Task Report. This report can be downloaded from the IEA Bioenergy Task 42 website: www.IEA-Bioenergy.Task42-Biorefineries.com.

A selection of biorefinery pilot and demo facilities in the partner countries can be found in Table 3.

3. Stakeholder Meetings

Workshops on biorefinery issues have been held in Austria, Canada, Ireland, the Netherlands, and Germany. The presentations given by mostly industrial stakeholders can be found at the IEA Bioenergy Task 42 website: www.IEA-Bioenergy.Task42-Biorefineries.com.

Table 3. Overview Biorefinery pilot and demo facilities in partner countries (selection)

Name	Feedstock	Products	Description (oa technology, capacity, status)	Classification	Info (contact person incl. phone and/or e-mail adress and/or website)
Austria					
Green Biorefinery Upper Austria	Grass/clover/ lucerne silage	Amino acids mixtures, lactic acid, biogas, fertilizer	Separation of lactic acid and amino acid mixtures out of silage juice by applying a combination of different separation technologies (nano-filtration, electro dialysis and ion exchange). Utilization of press cake for generating biogas; Demonstration scale (1t/h silage feed input)	Biogas and organic solution biorefinery	Dr. Horst Steinmüller steinmueller@energieinstitut-linz.at; Tel +43-732-2468-5656 Dr. Michael Mandl michael.mandl@joanneum.at Tel +43 316- 8762950
Canada					
Iogen Corporation demonstration plant Ottawa	Straw	Cellulosic ethanol, electricity, lignin	Fractionation, enzymatic hydrolysis and ethanol fermentation Began in 2004 30 tonnes/day feedstock and 2 million litres of ethanol per year	C6/C5 sugars and lignin biorefinery for bioethanol and chemicals	http://www.iogen.ca/ info@Iogen.ca
Lignol Innovations Corporation pilot plant	Wood, straw	Cellulosic ethanol, lignin, acetic acid, furfural and xylose	Organosolv-based fractionation and hydrolysis, enzymatic saccharification and fermentation	C6/C5 sugars and lignin biorefinery for bioethanol, chemicals and biomaterials	http://www.lignol.ca/ info@lignol.ca
Enerkem Westbury Industrial Demonstration Plant	Decommissioned electrical poles, forest residues,selected MSW	Second generation ethanol, green chemicals, such as: methanol, acetic acid and acetates	Gasification and catalytic synthesis Operating since 2009 Ethanol capacity of 5 million litres	Syngas biorefinery for second generation ethanol and green chemicals	http://www.enerkem.com westbury@enerkem.com
Enerkem Sherbrooke Pilot Plant and Research Facility	Tested 20 different feedstocks such as MSW, forest residues, straw, spent plastics construction and demolition wood, treated wood	Second-generation ethanol, syngas, and methanol	Gasification and catalytic synthesis Operating since 2003 Ethanol capacity of 475,000 litres	Syngas biorefinery for second generation ethanol and green chemicals	http://www.enerkem.com sherbrooke@enerkem.com
Syntec Biofuels Inc.	Wood, energy crops, agriculture residues	Ethanol, methanol, n-butanol and n-propanol	Gasification and catalytic synthesis and steam reforming – Syntac B2A technology	Syngas biorefinery for second generation ethanol and green chemicals	http://www.syntecbiofuel.com Tel + 604-648-2092

Denmark					
Inbicon Pilot and Demo Facility	Straw and other agricultural residues	Ethanol, feed (C5-molasses), heat and power, solid biofuel	Pilot facility based on biochemical conversion. Input 1 t/h. Start-up 2004. Demonstration plant under construction (start-up end 2009). Input 30,000 t/yr, output 4,300 t/yr of ethanol.	C6/C5 sugar and lignin platform biorefinery for bioethanol, animal feed, heat and power from lignocellulosic residues	http://www.inbicon.com miper@dongenergy.dk
Maxiflex Pilot Facility	Straw and other lignocellulosic residues	Ethanol, biogas, solid biofuel, fertilizer	Pilot facility based on biochemical conversion. Input 0.5 t/h and output 40 l/d of ethanol. Start-up 01.09.2009	C6/C5 sugar and lignin platform biorefinery for bioethanol, biogas, solid fuel and fertilizer from lignocellulosic residues	http://www.biogasol.com rsp@biogasol.com
France					
SICA Atlantique Demonstration Plant	Rapeseed, ethanol	FAEE	Fatty Acid Ethyl Esters demo plant (10 000 t/y), to be started - end of May		
Solvay Demonstration Plant	Glycerol	Epichlorhydrine	ECH production 10 000 t/y from biodiesel residue glycerol		
BioAmber (ARD-DNP) Demonstration Plant	Glucose	Succinic acid	To be started		http://www.bio-amber.com/
Futurol (Procethol 2G) R&D/Pilot Plant	Lignocellulose	Ethanol			
Germany					
CHOREN Industries GmbH, Freiberg	Wood	FT/BtL-biofuels	Carbo-V process, feedstock pre-treatment, gasification, FT-synthesis, BtL 15.000 t/a (sundiesel) demo plant	Wood-Biorefinery	Dr. Ines Bila Tel. +49 (0) 3731 2662 226 Ines.Bilas@choren.com www.Choren.de
Green Biorefinery Havelland	Alfalfa and wild mix grass	High valuable proteins, amino acids, lactic acid, fodder	Green biorefinery (30kt/yr): production of green juice for high valuable proteins and lactic acid, demo plant, scheduled in 2009	Green Biorefinery	biopos e.V. Teltow Tel. +49 (0) 3328-3322-10 kamm@biopos.de, web: www.biopos.de
Emsland-Stärke GmbH, Wietzendorf	Potato starch, biomass	Integrated unit for bioproducts and bioenergy	Private, Public (federal funding)), demonstration & commercial	Whole crop biorefinery	Uwe Hildebrand Tel +49 (0) 51969880-0

Netherlands					
Core Bio-MCN/ Biorefinery Cluster	Glycerol, solid lignocellulosic biomass	Biomethanol, biodiesel, bio-DME, biogas, biopower	200 kt/yr biomethanol demo-plant under construction (commissioning in 2009) – gasification and catalytic syngas technology; future capacity expansion to 1-2 Mt expected, incl. the production of more diverse bio-based energy carriers	Syngas biorefinery for biomethanol and other biofuels from glycerol and lignocellulosic biomass	http://www.biomcn.nl http://www.groningen-seaports.com
Cargill/Nedalco Sas van Gent	Wheat, corn	Food ingredients (starches, starch derivates, wheat proteins, glucose), bioethanol	1st-generation bioethanol plant: 2.2 Ml/a (2005); 2nd-generation demo bioethanol plant converting xylose to bioethanol: 2.0 Ml/a (end 2008)	C6/C5 sugar platform biorefinery for food ingredients and bioethanol from wheat and corn	www.nedalco.com
Greenmills – Port of Amsterdam	Used vegetable oils, greases, other organic biodegradable residues	Biodiesel, glycerine, biogas, bioethanol, compost	Integrated demo production of 200 Ml/a biodiesel, 10 MW_e power, 25 Mm^3/a biogas	Bio-oil and C5/C6 sugar biorefinery for biodiesel, bioethanol, biogas, power and heat from organic residues	www.greenmills.nl
ECN MILENA and PATRIG Pilot facilities	Lignocellulosic biomass (e.g., wood, agricultural residues)	MILENA: methane rich product gas PATRIG: torrified biomass	MILENA: indirect gasification (800 kW_{th}), operating since 2007, with OLGA it produces tars, methane, ethylene, benzene. PATRIG: 50-100 kg/h torrefaction plant based on novel moving-bed technology, operating since early 2008	Syngas and torrified wood biorefinery for biofuels (ao SNG), chemicals, power and heat from lignocellulosic biomass	MILENA: Bram van der Drift vanderdrift@ecn.nl PATRIG: Jaap Kiel kiel@ecn.nl

2.2.2 Activity Plan Second Triennium (2010 – 2012)

Three events per year for this Task are foreseen. Two of these events will normally be a combination of an open workshop for national industrial, governmental, NG and knowledge stakeholders, and a meeting of the Task members, organised in one of the participating countries. The other one will be an annual IEA Biorefinery Seminar coupled to an international biorefinery event (conference, workshop). This Seminar preferably will be organised together with other IEA Bioenergy Tasks, for example Task 39. During this Seminar information on concrete projects and implementations will be exchanged. The events will potentially be coupled to specific site visits, further increasing the knowledge transfer. To minimize long-distance travelling, and to receive as many as stakeholders as possible, the use of video conferencing will be encouraged. In between, Task Management and country representatives will prepare necessary documents, and maintain a website. The emphasis on specific objectives and preferences for assessments can only be fixed once there is certainty about participating countries and their stakeholders, especially interested industrial parties.

Initially, the following activities are identified:

1. Developing a **biorefinery complexity index**, similar to what they use in the petroleum industry (Nelson complexity index), based on the Classification System. The Classification System developed in the 2007 – 2009 period will be further extended and fine-tuned in the 2010 – 2012 period.
2. Identifying the most promising **bio-based products** – i.e. food, feed, added-value materials (a.o. fibre-based) and chemicals (functionalised chemicals and platform chemicals (building blocks)) **to be co-produced with bioenergy**, to maximise overall process economics and environmental benefits. The identification will include a rough estimation on current/future market volumes and prices. Market protection issues will be part of the assessment.
3. Assessing the **current status and development potential** of both **Energy-driven Biorefineries (incl. biofuels) and Product-driven Biorefineries.** These assessments will be based on a **Full Value Chain approach**, covering raw materials issues (crops, residues, algae, ...), conversion processes, and final product applications in an integrated approach. Primary production and logistics of the biomass will be an integral part of the assessments performed. Concerning Biofuel-driven Biorefineries, this activity will be performed in close co-operation with IEA Bioenergy Tasks 33, 34 and 39, and IEA Advanced Motor Fuels (a.o. algae-based biorefineries). The assessments will cover the following activities:
   - Identification of 10 – 15 of the most interesting biorefinery Value Chains (1-2 per country), including the integration/deployment options in existing industrial infrastructures .
   - Integration of these Value Chains in the Classification System.
   - Assessment of Full Value Chains (technically, economically, environmentally, and socially).
   - Performing national case studies. Financing opportunities (funding possibilities, venture capatilists, ...) will be part of the case studies.
   - Presentation of the main results in a brochure.
4. Providing a review of approaches and developing a guidance document for **sustainability assessment**, including economic, environmental and social acceptance aspects of biorefineries. National activities / case studies in Participating Countries will be taken as point-of-departure for methodology development and the assessment. This activity will be performed in close co-operation with IEA Bioenergy Tasks 29 and 38.

5. Preparing a **Summarizing Paper** concerning ‘Adding Value to the Sustainable Utilisation of Biomass on a Global Scale – Biorefinery’. Recommendations given in this paper on biorefinery-related technical, social, environmental, and economic issues, can be used by a.o. national/international governmental organisations for their policy developments.
6. **Disseminating biorefinery knowledge**
   - Between Participating Countries by the organisation of **bi-annual Task Meetings, workshops** inviting national stakeholders, and **visits to running pilot/demo and commercial facilities**. To limit the travelling effort of the country representatives, and to promote knowledge dissemination to national stakeholders, the use of video conferences will be promoted. Part of the internal bi-annual Task Meetings will be to inform each other of the specific biorefinery-related activities of the country representative organisations.
   - Between Task 42 and other related IEA Tasks (a.o. Task 39), and Task 42 and European, Canadian and Australian Technology Platforms (Suschem, Sustainable Forestry, Biofuels, ...) by organising **joint stakeholder workshops/seminars** addressing biorefinery issues. These activities preferably will be aligned with international biorefinery events.
   - Between National Task Representatives and their national stakeholders by inviting them to bi-annual Task Meeting related workshops, and informing one another on the latest developments within the biorefinery field (minutes bi-annual Task Meetings, newsletters).
   - External knowledge dissemination in general will be done by: i) set-up and management of the **Task website**, including linkage to many other national/international websites, and ii) preparation and distribution of a **Task newsletter** (at least 2 times a year). Part of the Task website will be an **open database with key data** concerning biorefinery pilot, demo and commercial plants within the Participating Countries (and abroad), **short films** showing the biorefinery field to the general public, a **focussed dialogue forum** to discuss biorefinery-related issues, and a **list of biorefinery-related publications**.
   - Internal knowledge dissemination will be done by means of a **protected intranet-site** coupled to the Task website.
   - **Stakeholder Forum Function**: Bringing together key stakeholders normally operating in different market sectors (e.g., agriculture and forestry, transportation fuels, chemicals, energy, etc.) in multi-disciplinary partnerships to discuss common biorefinery-related topics, to foster necessary RD&D trajectories, and to accelerate the deployment of developed technologies.
7. Update of the **Country Reports on Biorefinery Mapping and Biorefinery-related RD&D Programmes** to help national governments to define their national biorefinery policy goals and related programmes.
8. Developing and delivering a broad **Biorefinery Training Course** to enable students, policy makers and industrial stakeholders to become familiar with the integral concept-thinking of biorefineries. This course, covering general biorefinery aspects and dealing with a variety of more concept specific issues, will be organised minimally once during this three-year period in one of the participating countries, and potentially be made available for E-learning.

The activities are closely linked to existing national programmes, so the larger part of the budget has to be allocated from these national initiatives. About 30% of the Task budget will be available for specific activities, not covered in the national programmes.

2.3 Other related IEA Bioenergy Tasks

Besides Task 42, also in some of the other IEA Bioenergy Tasks deal with the issue of Biorefining. These Tasks are shown schematically in Figure 44, showing the central role of Task 42 within the overall IEA Bioenergy framework.

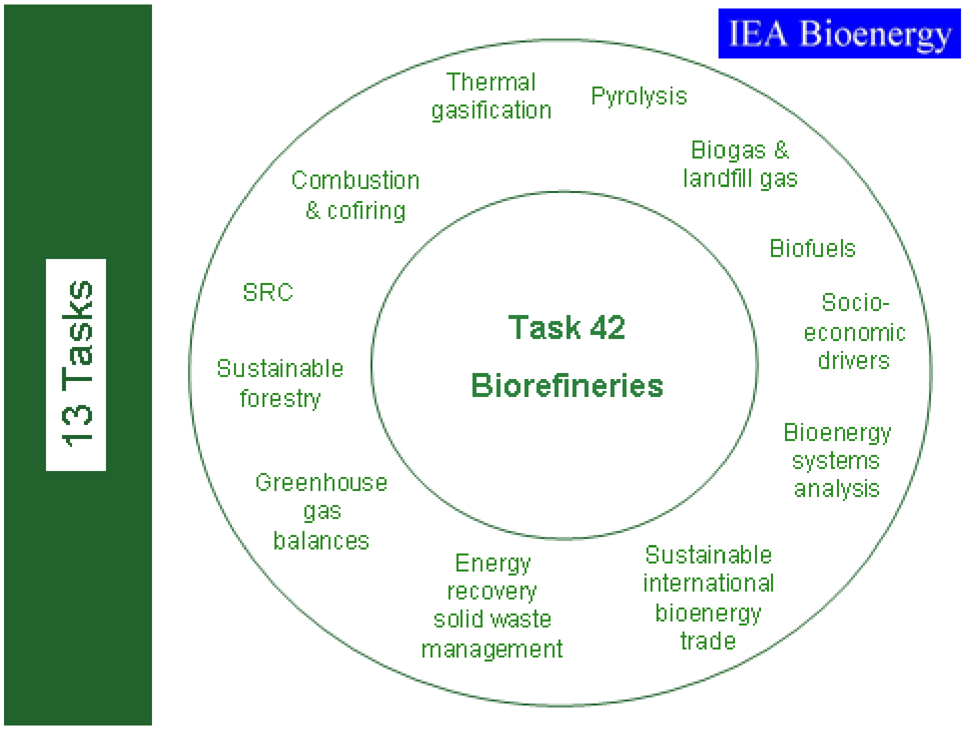


Figure 44 Overview central role Task 42 within the IEA Bioenergy Programme.

Examples:

- Within the Thermal Gasification and Pyrolysis Tasks (33 and 34) thermo-chemical biorefinery aspects are dealt with (ao syngas platform, catalytic pyrolysis, bio-oil upgrading)
- Within the Biofuels Task 39 Biofuel-driven Biorefineries are part of the task activities; specific attention is given to the production of biofuels and bio-based products from microalgae.
- Within the non-technical Tasks 29 (socio-economics), 38 (greenhouse gas balances), and 40 (sustainable international biomass trade) the application of biorefineries is part of their working programme.

NB There is a lot of biorefinery-related info available for the general public, see: www.ieabioenergy.com !

2.4 PyNe-network

Biorefineries have been explored in the PyNe activity co-funded by the EC within the ThermalNet Project and as part of IEA BioenergyTask 34 using fast pyrolysis as a central theme (Figure 45), and also as a supporting activity for integration into a refinery (Figure 46). One of the major contributions was a Round Robin exploring fast pyrolysis of lignin derived from bioethanol production processes as shown in Figure 46. A full report has been produced which is a pending publication.

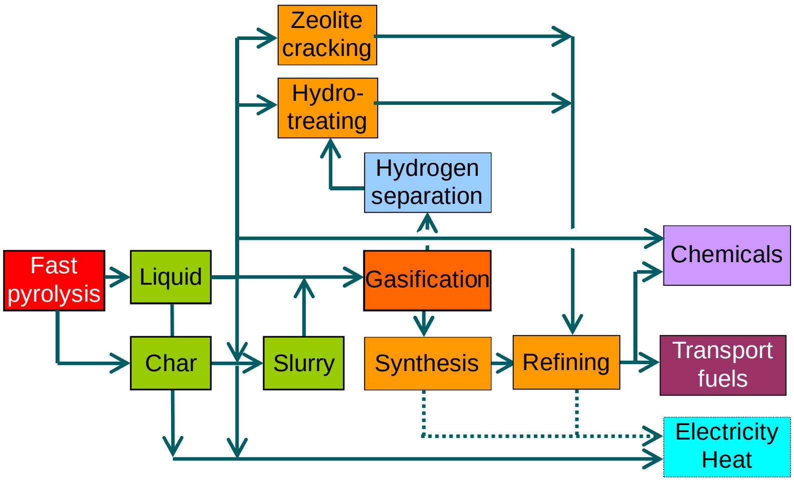


Figure 45 Fast pyrolysis driven Biorefinery.

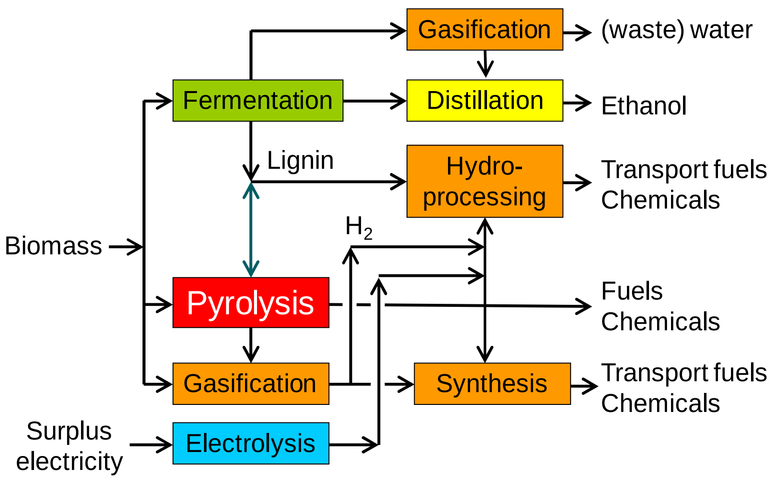


Figure 46 Fast pyrolysis as pretreatment for integration into a conventional oil refinery.

3. Advanced Biorefinery Processes: Views and Activities Key Stakeholders from Outside the EC (Internal Workshop) – Tasks 3.3/6.3

3.1 Introduction

As a part of the BIOREF-INTEG project on development of advanced biorefinery concept for integration with existing fuel producing complexes, a workshop " Knowledge Import from Outside EU on advanced Biorefineries" took place on 29th January 2009 in Osnabrück, Germany. The workshop was supposed to provide an overview of the current status of biorefineries outside EU through participation of representative scientists from Japan, Brazil, and USA. Shiro Saka (Kyoto University, Graduate School for Energy Science), Telma Franco (State University of Campinas), and Bruce Dale (Michigan State University) presented their views and activities on biorefineries in their countries.

3.2 Recent Progress in Biorefineries in Japan as Introduced by Supercritical Fluid Science and Technology

By Shiro Saka

The presentation of Shiro Saka was mainly focused on the supercritical treatment of different kinds of biomass, various products that could be extracted from biomass and several novel technologies for converting biomass into valuable, mainly liquid biofuels.

Supercritical fluid technologies are used for the pretreatment and conversion of various types of biomass (Figure 47). Depending on the specific technology a variety of products could be produced ranging from conventional liquid biofuels (ethanol and FAME) to diverse biochemicals and bioplastics materials. Waste biomass such as waste wood, waste paper or waste oils, and fats are used as raw materials in these concepts.

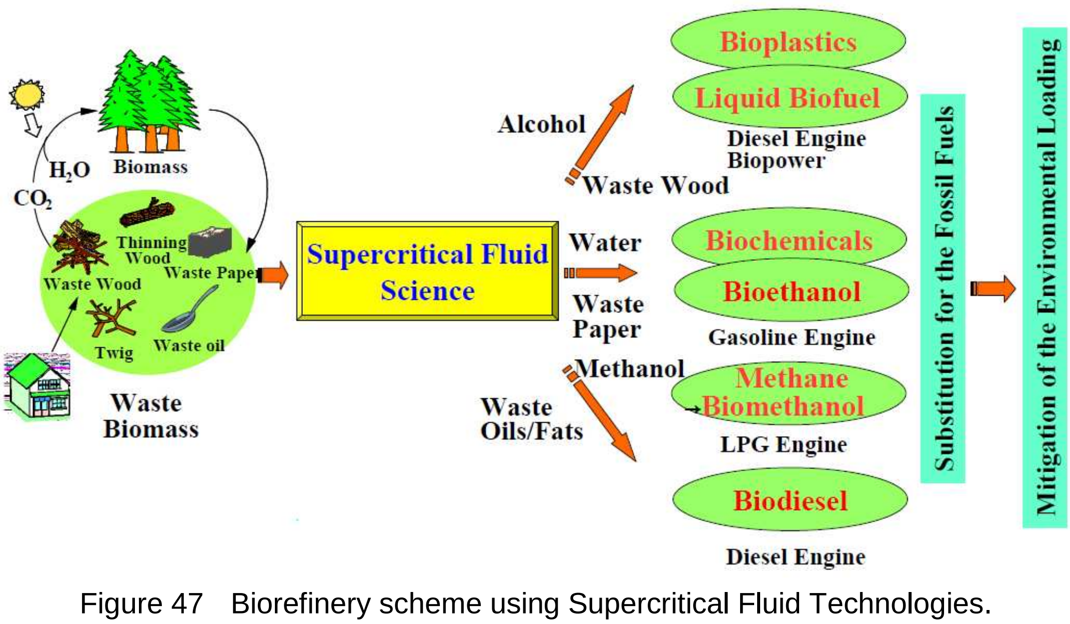


Figure 47 Biorefinery scheme using Supercritical Fluid Technologies.

A pure substance may be changed into 3 phases such as gas, liquid and solid. Among these, the critical point exists between the gas and liquid. Above the critical point, there exists the high-density fluid which cannot be condensed any more, even if temperature and/or pressure are increased. Such a substance is called supercritical fluid. In case of water under supercritical conditions production of ionic products is increased (hydrolysis reactions are pronounced) and the dielectric constant of water is decreased resulting in hydrophobic nature of the fluid.

3.2.1 Supercritical methanol treatment

Supercritical methanol treatment is carried out at 270℃ and 27MPa. Under these conditions lignin part of the biomass could be broken down to a variety of dimeric compounds which are different types of condensed, methyl-substituted phenolic compounds with very low reactivity and reactive oligo-phenolics with ether linkage between. Low reactivity of the C-C type of compounds is influenced by the steric hindrance of the C-C bond, which makes rather inaccessible for cleavage. These compounds are still unknown and it is too early to talk about their application, but certainly offer a potential for isolating added-value products from lignin in contrast to the current lignin application as a heating fuel.

Cellulose could also be treated in supercritical methanol to yield levoglucosan through the methanolysis-type (analogous to hydrolysis) of cellulose decomposition.

