Commercializing 1st- and 2nd-Generation Liquid Biofuels from Biomass

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Status of Advanced Biofuels Demonstration Facilities in 2012

A REPORT TO IEA BIOENERGY TASK 39

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bericht
report

Contents

List of Tables

List of Figures

Acronyms of Units

t/y	Tonnes per year
Ml/y	Million litres per year
mmgy	Million metric gallons per year
t/d	Tonnes per day
l/d	Litres per day
gal/d	Gallons per day
t/h	Tonnes per hour
Nm3/h	Normal cubic metres per hour
MW	Megawatt
bbl/day	Barrels per day
l/h	Litres per hour
kg/d	Kilograms per day
m3/a	Cubic metres per year
l/t	Litres per tonne
%m/m	Mass percentage
%V/V	Volume percentage

Glossary

biorefinery	the sustainable processing of biomass into a spectrum of marketable products (food, feed, materials, and chemicals) and energy (fuels, power, heat)
biochemical conversion	conversion technology based on enzymatic or microbiological processes
bio-oil	crude oil derived from biomass through pyrolysis; must be upgraded before using it as fuel
BtL-Diesel	Biomass to Liquid Diesel; diesel fuel derived from biomass through gasification and conversion of the resulting synthesis gas
butanol	alcohol that can be blended with gasoline
chemical conversion	conversion technology based on chemical reactions other than oxidation
CHP	combined heat and power production
commercial facility	facility operated continuously with high level of availability; facility operated under economical objectives; the product is being marketed
demonstration facility	facility demonstrating the capability of the technology for continuous production (operated mainly continuously); facility covering the entire production process or embedded into an entire material logistic chain; the product is being marketed; facility may not be operated under economical objectives
diesel-type hydrocarbons	hydrocarbons that can be used to substitute for diesel in diesel engines
DME	Di-Methyl-Ether; gaseous fuel produced from synthesis gas
ethanol	alcohol that can be blended with gasoline
FT-liquids	fuel produced through Fischer-Tropsch synthesis, can substitute for gasoline or diesel, depending on the fraction
gasoline-type fuel	fuel that can be used to substitute for gasoline in gasoline engiines
HVO	Hydrotreated Vegetable Oil; diesel-type liquid fuel produced through hydrotreatment of vegetable oils; rather referred to as diesel-type hydrocarbons in this report

jet fuel	fuel that can be used in aviation
methanol	alcohol that can be blended with gasoline
mixed alcohols	ethanol, methanol and higher alcohols
lignocellulosic biomass	feedstock consisting mainly of cellulose, hemicellulose, and lignin, such as woody materials, grasses, and agricultural and forestry residues
liquid or gaseous biofuels for transportation	fuels derived from biomass used in engines to provide a transportation service
operational	erection and start-up are complete, regular production has started
pilot facility	facility, which does not operate continuously; facility not embedded into an entire material logistic chain; only the feasibility of selected technological steps is demonstrated; the product might not be marketed
planned	plans are made but construction has not started yet
stopped	project is not longer being pursued, the reasons for which may vary
SNG	Synthetic Natural Gas; gaseous fuel, main component is methane, produced from synthesis gas
thermochemical conversion	conversion technology based on processes using heat (partly also pressure)
under construction	erection of the production facility has started

Abstract

A number of companies around the world pursue projects to develop and deploy advanced technologies for the production of biofuels. Plenty of options are available, e.g. on which feedstock to use, how to pretreat it and how to convert it, up to which fuel to produce. This report monitors the multi-facetted development, adds transparency to the sector and thus supports the development and deployment of advanced biofuels production technologies.

Main pathways under development can be classified into biochemical technologies, thermochemical technologies and chemical technologies. Biochemical technologies are usually based on lignocellulosic feedstock which is pretreated, hydrolysed into sugars and then fermented to ethanol. Alternative biochemical pathways process sugars or gaseous components into methanol, butanol, mixed alcohols, acetic acids, or other chemical building blocks. Most thermochemical technologies use gasification to convert lignocellulosic feedstock into synthesis gas, which can be converted into BtL-Diesel, SNG, DME or mixed alcohols. Alternative thermochemical pathways include pyrolysis of biomass and upgrading of the resulting pyrolysis oil. The most successful chemical pathway is the hydrotreatment of vegetable oil or fats to produce diesel-type hydrocarbons. Other pathways include catalytic decarboxylation, and methanol production from glycerin.

This report is based on a database on advanced biofuels projects. The database feeds into an interactive map which is available at http://demoplants.bioenergy2020.eu, and it is updated continuously. The report includes general descriptions of the main advanced biofuels technologies under development, a list of 102 projects that are being pursued worldwide, and detailed descriptions of these projects. All data displayed has been made available by the companies that pursue these projects. For this reason, the list of projects may not be complete, as some companies may still be reluctant to share data.

Since the previous edition of this report (2010), advanced biofuels technologies have developed significantly. Hydrotreatment as pursued by e.g. Neste Oil has been commercialized and currently accounts for app. 2,4% of biofuels production worldwide. Fermentation of lignocellulosic raw material to ethanol has also seen a strong development and several large scale facilities are just coming online in Europe and North America. As for thermochemical processes, the development is recently focusing on the production of mixed alcohols rather than BtL-Diesel. Economic reasons are driving this development, and concepts like the integration into existing industries and the production of several products instead of biofuel only (biorefinery concept) receive more attention lately. But, as expected, some of the projects for advanced biofuel production have failed.

As a result, companies are now more careful in making announcements of advanced biofuels projects, and several large-scale projects have been postponed recently, some even though public funding would have been granted. Nevertheless, the production capacity for biofuels from lignocellulosic feedstock has tripled since 2010 and currently accounts for some 140 000 tons per year. Hydrotreating capacity for biofuels has multiplied and stands at about 2 190 000 tons per year.

1 Introduction

In times of growing concern over the limitation of fossil resources and the impact of GHG emissions on the earth´s climate, utilization of renewable resources to provide energy has come into focus. Biomass as a raw material for production of heat, electricity and transport fuel provides for the largest part of renewable energy supply. And within the bioenergy sector, biofuels for transport receive special attention, as the transportation of people and goods is a necessity of our modern economy.

Around the globe, major players have established goals for the use of transport biofuels. The US has established EPA/RFS, the European Union has published the Renewable Energy Directive, and large producers such as Brazil have also set ambitious targets. But biofuels are not undisputed: concern is growing that biomass should rather be used for food and feed than for transport fuel production; tropical forests should not be deforestated; quality requirements for transport fuels are increasing as vehicle emission regulations are becoming more stringent; overall GHG emission savings of biofuels need to verified in order to be acceptable as biofuel. Thus the biofuel industry is aiming to utilize raw materials that can not be used for food production, raw materials that are not cultivated on land reserved for other uses, and to produce biofuels with premium quality over conventional fuels.