In general a conclusion can be made for supercritical alcohol treatment: going from methanol to decanol (increasing the C-atom) as solvent, alcohol-insoluble part of lignocellulose is decreasing. It can also be concluded that hemicellulose disappears (reaction and solubilization) first followed by cellulose and lignin. Lignin part of biomass is more or less solubilized depending on the alcohol applied.

3.2.2 Supercritical water treatment to produce ethanol

After treating lignocellulosic material under supercritical conditions using water as solvent (380℃, 40MPa, 0.1-0.3s), it is possible to separat e SC-water soluble and insoluble part using filtration technique (0). Leaving the liquid fraction to cool for 12h SC-water changes its properties (dielectric constant changes from 10 to 80) and the hydrophobic part of the solubilized material precipitates. Insoluble part could be washed with methanol to separate oily substances minimizing the insoluble part. Most of the sugars will remain in this case in the water phase. SC water-insoluble part could be washed with methanol and joined with the methanol phase from the SC water-soluble part. It is interesting that biomass cellulose structure is different from the cellulose obtained as precipitate after the SC water treatment of biomass. While cellulose from the biomass has crystalline structure which is very difficult to access and convert, SC water-treated cellulose is amorphous and much easier for further treatment. As contact time during the SC treatment increases, the amounts of fragmented, dehydrated products and low organic acids increases while the amounts of the products of direct hydrolysis is lower. This is expected since the first are subsequent products of the last. However this shows how sensitive SC water process is regarding its scale-up. If one has in mind residence times in order of millisecond, large scale processing using this technology shows lots of practical limitations.

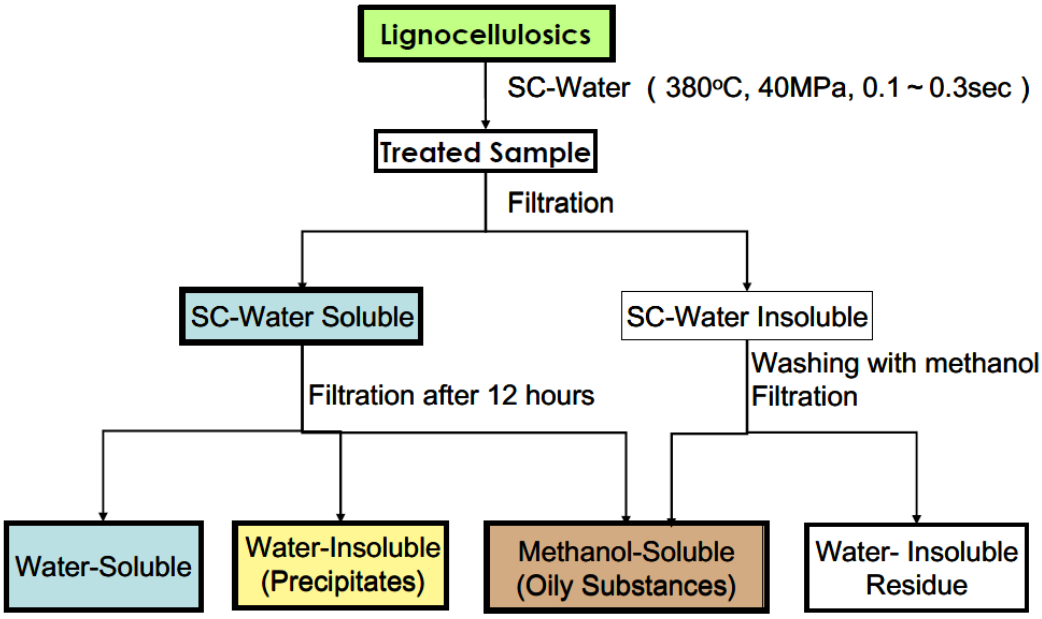


Figure 48 Separation scheme of lignocellulose treated in supercritical water (Saka and Ehara, Int. Symp. On "Hihgly Efficient Use of Energy and Reduction of its Environmental Impact", p.17-26, 2002).

In addition, a biorefinery-type process is proposed for the treatment of lignocellulosic materials that makes use of SC water treatment. SC water (400℃ and 40MPa) is injected to the reactor filled with biomass (0). Reactions are stopped by cooling the content using cold water. The insoluble part is separated in the filtration and the cake is washed with methanol to recover additional products. Water soluble part that contains saccharides is sent to enzymatic saccharification and further to ethanol fermentation. Methanol soluble part contains lignin derivatives that can be further treated or separated. Estimations are that only 5% of the starting biomass is left as insoluble part.

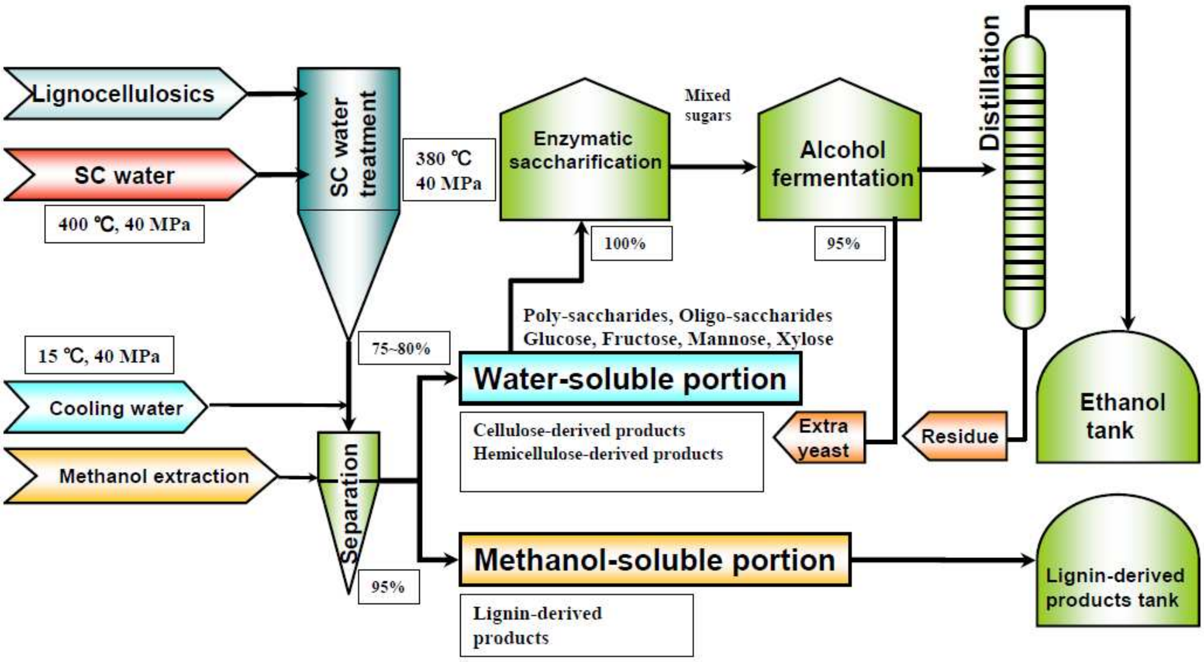


Figure 49 Supercritical water process for ethanol production from lignocellulose (Saka and Ehara, Energy Res., 24, p.178-182, 2003).

As an alternative to conventional ethanol fermentation (direct ethanol fermentation), indirect ethanol fermentation through acetic acid fermentation is proposed. The drawback of the conventional bioethanol process is that 1/3 of the energy content of C6 sugars is spent for yeast's metabolic activities. Via indirect ethanol fermentation, sugars are converted to acetic acid (Figure 50). In the next step acetic acid is esterified with alcohol. Hydrogenolysis of such ester gives ethanol on one hand and corresponding alcohol on the other. In the net material balance one mol of sugar reacts with 6 moles of hydrogen giving 3 moles of alcohol and water. In this way 100% of the energy content of the sugar is converted to ethanol (equation 1). However, additional 6 moles of hydrogen must be provided for this process. Another advantage of such process is the possible utilization of most of the lignocellulose hydrolysis products including both C6 and C5 sugars, glucuronic acid and oligosaccharides.

$$C_6H_{12}O_6 + 6\ H_2 \rightarrow 3\ CH_3CH_2OH + 3\ H_2O \qquad \text{(equation 1)}$$

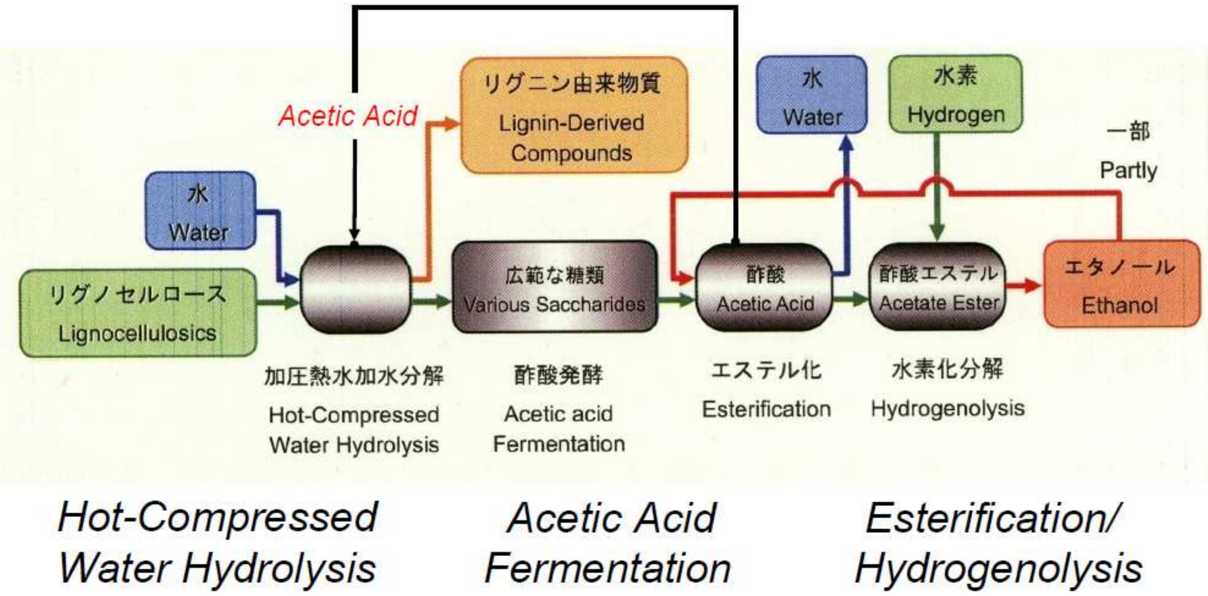


Figure 50 Route for indirect production of ethanol, converting sugars to acetic acid, subsequent esterification of this acid with ethanol, and finally hodrogenolysis into ethanol (NEDO pamphlet, p.20, Oct. 12, 2007).

3.2.3 Supercritical methanol technology for biodiesel production

Biodiesel production from vegetable oils is already a well established and studied process. Relatively uniform composition of vegetable oil and easy processing allows for high process yields and low processing costs. One of the problems occurring during vegetable oils processing are caused by the presence of free fatty acids in the oil. These acids undergo saponification reaction in the presence of alkali hydroxide and form products that can't be recovered and as such is wasted. In fresh vegetable oils free fatty acids are minor fraction amounting to 2-5%. However if waste oil is considered this amount can go up to 25%, which has large influence on the economics of the waste oil processing. At Saka's laboratory two methods have been developed for efficient conversion of waste oils to biodiesel.

The first method makes use of supercritical methanol treatment. Waste oil is mixed with methanol and treated under supercritical conditions (0). Triglycerides are directly converted to FAME and glycerin via a transesterification route, while free fatty acids are esterified to FAME and water.

Excess methanol is phase separated and the rest of the material is sent to the distillation unit where glycerin is taken from the bottom and biodiesel and methanol are separated in the top part of the column.

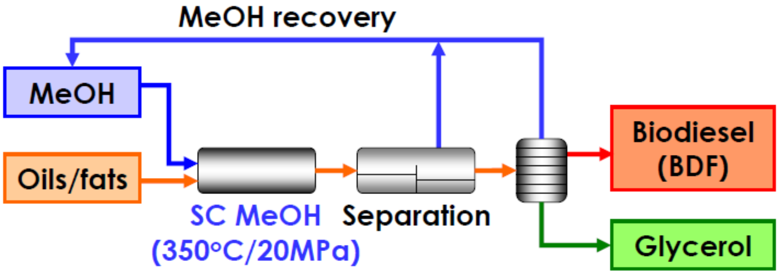


Figure 51 Production scheme for the production of biodiesel from waste oil, using a one step supercritical methanol method (Saka and Kusdiana, Fuel, 80, p.225-231, 2001).

The second method is carried out in two steps conversion process. In the first step triglycerides are treated with subcritical water to give free fatty acids and glycerin. In the second step fatty acids are esterified under supercritical conditions with methanol to yield FAME and water. These two steps are easy to combine due to the immiscibility of fatty acids and glycerin, which are separated prior to the second step. Water phase containing glycerin is treated to separate wastewater and glycerin. After the second step, methanol is phase separated from FAME and recycled back to the process.

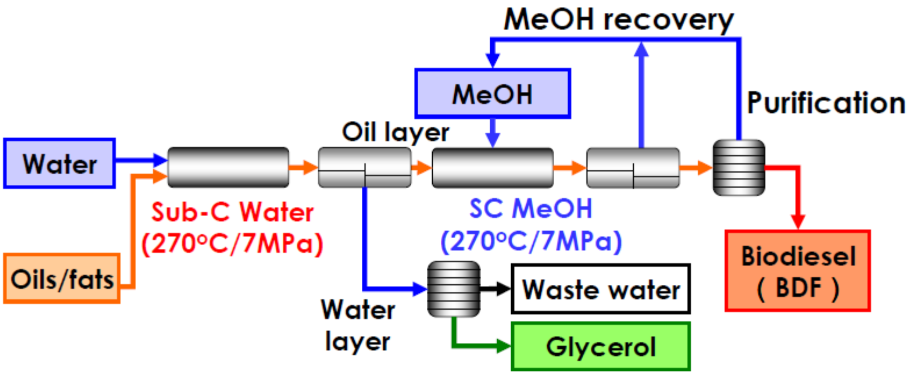


Figure 52 Production scheme for the production of biodiesel from waste oil, using a two step supercritical methanol method (Kusdiana and Saka, Appl Biochem Biotech, 115, p.781-791, 2004).

Such process for biodiesel production presents a robust option for conversion of wide range of oils and fats. While alkali catalyzed conventional biodiesel process is suitable for conversion of oils and fats with low content of free fatty acids and somewhat higher water content, and while acid catalyzed processes can tolerate higher free fatty acids and lower water content, the processes developed in Saka's Laboratory can use the whole range of oils and fats including the waste oils which are not at all suitable as raw materials for conventional processes (Figure 53).

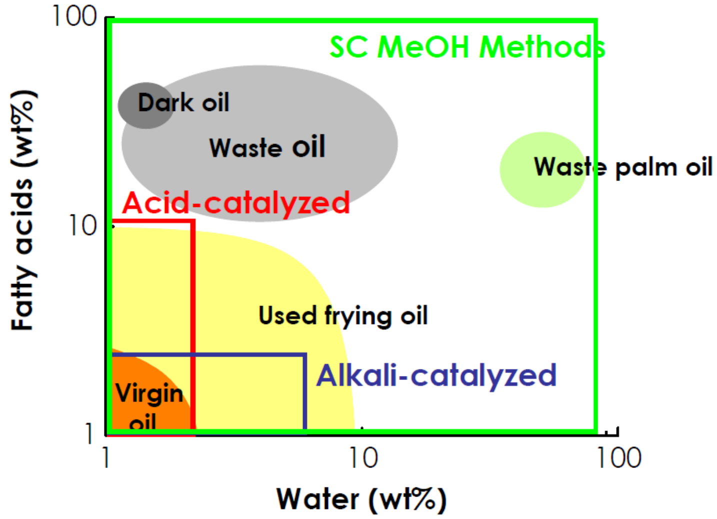


Figure 53 Applicability range of methods for various oils/fats (Saka, Japan Inst Energy, 84, p.413-419, 2005).

Glycerin is the byproduct of FAME biodiesel processes and its production worldwide is increasing every year. Its market price has gone down in recent years due to the large overproduction of this chemical. At Saka Laboratory a process is developed that allows the production of FAME biodiesel, without the production of glycerine, and which also results in an additional biodiesel fraction – triacetin. Methyl acetate ester, together with a given triglyceride is treated under supercritical conditions (350℃/20MPa) to yield a FAME fraction and triacetin (0). Free fatty acids present in vegetable oil are esterified to FAME and give acetic acid byproduct. The extent of methyl acetate could be separated in the distillation step and recycled back to the process. The mixture of triacetin and FAME is tested for the most important diesel properties. Properties like density, kinematic viscosity, cetane number, carbon residue, pour point, flash point, and cold filter plugging point were all in allowed range for diesel. Moreover all the properties comply with leading world standards related to the diesel fuel.

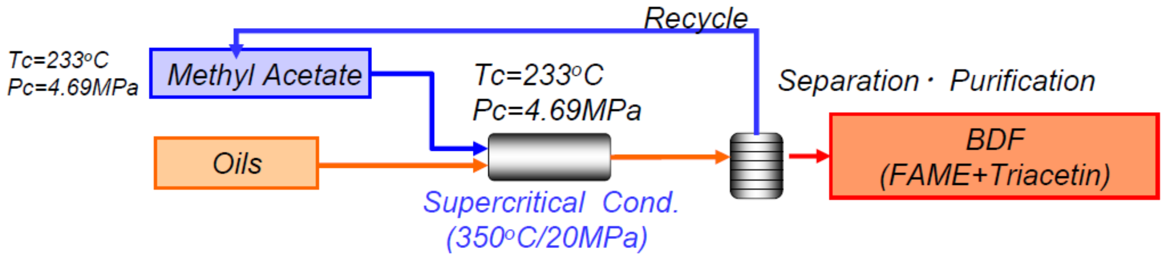


Figure 54 Production scheme for the production of FAME and triacetin (BDF) without production of glycerin, using a one step supercritical methylacetate method (NEDO pamphlet, p.21, Oct 12, 2007).

In addition a combined biodiesel and chemicals process is given in which vegetable oil is reacted with dimethyl-carbonate to yield FAME as biodiesel fraction and citramic acids and glyoxal as chemicals (Figure 55).

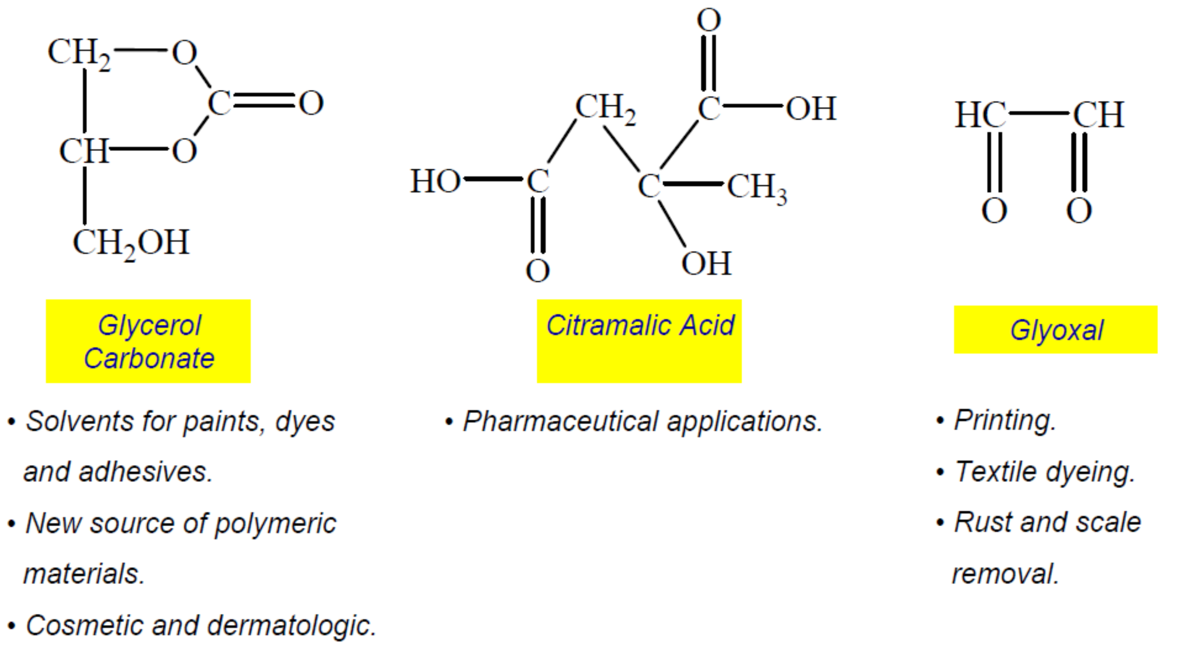


Figure 55 Reaction products from transesterification of triglyceride in dimethyl carbonate (Ilham and Ehara, Biores Technol, 100, p.1793-1796, 2009).

As a summary, an overview is given on the different super/subcritical processes for conversion of lignocellulosics and oil components to biofuels (bioethanol, biomethanol, biodiesel, and hydrogen) and biochemicals (value-added products from lignin, and biodiesel byproducts). Finally a logistic scheme is presented for utilization of various waste products (waste paper, woody, and agricultural waste, waste oils/fats (Figure 56).

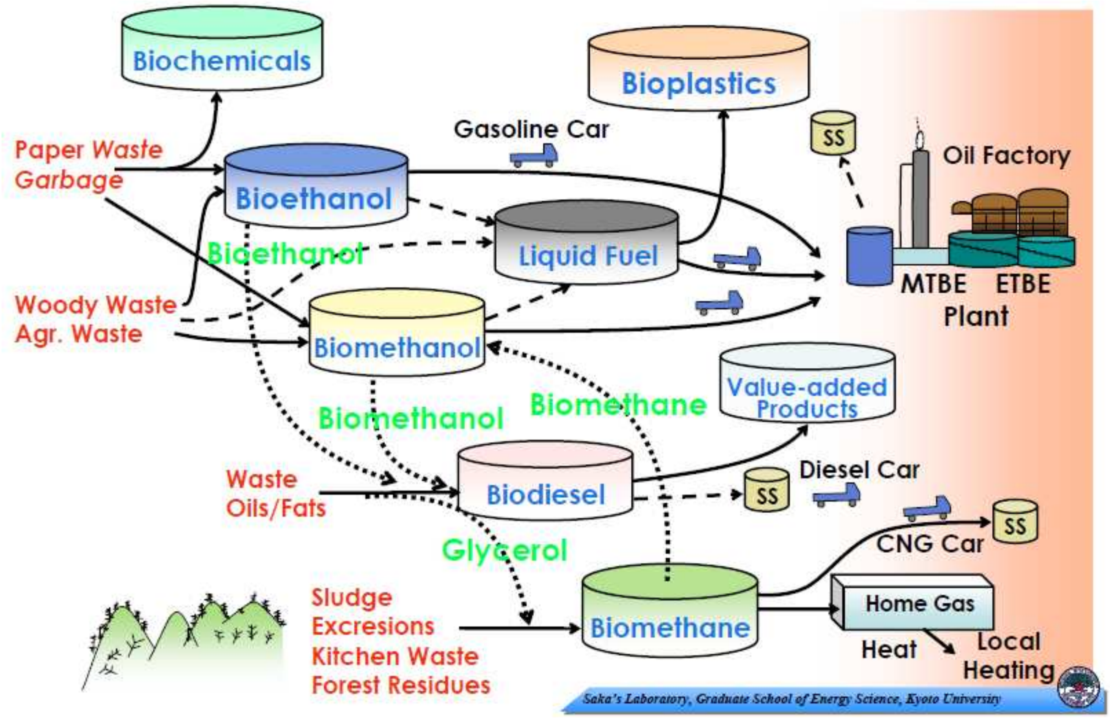


Figure 56 Logistic scheme of products obtained by supercritical processing of various waste products.

3.3 Advances and opportunities towards a biobased industry in Brazil

By Telma Teixeira Franco

Sugarcane as the main feedstock for bioprocessing in Brazil was a central point in the presentation of prof. Franco. After a short general story about Brazil, some historical facts regarding sugarcane production and processing were presented. Sugarcane is traditionally processed in the mills with flexible output. Ethanol and sugar are possible products. About 50% of sugarcane is turned into sugar and the other half is used for ethanol. Flexible output allows for switching to more sugar or more ethanol regime depending on the given market conditions. While two thirds of sugar produced in Brazil is exported, only 15% of ethanol is sold outside Brazil leaving 85% for internal use. 90% of ethanol in Brazil is used as transportation fuel. Flex fuel cars in Brazil can use ethanol/gasoline blends in any ratio.

At the moment, only one third of the energy contained in sugarcane – the sucrose – is converted to energy. The main challenge in Brazilian sugarcane industry today is the use of the whole sugarcane. Bagasse and cane trash (leaves and tops) are the fibrous part of the sugarcane plant, where two thirds of sugarcane energy is stored. Cane trash is traditionally burned at the field before the harvest, and bagasse is a solid leftover from the sugar extraction process. Recently field burning practice has been phased out, and mechanized harvesting is being used. This increases the amount of the solid lignocellulosic material, which is normally burned to provide heat and power for the mill. Extra heat is converted to electricity and is sold to the public grid providing additional valuable output from the mill.

An integration option is further presented where conventional sugarcane ethanol processing is combined with bagasse and trash conversion into ethanol. In order to convert it to ethanol, bagasse must undergo hydrolysis using enzymes as catalyst (0). Free sugars could be combined with extracted sucrose in ethanol fermentation, while lignin could be burned for energy. Optionally, C5 sugars from hemicellulose could be extracted and fermented separately from C6 sugars.

Relatively large amount of wastewater, also called vinasse (stillage), is left after distillation and at the moment it has been used for ferti-irrigation by spraying it over the sugarcane fields. It was shown that the production of ethanol could be significantly increased if the whole plant material is used for ethanol production. This amount could even be doubled if the so call “fibre cane”, or sugarcane with high biomass content, is used. Development of the varieties of sugar cane with high fibre content is the goal of Alellyx and Canavialis (now Monsanto), two small companies that are active in the field of genetic engineering of the sugar cane.

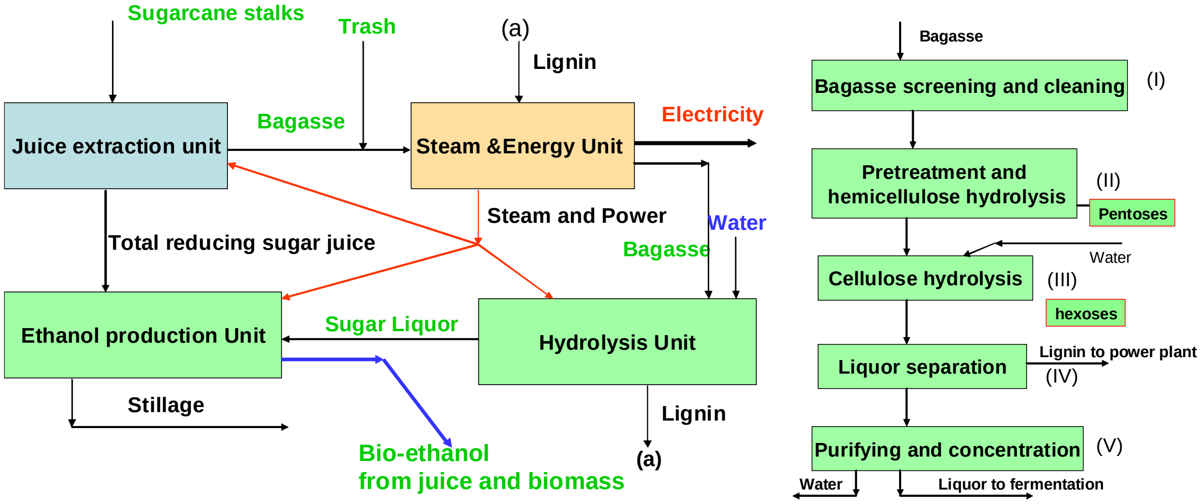


Figure 57 Process scheme for production of ethanol from sugar cane and bagasse (left) and incorporated hydrolysis steps (right).

Chemicals that can be produced from sugarcane are divided into several groups. The first group represents renewable biomass feedstock – cellulose and hemicellulose. Intermediate platform chemicals are the second product group with sugars such as fructose, glucose, sucrose, xylose, arabinose… The third group gathers fermented chemicals, or the direct fermentation products such as citric, fumaric, lactic and acetic acid, acetone, ethanol, butanol, lysine… Finally all other products from the further treatment of the fermented chemicals form fourth group called chemicals and products.

Sugarcane-related activities of Brazilian petrochemical companies are further presented. The most important players from the petrochemical field involved in sugarcane industry are Petrobras, Braskem, Oxiteno and Dedini, which is basically the largest project design and development company in Brazil.

Petrobras is developing the second generation ethanol technology, based on the mild acid hydrolysis pretreatment of bagasse. Pretreatment is followed by delignification stage to remove inhibiting components. Fermentation of the sugar-rich liquid is carried out using *Pichia Stipities* yeast strain. Cellulosic part resulted from the pretreatment is depolymerized using enzymes and further fermented with *Sacharomyces cerevisiae*. Finally both liquid phases are combined and distilled together to separate ethanol. Petrobras is also involved in the development of biodiesel from vegetable oil. Vegetable oils could be either transformed into FAME or blended in the refinery during the hydrotreating of the diesel fraction. Process of blending vegetable oil into diesel before the hydrotreating step (H Bio) in the oil refinery is currently operating in three refineries in Brazil (Figure 58).

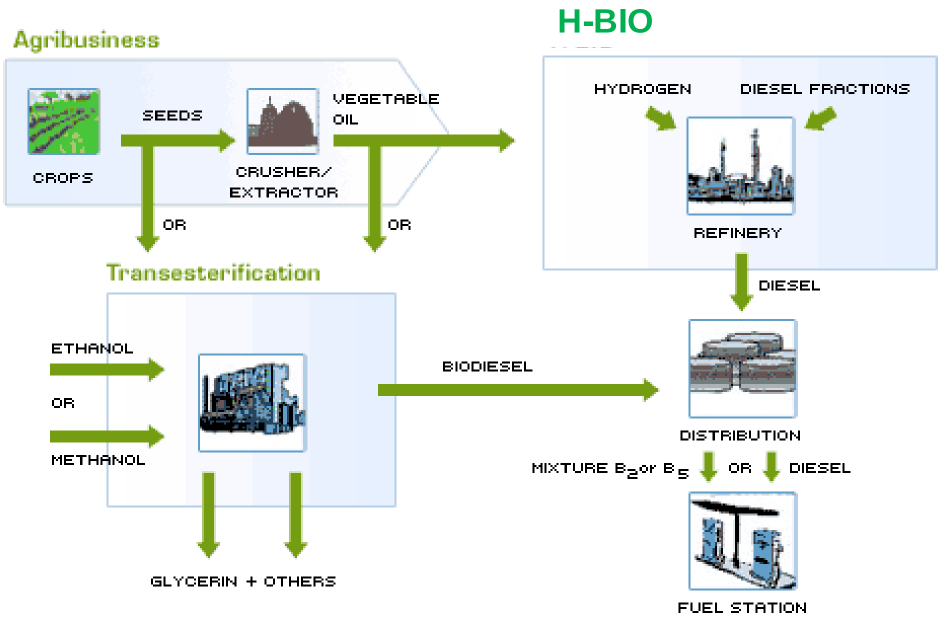


Figure 58 Process scheme for blending petroleum and biobased diesel at Petrobras.

Braskem is another petrochemical company which is a pioneer in green polyethylene production. Currently Braskem is a leading company in thermoplastic resins in Latin America. Green polyethylene is produced using sugarcane ethanol as feedstock. Ethanol is dehydrated to ethylene, which is further polymerized into polyethylene. Start up of the full scale commercial production of green polyethylene is scheduled for the first quarter of 2011.

Oxiteno's activities are in the field of oil fractionation and chemistry. The company is currently defining its priorities (Figure 59).

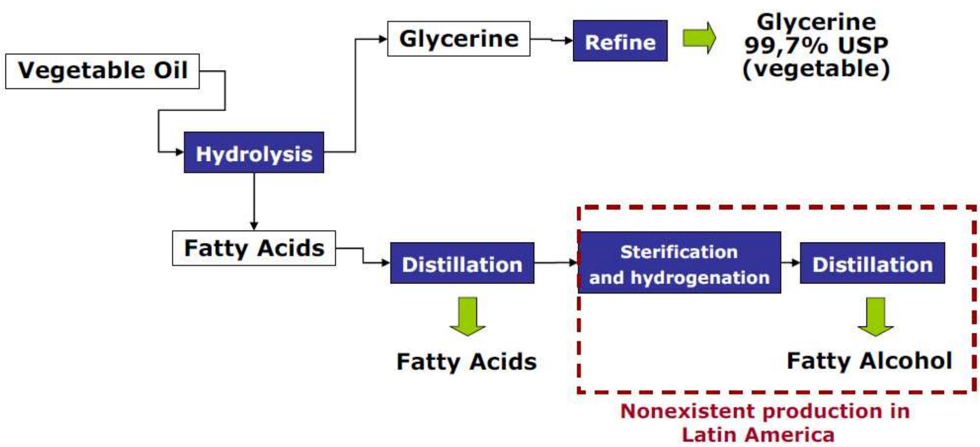


Figure 59 Vegetable oil chemistry and fractionation at Oxiteno.

Dedini is the largest process design and engineering company in Brazil and they are suppliers for almost 80% of the Brazilian market. They provide integrated solutions in sugarcane processing, so called turn-key system with the wholly integrated system of sugarcane crushing, extraction, fermentation, separation, as well as cogeneration plants with option of selling extra electricity to the public grid. The new industrial vision of Dedini is reflected through "The three BIO" concept. In other words maximization of the use of sugarcane and production of biofuels, bioelectricity and bioproducts.

Dedini initiated a large integration program of the biofuels plants. In the first stage bioethanol and biodiesel plants are integrated, where ethanol is used for vegetable oils esterification (Figure 60). Instead of methanol, ethanol is used to produce ethylester-fatty acids. Extra energy from the ethanol mill supplies the biodiesel plant as well, and a part of the biodiesel produced is used for agricultural activities. Main products from such kind of plant are biodiesel, bioethanol, glycerin, and electricity. This concept is already realized and Barralcool has already a running plant that produces 50kta of biofuels.

In the next stage a meat and vegetable oils production is integrated in the existing infrastructure, to achieve side-by-side farming and industrial production of bioproducts (Figure 60). Finally, the whole process is fully integrated into the grains and sugarcane productive chains.

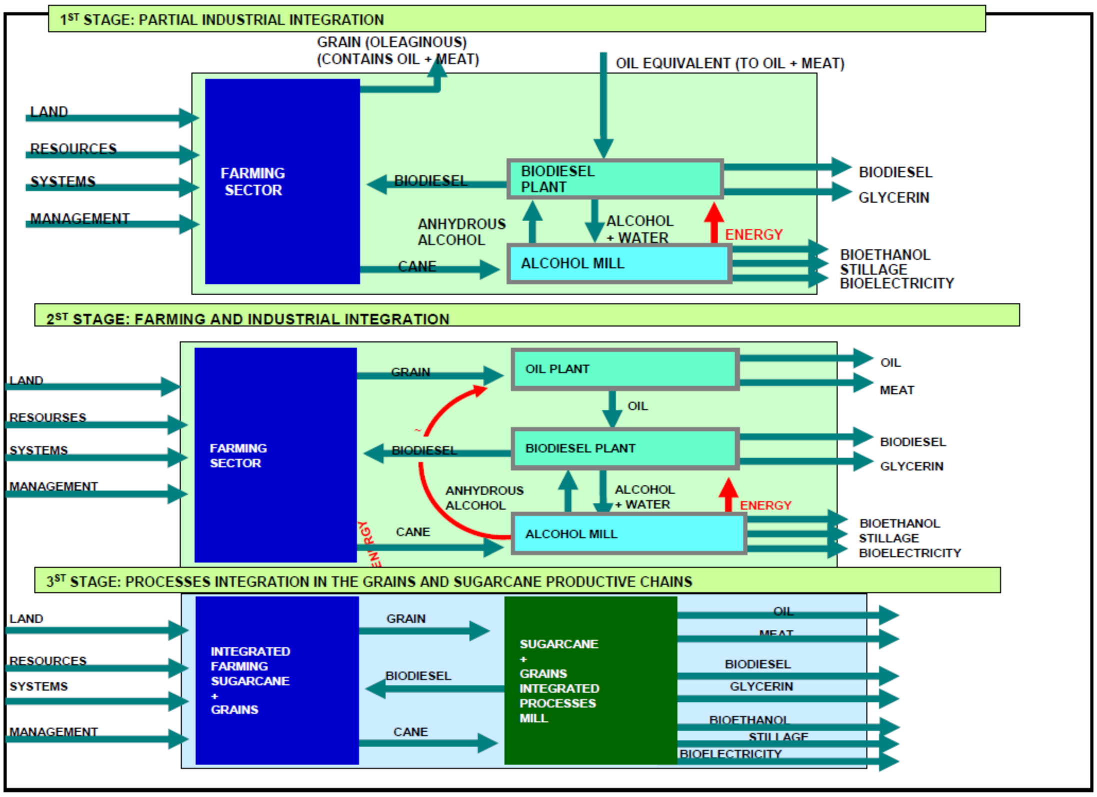


Figure 60 Integration scheme for a biofuels plant, developed by Dedini.

Another process development activity of Dedini is related to the reduction of process water intake in the sugarcane processing. Water content in the sugarcane stalk can be up to 70%. Efficient management of plant water is essential in reducing external water intake.

3.4 Current Status of Cellulosic Biofuels in the US

By Bruce Dale

ORNL and USDA very recently issued a report describing a scenario for producing 1.3 billion tons of biomass every year in the U.S. This is biomass above and beyond what is currently being produced for food, paper, fibre, and building products. This slide puts the recent ORNL-USDA ***Billion Ton Vision Study*** in context of petroleum displacement [222].

[222] ORNL & USDA Resource Assessment Study by Perlach et.al., April 2005, www.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf , visited 30 June 2009

Energy content of biomass was determined based on a detailed accounting of all the types of biomass included Billion Ton Vision report. The green dashed line represents the total biomass resource estimate from the ORNL/USDA study in terms of Crude Oil Equivalents (Figure 61). Energy contents of all biomass available for energy use were based on Higher (Gross) Heating Values, dry weight.

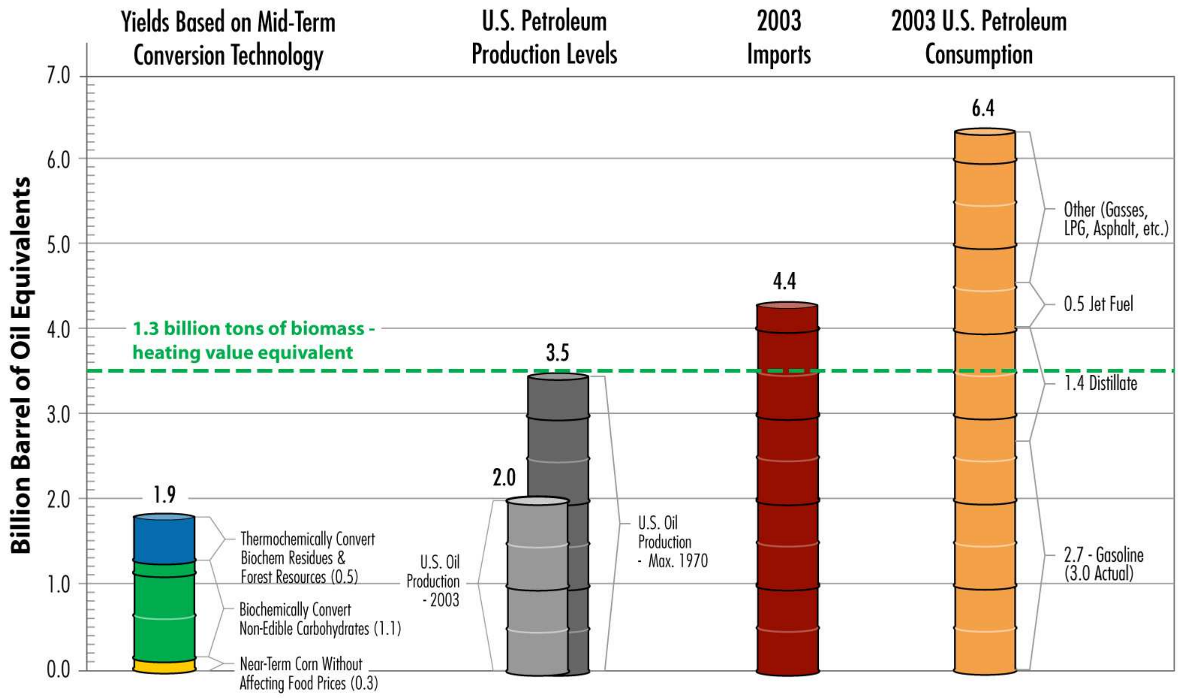


Figure 61 Significance of the 1.3 Billion Ton Scenario.

For near-term, EtOH from grains, the estimate (yellow barrel) was based on a very aggressive 20 billion gal ethanol per year as per estimate of NCGA. This is the level many experts believe can be achieved without significantly increasing food prices. 2005 capacity for grain EtOH in the U.S. is approx 4 billion gal. The huge benefit of grain EtOH is that the technology is cost competitive today; the disadvantage is that the total impact on petroleum displacement is very limited.

For mid-term, conversion technologies of lignocellulosic biomass are assumed. About 90 gal EtOH per ton of biomass (as per NREL's 2002 Design Report's Market Target). 72 gal EtOH per ton of biomass via thermochem (as per Rich Bain's Feb. 9, 2005 NREL tech memo). Includes all forest residues. Lignocellulosic biomass yields are based on "today's technology", assuming alcohol production. Clearly the **impact on petroleum displacement can be much larger with lignocellulosic resources**. Moreover, there is no competition with food. The main barrier keeping the U.S. from exploiting this huge sustainable resource is the availability of cost effective technology for converting the biomass into clean liquid fuels – this is the primary objective of DOE's Office of the Biomass Program.

Further improvements in ***Conversion Efficiency*** can dramatically change the impact biomass can have on displacing petroleum. Note the "gap" between 3.5 billion BOE resource potential versus 1.9 billion BOE of deliverable liquid fuels with today's technology. Reducing this gap, or improving the conversion efficiency of converting biomass into liquid fuels represents one of the largest scientific challenges for biofuels. Reducing this gap not only increase the amount of petroleum biofuels can replace, but can also improve the economics of biofuels. Like any commodity product, high yields or high conversion efficiency leads to lower commodity prices.

Currently, we use over 6 billion barrels of oil each year in the U.S. (Note: accounting differences depending upon whether including imported refined products, crude oil to Strategic Reserve, etc.). The United States (including Alaska) currently produces about 2 billion barrels of oil per year, only 67% of the U.S. biomass potential. U.S. oil production peaked in 1970-71 at approx 3.5 billion barrels per year. The U.S. has NEVER produced more than 3.5 billion barrels/year of oil. It is difficult to see how the U.S. can ever meet its tremendous demand for transportation fuels with domestic resources. Reducing the consumption by one third or one half may be necessary for the U.S. to achieve a balance between supply and demand of liquid fuels. We are certainly not doing so with petroleum, and it's difficult to see how we can do so with biofuels without some reduction in demand; **this underscores the importance of R&D on hybrid and fuel cell vehicle technology**.

For questions about MSW: U.S. produces about 200-300 million ton/yr of MSW. ORNL did include some cellulosic MSW in the billion ton report. It is kind of buried a bit in the report as the authors tried to separate resources attributable to forestlands and croplands. For example, urban wood waste was considered part of the MSW waste stream from forestlands. In the report, the authors say 28 million dry tons of this material is sustainably available. Their estimate included all that caveats dealing with current uses, contamination, recycling etc. They also included about 23 million dry tons of non-wood MSW from cropland.

Historical oil prices were during the last 30 years rather low. Average oil price was between 15 and 35$/bbl for more than 25 years. A study of Lynd and Wyman states that a price of lignocellulosic biomass of about 50$/t corresponds with about 15$/bbl of crude oil. The difference between that and the given market oil price represents a margin for biomass processing to biofuels. As long as the cost of processing doesn't exceed this level biofuels can be competitive with fossil fuels. Recent volatile crude oil prices caused this margin to be very high and very low, with at the moment (Feb. 2009) very low margin of less than 20$/t of biomass. It should be noted that biomass processing costs are very high, dominated by the pretreatment, enzymes and fermentation costs, and at the moment they are even higher than the cost of raw biomass. Therefore, decreasing the costs of processing is an imperative in biofuels process development. Brazilian experience tells us that there is hope in that sense. Historically, the gap between the cost of ethanol and fossil gasoline has been reduced over the last 20 years, particularly due to the reduction in the sugarcane processing costs, and at the moment Brazilian ethanol is a competitive option to the fossil gasoline.

Evolution of bioethanol-fuel production starts from sugarcane (Figure 62). Production of ethanol-fuels from sugarcane is the simplest of the commercial-scale technologies. Sucrose is already present in the sugarcane stalks, and after being extracted, sucrose is fermented into ethanol. Upon distillation and drying ethanol could be used as transportation fuel. To produce ethanol from corn or other grains in general, a relatively easy and efficient enzymatic hydrolysis step is required in addition to the sugarcane processing. Here an extra byproduct (DDGS) could be obtained, which is normally sold as animal feed to support the process economics. In lignocellulosic ethanol production another extra step is required in addition to ethanol-from-grains process. This step is pretreatment of the lignocellulosic material, where three components cellulose, hemicellulose and lignin are separated. The composite structure of lignocellulosic materials is very much resistant to any kind of treatment, and it is still a challenge to break it down without destroying the three components. Lignin features inhibiting effects to further enzymatic treatment of polymeric carbohydrates, thus it must be separated. Enzymatic hydrolysis of (hemi)cellulose is unlike enzymatic treatment of grains much more complex and requires longer contact times, and more of the expensive enzymes. Separated lignin could be used to provide energy for the further processing, but lignin has much better potential as a pool of various types of chemicals. A lot of knowledge on sugarcane and grains ethanol with a number of running plants worldwide is the current status quo in ethanol processing. Regarding lignocellulosic ethanol there is at the moment a lot of research going on.

There are already first pilot facilities running, with a number of announcements for large scale demonstration plants that should result in rapid commercialization of lignocellulosic ethanol technology. In other words, the current status of lignocellulosic biofuels is somewhere half way from research to commercialization.

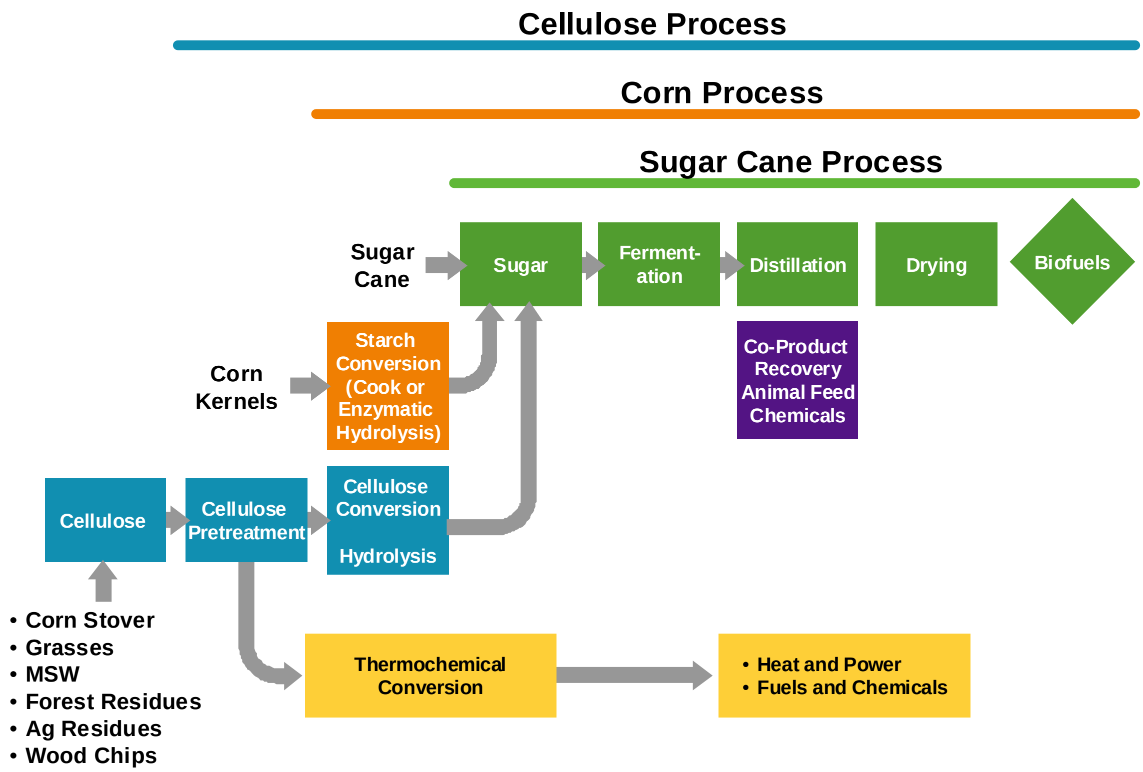


Figure 62 Biofuel production flowchart.