However, production technologies for this type of raw material and product are not yet mature but still under development. While proven in lab scale, testing and demonstration at larger scale is necessary before these technologies can successfully be implemented commercially. Demonstration at large scale surely puts high risk on the companies that wish to develop these technologies, as the first facilities are most likely not to make any profit. Large investments are required and public funding needs to complement private investments.

A number of different companies around the world pursue projects to develop and deploy advanced technologies for the production of biofuels. Plenty of options are available, e.g. on which feedstock to use, how to pretreat it and how to convert it, up to which fuel to produce. This report aims to cover the broad range of projects and technologies and to give an overview on who is pursuing them and where. As an update to a report published in 2010, it furthermore provides information on pathways that have been developed successfully and on such that have failed. The aim is to monitor the multi-facetted development, add transparency to the sector and thus support the development and deployment of advanced biofuels production technologies.

The report is based data that was provided by the companies that pursue projects for the production of advanced biofuels themselves. Some level of independent evaluation of this data was performed by the biofuels experts of IEA Bioenergy Task 39. Although efforts have been made to improve coverage in Asia and South America and Africa, major coverage is Europe and North America where the most information is available.

All data is stored in a database. This database feeds into this report and into an interactive map which is available at http://demoplants.bioenergy2020.eu. The database is updated continuously, whenever project owners provide new data.

The scope of projects under investigation comprises:

	Scope of Projects
Raw Material	lignocellulosic biomass, plant oils, sugar molecules, CO_2; algae biomass is explicitely excluded
Conversion Technology	advanced technology (still in the research and development (R&D), pilot or demonstration phase; not commercial)
Product	liquid or gaseous biofuels for transportation

and for which the project owner has provided at least the following data:

Minimum Data	project owner location of the production facility type of technology raw material product output capacity type of facility status and contact information
Optional Data	Additionally, project owners are asked to provide more detailed information, including company description, brief technology description, flow sheets and pictures etc.

Projects described are categorized as follows:

	Categories
Conversion Technology	biochemical thermochemical chemical
Type of Facility	pilot demonstration commercial
Status	planned under construction operational

Table 1: Scope of projects listed in this report and categorization

2 Objectives and Definitions

In this report, the definition of "conventional" and "advanced" biofuels as defined in the IEA Technology Roadmap: *Biofuels for Transport* is used. “Biofuel” refers to all liquid and gaseous transportation fuels produced from biomass – organic matter derived from plants or animals. Biofuels are commonly divided into first-, second- and third-generation biofuels, but the same fuel might be classified differently depending on whether technology maturity, GHG emission balance or the feedstock is used to guide the distinction. The definition used here is based on the maturity of technology, and the terms “conventional” and “advanced” for classification.

Conventional biofuel technologies include well-established processes that are already producing biofuels on a commercial scale. These biofuels, commonly referred to as first-generation, include sugar- and starch-based ethanol, oil-crop based biodiesel and straight vegetable oil, as well as biogas derived through anaerobic digestion. Typical feedstocks used in these processes include sugarcane and sugar beet, starch-bearing grains like corn and wheat, oil crops like rape (canola), soybean and oil palm, and in some cases animal fats and used cooking oils.

Advanced biofuel technologies are conversion technologies which are still in the research and development (R&D), pilot or demonstration phase, commonly referred to as second- or third-generation. This category includes hydrotreated vegetable oil (HVO), which is based on animal fat and plant oil, as well as biofuels based on lignocellulosic biomass, such as ethanol, Fischer-Tropsch liquids and synthetic natural gas (SNG). The category also includes novel technologies that are mainly in the R&D and pilot stage, such as algae-based biofuels and the conversion of sugar into diesel-type biofuels using biological or chemical catalysts.

The principle pathways of advanced biofuels technologies are shown in Figure 1:

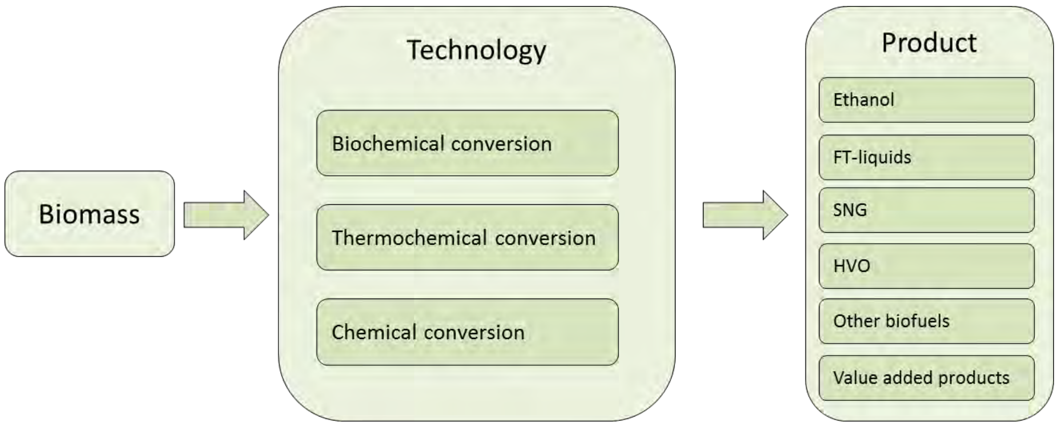

Figure 1: Principle pathways of advanced biofuels technologies

3 Advanced Biofuels Technology Options

3.1 Biochemical Conversion of Lignocellulosic Biomass

3.1.1 Yeast Fermentation to Ethanol

In contrast to the traditional bioethanol production from sugar and starch, the production based on lignocellulosic material requires additional processing steps. The reason is that the cellulose (source of C_6 sugars such as glucose) as well as hemicellulose (mainly source of C_5 sugars such as xylose) is not accessible to the traditional bioethanol producing micro-organisms.