At this stage of development, it is already possible to estimate particular processing costs and to define the cost drivers. In the case of biorefineries, biomass feedstock accounts for over 30% of the processing costs (Figure 63). Among other costs, pretreatment costs represent 18% of the total processing costs. Pretreatment of the biomass has a central role in the processing and directly influences all process steps. Cost drivers in the biological processing such as feedstock, or enzymatic hydrolysis are directly dependant on the type of pretreatment. Cost of enzymes represents 10% of the processing costs, but only after its price is decreased 10 times, which is expected after the commercialization starts. Reduction that could be obtained from energy of the residual materials is neutralized with the capital charges for related equipment. In all the costs capital charges represent a significant share.

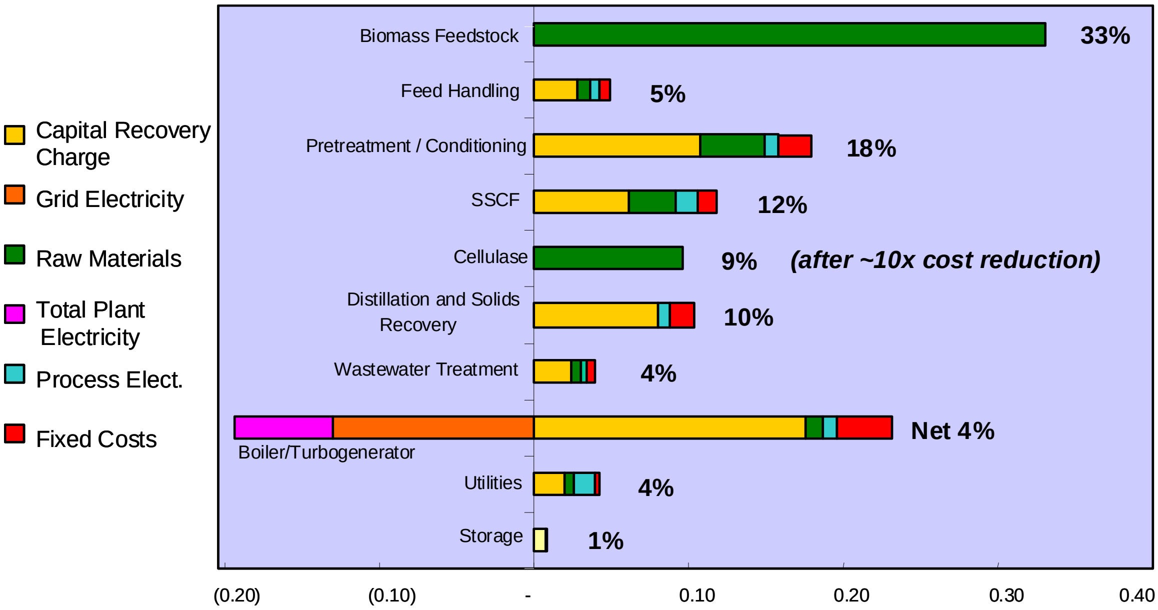


Figure 63 Key processing cost elements of biofuel production from cellulosic resources (Biomass Refining CAFI).

As far as the R&D financial support in the US is concerned, there are four main types of funding support schemes:

- Federal process development support through DOE programs with almost 800M$ for large and processing demonstration plants and for new integrated technologies.
- Supply chain projects through USDA with much smaller politically oriented projects amounting about 100M$.
- Private support with venture capital and corporate R&D support with funding of several billion dollars.
- Federal research support with 3 bioenergy research centers with 400M$ over 5 years period, and some small projects.

Some of the big players in the biofuels industry like Abengoa Bioenergy, Bluefire Ethanol, Broin Companies (now POET), Iogen, Range Fuels and others already started investing in the large scale plants. However, the level of investments in pretreatment technologies is rather disappointing. The funding balance between the processing and the feedstock presently is much more on the side of processing. The prediction for the future is shifting the balance to the feedstock side, due to a number of bottlenecks in the upstream. Biomass growth yields, properties, harvesting and transport logistics, a number of sustainability issues are just few of the problems that has to be addressed. In the processing domain there are three major challenges at the moment. The first challenge is development of effective, economically viable pretreatment method to increase digestibility of cellulose and hemicellulose. The second challenge is related to complete utilization of all biomass components. Especially lignin is a pool of unexplored compounds and currently it has been used as fuel for the process. Taken together, these advances will significantly alter how we provide calories & protein to feed animals, particularly ruminant animals. Providing enough animal feed as biorefinery (by)product a "food vs. fuel" would no longer be an issue.

One of the key expertise and research focus of Buce Dale's lab is the pretreatment of lignocellulosic biomass through development of AFEX (Ammonia Fiber EXpansion) pretreatment process (Figure 64). An economic objective is to create clean, fermentable sugars at the price level of 0.06$/lb (0.13$/kg) using AFEX pretreatment.

Combination of the high temperature and rapid pressure relief opens up the biomass structure and makes polysaccharides accessible for subsequent enzymatic treatment. Ammonia used for pressurizing the reactor is recycled and reused again. One of the main advantages of AFEX is that this is "dry-to-dry" process. Concentrations of the biomass could be very high and much higher than with other pretreatment methods. Typical process conditions are 20-30bar, 70-140℃, 5-10min residenc e time. After 72h of enzymatic hydrolysis, AFEX-treated corn stover glucan is 90% converted to glucose, compared to 30% with untreated corn stover. Another feature of AFEX pretreated lignocellulose is the possibility of pelletizing the material. The pellets have a higher density than the just pretreated material, which facilitates transportation to facilities for ethanol production. Open structure of the lignocellulose doesn't require any binding agent and sticks well in the pellets.

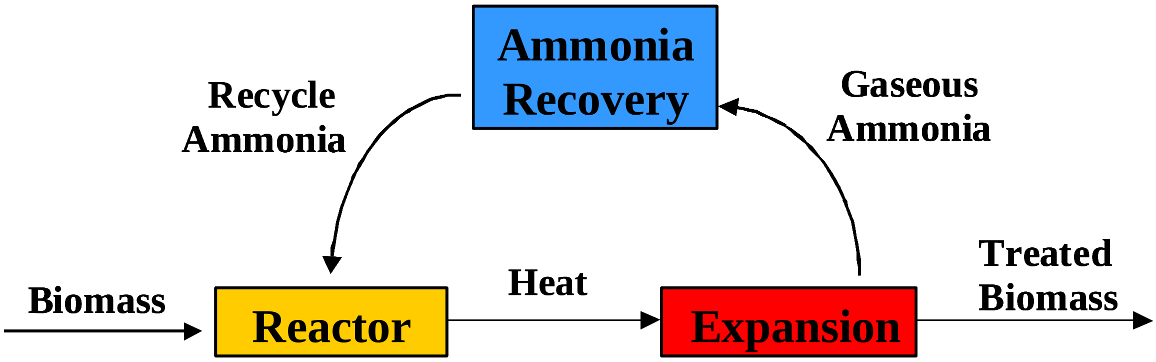


Figure 64 AFEX process scheme.

An illustrative example of the status quo in biorefineries is the comparison of the current state of the art process with cows (40L mobile cellulose biorefinery). At this moment efficiency of the cow is about 3 times higher than efficiency of the most sophisticated lignocellulosic biorefinery.

In addition, there is an option to integrate the centralized (AFEX) pretreatment centre with an upstream biomass production chain and the farmers on one side and an advanced biorefinery on the other (0). An idea is to build larger biorefineries in highly productive areas and/or in the remote areas, and to have as an effect sustainable rural economies that produce sustainable biofuels.

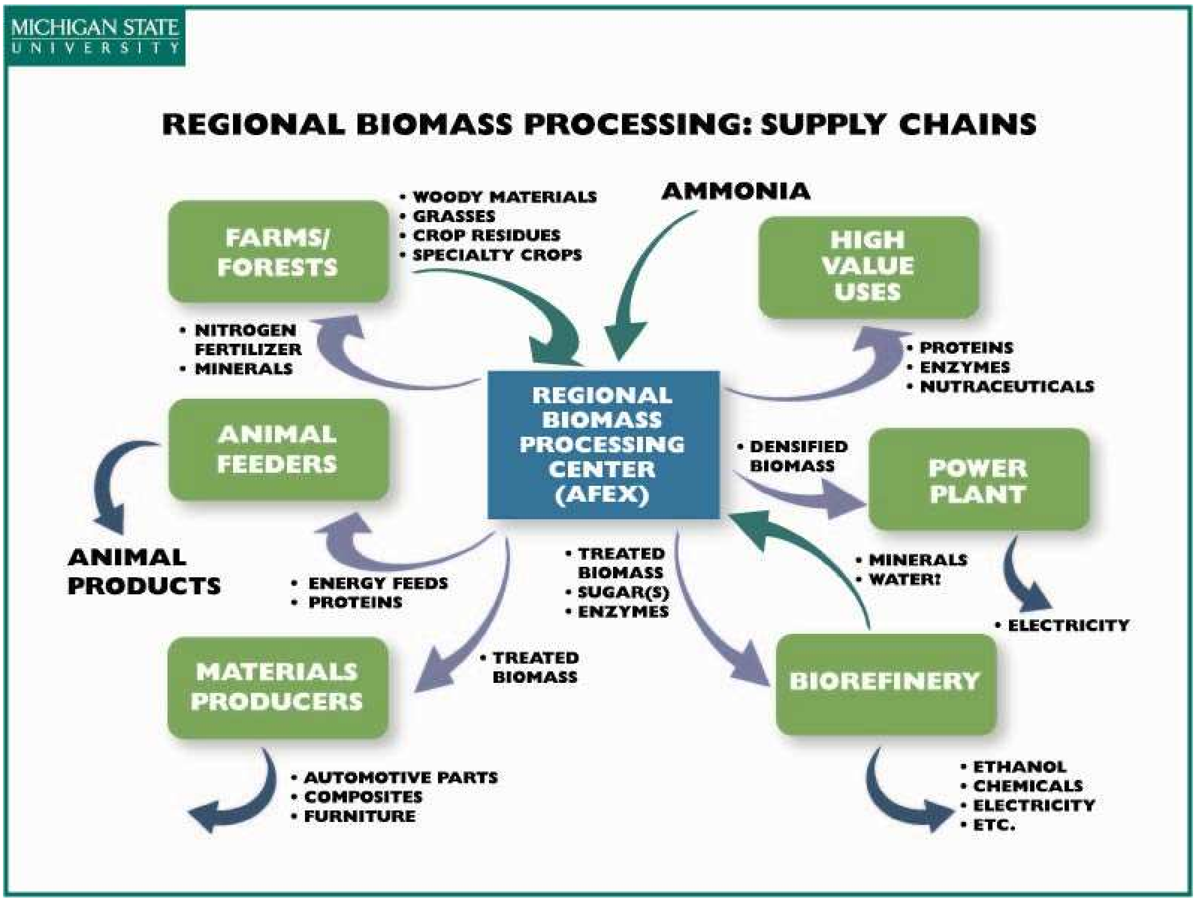


Figure 65 Possible integrated biorefinery scheme around the centralized AFEX technology.

3.5 Conclusions

Topics discussed in the presentations covered a wide range of techniques for extracting valuable chemicals and materials from biomass. The current status quo in commercial biofuels production with conventional bioethanol and biodiesel technologies is presented. Beside that novel approaches in the treatment of biomass were shown that involved efficient methods for conversion of existing lignocellulosic materials into already known and also novel chemicals and materials. A strong focus is set on utilization of waste materials for production of conventional and new types of biofuels.

Shiro Saka (Japan) presented several novel processes based on supercritical conversion technologies. Beside supercritical water, methanol could also be used as solvent in this process. Advantage of the supercritical processes is elimination of the pretreatment step, which consumes lots of energy and requires expensive equipment. Disadvantage of the supercritical technology is that processes take place in milliseconds, which poses practical limitations during up-scaling. Another advantage of the supercritical treatment is compatibility of waste oils as feedstock. Free fatty acids present in the waste oils in higher extent than in the raw vegetable oils are converted to biodiesel and the process is at the same time more environmental-friendly and more efficient. Another feature of the proposed processes is conversion of glycerin to biofuels or biochemicals, which eliminates current overproduction of this chemical. A variety of chemicals could be obtained from lignin when supercritical treatment is applied, instead of just burning it as a source of energy, which is the current practice. Finally, the presentation is concluded with an option for integrated biorefinery that uses various waste materials and converts them to biofuels/chemicals/energy making use of proposed supercritical technologies.

Telma Franco gave general overview of Brazilian biofuels industry with the focus on sugarcane processing. Brazil is the world's largest bioethanol producer with about 6 million cubic meters production in 2008. Ethanol in Brazil is produced from sugarcane in a process which combines the production of ethanol and sugar. Only 15% of this amount is exported and the rest is used internally. The main challenge in the processing of the Brazilian sugarcane today is developing the 2nd generation technology for conversion of fibrous residue (bagasse) into ethanol. At the moment bagasse is being burned to provide energy for the processing. Extra energy is converted to electricity and sold on the market. Another component of the sugarcane plant is cane trash, which is the field residue, dry leaves and tops of the plant. Current harvesting practice includes burning the sugarcane field prior harvesting, where cane trash is burned and the stalks are used for ethanol production. This practice is slowly being abandoned and more and more mechanized harvesting is used. Cane trash represents one third of the whole plant on the energy basis. Using both bagasse and cane trash in the process, production of ethanol could be doubled. In this way efficiency of the process will be significantly increased and focus would be set out of the land use, which is a hot topic in the environmental discussions. In addition activities of the large petrochemical companies and other biotech SMEs in Brazil are discussed with the most interesting bioplastic production by Braskem. Braskem initiated a project on production of green polyethylene from sugarcane ethanol. Such polyethylene is essentially the same as fossil based polyethylene. The only difference is that green polyethylene is produced from renewable resources. Finally, some activities of Dedini – the largest process development company in Brazil are discussed. Dedini is the largest process design and engineering company in Brazil and they are suppliers for almost 80% of the Brazilian market. They provide integrated solutions in sugarcane processing, so called turn-key system with the wholly integrated system of sugarcane crushing, extraction, fermentation, separation, as well as cogeneration plants with option of selling extra electricity to the public grid. One of the new plant concepts is combination of ethanol and biodiesel production in a fully integrated plant. Biodiesel and ethanol are produced in the campaigns, with ethanol being used for esterification instead of currently used methanol.

In the presentation of Bruce Dale several incentives of the US Government were discussed, which have as main objective the reduction of the US dependency on the foreign oil. Renewable resources and biomass among them is one of the key priorities in this regard. Dale points out the importance of the pretreatment in the lingnocellulosic ethanol as the central point of the ethanol processing. Until now sugarcane and corn grains) processing to produce ethanol is mastered, while lignocellulose to ethanol technology is at about half way to commercialization. Cost drivers in the 2nd generation ethanol production are raw materials cost with about 30% of the total processing costs and the costs of enzyme for hydrolysis with estimated 10% of the total costs, but only after the optimization of the enzymes production. The structure of the investments in the development of the next generation ethanol in the US reveals that private and corporate funding schemes represent a major share in the investments. Dale also predicts shifting of the research focus from the processing to more pretreatment and upstream activities in the biomass chain. In addition Dale shows some details on the pretreatment method developed at Michigan State University. AFEX (Ammonia Fiber EXpansion) is an advanced method for pretreatment of lignocellulose, which uses ammonia in combination with high pressure and temperature for efficient preparation of the biomass for subsequent enzymatic hydrolysis. An economic objective of AFEX pretreatment is to produce free fermentable sugars at the cost of 0.13$/kg, which should be reasonable starting point for further ethanol production. Finally, a biorefinery logistic scheme is presented, with regional pretreatment and processing centers that are expected to result in sustainable rural economy that produces clean fuels from renewable resources.

4. International Co-operation – Task 6.6

4.1 European Technology Platforms, Advisory Councils and F]

<table>
<tr><td>Name platform</td><td>European Biofuels Technology Platform (EBTP)</td></tr>
<tr><td>Website</td><td>http://www.biofuelstp.eu</td></tr>
<tr><td>Contact</td><td>info@biofuelstp.eu</td></tr>
<tr><td colspan="2"><u>Introduction</u>

The mission of the European Biofuels Technology Platform (EBTP) is to contribute to the development of cost-competitive world-class biofuels value chains, to the creation of a healthy biofuels industry, and to accelerate the sustainable deployment of biofuels in the European Union, through a process of guidance, prioritisation and promotion of research, technology development and demonstration. To this purpose the following activities will be pursued: 1) elaborate and update, when appropriate, a Strategic Research Agenda (SRA) with detailed identification of key RD&D working lines for the next 10 years, 2) elaborate and update, when appropriate, a Deployment Strategy which identifies the key elements required to implement the SRA, such as mechanisms to mobilise investments, demonstration activities, regulations, education and training actions and communication, 3) facilitate the deployment of the SRA by: 3.1) stimulating EU private and public investment in RD&D projects implementing SRA relevant programmes that make best use of all available support instruments, such as EC's Framework Programme and the European Strategic Energy Technology Plan (SET-Plan), 3.2) coordinating with other bodies and initiatives engaged in biofuels RD&D, including other EU Technology Platforms, Member State initiatives and international (ex-EU) cooperation, and 3.3) identifying on-going biofuels RD&D activities relevant to the SRA and stimulating appropriate synergies between actors and projects, and 4) communicate on the platform activities, with due consideration to public perception and understanding of biofuels.</td></tr>
<tr><td colspan="2"><u>Biorefinery Issues</u>

The development and implementation of <u>Advanced</u> Biofuel-driven Biorefineries is the framework of the activities of the EBTP. On it's website info can be found concerning a.o.: RD&D mapping (lab, pilot and demo) initiatives, biomass resources, biomass conversion to biofuels for transport, biofuels use, biofuels markets, full chain sustainability aspects.</td></tr>
<tr><td><u>Biorefinery-related documents/reports (selection)</u></td><td>• EBTF strategic research agenda.
• Biofuels vision report, vision for 2030 and beyond.
• Other reports.</td></tr>
<tr><td colspan="2"></td></tr>
</table>

Name platform	**European Technology Platform for Sustainable Chemistry (SUSCHEM)**
Website	www.suschem.org
Contact	suschem@suschem.org

Introduction

The European Technology Platform for **Sus**tainable **Chem**istry seeks to boost chemistry, biotechnology and chemical engineering research, development and innovation in Europe. Chemistry is ubiquitous and is vital for the quality of modern life. More and better use of chemistry will enable European society to become more sustainable. This requires major chemical innovations and a successful and healthy EU chemical industry. SusChem brings together a wide spectrum of organizations and individuals. Three working groups coordinate the SusChem activities: 1) the R&D&I group includes the three key SusChem technology areas: Industrial Biotechnology, Materials Technology, and Reaction & Process Design, 2) the Advocacy/Outreach group covers overarching innovation related issues, 3) the Cooperation group is responsible for SusChem's relation to other groups, bodies and networks relevant to the achievement of SusChem's vision. The technologies and activities covered by SusChem aim to be at the heart of future sustainable development initiatives and to be critical to continuing and increasing competitiveness of European enterprises across all sectors. The research topics brought forward by SusChem address the great challenges and needs faced by our society today including energy use, transport, health, and communication technology.

Biorefinery Issues

Development, implementation and communication of sustainable chemistry, industrial biotechnology, materials technology, reaction and process design and overarching innovation. SusChem also pays attention to communication with the public.

Biorefinery-related documents/reports (selection)	• SUSCHEM strategic research agenda. • SUSCHEM vision paper for 2025 and beyond, and other reports. • Implementation Action Plan.

Brokerage event for new FP7 call announced, Brussels, 15 September 2009, in cooperation with the ETPs Biofuels, Plants for the Future, and Forest-Based Sector

Name platform	**Forest-Based Sector Technology Platform (FTP)**
Website	www.forestplatform.org
Contact	mail@forestplatform.org

Introduction

The Forest-Based Sector Technology Platform (FTP) is a European partnership for research and development. The platform is an initiative of the European Confederation of Woodworking Industries (CEI-Bois), the Confederation of European Forest Owners (CEPF) and the Confederation of European Paper Industries (CEPI), later joined by the European State Forest Association (EUSTAFOR). The FTP is an industry-driven platform for collaboration in a sector which makes crucial contributions to the sustainable development and competitiveness of Europe. The FTP has as its vision (for the year 2030): *The European forest-based sector plays a key role in a sustainable society. It comprises a competitive, knowledge-based industry that fosters the extended use of renewable resources. It strives to ensure its societal contribution in the context of a bio-based, customer-driven and globally competitive European economy.* The FTP sets up dedicated Task Forces (TF) to deal with important issues within the forest-based sector. The TFs focus on paving the way for innovative R&D related to the forest based sector by describing the current situation, identifying industry interest, challenges and needs of innovation, and by aiming to enhance FTP's success in the 7th Framework program. Successful FP6 and FP7 projects are linked on the website.

Biorefinery Issues

The FTP aims to develop: selective and efficient separation and conversion processes, biorefineries for wood-based solid and liquid biofuels, recycled fibre biorefineries, and above-sector synergies with the agricultural and chemical sector. Also, the platform aims to address the socio-economic impacts of biorefinery developments.

Biorefinery-related documents/reports (selection)	• FTP strategic research agenda. • FTP vision for forest based sector in 2030. • FTP general presentation. • Other documents.

Name platform	**European Technology Platform Plants for the Future**
Website	http://www.epsoweb.org/catalog/tp
Contact	secretariat@plantetp.org

Introduction

The European Technology Platform (ETP) 'Plants for the Future' is a stakeholder forum for the plant sector, including plant genomics and biotechnology. It provides a 20-year vision and a short-, medium- and long-term Strategic Research Agenda for Europe's plant sector setting out a consensus on the research needed to fulfil the vision. Its members come from industry, farmer organizations, academia and other stakeholder groups. During 2008-2010 the Plant ETP will work with a focus on promoting and advocating strategic research and internationally competitive research. Five challenges for Europe's society and economy to which the plant sector can contribute, are: Healthy, safe and sufficient food and feed, Plant-based products – chemicals and energy, Sustainable agriculture, forestry and landscape, Vibrant and competitive basic research, Consumer choice and governance. Education, communication and innovation embracement including general policy statements will be complementary tasks with second priority.

Biorefinery Issues

The five challenges for Europe's society and economy to which the plant sector can contribute, which have been identified in the strategic research agenda inlcude: Healthy, safe and sufficient food and feed, Plant-based products – chemicals and energy, Sustainable agriculture, forestry and landscape, Vibrant and competitive basic research, Consumer choice and governance.

Biorefinery-related documents/reports (selection)	• Strategic research agenda 'Plants for the Future' and action plan. • European vision for plant genomics and biotechnology for 2025. • Other documents.

Name platform	**Fuel Cells and Hydrogen – Joint Technology Initiative**
Website	http://ec.europa.eu/research/fch
Contact	secretariat@fchindustry-jti.eu

Introduction

The Fuel Cells and Hydrogen Joint Undertaking (FCH JU) is a unique public private partnership supporting research, technological development and demonstration activities in fuel cell and hydrogen energy technologies in Europe. Its aim is to accelerate the market introduction of these technologies, realizing their potential as an instrument in achieving a carbon-lean energy system.

Fuel cells, as an efficient conversion technology, and hydrogen, as a clean energy carrier, have a great potential to help fight carbon dioxide emissions, to reduce dependence on hydrocarbons and to contribute to economic growth. The objective of the FCH JU is to achieve these benefits through a concentrated effort from all sectors. Through the FCH JU, the members (the European Commission, fuel cell and hydrogen industries represented by the NEW Industry Grouping and the research community represented by Research Grouping N.ERGHY) pool resources and jointly plan activities in order to overcome barriers to the commercial deployment of fuel cell and hydrogen technologies. Industry's lead role in defining priorities and timelines of the JU, together with the European Commission and the research community, will ensure that the agenda is focused on market introduction of fuel cell and hydrogen technologies. Focus is on automotive sector, stationary fuel cells (domestic and commercial), and portable applications. RTD activities are supported by way of annual competitive calls for proposals, organized according to the strategic priorities set out in annual and multi-annual Implementation Plans.