Following processing steps may be found in a general lignocellulose to bioethanol production processes:

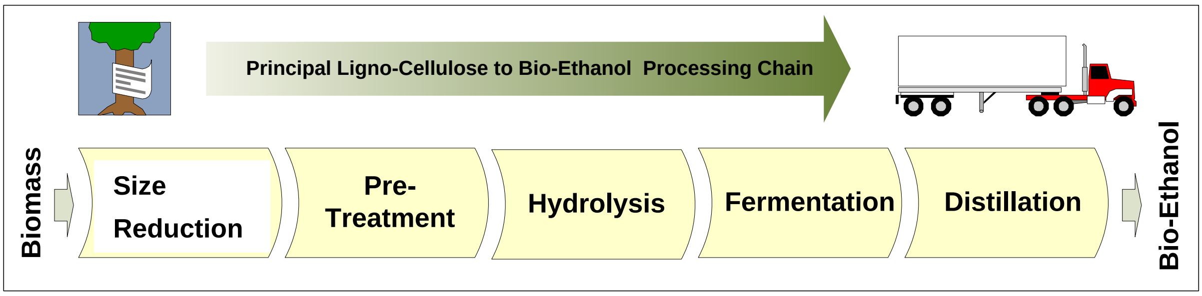

Figure 2: Processing steps in lignocellulose to bioethanol production

Within the first step, the size is reduced through milling or chopping. This straightforward step is performed by various types of mills in order to increase the accessibility of the processed material for the pretreatment step.

The main purpose of the pretreatment is to increase the reactivity of the cellulose and hemicellulose material to the subsequent hydrolysis steps, to decrease the crystallinity of the cellulose and to increase the porosity of the material. Only after breaking this shell the sugar containing materials become accessible for hydrolysis.

A general classification of the pretreatment methods into three groups may be undertaken: chemical, physical und biological pretreatment methods.

Well known chemical pretreatments run on concentrated and diluted acids (H2SO4 generally); diluted acids allow reducing corrosion problems and environmental issues but give lower yields. Still under research are methods using ammonia, lye, organosolv and ionic liquids. In terms of physical pretreatment, steam explosion has been frequently applied and delivers high yields; ammonia fibre explosion requires less energy input but raises environmental issues; methods under development are liquid hot water and CO2- explosion which promise less side-products or low environmental impact respectively. Not well known and not much used are biological processes based on conversion by fungi and bacteria.

The main purpose of the hydrolysis is the splitting of the polymeric structure of lignin-free cellulosic material into sugar monomers in order to make them ready for fermentation. At this stage one should distinguish between the hydrolysis of the C5 dominated hemi-celluloses and the hydrolysis of the C6 based celluloses.

Cellulose is chemically very stable and extremely insoluble. Although acid hydrolysis of the celluloses is possible and has been applied previously, the current state-of-art method is enzymatic hydrolysis by a cellulase enzyme complex produced for example by the fungus Trichoderma reesei. The complex is composed by three proteinic units: endocellulase breaks the crystalline structure to generate shorter chain fragments; exocellulase works on (1→4) glucosidic bonds of linear cellulose to release cellobiose (it is composed by two sugar units); cellobiase (or β-glucosidase) finally works on cellobiose and splits off glucose to make the material suitable for fermentation.

In contrast to the crystalline structure of cellulose, hemicellulose has a mainly amorphous structure. This results in a significantly easier way of hydrolysis. The hydrolysis of hemi-celluloses may be performed by diluted acids, bases or by appropriate hemi-cellulase enzymes. In several process set-ups the hydrolysis already happens in the pretreatment step.

The fermentation of the C5 and C6 sugars obtained from pretreatment and hydrolysis of lignocellulose faces several challenges:

- Inhibition from various by-products of pretreatment and hydrolysis such as acetates, furfural and lignin. The impact of these inhibitors is even larger on the C_5 sugar processing.
- Inhibition from the product itself = inhibition from bioethanol leading to low titer (ethanol concentration)
- Low conversion rates for C5 sugars

Currently there are two basic R&D strategies in the field of fermentation: either ethanologens like yeasts are used and the ability to use C5 sugars is added to them, or organisms capable of using mixed sugars (such as E. coli) are modified in their fermentation pathway in order to produce bioethanol. Further research activities focus on the increase of robustness towards inhibition as well as fermentation temperature.

The upgrading of ethanol from lower concentrations in beer to the required 98.7%m/m is performed employing the following known and widely applied technological steps:

- Evaporation of ethanol from beer: in this step the first evaporation of ethanol is performed in order to obtain 'crude' ethanol with concentration ~45%V/V.
- Rectification: in rectification the ethanol concentration is increased to ~96%V/V
- Dehydration: by dehydration the remaining azeotropic water is removed in order to obtain the fuel bioethanol with concentration 98.7%m/m[1] and water content below 0.3% m/m[1].

[1] According to EN 15376

Particularly in case of enzymatic hydrolysis, various overall process integrations are possible. In all cases a pretreatment is required. The subsequent processing steps differ in the alignment of the hydrolysis C5 fermentation and C6 fermentation steps. It is clear, that in the practical implementation there will be various modifications to the mentioned methods, however, typical processes can be defined as

- SHF – Separate Hydrolysis and Fermentation
- SSF – Simultaneous Saccharification and Fermentation
- SSCF – Simultaneous Saccharification and Co-Current Fermentation
- CBP – Consolidated BioProcessing

The SSCF - Simultaneous Saccharification and Co-Current Fermentation set-up is currently the best developed lignocellulose processing method where hydrolysis and C5 and C6 fermentation can be performed in a common step. The CBP - Consolidated BioProcessing (previously also called DMC - Direct Microbial Conversion), though, envisages a unique step between pretreatment and distillation, unifying cellulase production, C5 and C6 hydrolysis and C5 and C6 fermentation. From today's point of view, the establishment of CBP would mark a significant step forward, in terms of efficiency and simplicity of the process, yet it requires further research and development.

3.1.2 Microbial Fermentation via Acetic Acid

Microbial fermentation of sugars can – in contrast to the more commonly used yeast fermentation to ethanol – also use an acetogenic pathway to produce acetic acid without CO_2 as a by-product. This increases the carbon utilization of the process. The acetic acid is converted to an ester which can then be reacted with hydrogen to make ethanol.

The hydrogen required to convert the ester to ethanol can be produced through gasification of the lignin residue. This requires fractionation of the feedstock into a sugar stream and a lignin residue at the beginning of the process. This process is applied by ZeaChem.

3.1.3 Microbial Fermentation via Farnesene

Engineered yeast can be used to convert sugar into a class of compounds called isoprenoids which includes pharmaceuticals, nutraceuticals, flavors and fragrances, industrial chemicals and chemical intermediates, as well as fuels. One of these isoprenoids is a 15-carbon hydrocarbon, beta-farnesene.

Beta-farneses can be chemically derivatized into a variety of products, including diesel, a surfactant used in soaps and shampoos, a cream used in lotions, a number of lubricants, or a variety of other useful chemicals. This process is applied by Amyris.

3.1.4 Yeast Fermentation to Butanol

As actually there is an excess of ethanol in the US and Brazil, there is significant interest in the production of butanol. Yeast can be engineered to produce butanol instead of ethanol. Butanol may serve as an alternative fuel, as e.g. 85% Butanol/gasoline blends can be used in unmodified petrol engines. Several companies are developing butanol-producing yeasts; however none of them has so far made information available to the authors of this report.