Biorefinery Issues

The current topics are: Transport & Refuelling Infrastructure, Hydrogen Production & Distribution, Stationary Power Generation & Combined Heat & Power (CHP), Early Markets, and Cross-Cutting Activities.

Biorefinery-related documents/reports (selection)	• Strategic research agenda: European Hydrogen and Fuel Cell Technologies. • Vision document: Hydrogen Energy and Fuel Cells. • Deployment strategy Hydrogen and Fuel Cell Technologies • Other documents.

Name platform	**European Road Transport Research Advisory Council (ERTRAC)**
Website	www.ertrac.org
Contact	info@ertrac.org

Introduction

The European Road Transport Research Advisory Council was established to mobilize all stakeholders, develop a shared vision, and ensure timely, co-ordinated and efficient application of research resources to meet the continuing challenges of road transport and European competitiveness. It aims to: 1) provide a strategic vision for the road transport sector with respect to research and development; 2) define strategies and roadmaps to achieve this vision through the formulation and maintenance of a Strategic Research Agenda (SRA) and Strategic Research Recommendations (SRR); 3) stimulate increased effective public and private investment in road transport research and development; 4) contribute to improving co-ordination between the European, national, regional and private research and development actions on road transport; 5) enhance the networking and clustering of Europe's research and development capacity; 6) promote European commitment to research and technological development ensuring that Europe remains an attractive region for researchers and competitive industries.
The Research Areas and Working Groups consist of experts responsible for the creation and co-ordination of the draft documents of the Strategic Research Agenda and Recommendations. In order to accomplish this mission, Workshops with invited technical experts from all sectors of road transport are organized.

Biorefinery Issues

The ERTRAC activities focus on four research areas: Environment, energy and resources, Safety and security, Transport, mobility and infrastructure, and Design and production systems.

Biorefinery-related documents/reports (selection)	• The Strategic research agenda and a vision 2020 document can be found here. • Other documents and newsletter can be found here.

Name platform	**European Algae Biomass Association (EABA)**
Website	www.eaba-association.eu
Contact	eaba@eaba-association.eu

Introduction

The general objective of the European Algae Biomass Association (EABA) is to promote mutual interchange and cooperation in the field of algae biomass production and use, including biofuels uses and all other utilisations. Its main target is to act as a catalyst for fostering synergies among scientists, industrialists and decision makers in order to promote the development of research, technology and industrial capacities in the field of algae. Algae and aquatic biomass are increasingly raising the interest of the scientific community, industry representatives as well as political decision makers as they represent one of the most promising renewable sources for a wide range of third-generation low-carbon applications in the field of renewable energies, biofuels (including jet fuels), nutrients, pharmaceuticals, animal feed or bio-based products (bio-plastics, bio-cosmetics, etc.). A number of technical, legal and scientific obstacles need to be solved in order to bring down the final price of algae biomass to an economic level and to produce a fully reliable quality product. The objective of the EABA is to support the efforts of the various actors in the algae sector in order to make this happen.
EABA intends to provide a basis for: representing the European algae biomass industry and scientific community at international level; making algae research and industry alive in public debate; promoting investment and financial support in the field of algae; studying economic, technical, environmental, social problems and effects which may be related by the algae sector.

Biorefinery Issues

Studying all economic and technical problems which may impact the algae sector in the European Union and related countries and studying all the direct and indirect environmental, social and economic effects of algae production and use

Biorefinery-related documents/reports (selection)	• Draft Scope and Objectives of the EABA.

4.2 Network-of-Excellence Bioenergy [VTT, Aston]

Name	**Network-of-Excellence Bioenergy (NoE Bioenergy)**
Website	www.bioenergy-noe.com
Status	Running: 1.1.2004-30.11.2009
Contact	Kai.Sipila@vtt.fi

Introduction

To accomplish the goals of the EU "White Paper" (+ 108 Mtoe/a in the EU from renewable sources of energy between 1995 and 2010) and of the "Kyoto Protocol" (- 8% GHG emissions in the EU by 2008/12) the use of bioenergy has to be increased significantly. A Network of Excellence (NoE) will support this through technology development and implementation, policy actions and market strategies. The RTD programme of the NoE will cover all processes, components and methods necessary for establishing successful "bioenergy chains" to produce heat, electricity and biofuels for the energy end use market: Planting and harvesting of biomass; solid fuels from agricultural and forestry residues and organic waste components; combustion, gasification and synthesis, pyrolysis, anaerobic digestion and fermentation of biomass feed stock; production of liquid biofuels and hydrogen; heat and power production plants; analyses of socio-economic, policy, market and environmental issues including greenhouse gas balances.

Management of the NoE and integrating activities will assure that the ongoing RTD activities of the partner institutions will be integrated in such a way that eventually a jointly executed RTD programme will be established in a "Virtual Centre of Excellence". To assure a far reaching and long range impact of the experience and know-how within the NoE, activities to spread excellence will be carried out. An industrial and SME advisory group will be established. To support the creation of the European Research Area in the field of bioenergy, the NoE will cooperate with a future ERA-NET project on bioenergy, which will be linking the national R&D programmes.

The creation of a NoE is a first-time effort for both the European Commission and the partners. It therefore should be attempted with a set-up, which is manageable, i.e. with 8. The Network is clearly focused on the integration process, which will be planned and reviewed after every 18 months period under strategic and leadership aspects. The duration of the NoE is 5 years.

Biorefinery Issues

The scope of Bioenergy NoE is the entire field of bioenergy. However, liquid biofuels for transport, renewable electricity production, agro-bioenergy and emission trading have been the main focus areas reflecting the RTD needs and policy issues brought forward by the SET plan targets.

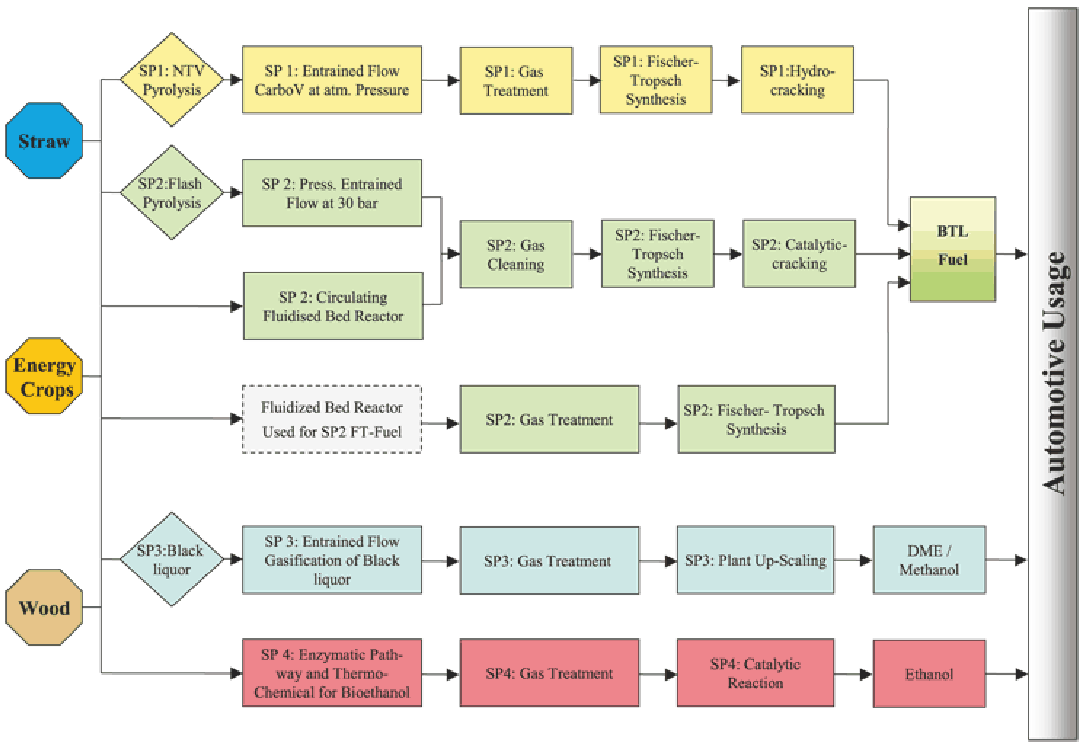
Biorefinery-related documents/reports (selection)	• Market potential of high efficiency CHP and waste based ethanol production in European pulp and paper industry. http://www.vtt.fi/inf/pdf/tiedotteet/2009/T2500.pdf • Bioenergy in Europe: Implementation of EU directives and Policies relating to Bioenergy in Europe and RD&D Priorities for the Future. http://www.vtt.fi/inf/pdf/tiedotteet/2008/T2441.pdf • Bioenergy in Europe: opportunities and Barriers. http://www.vtt.fi/inf/pdf/tiedotteet/2006/T2352.pdf • Advanced Education and Training in Bioenergy in Europe A synopsis of current education and training provisions in bioenergy at Masters and PhD levels in EU countries. www.bioenergynoe.com • Newsletter, publications at: www.bioenergynoe.com

4.3 European Projects

Name Project	**RENEW**
Website	www.renew-fuel.com
Status	Completed: 010104 – 010108
Contact	See at www.renew-fuel.com/fs_contact.php

<u>Introduction</u>

The main mission of RENEW was to prove different concepts of fuel production from biomass (see Figure below). Production routes for BTL fuels would be demonstrated and the full supply chain would be assessed in terms of biomass potential, life cycle, costs and technological options. Further, the project aimed to provide the scientific and technological basis for the transition into a sustainable and environmentally friendly road- transport based on renewable fuels.



<u>Biorefinery Issues</u>

Topics addressed include dimethylether (DME) production from black liquor using gasification, ethanol production using enzymatic and thermochemical pathways, and BTL fuel production using pyrolysis.

<u>Biorefinery-related documents/reports (selection)</u>	• Final scientific report and Executive summary of the RENEW project can be found here. • Many other can be found here.

Name Project	**ECOBINDERS (EC FP6 – Integrated Project)**
Website	www.ecobinders.net
Status	Completed: 010305 – 010308
Contact	richard.gosselink@wur.nl

Introduction

The risk of toxic and strongly debated wood preservation materials and specific binders starts only now to be taken very seriously by politics and by the public. Currently, about 6.5 million m3 preserved wood is annually produced in Europe and finds its way to the consumer in several commonly used end products. The European consumption of resins, produced from non-eco friendly starting materials, for wood based panel production in 2003 was close to 4 million tons. Through the expected new products that will emerge from this ECOBINDERS project into society, the amount of toxic materials found in every household in Europe today, will be diminished significantly.
ECOBINDERS aimed to develop new sustainable processes and products using furan and/or lignin based binders for high added-value, environmentally friendly products and services in SME intensive industries. These binders will be used in conjunction with natural fibres and are inherently non-toxic, environmentally friendly, emission-free and water resistant. Furthermore, a reduction of CO2 emission will be established.
The main objectives were to develop: 1) a new class of biomass based binders consisting of furans and/or sulphur-free lignin; 2) innovative and sustainable processes for these multifunctional binders by using an integrated chain approach combining multi-sectorial interests; 3) durable wood : a sustainable alternative for currently used, but strongly debated toxic wood protection agents (a.o. chromated copper arsenic salts); 4) emission-free panel & boards for indoor use to replace the traditionally used, formaldehyde releasing, products; 5) water and organic solvent resistant 3D design products for in- and outdoor use.

Biorefinery Issues

ECOBINDERS has focussed on the development of eco-friendly, emission-free, moisture resistant and 100% renewable resins based on furans and lignin for applications of wood based products.

Biorefinery-related documents/reports (selection)	• An extensive list of publications is available here. • Ecobinders Newsletter.

Name Project	**NILE (EC FP6 – Integrated Project)**
Website	www.nile-bioethanol.org
Status	Running: 011005 – 011009
Contact	See at www.nile-bioethanol.org/contact.html

Introduction

The objective of the project 'New Improvements for Ligno-cellulosic Ethanol (NILE)' is to propose the best process for a cost effective production of clean bioethanol from lignocellulose to be used in combustion engines. Its overall objective is to develop cost effective production of clean bioethanol from lignocellulosic biomass (LCB), enabling its use as a transport biofuel. NILE will develop, investigate and evaluate new technologies for efficient conversion of lignocellulose to bioethanol. These technologies will be verified using a unique and fully integrated pilot plant providing reliable data for global socio-economic and environmental assessments and for the design of a future demonstration unit.
The activities of NILE aim at overcoming critical hurdles in process development, and key issues are: 1) decreasing the cost of enzymatic hydrolysis of lignocellulose to fermentable sugars using new engineered enzyme systems; 2) removing current intrinsic limitations in the conversion of fermentable sugars to ethanol; 3) validating the engineered enzyme systems and yeast strains in a fully integrated pilot plant. Validation includes all process steps and recycling of process streams; 4) analyzing socio-economic and global environmental impacts of the production and use of bioethanol from LCB based on the new data obtained; 5) dissemination and training of target groups.
By its integrated structure, NILE supports the development of research activities in close connection with industrial processes, their validation, their technical and socio-economic assessments, their dissemination as well as training activities. Produced lignocellulosic bioethanol will be checked for automotive applications.

Biorefinery Issues

The project is dedicated to obtaining new efficient enzymes and yeasts for hydrolysis of biomass and production of ethanol, suitable for large-scale use. Pilot plants will be used i) to validate the enzyme process technologies and ii) to design, optimise and integrate the process, iii) to determine mass and energy balances and cost estimates. Life cycle impacts of bioethanol from lignocellulosic feedstock will be included.

Biorefinery-related documents/reports (selection)	• NILE contributes to a technical training course: 'European Master in Renewable Energy'. • NILE Brochure 'Advances in Lignocellulosic Ethanol'. • NILE newsletter. • NILE Project Leaflet.

Name Project	**VIEWLS**
Website	www.tmleuven.be/project/viewls
Status	Completed: 2003-2005
Contact	André Wakker (a.wakker@nrg.eu)

Introduction

The main objective of this project was to assist policy makers and industrial organisations in identifying the possibilities and strategies towards large scale sustainable production, use and trade of biofuels for the transport sector in and from Central and Eastern European countries.

The project is co-ordinated by Novem, the Netherlands Agency for Energy and the Environment. Other project partners were: ECN (NL), Copernicus Institute of the University of Utrecht (NL), Joanneum Research Institute (AT), CIEMAT (ES), UBC (CA), COWI (DK), STEM (SE), IEA-BA-39 (USA), IE (DE), Chalmers University (SE), ECBREC (PL), USAMBV (RO), RILOG (CZ), HIAE (HU), ADEME (FR), NTUA (GR), BLT (AT), TML (BE).

Results

The major finding of the VIEWLS project is that the potential role of biofuels to the transport sector in Europe can be very significant and can go beyond the indicative EC Directive targets. All current biofuels perform better on CO2-eq. emissions as compared to fossil fuels, and this will even improve in the future. Given the current (2005) crude oil price developments, biofuels are about to reach competitive status, though future biofuels will require further development. The Eastern and Central European Region can become the biofuel barn to (partly) secure the transport fuel needs of Europe, but this will require transitional changes in the agricultural management system and a gradual shift from current biofuel resources to ligno-cellulose rich and –based resources.

Conclusion

The market perspectives for biofuel in Europe seem very promising – a potential share of 20% by 2030 would be possible at relatively low CO2 emission reduction costs, but need the right policy and industrial strategic decisions, with a long term viewpoint. Current biofuel developments need to be supported to prepare the transport and the agricultural sectors for these necessary changes. The car manufacturers, oil companies and biofuel industries as well as agro-industrial institutes, knowledge institutes and potential end-users need to start building sustainable partnerships to take up these new activities.

Biorefinery Issues

Main focus on issues related to the large scale sustainable production, use and trade of biofuels for the transport sector in Europe.

Biorefinery-related documents/reports (selection)	The project final report can be found at: http://www.tmleuven.be/project/viewls/final_report_viewls.pdf

Name Project	**REFUEL**
Website	http://www.refuel.eu
Status	Completed: 2005-2007
Contact	Marc Londo (londo@ecn.nl)

Introduction

The EU biofuels target for 2020 can be met with conventional feedstocks and current technology without major agricultural land use changes and environmental consequences. Yet, only advanced, second-generation biofuels are expected to provide a substantial contribution to reducing greenhouse gas emissions and increasing energy security. The introduction of these advanced biofuels requires supporting measures on several policy levels. These are the key conclusions of the REFUEL project, commissioned by the EU's Intelligent Energy Europe programme. The two-year project is coordinated by the Energy Research Centre of the Netherlands, and implemented by a consortium of seven European institutes with different disciplinary backgrounds.

The EU's 10% target for biofuels by 2020 can be met by domestic production of conventional, firstg eneration biofuels, and moderate imports. However, advanced, or second-generation biofuels would result in more climate benefits. These biofuels, produced from residues and woody or grassy plants, show substantially higher yields per hectare of land, and provide far better opportunities for the EU industry to develop an innovative sector. Any biofuels policy promoting these benefits leads to improved opportunities for second-generation biofuels, the REFUEL analyses show. In comparison, conventional biofuels (biodiesel from oil crops and bioethanol from sugar crops, cereals) perform less adequately on these most commonly used arguments for increasing biofuels use.

However, for advanced biofuels to enter the market, various obstacles will need to be tackled. Required production technology needs to be further developed and deployed, as well as new supply chains for agricultural and forestry residues and crops. Overcoming these hurdles will require a favourable and stable investment climate. Furthermore, REFUEL shows that cross-sector strategies can help reduce these barriers. Examples are the initial development of biomass supply chains for power generation, or integration of biofuel plants in district heating systems. In this context, the role of the Central and Eastern European countries will be pivotal, as this region has most of the feedstock potential.

Biorefinery Issues

Development of a roadmap for biofuels (see the introduction)

Biorefinery-related documents/reports (selection)	All public deliverables can be found at: http://www.refuel.eu/publications

Name Project	**BIOCOUP (EC FP6 – Integrated Project)**
Website	www.biocoup.eu
Status	May 2006 – May 2011
Contact	Yrjo Solantausta (yrjo.solantausta@vtt.fi)

<u>Introduction</u>

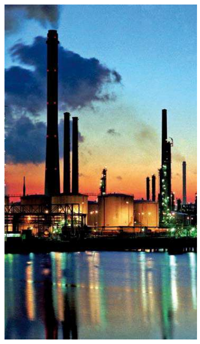
Biomass represents today nearly two-thirds of all the renewable energy sources, and it is it only renewable source that can be used to produce competitively-priced liquid fuels for transport. It will therefore play a significant role in the growing production and use of renewable energies. One key challenge is to optimise reliable, efficient and cost effective technologies for the conversion of biomass.

The BIOCOUP Integrated Project coordinated by VTT in Finland is aimed at developing a chain of process steps to allow a range of different biomass feedstocks to be co-fed to a conventional oil refinery to produce energy and oxygenated chemicals. The overall objective is to respond to the increasing demand of biofuels with a new innovative processing route.

<u>Biorefinery Issues</u>

The core innovation derives from integration of bio-feedstock procurement with existing industries (energy, pulp and paper, food) and processing of upgraded biomass forms in existing mineral oil refineries. This will allow a seamless integration of bio-refinery co-processing products to the end-consumers for products, such as transport fuels and chemicals, and thus provide an important stimulus to biomass acceptance and further technological development of biomass production routes. The following subjects are dealt with:

- fractionation and liquefaction of biomass
- de-oxygenation of bio-oils
- evaluation of upgraded bio-oils in standard refinery units
- production of chemicals from biomass
- scenario and life cycle analysis
- dissemination activities.



<u>Biorefinery-related documents/reports (selection)</u>	• http://www.biocoup.com/uploads/media/Biocoup_brochure.pdf • http://www.biocoup.com/fileadmin/user/pdf/publi/26_BIOCOUP_Oct08.pdf

Name Project	**BIOSYNERGY (EC FP6 – Integrated Project)**
Website	www.biosynergy.eu
Status	Running: 010107 - 010111
Contact	info@biosynergy.eu

Introduction

BIOSYNERGY - BIOmass for the market competitive and environmentally friendly **SYN**thesis of bio-products together with the production of secondary en**ERGY** carriers through the biorefinery approach. The use of biomass as feedstock for the production of transportation fuels – and to a lesser extent energy – is still more costly than the use of fossil resources. The aim of BIOSYNERGY is to contribute to the cost-effective use of biomass –especially lignocellulose and residues– by sound techno-economic process development of integrated production of value-added chemicals, transportation fuels and energy by process development from lab-scale to demonstration at pilot-scale. BIOSYNERGY works towards achieving sustainable management of Europe's natural resources and their integration with human activities, specifically in the bioenergy, fuels and chemical industry. The project will be instrumental in the establishment of facilities for integrated co-production of bulk quantities of chemicals, fuels and energy from a range of biomass feedstocks in Europe. BioSynergy has great potential impact as it will set up pilot plants of the most promising technologies for a bioethanol side-streams biorefinery. It will do so in close collaboration with the lignocellulose-to-bioethanol pilot-plant of Abengoa Bioenergía Nuevas Tecnologías that is under construction in Salamanca, Spain. The BioSynergy project is supported by the European Commission through the Sixth Framework Programme for Research and Technological Development (2002 – 2006) with a grant up to 7.0 million € under contract number 038994 – (SES6). The project addresses Thematic Priority "Sustainable development, global change and ecosystems". The project is performed by a consortium comprising 17 partners from industry, universities and research institutes from 10 EU countries. Project co-ordinator: ECN, The Netherlands.

Biorefinery Issues

BIOSYNERGY works towards achieving sustainable management of Europe's natural resources and their integration with human activities, specifically in the bioenergy, fuels and chemical industry. The project will be instrumental in the establishment of facilities for integrated co-production of bulk quantities of chemicals, fuels and energy from a range of biomass feedstocks in Europe. BioSynergy has great potential impact as it will set up pilot plants of the most promising technologies for a bioethanol side-streams biorefinery.

Biorefinery-related documents/reports (selection)	• Biorefinery Course: "ADDING VALUE TO THE SUSTAINABLE UTILISATION OF BIOMASS" • Advanced Biorefinery Concepts: A Feasibility and Reality Check • Biosynergy Project Brochure

Name Project	**BIOPOL (EC FP6 – SSA)**
Website	www.biorefinery.nl/biopol
Status	Completed: 010307 – 300409
Contact	Bert Annevelink (bert.annevelink@wur.nl)

Introduction

BIOPOL is a recently completed two-year research project funded by the European Commission. The overall goal of the project was to assess the status of innovative biorefinery concepts and the implications for agricultural and forestry policy. The BIOPOL project was conceived to assess the current status of biorefinery activities in Europe and to explore future scenarios for development. By systematically accounting for the potential technical, political, social and industrial impacts of such scenarios the outputs are intended to help guide policy making in this complex area. In addition, by bringing together several complimentary research disciplines the insights gained can help frame future research directions both in Europe and elsewhere. The project cooperated with Biorefinery Euroview.

A key objective of the BIOPOL project was to provide an overview of existing biorefineries, pilot plants and major RTD projects in the EU. In total 34 existing or planned biorefineries were identified and classified. In addition, 45 biorefinery-related major R&D, pilot and demonstration projects were identified in the EU. The majority of the identified biorefineries (23 out of 34) and biorefinery projects (28 out of 45) are located in Western Europe, followed by Northern and Southern Europe. About 75% of the biorefinery sites are located in an area comprising Northern France, Germany, Denmark, Belgium, the Netherlands, and the UK. These 6 countries possess both a variety of suitable feedstocks for biorefinery applications *and* intensive (petro)chemicals production.

Biorefinery Issues

A selection of the most important recommendations is provided here.

- Communication strategies will be required to further inform industry and the public of the benefits of biorefineries compared to other uses of biomass;
- Visible demonstration projects and networks could be vital in building a supportive biorefinery community;
- Although the chemical industry is often seen as the most attractive partner for biorefining activities, they display low enthusiasm compared to the pulp & paper and sugar/starch sectors, who may be more dynamic partners in the near-term;
- Widespread suspicion of subsidies for bio-based products exists, especially following recent experiences with biofuels. Thus, a diverse and integrated policy mix is recommended, including incentives for advanced and flexible bioprocessing demo plants;
- Consumer appetite for paying extra for bio-based products is not yet high and so the success of biorefinery products may rely on functional superiority. Both product development and feasibility studies for integrating into bulk chemical economics is encouraged;
- Policy makers must confront potentially challenging issues such as genetic modification, which could undermine other efforts to progress attractive biorefinery concepts.