3.1.5 Microbial Fermentation of Gases

Combining thermochemical and biochemical technologies, gas produced through biomass gasification may be converted into alcohols in a fermentative process based on the use of hydrogen, carbon monoxide and carbon dioxide. Beside alcohols such as ethanol and butanol, other chemicals such as organic acids and methane can be obtained. The main advantage of the microbiological processes is the mild process conditions (similar to biogas production); also, the low sensitivity of the microorganisms towards sulphur decreases the gas cleaning costs. The main disadvantage is the limited gas-to-liquid mass transfer rate requiring specific reactor designs. Companies developing this type of process include Coskata, INEOS and Lanza Tech.

Utilisation of gases for the production of algal biomass as an intermediate product could also be seen as a microbial fermentation of gases technology. However, algal biofuels are out of scope of this report.

3.2 Conversion in Biorefineries

Recently, attention has been drawn to the biorefinery concept that allows to produce bio-based chemicals and materials besides bioenergy (biofuels for transport and heat/power), making the system more efficient from a technical, economical and environmental point of view and society progressively independent from fossil energy. In fact, the chemical pathways to succinic acid or ethyl-levulinate, both higher value chemicals, may prove to be more profitable and may dominate over biofuel production only.

According to the definition of IEA Bioenergy Task 42, a biorefinery is the sustainable processing of biomass into a spectrum of marketable products (food, feed, materials, and chemicals) and energy (fuels, power, heat). This definition includes a wide amount of different processing pathways. IEA Bioenergy Task 42 has developed a classification scheme for the description of different biorefineries. This classification includes the description of feedstocks, processes, platforms and products. An example is shown in Figure 3 on the next page.

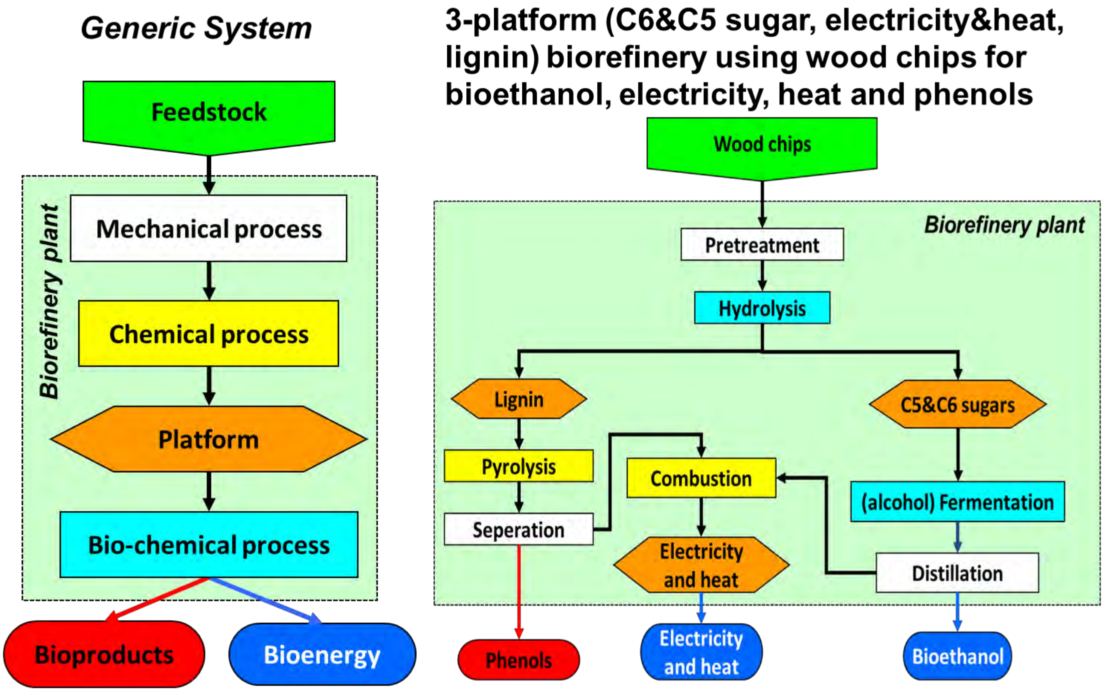

Figure 3: Classification scheme of a biorefinery: generic scheme (left), example (right)

This chapter is focused on energy driven biorefineries that use lignocellulosic feedstock to produce energy carriers and upgrade process residues to value added products. Cellulose and hemicellulose are most conveniently used for energy production with a conversion rate of up to 100%. Lignin represents a residue in the sugar fermentation system for ethanol production, as microorganisms can metabolize only sugars (which form cellulose and hemi-cellulose) but not aromatic alcohols (which are the main component of lignin).

Lignin can be deployed for energy production through combustion, gasification or pyrolysis, (working methods are described in chapter 3.3). Furthermore, it is a good feedstock for chemicals and materials manufacturing, utilising lignin as it is or after depolymerisation. Lignin has a high reactivity and a high binding capacity making it a good stock for materials and macromolecules modifications and manufacturing. Due to its complexity of structure, it can also be depolymerised gaining a lot of different compounds.

As the utilisation of cellulose and hemicellulose for ethanol production has been described in the section 3.1.1, this section focusses on the processing of lignin into biobased products.

3.2.1 Composition of Woods and the share of Lignin

The main components of wood are cellulose, hemicellulose and lignin. The proportion of these macromolecules varies according to the plant specie. Figure 4 shows the location and structure of lignin in lignocellulosic material. Generally the lignin levels are more variable across softwoods as they are across hardwoods.

One of the challenges about the use of different kinds of raw materials is creating a planning model to know in advance the quantity of each output that can be obtained and what pathway is the most convenient.

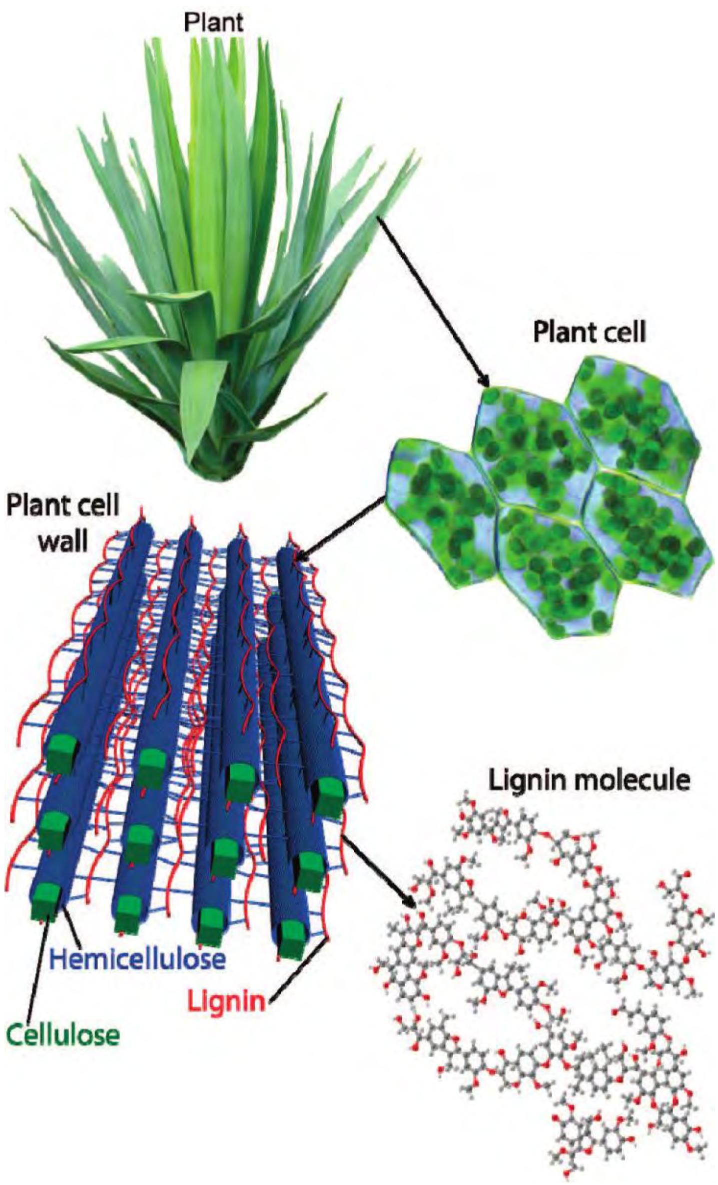

Figure 4: Schematic representation of the location and structure of lignin in lignocellulosic material.

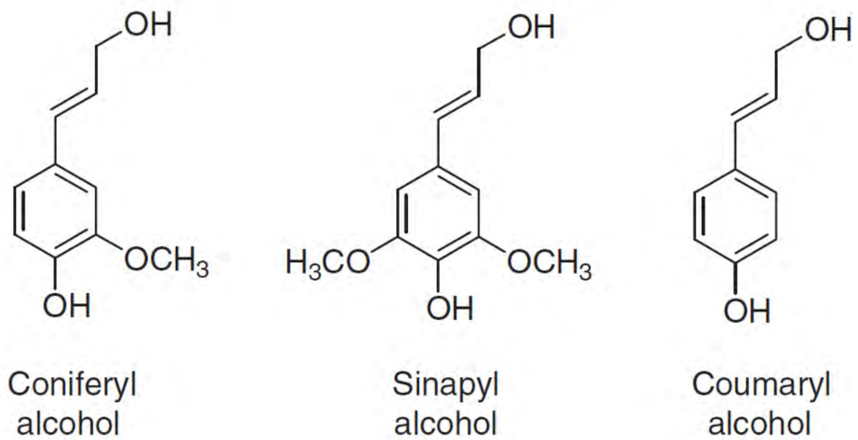

Figure 5: Phenyl propanoid units employed in the biosynthesis of lignin

Cellulose is the most abundant among the three main components of wood. Its structure is a linear chain of anhydro-D-glucose units linked with β-(1→4) bonds.

Hemicellulose also has a linear structure, but it is composed of a range of sugar units, such as glucose, xylose, mannose, galactose, arabinose and uronic acids, which contain 5 carbon atoms.

Lignin is a big biological macromolecule that gives strength to vegetable cell walls. Its structure is more complex than that of cellulose and hemicellulose. It is a three-dimensional amorphous polymer composed of crosslinked phenylpropanoid units, having a different relative quantity depending on the kind of plant.

Lignin creation takes place from polymerization of coniferyl alcohol (common in softwoods), syringyl alcohol (more present in hardwoods) and coumaryl alcohol (mainly found in grasses), as shown in Figure 5. These monolignol units are randomly connected through carbon-carbon (C-C) and carbon-oxygen (C-O or ether) bonds.

In fact, the structure of the lignin polymer is not-well identified. It varies widely, depending on the plant, extraction methods and depolymerisation conditions. Research on which products can be obtained through what kind of extraction is still on-going.

Lignin is the main component of non-fermentable residues from fermentation for ethanol production and from pulp milling for paper manufacturing. The method of extraction will have a significant influence on the composition and properties of lignin. The choice of the appropriate method of extraction is linked to the nature of raw material, the integration into production systems and the final uses of lignin.

Sulfite lignin

The most frequent method for lignin extraction in paper and pulping industries is the sulfite method. The sulfite extraction method produces water soluble lignosulfonates, after treating with sulfite and sulphur dioxide at 140-160ºC and pH value swinging between 1,5 and 5. Several purification steps are then required to obtain a lignosulfonate fraction with high purity, including fermentation to convert the residual sugars to ethanol and membrane filtration to reduce the metal ion content (Mg, Na or NH_4^+).

Kraft lignin

Strong alkaline conditions using sodium hydroxide and sodium sulphide with gradually increasing temperature are used in the kraft (or sulphate) process. Sodium sulfite produces more extended lignin chains that are better suitable for the use as dispersants, while calcium sulfite leads to more compact lignin. Because of its chemical and structural properties, lignosulfonates are very reactive, therefore suitable for ion-exchange applications (substituting metals and in industry and agriculture) or for production of dispersants, surfactants, adhesives and fillers. The lignin may be recovered from the black liquor by lowering the pH to between 5 and 7,5 with acid (usually, sulfuric acid) or carbon dioxide.

Kraft lignin is hydrophobic and needs to be modified to improve reactivity or to be used for the reinforcement of rubbers and in plastic industry. Furthermore, lignin linkages are susceptible to alkaline cleavage, ethers under relatively mild conditions especially. The sulfur content of sulfite and kraft lignins is one of the major factors restricting its use in speciality applications, and so most of its lignin is currently used for energy generation.

Soda lignin

The soda process that is widely used on non-wood material can also be employed for lignin extraction. It takes place in 13–16 wt% base (typically sodium hydroxide) during biomass heating in a pressurised reactor to 140–170 ºC. As soda lignin contains no sulfur and little hemicellulose or oxidised defect structures, it can be used in high value products.