Biorefinery-related documents/reports (selection)	All public deliverables can be found at: www.biorefinery.nl/biopol/public-deliverables

Name Project	**Biorefinery EUROVIEW (EC FP6 – SSA)**
Website	www.biorefinery-euroview.eu/biorefinery/public/index.html
Status	Completed: 010307 – 300409
Contact	Christophe Luguel (luguel@iar-pole.com) / Guillaume JOLLY (jolly@iar-pole.com)

Introduction

The BIOREFINERY EUROVIEW project aimed at preparing for future EU research and technological development activities, including monitoring, assessment activities in the field of biorefineries, and the implications for agriculture and forestry policy. This approach meets the Treaty objectives of strengthening the scientific and technological bases of EU industry and encouraging the latter to become more competitive at international level. The project cooperated with BIOPOL.

The BIOREFINERY EUROVIEW was designed to support European policy (agriculture, forestry, energy and research policies in particular) and to strengthen the European Research Area, in order to increase the competitiveness of European territorial systems in the biorefinery field. The main objectives were:

- Studying existing or planned European biorefineries
- Identifying socio-economic factors and regulatory aspects which improve or slow down the development of biorefineries
- Building a range of forecasting scenarios for biorefinery development
- Selecting the concepts and the operational policies for the future development of biorefineries

Policy suggestions included standardised LCA methodologies for marketing bio-based products, setting appropriate targets for use of bioproducts in specific sectors, such as mulching films, taking a strategic approach to funding infrastructure projects, and addressing public concerns including GMOs. Overall, there is a clear indication that the EU would benefit from a cohesive legislation strategy to develop the fragmented existing markets for bio-based products, such as plastics and vitamins.

Biorefinery Issues

The project identified 4 main biorefinery concepts on the basis of either feedstock or technology, giving rise to overlap as well as synergies between the different concepts. The project pointed out that biorefineries based on oil, sugar or starch are already existing biorefineries, but that a lot of research still needs to be done concerning the lignocellulosic biorefinery. The interactions between the different concepts were demonstrated, for instance where the outputs of one process can be suitable inputs to a different biorefinery facility. On example is the potential use of residues from the oilseed, green or cereal biorefinery in a lignocellulosic biorefinery for the production of cellulose fibres, chemicals, lignin and/or energy. Although biorefinery concepts are becoming increasingly complicated as new technologies emerge, the four main types presented remain valid and useful to cover all research in this field. Translating the complexity of these classifications into real-world developments is possible, however, and exemplified by the Rodenhuizedock biorefinery in the port of Ghent.

Biorefinery-related documents/reports (selection)	Public reports can be found on the website.

Name Project	**SUSTOIL**
Website	www.sustoil.org
Status	Running: 010608 – 310510
Contact	info@sustoil.org

Introduction

To achieve the goal that in 2030 25% of the EU's transport fuel will be used by clean and CO2-efficient biofuels, the transition to second generation biofuels will be needed. Besides this, implementation will be necessary of currently available biofuels, including biodiesel, via integrated production of energy and other added-value products through biorefineries. The SUSTOIL project reviews the state of knowledge on the different stages of the biodiesel production by collecting the results of previous and on-going projects both from governmental sources and scientific literature. The study focuses on the major EU oil-rich crops, namely rapeseed, sunflower and olive. The key objective is to improve the economics of biodiesel production by adding value to its major by-products, like proteins, rape meal, glycerol, levulinic acid etc. This project is led by the Green Chemistry Centre of Excellence, based at the University of York, United Kingdom and the expertise of 23 project partners is integrated.

Biorefinery Issues

The aim of SUSTOIL is to develop advanced biorefinery schemes to convert whole EU oil-rich crops (rapeseed, sunflower, olive) into energy (fuels, power, heat), food and bioproducts (chemicals and/or materials) making optimal uses of the side streams generated during farming/harvesting, primary processing (e.g. oil extraction and refining) and secondary processing (e.g. transesterification).

Biorefinery-related documents/reports (selection)	An introduction to the project can be found in Newsletter 1. An overview of the first results are addressed in Newsletter 2. Further detailed reports like Deliverable reports can be found here.

Name Project	**STARCOLIBRI (EC FP7 – SSA)**
Website	www.star-colibri.eu (under construction)
Status	Started: 011109 – 311011
Contact	Johan Elvnert (johan.elvnert@mindpuls.eu)

Introduction

For the first time in Europe a real critical mass along the whole value-chain, and in all aspects of the biorefinery concept,will be achieved by the close collaboration of five industry-driven European Technology Platforms, five excellent research partners with complementary expertise, and the International Civil Society Organisation IUCN, who will validate the impact on the global sustainability of the results. The collaboration in this Coordination and Support Action is called Star-COLIBRI, and its main objectives are to promote coordination and work to overcome fragmentation in the field of biorefineries research; to facilitate information exchange and cross-fertilization; to support break-through innovations by speeding up and facilitate industrial exploitation of research results. The Star-COLIBRI project will accomplish these targets by working in two parallel but mutually dependant processes: The first process has longer term objectives and it will provide a framework for collaborations and information exchange, common vision and a roadmap for 2020. It will also directly contribute to policy initiatives such as the European Lead Market Initiative on Bio-Based Products. The second process has shorter term objectives and aims to the immediate support and coordination of ongoing biorefinery research projects with potential high impact. The new strategy developed for this is called StarClustering. Better coordination of national research funding through an ERA-Net Liaisons Office will also be achieved.

Biorefinery Issues

In order to maximise potential impact when it comes to coordinating and supporting ongoing research projects, which is one of the main objectives of the Joint Biorefinery Call, the Star-COLIBRI project will apply a new and innovative project clustering strategy. The strategy focuses on promoting project clusters as role-models that consist of a large, leading research project (often EU-funded) or a demonstration facility: a “Star-project”, and several smaller, more specific “comet like” projects, i.e. projects of excellence often funded at the national level with a shorter lifetime and fewer resources. We call the strategy “StarClustering”.

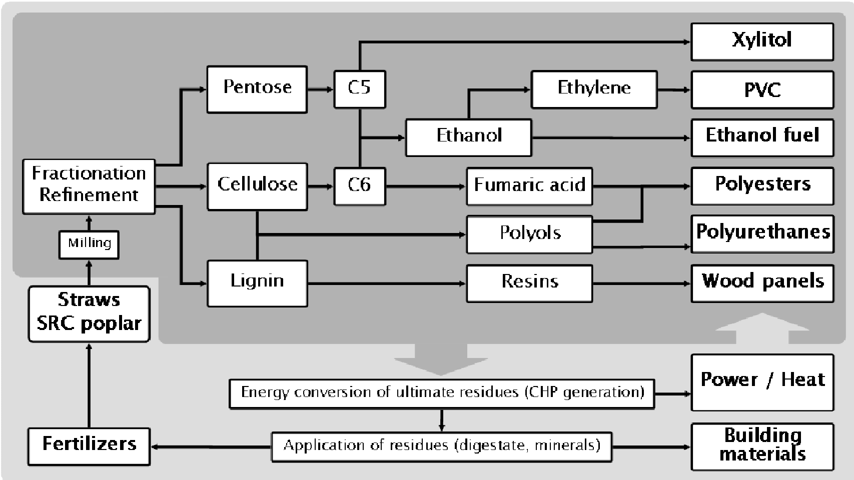
The first step of the StarClustering strategy is to identify the Star projects. The second step is to identify Comet projects that could facilitate the success of the Star projects. The idea is then to analyse the work plan, objectives and preliminary results to identify gaps, overlaps and complementarities and in doing so try to show how mutual benefits can be achieved by establishing a closer collaboration and a more open information exchange. This analysis will then serve as the basis for starting negotiations for an agreement between the projects of a joint collaboration and information sharing in order to form a StarCluster.

Biorefinery-related documents/reports (selection)	No documents available yet

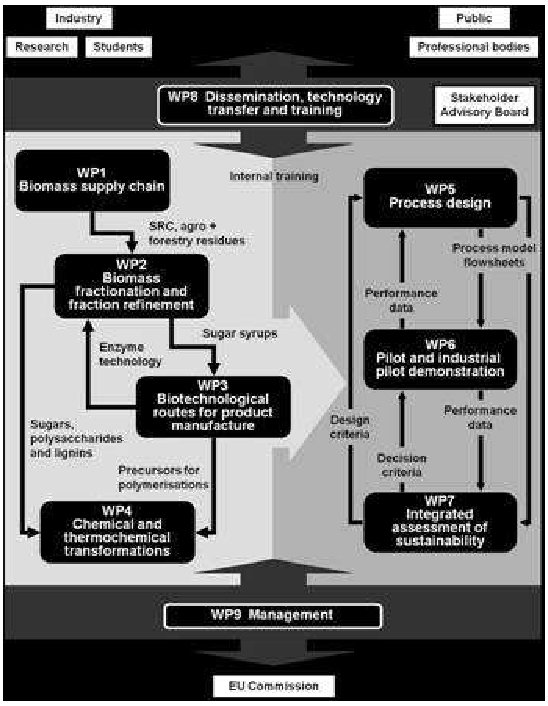
Name Project	**BIOCOmmodity bioREfinery – BIOCORE** (EC FP7 – Colloborative Project (grant no.: 241566))
Website	Not available yet
Status	Will start April 2010 -
Contact	Michael O'Donohue (modonoh@insa-toulouse.fr)

Introduction

The overall objective of BIOCORE is to create and demonstrate a lignocellulosic biorefinery for sustainable processing of agricultural residues (wheat and rice straws), SRC wood (poplar) and hardwood forestry residues, into 2G biofuels, chemicals, polymers, speciality molecules, heat and power. Several biorefinery chains from feedstock to end products will be demonstrated on industrial pilot-scale.



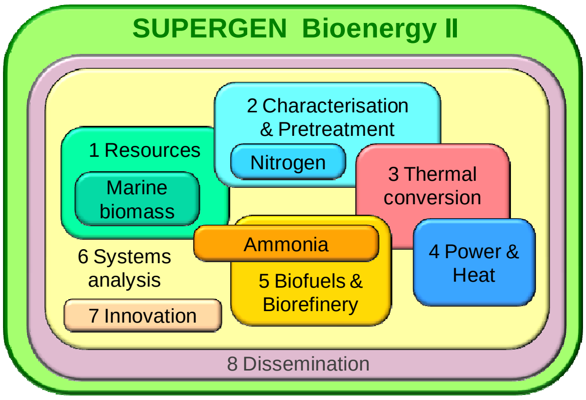
Biorefinery Issues



Name Project	**SUPERGEN Bioenergy**
Website	www.supergen-bioenergy.net
Status	6 years into an 8 year programme
Contact	Tony Bridgwater or Emma Wylde at Aston University a.v.bridgwater@aston.ac.uk e.wylde@aston.ac.uk

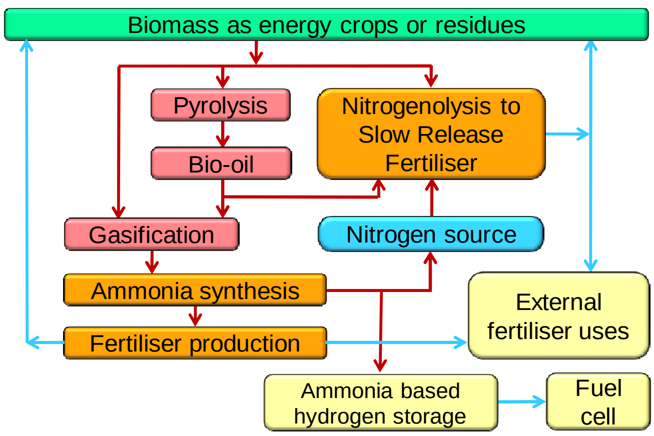
<u>Introduction</u>

We are studying the production of different types of biomass and investigating their behaviour in thermal conversion processes, with particular emphasis on the interaction and interface between production and conversion. Conversion processes are being investigated to improve their performance. Finally the bioenergy products are being expanded to include transport fuels and renewable chemicals within the context of a biorefinery. A wide range of system studies are included to evaluate the performance, cost, and socio-economic benefits of a wide range of bioenergy chains.

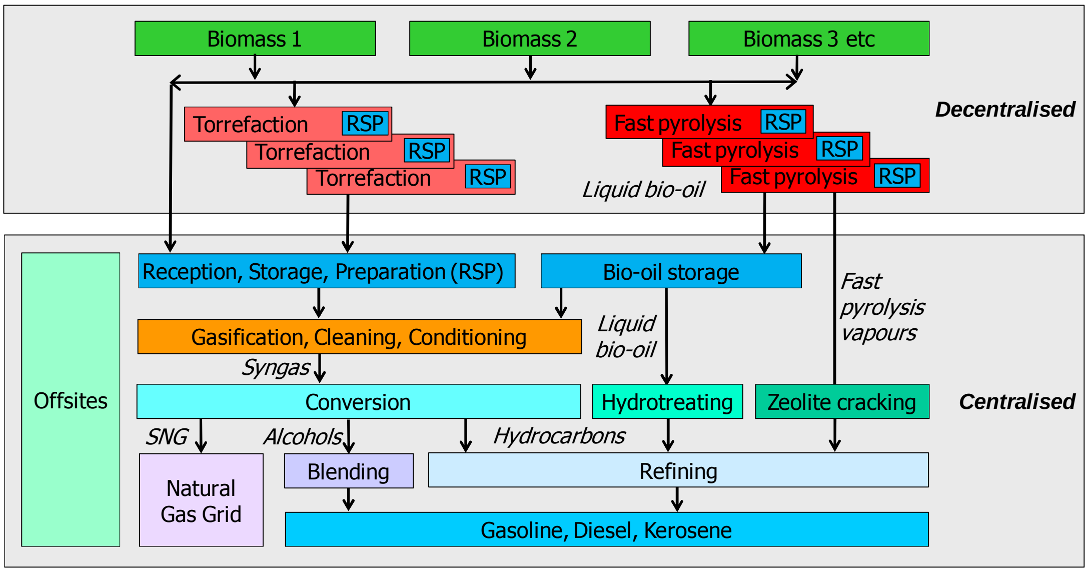


<u>Biorefinery Issues</u>

There are two main aspects of biorefinery evaluation in SUPERGEN Bioenergy - Nitrogenous fertilisers and Biofuel production. Nitrogenous fertilisers are being studied both as slow release fertiliser through nitrogenolysis – a variation of fast pyrolysis, and conventional gasification and ammonia synthesis as summarised in the figure below.



Biofuels are being studied utilising both fast pyrolysis and gasification as primary processing steps both centralised and decentralised followed by synthesis of hydrocarbons and alcohols from syngas and upgrading of fast pyrolysis products. These are depicted in the figure below.



Biorefinery-related documents/reports (selection)	Reports and publications are not yet available publicly.

Name Project	**Dibanet (CP)**
Website	http://www.dibanet.org/
Status	Started July 2009 for 42 months
Contact	fp7dibanet@gmail.com

Introduction

DIBANET aims to:

- Optimise the yields of levulinic acid, from the conversion of biomass.
- Improve the energy balance & the total biofuel yields possible from a feedstock by sustainably utilising the residues in pyrolysis processes to produce a bio-oil that will be upgraded to a DMB.
- Reduce the energy & chemical costs involved in producing ethyl levulinate from levulinic acid & ethanol.
- Select key biomass feedstocks for conversion to levulinic acid, analyse these & develop rapid analytical methods that can be used in an online process.
- Analyse the DMBs produced for their compliance to EN590 requirements &, if non-compliant, suggest means to achieve compliance.

DIBANET will enhance co-operation between the EU & LA in biofuels by:

- Developing a tightly-integrated online network of key players in the EU & LA.
- Organising public meetings between key stakeholders from both regions.
- Training PhD & post-doctoral researchers from the opposite region.
- Develop an inter-regional Technology Transfer Business Plan for the most effective exploitation of the DIBANET technologies. This will consider the combined needs of the EU & LA & the potential for trade.

Biorefinery Issues

Integration of levulinic acid production for production of diesel miscible biofuels (DMB) with processing and upgrading of side-streams and residues for further added-value bioenergy and biofuel products. The project will include feedstock processing by thermal routes for comparison with biological routes via levulinic acid. Additional chemical product will be explored for optimising integrated process performance.

Biorefinery-related documents/reports (selection)	None yet available

Name Project	**BioTop (FP7 – SICA, project no. 213320)**
Website	www.top-biofuel.org
Status	2008 – 2010?
Contact	Dominik Rutz (dominik.rutz@wip-munich.de)

Introduction

The overall objective of the BioTop project is to identify technical opportunities and research needs for Latin America in order to maximize synergies in the biofuels sectors of Latin America and Europe. Thereby, the following specific objectives are:

- to provide a broad overview of the existing biofuel sectors in all Latin American countries. This also includes a broad overview of biofuel policies and strategies focusing on RTD in the field of 2nd generation biofuels in both LA and the EU up to 2030;
- to identify priorities, needs and opportunities in the field of RTD for sustainable biofuel production and biomass conversion technologies at both the national and the regional level in Latin America;
- to inform European and Latin American actors in the biofuel sector about specific, mutually interesting areas for increased collaboration and partnerships;
- to harmonize the agenda between Latin America and the EU on sustainable biofuel production and the integration of biofuels into the energy matrix;
- to facilitate and advance mutual knowledge and technology transfer between biofuel stakeholders in LA and the EU;
- to make recommendations on RTD and policies for the production and utilization of biomass conversion technologies.

Biorefinery Issues

BioTop provides a broad overview of the existing biofuels sector in Latin American counties. Key focus of the project is the identification and assessment of improved 1st and 2nd generation biofuel conversion technologies. Sustainability, standardization and trade aspects of future large-scale biofuel production are investigated, and scenarios, roadmaps and recommendations are developed. Exchanges between stakeholders active in RTD of biofuel conversion technologies are promoted and BioTop activities are effectively linked with existing networks. Outcome of the BioTop project is increased awareness about EU-LA opportunities for collaboration in the area of biofuels and the identification of suitable areas for biofuels RTD cooperation.

Biorefinery-related documents/reports (selection)	• http://www.top-biofuel.org/images/stories/pr-reports-website/ANNEX-1-11_WP3_D3-1_Task-3-4_Biorefineries.pdf • http://www.top-biofuel.org/images/stories/pr-reports-website/ANNEX-1-8_WP3_D3-1_Task-3-1_Bioethanol.pdf • http://www.top-biofuel.org/images/stories/pr-reports-website/ANNEX-1-6_WP2_D2-3_LA-biofuel-markets.pdf

Name Project	**Canebiofuel (CP)**
Website	www.canebiofuel.org
Status	1 March 2009 – 1 March 2011
Contact	Nina (Ms.) Eriksen, Phone: +45 444 638 00

Introduction

The overall objective of CaneBioFuel is to create a scientific and technological platform for the development of a commercially viable process for converting sugar cane biomass into fermentable sugars. The proposed project seeks to identify which fraction of the sugar cane biomass is most adequate for an enzyme based conversion technology to produce fuel ethanol. Furthermore, the project is focused on integrating the developed technology into existing fuel ethanol production to ensure fast and cost-efficient industrial deployment. In fulfilling this overall objective, the CaneBioFuel project will significantly push the State-of-the-Art with regard to 2nd Generation biofuels. Currently, no commercial 2nd Generation plants are in operation even though several research projects have focused on making this a reality. The major novelty of the CaneBioFuel project, therefore, will be the creation of the foundation required for upscaling and the establishment of the first commercial plant for conversion of sugar cane biomass.

Biorefinery Issues

The project will focus on developing a detailed understanding of the dynamic impact between pretreatment and enzymatic hydrolysis in order to specifically design the process and enzymes for cost-effective cellulose conversion. The main technical barriers in the project relate to the application of an integrated approach, achieving economically attractive production of 2nd generation ethanol based on sugar cane biomass as opposed to converting biomass into energy or other alternative use. Moreover, challenges are related to achieving process compatibility with existing plants and the accomplishment of a simple and cheap process.
The project will focus on the following RTD activities:

- Detailed characterization of structural components in sugar cane bagasse and trash
- Understanding the treatability of various fractions
- Pretreatment of biomass with focus on integration with existing technology
- Enzyme development for improved cellulose hydrolysis
- Process simulation and cost estimation

Biorefinery-related documents/reports (selection)	-

Name Project	**Babethanol (CP)**
Website	www.babethanol.com
Status	Will start in 2010?
Contact	Gerard Vilarem – INPT (F)
Introduction No info yet, website under construction.	
Biorefinery Issues	
Biorefinery-related documents/reports (selection)	

5. Assessment Info and Applicability for BIOREF-INTEG

5.1 Cross-table coupling most promising results of this Knowledge-import activities to the market sectors assessed within Bioref-Integ

Sector (S) **Applicable info**	BE	BD	P&P	OR	PP	FI	A
Green Biorefinery issues for the production of both juice and fibre fraction derived biobased products and bioenergy from grass and other relatively wet agroresidues (see 1.2).			X		X		X
Acid catalyst development for the conversion of animal fat and vegetable oils into an oil-fraction without free fatty acids. Contamination of the base catalyst used in conventional biodiesel processes is prevented (see 1.3).		X				x	
A ionic hydrogenation process to convert glycerol (by-product of biodiesel production) into 1,3-Propanol, which is used in DuPont's Sorona polymer (see 1.3).		X					
Ethanolysis of vegetable oils into biodiesel (see 1.3).		X					
Improved chemicals and plastics from oilseeds (1.3).		X					X
Soybean oil based resins and composites (see 1.3).		X					X
Biodiesel from sesame-oil from wild trees in Africa, NA, and the Caribbean (see 1.3).		X					
A technology to genetically modify yeast such that it can produce biodiesel from sugar cane or cellulosic biomass (Amyris, see 1.4.2).	X	X	X				
Prehydrolysis technology development, producing catalytic cellulignin and a prehydrolysate. The first is used as fuel and as animal feed. The second is used for production of chemicals from biomass (furfural, ethanol and xylitol) (BEM Programme, see 1.4.2).	X		X				
Patented Concentrated Acid Hydrolysis Technology with an efficient separation of acid and sugars by chromatographic separation using commercially available ion exchange resins, without diluting the sugar. High sugar concentration at high purity, the ability to ferment C6 and C5 sugars efficiently with conventional microbes, and the ability to handle silica in biomass feedstocks (BlueFire, see 1.4.2).	X		X				
Full cellulosic biomass derived sugar conversion into ethanol - 36 million gallon of ethanol/year from 2012 (BP/Verenium, see 1.4.2).	X						
Platform chemical 3-hydroxypropionic acid from carbohydrate raw materials, to be used to make 1,3-propanediol, acrylic acid, malonic acid, and acrylamide (Cargill, see 1.4.2).	X			x			
Fuel ethanol from casava (Cofco, see 1.4.2)	X			x			
Syngas to bioethanol (Coskata, see 1.4.2)	X		X	x			
A 250,000 gallon/a switchgrass to ethanol demonstration plant (DOE BESC, see 1.4.2).	X						
BES: Bioethanol sector, BDS: Biodiesel sector, P&PS: Pulp/paper sector, ORS: Oil refinery sector, PPS: Power production sector, FIS: Food industry sector, AS: Agrosector. X: highly relevant info; x: revevant info.							