Other lignins

Through the increased use of lignocellulosic raw materials for the production of transport biofuels, additional sources of lignin will become available through various pretreatment technologies, such as physical methods (steam explosion, pulverising and hydrothermolysis). The main chemical methods are the use of ammonia expansion, aqueous ammonia, dilute and concentrated acids (H_2SO_4, HCl, HNO_3, H_3PO_4, SO_2) as well as alkali (NaOH, KOH, $Ca(OH)_2$) and ionic liquids. Significantly, all the approaches under development for production of biofuels from lignocellulosics are likely to produce lignin with little or no sulfur, increasing the scope for manufacturing value added products.

Another method is to use organic solvents (ethanol, formic acid, acetic acid, methanol) producing so called organosolv lignin. The benefits of organosolv lignin over sulfonated and kraft lignins include no sulfur, greater ability to be derivatised, lower ash content, higher purity, generally lower molecular weight and more hydrophobic. This delignification process is not used widely because the pulp produced is of low quality and causes corrosion of the plant equipment.

Lignin separation can be carried out through Ionic Liquid application, usually at 170–190 ºC. Ionic Liquids typically are large asymmetric organic cations and small anions, typically have negligible vapour pressure, very low flammability and a wide liquidus temperature range. Lignins are recovered by precipitation, allowing the Ionic Liquid to be recycled. The final output has a low content of ash, sulphur and hemicellulose and can be used for production of low molecular weight compounds.

3.2.2 Lignin Utilization

As mentioned before, lignin is a complex biological molecule, with a non-precise structure but varying in base of origins, working conditions and extracting method. This aspect will not be relevant if it is redeployed for energy production.

Lignin combustion

The most common use is lignin combustion, usually to recover energy and/or heat for recycling into the system. Although about 40% of the dried lignin-rich solid stream after ethanol production from plant polysaccharides is employed for thermal requirement of ethanol production, the remaining 60% can be utilized as a feedstock for biogasoline, green diesel and chemicals.

Lignin blending

Due to its high reactivity and binding capacity lignin is widely employed for blending with other polymers, natural or not – sometimes after modification for enhancing its blending properties.

- Lignin can be added to resins for formulation of adhesives, films, plastics, paints, coatings and foams.
- Lignin blended with polymers enhances the mechanical resistance, thermal stability and resistance to UV radiation, which is a promising application in particular in the plastic industry.
- In food packaging and medical applications lignin reduces the permeability towards gases (carbon dioxide, oxygen) and water, and leads to a lower degradation rate and flammability.
- In the case of PVC- and formaldehyde-based resins and plastics lignin-blended materials show less toxicity, again much appreciated in food and pharmaceutical businesses.
- Adding lignin improves mechanical behaviour of rubber-derived products and drilling muds, physical features of animal feed, pesticides and fertilizers, and for dust control and oil recovering.
- Due to its capacity to react with proteins, lignin is utilized in the manufacturing of cleaners, carbon black, inks, pigments and dyes as well as in the production of bricks and ceramic and in ore laboratories.
- Despite the increase in resistance, most of these blended materials become more processable, recyclable and biodegradable, improving manufacturing characteristics (holding down energy and economic inputs) and making them more eco-friendly.

Lignin melting

One of the most important opportunities of lignin utilization is the production of carbon fibres by melt spinning processes, mainly interesting for vehicles industries.

Depolymerisation

On the other hand the complexity of the lignin structure allows obtaining a lot of products derived from depolymerisation. Depolymerisation mainly produces BTX (benzene, toluene and xylene) that can be further modified. Besides, other smaller molecules are gained, such as phenols and lower molecular-weight compounds of which the latter cannot be created through the conventional petrochemical pathway. All these chemicals can be used for many different applications in the chemical industry (electrical equipment, pharmaceuticals, plastics, polycarbonates, textiles, etc.). Yet there is currently no selective depolymerization technique of lignin, thus controlling the qualitative and quantitative features of products is a considerable challenge.

3.3 Thermochemical Conversion: Production of Biofuels via Gasification

Although thermochemical processes include gasification, pyrolysis and torrefaction, this section focusses on the production of biofuels via gasification, as these technologies are currently the best developed.

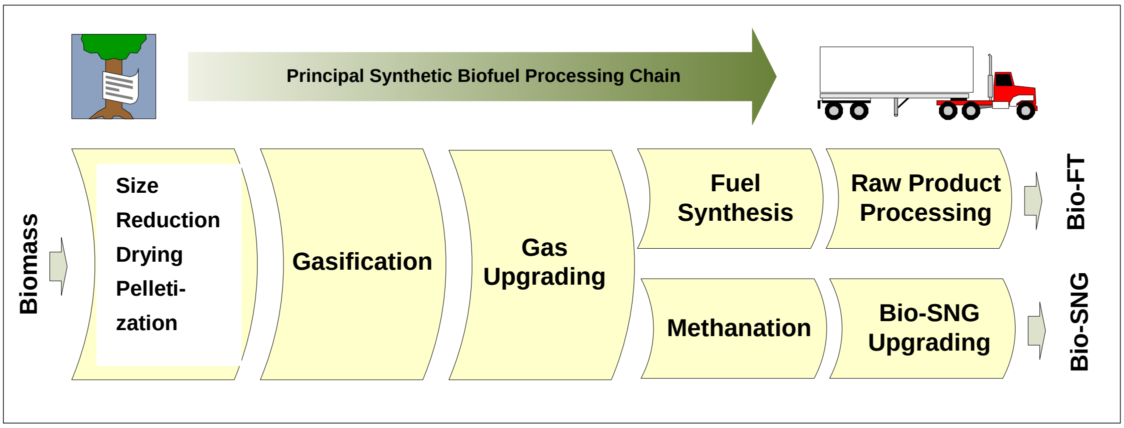

Figure 6: Principal synthetic biofuel processing chain

3.3.1 Syngas Production and Cleaning

The production of biofuels using the thermochemical route differs significantly from the lignocellulosic ethanol production. Within this production scheme the biomass is first thermally fragmented to synthesis gas consisting of rather simple molecules such as: hydrogen, carbon monoxide, carbon dioxide, water, methane, etc. Using this gaseous material the BtL fuels may be re-synthesized by catalytic processes. Alternatively methanation may be performed in order to obtain bio-SNG as substitute for natural gas.

After the size reduction, the material is moved into the gasifier where it transforms into gas (mainly composed by hydrogen and carbon monoxide) and solid by-products (char or ashes and impurities). Gasification takes place under shortage of oxygen (typically λ = 0.2-0.5). The product gas has a positive heating value, and, if char is produced, this also has a positive heating value. By reducing the amount of available oxygen, other processes are triggered, called pyrolysis and liquefaction.