Sector (S) **Applicable info**	BE	BD	P&P	OR	PP	FI	A
Mild ammonia pretreatment of biomass combined with the use of a modified Zymomonas mobilis – high ethanol yield and high tolerance to ethanol. (DuPont Danisco Cellulosic Ethanol LLC, see 1.4.2).	X						
Small-scale modular biorefinery development (Energenetics Energies, see 1.4.2).							X
Ionic liquids for biomass fractionation (Energy Biosciences Institute, see 1.4.2).	X						
Recombinant yeast that can co-ferment glucose and xylose (GreenTech America, see 1.4.2).	X						
Lignocellulosic ethanol production plant in Saskatchewan (Iogen, see 1.4.2).	X						
One step enzymatic saccharification of a model cellulose by using ionic liquid and a cellulase (Kyushu University, see 1.4.2).	X						
Mild pretreatment with engineered microorganisms that produce cellulase to hydrolyse cellulose and ferment sugars into ethanol – all in one step - Consolidated Bio-Processing (CBP) technology (Mascona, see 1.4.2). Also the combination of CPB microorganisms with steam explosion is possible (Bruce Dale, Osnabrück workshop).	X		X				
Oleaginous yeast *Rhodotorula glutinis* development, which has the ability to produce up to 70% of its weight as oil in the form of triacylglycerol (TAG), which can be a feedstock for biodiesel production. Feedstock for the yeast can be glucose and glycerol (Mississippi State University, see 1.4.2).		X					
Decrystallization of cellulose in triflouroacetic acid at 0℃, resulting in hydrolysis reactivity close to corn starch (PNNL, see 1.4.2).	X						
Methane from anaerobic digestion of liquid waste of a corn cob based ethanol pilot plant for energy supply of that pilot plant (POET, see 1.4.2).	X				X		
A hybrid gasification and fermentation biorefinery that converts food waste into ethanol, and that converts paper, cardboard, and plastics into producer gas (low molecular weight hydrocarbons) by way of gasification. Both biofuels power a modified diesel generator. The whole biorefinery is built to slide into a standard shipping container for easy transportation (LORRE at Purdue University, see 1.4.2).	X			x	X		X
A patented counter-current technology that efficiently fractionates cellulosic biomass within one pressurized reaction chamber into hemi-cellulose, lignin, and cellulose (PureVision, see 1.4.2).	X		X				
Extraction of methacrylate monomers from biomass, before it is converted into cellulosic ethanol (Rohm & Haas, Ceres, see 1.4.2).	X			x			
Bio-Synfining™ process to transform a wide variety of renewable feedstocks such as vegetable oils, fats, and greases into synthetic diesel and jet fuel (Syntroleum, see 1.4.2).		X		x			
BES: Bioethanol sector, BDS: Biodiesel sector, P&PS: Pulp/paper sector, ORS: Oil refinery sector, PPS: Power production sector, FIS: Food industry sector, AS: Agrosector. X: highly relevant info; x: revevant info.							

Sector (S) **Applicable info**	BE	BD	P&P	OR	PP	FI	A
Production of biofuels from used cooking oil and animal fats (Dynamic Fuels, see 1.4.2).		X					
Genetically engineered *Escherichia coli* bacteria that ferment both C6 (hexose) and C5 (pentose) sugars present in cellulosic biomass (Verenium, see 1.4.2).	X						
High yield simultaneous decomposition and fermentation of cellulosic biomass (both C5 and C6 sugars) to ethanol by the C3 Process ((Qteros, see 1.4.2).	X						
Microbes from a termite stomach to ferment cellulosic biomass into acetic acid (for ethanol production), avoiding CO_2 byproducts (Zeachem, see 1.4.2).	X						
Integrated sugar and syngas platform biorefinery for lignocellulosic bioethanol production (Zeachem, see 1.4.2).	X		X	x			
New bacteria strains from hot springs in Iceland for hydrogen or bioethanol production from wastewater produced in sugar beet and potatoe factories (Un. Of Akureyri, see 1.4.2)	X					X	x
Carbonizing-gasification gas engine power generating system which can use a mixture of wood and waste biomass as fuel (CRIEPI, see 1.4.3).					X		
Pyrolysis and gasification technology developments and implementations in China (China Biomass Development Centre, see 1.4.3).				x	X		
Heterogeneous Mg-Al hydrotalcite base catalysts for the conversion of poultry lipids to biodiesel (Clemson University, see 1.4.3).		X					
A method to make synthetic cellulosomes, enzymes found in termites and the first stomachs of cows, that are able at breaking down cellulose from plants (ConocoPhillips, see 1.4.3).	X						
Fast pyrolysis process (Dynamotive, see 1.4.3).				x	X		
Rapid Thermal Process (RTP)™ technology to convert wood into bio-oil in less than 2 seconds (Ensyn, see 1.4.3).				x	X		
Small scale pyrolysis for the production of hydrogen and Ecoss fertilizer (Eprida, see 1.4.3).				x	X		
New types of pyrolysis reactors; and catalysis systems for converting syngas into ethanol (Iowa State University, see 1.4.3).	X			x			
Integrated system of thermochemical and catalytic technologies to efficiently produce ethanol from plant biomass (Iowa State University, see 1.4.3).	X			x			
Treating of fuel ethanol with ozone and activated carbon to economically remove impurities so that the alcohol can be used by the beverage industry (Iowa State University, see 1.4.3).	X					x	
Catalytic deoxygenation of fatty acids into alkanes and alkenes, using ZnO, alumina and zeolite ZSM-5 (Kansas State University, see 1.4.3).		X		x			
BES: Bioethanol sector, BDS: Biodiesel sector, P&PS: Pulp/paper sector, ORS: Oil refinery sector, PPS: Power production sector, FIS: Food industry sector, AS: Agrosector. X: highly relevant info; x: revevant info.							

Sector (S) Applicable info	BE	BD	P&P	OR	PP	FI	A
A process which converts biomass into product gas, which is subsequently reformed with steam into syngas. After cleaning, the syngas is passed over a proprietary catalyst and transformed into ethanol and methanol. Energy recovered during this step and subsequent steps is used to generate power (RangeFuels, see 1.4.3).	X			x	X		
A thermal-mechanical and enzymatic hydrolysis process, making use of virtually no acids (KL Energy Corp., see 1.4.3).	X						
Thermochemical Biorefinery of cellulosic biomass into alcohols (NREL, see 1.4.3).	X			x			
Sub en supercritical biomass conversions : transformation of biomass into sugars and other compounds (ao erythrose), organic acid esterfication in supercritical alcohols (University of Iowa, see 1.4.3).	X	x					
Lignin valorization (DOE, ISU, Kyoto State University, Virginia State University, see 1.4.3).	X		X				
A catalytic technique to efficiently extract algal oils without killing the organisms. A porous honeycomb system absorbs the oil and leaves the organisms. The intention is that the system will be ultimately integrated with the biodiesel catalyst (Catilin, see 1.5.1)		X					
Cyanobacteria (a form of prokaryotic algae) to divert biosynthetic pathways away from glycogen synthesis and toward lipid synthesis (NREL, see 1.5.1).		X					
Algae-derived oil production in standard industrial facilities quickly, efficiently and at large scale (Solazyme, see 1.5.1).		X					
Pilot-plant biodiesel production from microalgae in Hawaii (Shell, see 1.5.1)	X						x
Development of cost-effective algae-biofuel production systems (DOE, see 1.5.1)	X						
Macroalgae for biobutanol production (Dupont, see 1.5.2).							x
Microorganisms for macroalgae fermentation into ethanol – 100 ha pilot-plant in Chile (BAL, see 1.5.2)	X						
Biofuels from seaweed in Indonesia (KITECH, see 1.5.2).	X	X					
Offshore seaweed farming (PNNL, see 1.5.2)	X	X					
10,000 square kilometres seaweed farm in the Sea of Japan (TU/Mitsubishi, see 1.5.2)	X	x					
Extraction of biofuels from macroalgae with supercritical CO2 (Un. Of Bari, see 1.5.2)	X	X					
Conversion of macroalgae to ethanol through fermentation (British and Irish institutes, see 1.5.2)	X						
BioRefinex technology, a thermal hydrolysis process for biorefining organic waste and residual materials, including animal carcasses and food waste. The technology breaks down complex protein into amino acids and peptides and claims to inactivate prions. (Biosphere Technologies, see 1.6).	X				X		
Renewable diesel production process (BP, see 1.6).		X		X			

BES: Bioethanol sector, BDS: Biodiesel sector, P&PS: Pulp/paper sector, ORS: Oil refinery sector, PPS: Power production sector, FIS: Food industry sector, AS: Agrosector.

X: highly relevant info; x: revevant info.

Applicable info / Sector (S)	BE	BD	P&P	OR	PP	FI	A
Integrated manure utilization system – IMUS (Highmark Renewables, see 1.6).							
A process using proprietary organisms which can convert CO_2 and sunlight into 185,000 liter ethanol per hectare per year (Joule Biotechnologies, see 1.6).	X						
Jatropha biodiesel plants (India, Nigeria, Ghana, see 1.6).		X					
Glycerine to methanol (BIOMCN, see 1.6).		X		x			
Supercritical Fluid Technologies (see 3.2)	X	X					
Supercritical water traetment for ethanol production (see 3.2.2)	X						
Supercritical methanol technology for biodiesel (see 3.2.3)		X					
Bioethanol from sugarcane (see 3.3)	X						
Cellulosic biofuels in the US (see 3.4)	X						
Ammonia Fiber Expansion (AFEX) pretreatment (see 3.4)	X						
Biofuel-driven Biorefineries – IEA Bioenergy Task 42 (see 4.1)	X	X	x	x	X	x	x
European TP SUSCHEM (see 4.1)	x	x	x	x	X	x	x
European FTP (see 4.1)	x		X	x	X		
European Plants for the Future TP (see 4.1)	x	x	x	x	X	x	x
JTI Fuel Cells and Hydrogen (see 4.1)					X		
ERTRAC (see 4.1)	x	x					
European Algae Biomass Assiciation (see 4.1)	X	X				x	x
NoE Bioenergy (see 4.2)	x	x	x	x	X	x	x
RENEW (see 4.3)	X						
Ecobinders (see 4.3)	x						
NILE (see 4.3)	X						
VIEWLS (see 4.3)	x	x					
REFUEL (see 4.3)	x	x					
BIOCOUP (see 4.3)		X		X			
BIOSYNERGY (see 4.3)	X			x			
BIOPOL (see 4.3)	x	x	x	x	X	x	X
EUROVIEW (see 4.3)	x	x	x	x	X	x	X
SUSTOIL (see 4.3)		X		x		x	
STARCOLIBRI (see 4.3)	x	x	x	x	X	x	x
BIOCORE (see 4.3)	X			x	X	x	X
SUPERGEN (see 4.3)				X	X	x	x
DIBANET (see 4.3)		x		x			x
BIOTOP (see 4.3)	x	x					
CANEBIOFUEL (see 4.3)	X						
BES: Bioethanol sector, BDS: Biodiesel sector, P&PS: Pulp/paper sector, ORS: Oil refinery sector, PPS: Power production sector, FIS: Food industry sector, AS: Agrosector. X: highly relevant info; x: revevant info.							

5.2 Selected cases for assessment in WP4 and WP5

In the text below 7 cases are described in more detail, which offers the opportunity for an assessment of these cases in WP4 and WP5 of the Bioref-Integ project (to be decided by the WPLs). These cases are:

- PureVision – biomass fractionation technology
- AFEX – Ammonia Fiber EXpansion pretreatment process
- AVAP™ pulp mill based biorefinery technology
- Energetics – Mini Biofuel Refineries
- CCUR – innovative bioethanol coupled proteins extraction system
- Ames – glycerol into 1,3-Propanediol using ionic hydrogenation
- ISU – Free Fall pyrolysis reactor

5.2.1 PureVision

Process description

PureVision (Fort Lupton, CO, US) claims that its biomass fractionation technology converts wood, energy crops and agricultural residues into biomaterials that can be used to produce practically anything made with fossil-based feedstocks, including: biofuels, bio-based chemicals, composites, pulp and paper products and energy[223] [224]. PureVision claims that its technology efficiently separates (fractionates) the primary constituents of cellulosic biomass within one pressurized reaction chamber into three streams: hemi-cellulose, lignin, and cellulose (Figure 1863)[225]. The cellulosic biomass is purchased and size-reduced and fed into a pressurized reaction chamber designed for counter-current processing. The technology can be accomplished in a single stage or in multi-stages, depending upon the desired products. The counter-current extraction removes and recovers the hemicellulose and lignin fractions in two liquid streams, resulting in a solid fraction containing a relatively pure cellulose or fibre. This patented biomass fractionation process occurs within approximately 10 minutes. A scientific paper by employees of PureVision suggests that the process involves an extruder with dynamic plugs[226]. The cellulose, lignin and fermentable (hemi-cellulose) sugars are sold by PureVision for further processing.

In a two-stage setup, the target within the reaction chamber is to first wash out most of the hemicellulose in the form of hemicellulose sugars, while keeping as much of the lignin and cellulose intact in a solid form. After the solids enter the second half of the reaction chamber, the pH, temperature and pressure are adjusted to wash and remove as much lignin as possible. These two washing stages yield (1) the xylose-rich liquor fraction, (2) the lignin-rich liquor fraction, and (3) the remaining solid and relatively pure cellulose fraction.

In the first stage most of the solid hemicellulose can be converted into hemicellulose sugars. These sugars can then be fermented to produce products such as: ethanol, xylitol or furfural or can be processed into a purified xylose stream. The first wash liquor fraction also contains smaller portions of the lignin, cellulose, protein, and ash components of the biomass, most of which can be recovered.

[223] Patent WO 2008/019228 A2
[224] http://www.purevisiontechnology.com/index.html, visited 8 July 2009
[225] http://www.purevisiontechnology.com/technology.html, visited 8 July 2009
[226] K.L. Kadam. C.Y. Chin, L.W. Brwon, Flexible biorefinery for producing fermentation sugars, lignin and pulp from corn stover, J. Ind Microbiol Biotechnol, 35, 2008, 331-341.

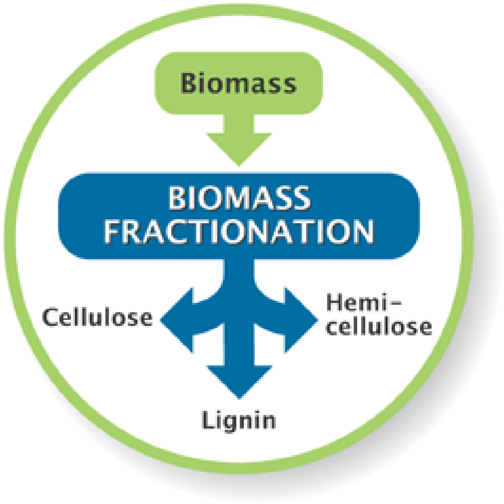


Figure 66 Schematic representation of PureVision's fractionation technology.

After the counter-flow washing of the hemicellulose occurs, most of the lignin and possibly the remaining hemicellulose are washed out in a second stage. This second stage wash liquor fraction contains most of the lignin and any targeted amount of the remaining hemicellulose sugars. This lignin-rich fraction is then further processed to produce a high quality, low-molecular weight lignin that can be sold as an industrial raw material to produce industrial and consumer products. The lignin can also be used as a bio-fuel to provide energy for making electricity and steam to run the biorefinery.

The remaining cellulose fraction is between 90% to 97% cellulose, as most of the lignin, hemicellulose and extractives have been stripped off in the wash liquor fractions. Because of the high purity of the cellulose fraction, it can be sold as a pulp or enzymatically hydrolyzed into glucose. PureVision claims that the obtained cellulose requires far less enzymes to produce glucose compared to competing technologies.

The processing variables can be chosen so as to optimize the process for the desired main product, e.g. pulp for making paper products or dissolving pulps or cellulose acetate, sugars for making ethanol or other industrial chemicals or bio-plastics (Figure 1964).

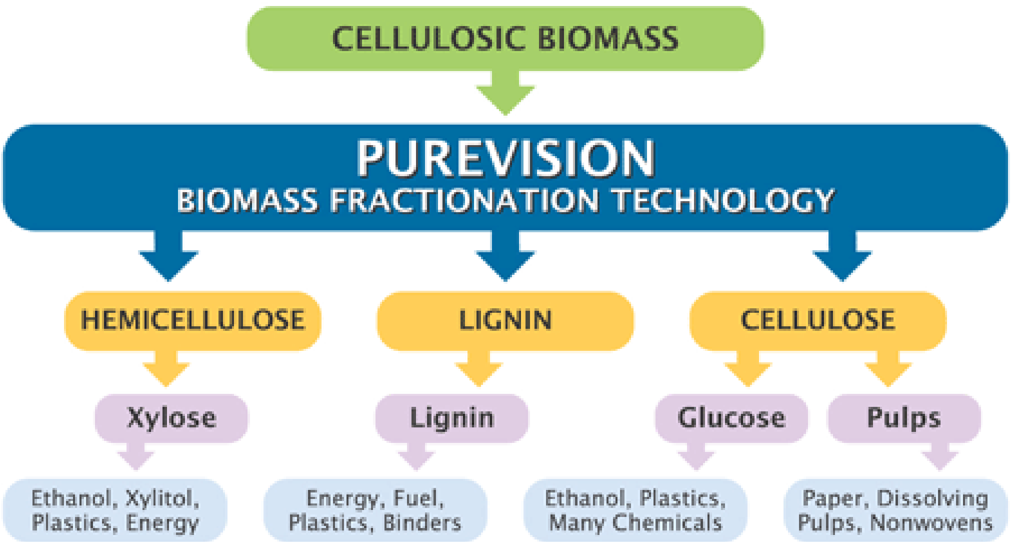


Figure 67 Schematic representation of PureVisions' technology to refine biomass into products.

Problems tackled
The formation of unwanted side products is prevented by the mild conditions. Counter current extraction allows reduced usage of chemicals, high yields, high concentrations and high purities.

5.2.2 AFEX

Process description
One of the key expertise and research focus of Bruce Dale's lab is the pretreatment of lignocellulosic biomass through development of the AFEX (Ammonia Fiber EXpansion) pretreatment process (Figure 6465). An economic objective is to create clean, fermentable sugars at the price level of 0.06$/lb (0.13$/kg) using AFEX pretreatment. Combination of the high temperature and rapid pressure relief opens up the biomass structure and makes polysaccharides accessible for subsequent enzymatic treatment. Ammonia used for pressurizing the reactor is recycled and reused again. One of the main advantages of AFEX is that this is "dry-to-dry" process. Concentrations of the biomass could be very high and much higher than with other pretreatment methods. Typical process conditions are 20-30bar, 70-140℃, 5-10min residence time. After 72h of enzy matic hydrolysis, AFEX-treated corn stover glucan is 90% converted to glucose, compared to 30% with untreated corn stover. Another feature of AFEX pretreated lignocellulose is the possibility of pelletizing the material. The pellets have a higher density than the just pretreated material, which facilitates transportation to facilities for ethanol production. Open structure of the lignocellulose doesn't require any binding agent and sticks well in the pellets.

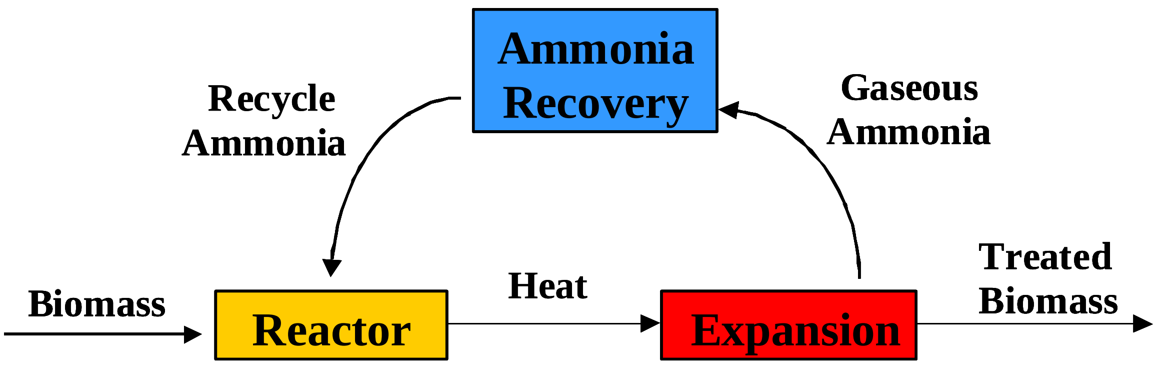


Figure 68 AFEX process scheme.

In addition, there is an option to integrate the centralized (AFEX) pretreatment centre with an upstream biomass production chain and the farmers on one side and an advanced biorefinery on the other (066). An idea is to build larger biorefineries in highly productive areas and/or in the remote areas, and to have as an effect sustainable rural economies that produce sustainable biofuels.

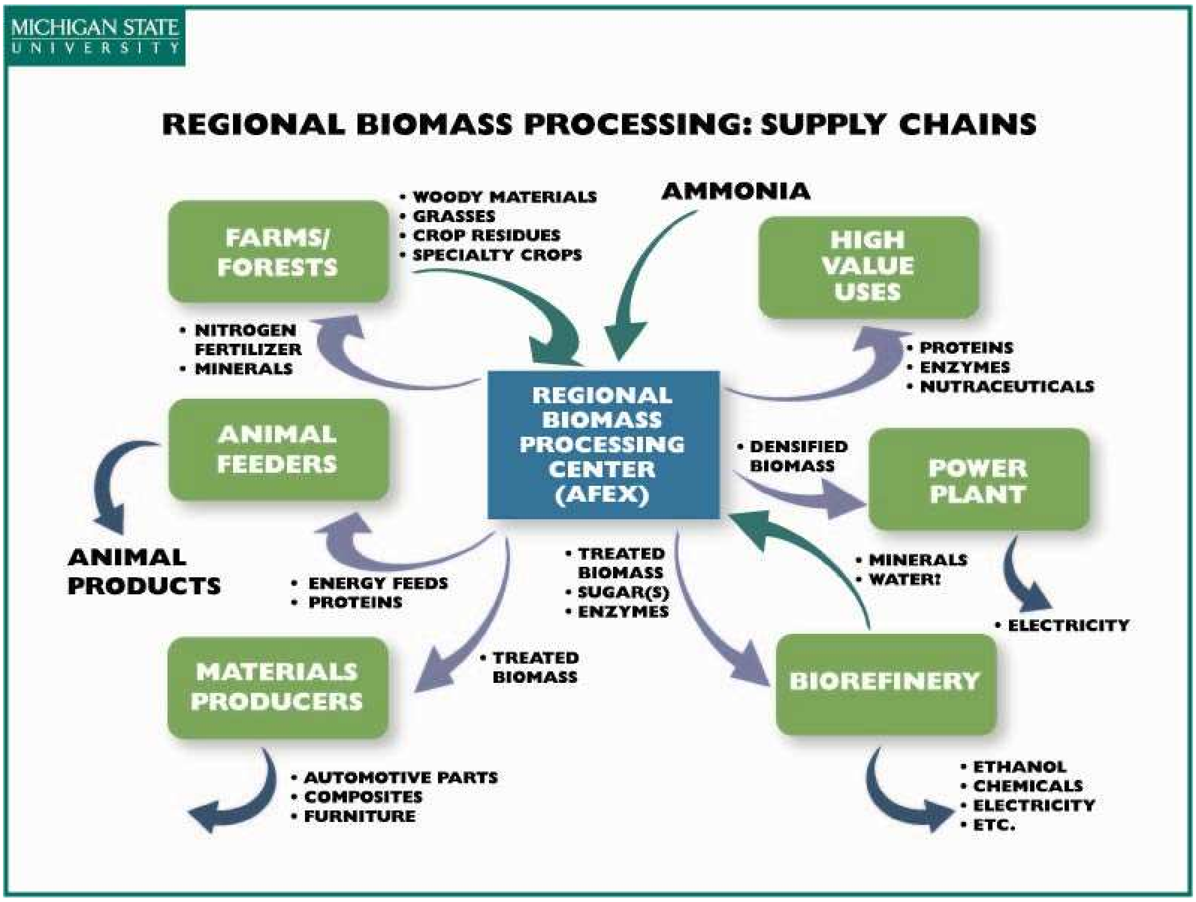


Figure 69 Possible integrated biorefinery scheme around the centralized AFEX technology.

Problems solved
AFEX opens up lignocellulosic complex: a 90% glucan yield from cellulose after 72 hours of enzymatic treatment is possible. After AFEX pretreatment, the product is easily pelletized to 400 kg/m^3 (lignin serves as glue). The densified biomass allows long distance transport and cntralized large scale processing. All these problems are tackled without running into new problems such as high demand for chemicals (ammonia is a gas and is easily recycled).

5.2.3 American Process Inc.

Process description
American Process Inc. of Atlanta provided its proprietary American Value Added Pulping, AVAP™ (patent pending) pulp mill based biorefinery technology and process design for the consortium of several members at the Flambeau River Biorefinery LLC[227]. An application for DOE biorefinery demonstration solicitation was submitted based on this process.
Wood chips are pulped in the presence of ethanol and sulfur dioxide. The cooking temperature and duration as well as the pre-processing and post digestion treatment are tailored to match the desired properties of the pulp and yield of coproducts.
Pulping in aqueous ethanol facilitates penetration of woodchips without fear from condensation reactions, while acid aids in rapid solubilization of lignin and hemicelluloses. Spent liquor sugars are subjected to a secondary treatment in the AVAP™ reactor to ensure their hydrolysis to monomers sugars. Separation of the lignin is achieved by reduction in solubility and subsequent precipitation.