The gasification processes may be distinguished according to the used gasification agent and the way of heat supply. Typical gasification agents are: oxygen, water, and air (carbon dioxide and hydrogen are also possible). Two types of processes are distinguished based on how heat is supplied. In autotherm processes the heat is provided through partial combustion of the processed material in the gasification stage. In the second type of processes, the allotherm processes, the heat is provided externally via heat exchangers or heat transferring medium. In these processes the heat may come from combustion of the processed material (i.e., combustion and gasification are physically separated) or from external sources.

The choice of the gasification agent is based on the desired product gas composition. The combustible part is mainly composed of hydrogen (H2), carbon monoxide (CO), methane (CH4) and short chain hydrocarbons, moreover inert gases. A higher process temperature or using steam as gasification agent leads to increased H2 content. High pressure, on the other hand, decreases the H2 and CO content. A change of H2/CO ratio can be observed varying steam/O2 ratio as gasification agent. Moreover, when using air as gasification agent, nitrogen is present.

In case the product gas is used for a subsequent fuel synthesis, the use of air as gasification agent is not favourable (due to the resulting high N2 content in the product gas).

The gasifier types can be classified according to the way how the fuel is brought into contact with the gasification agent. There are three main types of gasifiers:

- Fixed-bed gasifier
  - Updraft gasifier
  - Downdraft gasifier
- Fluidized bed gasifier
  - Stationary fluidized bed (SFB) gasifier
  - Circulating fluidized bed (CFB) gasifier
- Entrained Flow Gasifier

The amount and kind of impurities depend on the type of biomass used as fuel. Impurities can cause corrosion, erosion, deposits and poisoning of catalysts. It is therefore necessary to clean the product gas. Dust, ashes, bed material and alkali compounds are removed through cyclones and filter units, the tar through cooling and washing the gas using special solvents or by condensation in a wet electro filter. Components having mainly poisonous effects are sulphur compounds that can be withdrawn by an amine gas treating, a benfield process or similar process, and nitrogen and chloride for which wet washing is required.

The cleaned product gas will then be upgraded.

- An optimal H_2/CO ratio of 1,5 – 3,0 is obtained by the Water-gas-shift (WGS) reaction: CO + $H_2O \leftrightarrow CO_2 + H_2$.
- The gas reforming reaction converts short-chain organic molecules to CO and H_2 (for an example: $CH_4 + H_2O \leftrightarrow CO + 3\ H_2$).
- CO_2 removal can be performed by physical (absorption to water or other solvents) or chemical (absorption to chemical compounds) methods. Other absorption methods are based on pressure or temperature variations.

3.3.2 Fuel Synthesis

3.3.2.1 Fischer-Tropsch Liquids

Starting form the synthesis gas (=the cleaned and upgraded product gas) several fuel processing pathways are possible. One of these is the Fischer-Tropsch (FT) process, through which alkanes are produced in fixed bed or slurry reactors using mostly iron and cobalt as catalysts. In the case of the High Temperature Fischer-Tropsch (HTFT) synthesis (300 –

350°C and 20 – 40 bar), products obtained are basic petrochemical materials and gas. The Low Temperature Fischer-Tropsch (LTFT) technology (200 – 220°C and less 20 bar) provides outputs for diesel production. The raw product, though, cannot be directly used as fuel, it needs to be upgraded via distillation to split it into fractions; via hydration and isomerization of the C_5 – C_6 fraction and reforming of the C_7 – C_{10} fraction in order to increase the octane number for petrol use; and via cracking by application of hydrogen under high pressure in order to convert long-chain fractions into petrol and diesel fraction.

3.3.2.2 Synthetic Natural Gas

The upgrading to SNG (synthetic natural gas) requires methanation of the product gas, desulfuration, drying and CO_2 removal. In the methanation step (catalyzed by nickel oxide at 20-30 bar pressure conditions) carbon monoxide reacts with hydrogen forming methane and water:

$CO + 3\ H_2 \leftrightarrow CH_4 + H_2O$.

The withdrawal of CO_2 can be performed by water scrubbing (a counter-current physical absorption into a packed column) and Pressure Swing Adsorption (an absorption into a column of zeolites or activated carbon molecular sieves followed by a hydrogen sulphide removing step) technologies. Natural gas quality is reached at 98% methane content. The final step is the gas compression (up to 20 bar for injection into the natural gas grid, up to 200 bar for storage or for use as vehicle fuel).

3.3.2.3 Mixed Alcohols

Starting form a suitably upgraded product gas, it is possible to synthesize alcohols as main products via catalytic conversion. The higher alcohol synthesis (HAS) follows the reaction: $3\ CO + 3\ H_2 \leftrightarrow C_3H_5OH + CO_2$; using a number of catalysts (alkali-doped, methanol, modified FT-catalysts). As HAS is a highly exothermic process, the optimization of heat removal is of particular interest. The product upgrading of the obtained alcohol mixture consists typically of de-gassing, drying and separation into three streams: methanol, ethanol and higher alcohols.

3.4 Chemical Technologies

3.4.1 Hydrotreatment of Oils

Chemical reaction of vegetable oils, animal-based waste fats, and by-products of vegetable oil refining with hydrogen produces hydrocarbons with properties superior to conventional biodiesel and fossil diesel. The product is sulfur-, oxygen-, nitrogen- and aromatics-free diesel which can be used without modification in diesel engines. These diesel-type hydrocarbons, also referred to as Hydrotreated vegetable oil (HVO) or a renewable diesel, can even be tailored to meet aviation fuel requirements. Companies applying this type of technology include NesteOil and Dynamic Fuels.

3.4.2 Catalytic Decarboxylation

For the decarboxylation process, crude fat feedstock is first converted into fatty acids and glycerol. The fatty acids are then put through catalytic decarboxylation, a process which decouples oxygen without using hydrogen. The process is capable of processing unsaturated as well as saturated fatty acids into true hydrocarbons. What makes the process unique is that it does not change the type of saturation. This is what makes the production of renewable olefins possible. However, when necessary to create fuels from unsaturated fats, introduction of a small amount of hydrogen during the catalytic decarboxylation step will readily yield a saturated hydrocarbon ideally suited for fuels. The company Alipha Jet is developing this technology.

3.4.3 Methanol Production

Crude glycerine (residue from biodiesel plants) is purified, evaporated and cracked to obtain syngas (synthesis gas), which is used to synthesise methanol. Methanol is an extremely versatile product, either as a fuel in its own right or as a feedstock for other biofuels. It can be used as a chemical building block for a range of future-oriented products, including MTBE, DME, hydrogen and synthetic biofuels (synthetic hydrocarbons). The company BioMCN is applying this technology.