[227] http://www.apiweb.com/doc/AVAP_Paper.pdf

Co-product lignin sales compete with energy production from bark and forest residues. Lignin and biomass gasification produces synthesis gas, which can today be used for energy production, and tomorrow as a feedstock for additional biochemical production. The absence of sodium eliminates expensive Kraft recovery cycle and enables a simpler recovery cycle. Energy to this recovery cycle is provided to a large extent by use of vapor compression in a patent pending process equipment, LEESS™, which concentrates the liquor, regenerates the processing ethanol and isolates the condensate for by-product recovery and process reuse.
High product yield is the ultimate goal in any bioconversion process. The process configuration of this recovery cycle is specifically designed for recovery of chemicals and high conversion rates. Majority of the sugars are fermentable by Baker's yeast, Saccharomyces cerevisiae. A proprietary 3rd party pentose converting micro-organism boosts the ethanol yield. A schematic of the process can be seen below. Oxygen delignification and two-stage bleaching of the AVAP™ pulp produce brightness to paper grades. Preliminary engineering for the gasification and ethanol islands were provided by ThemoChem Recovery International (TRI) and Xethanol respectively.AVAP (American Added Value Pulping).

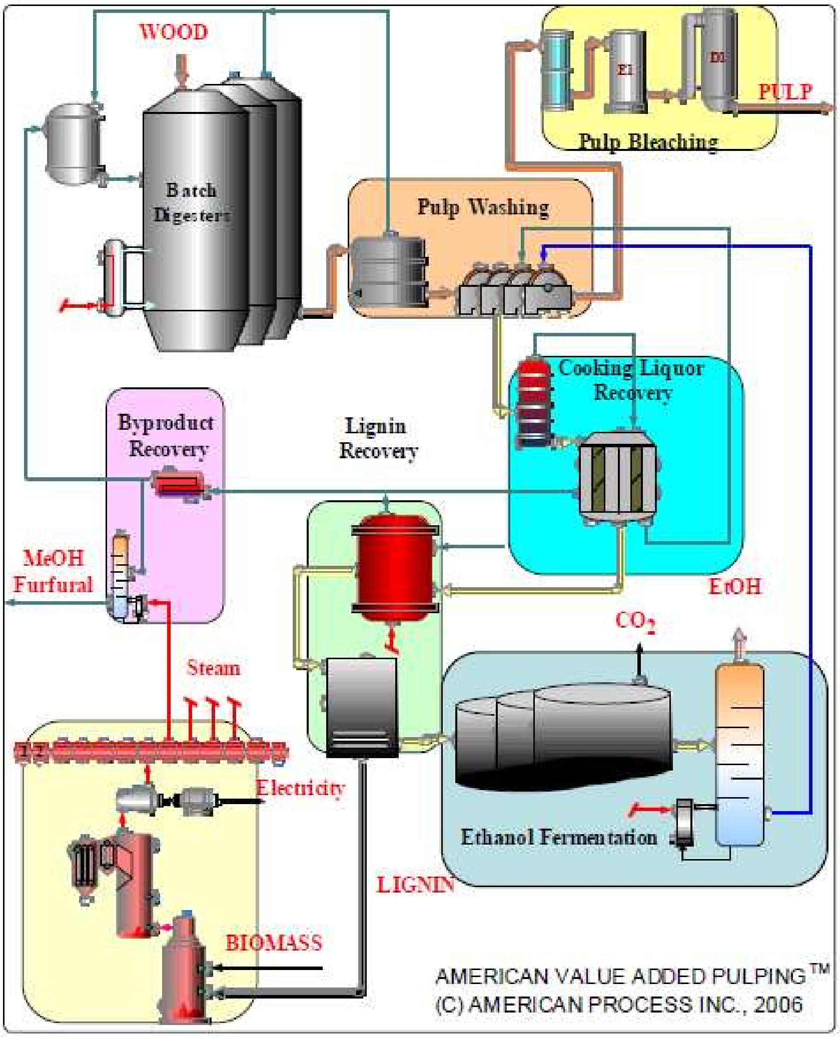


Figure 70 American Process Inc. – Value Added Pulping Process

Problems solved
Not only pulp, but also ethanol, methanol and furfural are produced. Hemi cellulose is not wasted but sold as a product (furfural). The purified lignin can be used for buring of for added value products.

5.2.4 Energenetics

Process description
EnerGenetics Energies LLC is developing smaller-scale modular biorefinery called "Mini-BioFuel Refineries" or MBR. The company focuses on a wide variety of products from biomass: PLA, PHA, resistant starches, higher quality oils, corn protein isolate, fluffy fibre cellulose, bio-butanol. It uses wet micro-milling and thus produces a proteins isolate (sold at 6000 USD/ton) and fibres in a solid phase. It uses genetic crops that produce neutraceuticals such as anti-oxidant. Ethanol is only produced as a by-product. Membranes are used instead of distillation. This prevents loss of DGS quality. The concept of Mini biofuel refineries allows smaller scale plants and thus less transport costs.

Problems tackled
The process focusses on high added value products such as: Nutraceuticals, Protein isolate (sold @ 6 USD/kg) and fibres in solid phase. Ethanol is produced as a by-product. The usage of membranes reduces the energy demand. The concept of Mini-Biofuel Refineries allows smaller scale plants and thus less transport costs.

5.2.5 CCUR

Process description / Problems tackled
The Center for Crops Utilization Research (CCUR) has developed a process scheme that recovers oil and proteins from corn before the actual ethanol fermentation (figure 68). Ethanol from the process is used to extract the oil. Sodium hydroxide is used to dissolve the proteins.The oil and proteins can be sold at high value. The proteins are not damaged by DGS drying. At the same time, the amount of DGS is reduced.

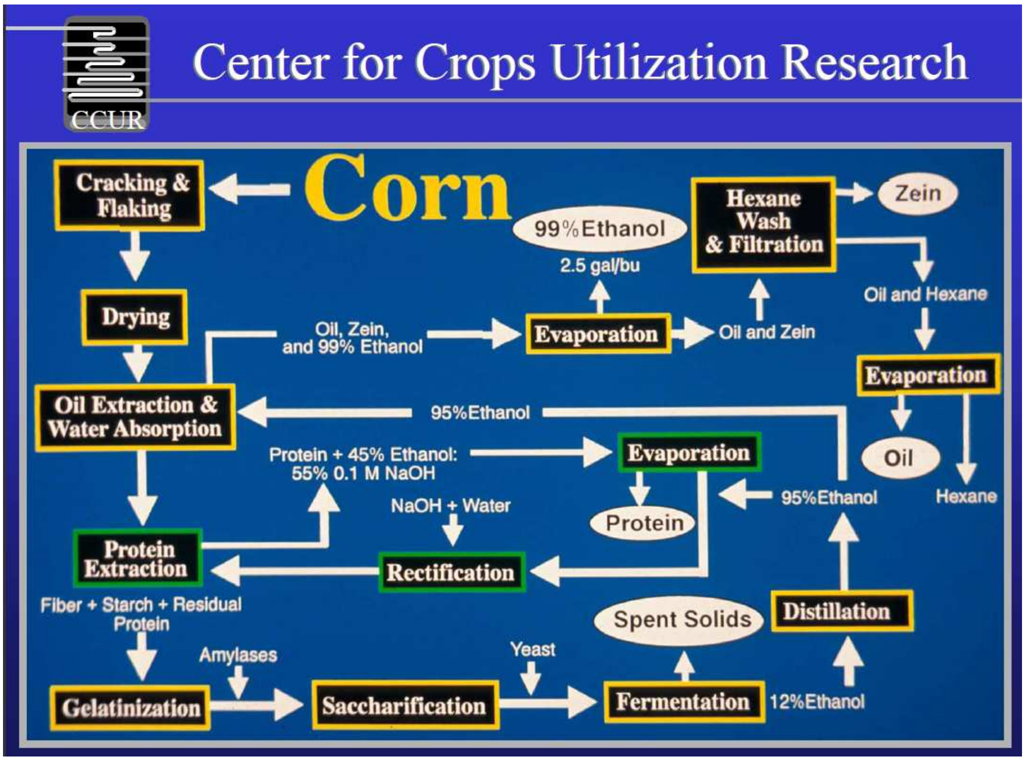


Figure 71 CCUR Innovative Protein Extration System.

5.2.6 Ames

Process description
Ames Laboratory has developed a process to convert glycerol, a by-product of biodiesel production, by using ionic hydrogenation in similar porous structures into 1,3-Propanol, which is used in DuPont's Sorona polymer.

Problems solved
The production of glycerol as by product is prevented. 1,3 propanol is a high value product that could make production of biodiesel profitable.

5.2.7 Iowa State University

Process description
Iowa State University has established a free Fall reactor, as an alternative for the fluidized bed reactor (Figure 3368)

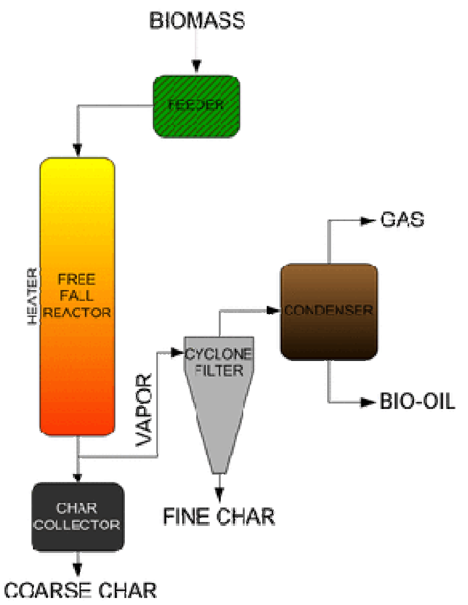


Figure 72 Scheme of Free Fall reactor at Iowa State University.

Problems solved
The free fall reactor prevents problems with clogging. Through the production of bio-oil (pyrolysis) no Fischer Tropsch synthesis is needed. Therefore, the process can run at a smaller scale and less transport costs will be involved. A solid (densified) fuel is produced.

Appendices

Appendix A Abbreviations

ADt	Air dried tonne
bbl	Barrel
BDF	Biodiesel Fuel
BDT	Bone dry tonne
DME	Dimethyl Ether
BPD	Barrel per day
BTL	Biomass to liquid
BTX	Benzene, toluene, and xylene
CBP	Consolidated Bio-Processing technology
DDCE	DuPont Danisco Cellulosic Ethanol LLC
ECOSS	Enriched Carbon, Organic Slow-release Sequestering
EERE	Office of Energy Efficiency and Renewable Energy (at DOE)
ETBE	Ethyl-tert-butyl ether
FAME	Fatty acid methyl ester
FCC	Fluid catalytic cracking / Fossil carbon content
FGB	First generation biofuel
FTD	Fischer-Tropsch diesel
HDO	Hydrodeoxygenation
HDS	Hydrodesulfurization
HTL	Hydrothermal liquefaction
HTU	Hydrothermal upgrading
ICBR	Integrated Corn Biorefinery Research program
IGCC	Integrated Gasification Combined Cycle
LORRE	Laboratory of Renewable Resources Engineering
Mbbl	1,000 bbl
MMbbl	1,000,000 bbl
MJ	Mega joule
MSW	Municipal solid waste
MT	Metric tonne
NCAUR	USDA-ARS National Center for Agricultural Utilization Research
NREL	U.S. National Renewable Energy Laboratory
ORNL	Oak Ridge National Laboratory
PNNL	Pacific Northwest National Laboratory
SGB	Second generation biofuel
TAEE	Tert-amyl ethyl ether (amyl = C_5H_{11})
TGB	Third generation biofuel
TOE	Tonne of oil equivalent
USDA	US Department of Agriculture

Appendix B Conversion factors

Quantity 1	Quantity 2	Source
1 Acre	0.405 ha	www.conversion-metric.org, visited 1 September 2009
1 Barrel	42 US Gallon	en.wikipedia.org/wiki/Bbl, visited 29 June 2009
1 L diesel	36.4 MJ	bioenergy.ornl.gov/papers/misc/energy_conv.html
1 L diesel	0.84 kg	bioenergy.ornl.gov/papers/misc/energy_conv.html, visited 23 June 2009
1 US Gallon	3.785 L	en.wikipedia.org/wiki/Bbl, visited 29 June 2009

Appendix C Biomass Program: general info

The Biomass Program of the US Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy (EERE), works with industry, academia and the national laboratory partners on a balanced portfolio of research in biomass feedstocks and conversion technologies [228]. The budget in 2008 was US $ 198 million. The Biomass Program is inspired by the (former) presidents administration which established a goal to reduce US gasoline consumption by 20 percent in 2017 through efficiency and alternative fuels and to displace 30 percent of gasoline consumption with biofuels by 2030 (0). Therefore, the Biomass Program is focusing its R&D efforts to ensure that cellulosic ethanol is cost competitive by 2012. The Biomass Program aims to help transforming the US renewable biomass resources into cost competitive, high performance biofuels, bioproducts, and biopower, through integrated biorefinery research, development, and demonstration efforts. Another major effort of the Program is to further develop infrastructure and opportunities for market penetration of biobased fuels and products.

The Biomass Program is aware that, in addition to strong technical research and deployment activities, effective policy is critical to fostering both supply and demand for bioenergy. There are a variety of Federal and state policies supporting and guiding the development and use of biofuels. These policies range in purpose from directing and funding biofuels research, development, and deployment; to ensuring interagency coordination of biofuels-related efforts; to requiring assessments of existing biofuels policies and programs. Other policies encourage the use of biofuels, or require their production, while still others guide the use of the resources used to produce biofuels. Regardless of the specific purpose, most biofuels-related legislation is directed towards reducing dependence on foreign sources of oil, thereby increasing diversity and security of the nation's energy portfolio.

The Biomass Program conducts research and development in the four key areas of technology required to produce biomass feedstocks and convert them to useful biofuels, value-added products, and power. These technology areas are: Feedstocks, Processing and Conversion, Integrated Biorefineries, and Infrastructure (0) [229]. The majority of the Biomass Program's R&D is focused on Biochemical and Thermochemical conversion technologies. A scheme of the biochemical platform integration is presented in Figure 75.

[228] http://www1.eere.energy.gov/biomass/about.html, visited 8 July 2009
[229] http://www1.eere.energy.gov/biomass/technologies.html, visited 8 July 2009

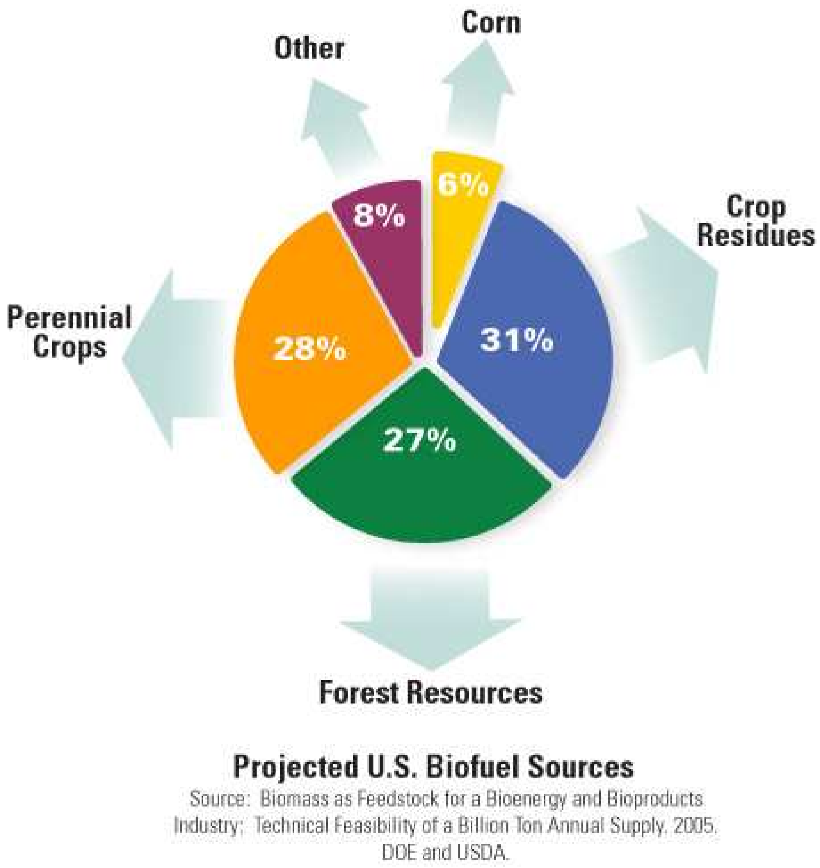


Figure 73 Breakdown of the projected US biofuel sources.

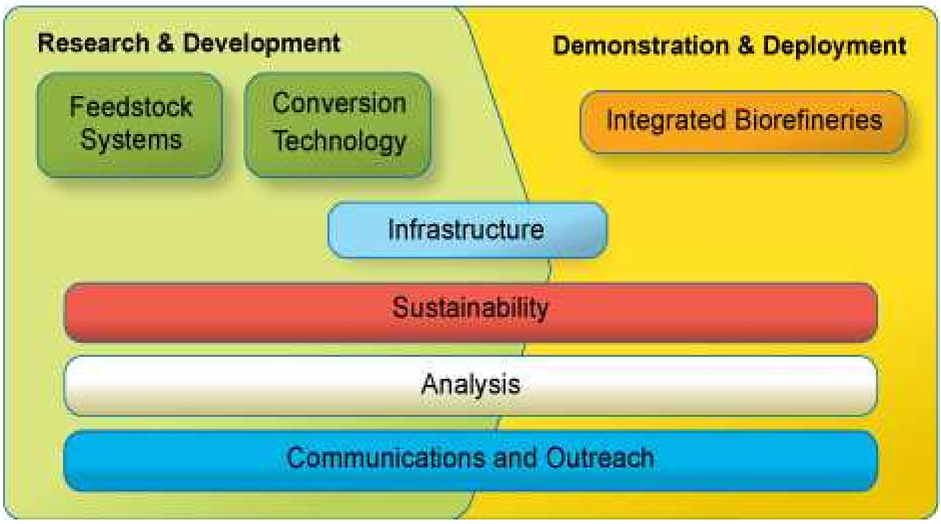


Figure 74 Biomass Program structure.

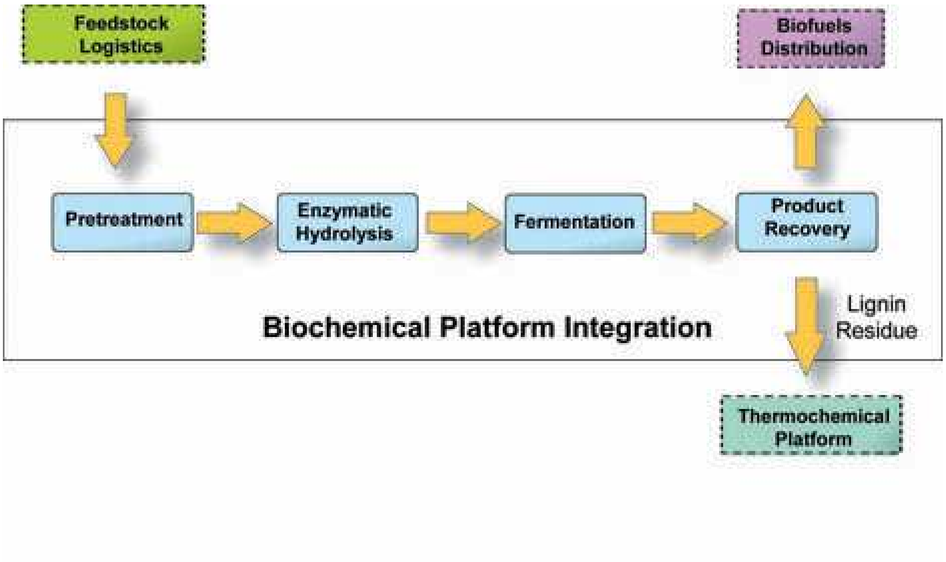


Figure 75 Biochemical Platform Integration.

On February 28, 2007, the DOE selected six integrated cellulosic biorefinery projects to develop commercial-scale integrated biorefineries demonstrating the use of a wide variety of cellulosic feedstocks such as corn fiber, wood wastes, agriculture residues, municipal solid wastes and potential energy crops. The goal was to demonstrate that integrated biorefineries can operate profitably once their construction costs are covered and can be replicated. DOE announced to invest up to $385 million in the six projects over the next four years. When fully operational, these facilities will be capable of producing more than 130 million gallons of ethanol per year. Of the six selected companies, to date only five are proceeding the intended development of commercial scale biorefineries. BlueFire Ethanol, Inc., Poet, and Abengoa Bioenergy focus on biochemical processes to free the sugars from the biomass and then ferment them into alcohol. Range Fuels plans to use thermochemical processes to first gasify the biomass into a "synthesis gas." The synthesis gas will then be further converted to biofuels. Early June 2008, Alico has stopped its activities in their foreseen commercial scale bioethanol plant based on thermochemical technology [230], however, New Planet Energy LLC, who was already involved in the Alico bioethanol plant, has taken over the lead. Iogen has announced in June 2008 that it will stop its planned development of a commercial plant in Shelley (ID, US), but continues to build one in Saskatchewan, Canada [231]. The activities of the continuing project are described in more detail in sections 0 and 0 of this report.

On January 29, 2008, the Department of Energy (DOE) announced it will provide up to $114 million, over four years, to support the development of small-scale cellulosic biorefineries. The projects will develop biorefineries at 10% of commercial scale that produce liquid transportation fuels as well as biobased chemicals and bioproducts used in industrial applications. Projects selected to negotiate awards will use novel approaches and a variety of cellulosic feedstocks to test new conversion processes. Combined with industry cost share, more than $331 million will be invested in these four projects. The projects are led by Pacific Ethanol (Boardman, OR), Lignol (Commerce City, CO), ICM (St.Joseph, MO) and New Page (Wisconsin Rapids, WI) [232], and the activities are described in more detail in sections 0 and 0 of this report.

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[230] http://www.reuters.com/article/pressRelease/idUS10820+03-Jun-2008+BW20080603, visited 8 July 2009
[231] http://earth2tech.com/2008/06/04/iogen-suspends-us-cellulosic-ethanol-plant-plans
[232] http://www.nrbp.org/updates/2008-04/grabowski.pdf, visited 8 July 2009

Appendix D Biomass Program: partners

The National Bioenergy Center (NBC) is a virtual management center responsible for overseeing the research performed by the National laboratories. Ongoing efforts by bioenergy programs at Argonne National Laboratory (ANL), Idaho National Laboratory (INL), National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory (ORNL), and Pacific Northwest National Laboratory (PNNL) are all generally overseen by the NBC. The NBC is responsible for performing analysis that supports the agenda OBP agenda and other related goals, and is based at NREL.

The NBC actively collaborates with industry, academia, other EERE programs, and other governmental research, development, and commercialization programs to support the achievement of biomass goals and help reduce the production cost of biofuels.

The National Renewable Energy Laboratory (NREL) is the lead laboratory in the NBC and is working to develop economical and efficient biomass pretreatment and conversion technologies. NREL's biomass research and development (R&D) efforts encompass the activities at each stage of the biorefinery including both biochemical and thermochemical conversions. NREL also has a process development unit (PDU) available to evaluate the efficiency and ethanol yield due to different feedstock compositions.

Figure 76 Organization chart of Biomass Program partners.

The biomass-related efforts at Idaho National Laboratory (INL) focus on the major science and technology needs associated with the cost-effective harvesting, collection, and utilization of waste biomass and agricultural waste. In partnership with industry, INL is currently investigating methods to enhance cost-effective agricultural processes, which can reduce the cost of supplied feedstocks.

Oak Ridge National Laboratory (ORNL) specializes in feedstock and environmental R&D to improve the yield, quality, and sustainability of biomass. Research focuses on evaluating the environmental effects of collecting agricultural residues and planting alternative crops on traditional cropland. ORNL also partners with industry to develop methods for biomass conversion to commodity chemicals.

Work at Argonne National Laboratory (ANL) is concentrated on analysis of vehicle systems, emissions, and their environmental impact on the environment. ANL has developed a well-to-wheels analysis that compares alternative vehicle technologies to conventional systems. ANL also collaborates with industry to develop new bioproducts that can benefit the economics of the integrated biorefinery.

Pacific Northwest National Laboratory(PNNL) efforts are focused on developing novel thermochemical processes to convert biomass bioproducts, fuels, and energy. Specifically, PNNL specializes in the use of catalysis to convert biomass to higher value fuels and products. Additionally, PNNL works with industry to find and develop new fungal species to improve the biochemical production of bioproducts.