Without doubt there are numerous technology developments ongoing, but this report can not undertake to describe them all. E.g. the advancement of conventional biofuel production technologies such as biodiesel, ethanol from sugar and starch, and biogas technologies, however important, is not subject in this report.

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4 List of Facilities

In this section the main data for all projects that are currently visible in the online map (http://demoplants.bioenergy2020.eu) is listed. Units used are t/y (tons per year) and MW (megawatt).

4.1 Biochemical Technologies

Company	**Location**	**Country**	**Input Material**	**Product**	**Output**	**Unit**	**Type**	**Status**	**Start-up**
Aalborg University Copenhagen	Bornholm	Denmark	wheat straw, cocksfoot grass	ethanol; biogas	11	t/y	pilot	operational	2009
Abengoa Bioenergy	Babilafuent, Salamanca	Spain	cereal straw (mostly barley and wheat)	ethanol	4000	t/y	demo	operational	2008
Abengoa Bioenergy Biomass of Kansas, LLC	Hugoton	United States	corn stover, wheat traw, switch grass	ethanol + 18 MW power	75000	t/y	commercial	under construction	2013
Abengoa Bioenergy New Technologies	York	United States	corn stover	ethanol	75	t/y	pilot	operational	2007
Abengoa Bioenergy, S.A.	Arance	France	agricultural and forest residues	ethanol	40000	t/y	demo	planned	2013
Aemetis	Butte	United States	switchgrass, grass seed, grass straw and corn stalks	ethanol	500	t/y	pilot	operational	2008
Amyris, Inc.	Campinas	Brazil	sugarcane	diesel-type hydrocarbons	n.s.		demo	operational	2009
Amyris, Inc.	Emeryville	United States	sugarcane	diesel-type hydrocarbons	n.s.		pilot	operational	2008
Amyris, Inc.	Piracicaba	Brazil	sugarcane	diesel-type hydrocarbons	n.s.		commercial	operational	2010
Amyris, Inc.	Brotas	Brazil	sugarcane	diesel-type hydrocarbons	n.s.		commercial	operational	2012
Amyris, Inc.	Pradópolis	Brazil	sugarcane	diesel-type hydrocarbons	n.s.		commercial	planned	2013

Company	Location	Country	Input Material	Product	Output	Unit	Type	Status	Start-up
Amyris, Inc.	Decatur	United States	corn dextrose	diesel-type hydrocarbons	n.s.		commercial	operational	2011
Amyris, Inc.	Leon	Spain	sugar beet; dextrose	diesel-type hydrocarbons	n.s.		commercial	operational	2011
Beta Renewables (joint venture, Mossi & Ghisolfi Chemtex divison, with TPG)	Rivalta Scrivia	Italy	corn stover, straw, husk, energy crops (Giant Reed), woody biomass	Ethanol; various chemicals	250	t/y	pilot	operational	2009
Beta Renewables (joint venture, Mossi & Ghisolfi Chemtex divison, with TPG)	Crescentino	Italy	lignocellulosics: Straw, energy crops (giant reed)	ethanol	60000	t/y	commercial	operational	2012
BioGasol	Aakirkeby, Bornholm	Denmark	straw, various grasses, garden waste	ethanol; biogas; lignin; hydrogen	4000	t/y	demo	planned	2013
Blue Sugars Corporation	Upton	United States	sugarcane bagasse and other biomass	ethanol; lignin	4500	t/y	demo	operational	2008
Borregaard AS	Sarpsborg	Norway	sugarcane bagasse, straw, wood, energy crops,other lignocellulosics	ethanol; lignin; various chemicals	110 ethanol; 200 lignin	t/y	demo	operational	2012
Borregaard Industries AS	Sarpsborg	Norway	sulfite spent liquor from spruce wood pulping	ethanol	15800	t/y	commercial	operational	1938
BP Biofuels	Jennings	United States	dedicated energy crops	ethanol	4200	t/y	demo	operational	2009
Chempolis Ltd.	Oulu	Finland	non-wood and non-food lignocellulosic biomass such as straw, reed, empty fruit bunch, bagasse, corn stalks, as well as wood residues	ethanol; various chemicals	5000	t/y	demo	operational	2008
Clariant	Straubing (München)	Germany	wheat straw and other agricultural residues	ethanol	1000	t/y	demo	operational	2012

Company	Location	Country	Input Material	Product	Output	Unit	Type	Status	Start-up
DuPont	Vonore	United States	lignocellulosics: corn stover, cobs and fiber, switchgrass	ethanol	750	t/y	demo	operational	2010
Fiberight LLC	Lawrencevil-le	United States	municipal solid waste	ethanol; power	3	t/y	demo	operational	2012
Fiberight LLC	Blairstown	United States	municipal solid waste	ethanol; power	18	t/y	commercial	idle while reconfiguring the process	2013
Frontier Renewable Resources	Kincheloe	United States	wood chip	ethanol; lignin	60000	t/y	commercial	planned	
GraalBio; commercialising Beta Renewables technology		Brazil	sugarcane bagasse and straw	ethanol	65000	t/y	commercial	planned	2013
Inbicon (DONG Energy)	Kalundborg	Denmark	wheat straw	ethanol; c5 molasses	4300	t/y	demo	operational	2009
Inbicon (DONG Energy)	Fredericia	Denmark	straw	ethanol; c5 molasses	n.s.		pilot	operational	2003
Inbicon (DONG Energy)	Fredericia	Denmark		ethanol; c5 molasses	n.s.		pilot	operational	2005
INEOS Bio	Vero Beach	United States	vegetative Waste, Waste wood, Garden Waste	ethanol + 6 MW power	24000	t/y	commercial	under construction	2013
Iogen Corporation	Ottawa	Canada	wheat/oat/barley straw, corn stover, sugar cane bagasse and other agricultural residues	ethanol	1600	t/y	demo	operational	2004
Iowa State University	Boone	United States	grains, oilseeds, vegetable oils, glycerin	ethanol; FT-liquids	200	t/y	pilot	operational	2009
LanzaTech BaoSteel New Energy Co., Ltd.	Shanghai	China	industrial flue gasses	ethanol	300	t/y	demo	operational	2012
LanzaTech New Zealand Ltd	Parnell	New Zealand	industrial flue gasses	ethanol	90	t/y	pilot	operational	2008

Company	Location	Country	Input Material	Product	Output	Unit	Type	Status	Start-up
LanzaTech (Beijing Shougang LanzaTech New Energy Co, Ltd.)	Beijing	China	industrial off gas	ethanol	300	t/y	demo	under construction	2013
LanzaTech, Inc.	Georgia	United States	Woody biomass, biomass syngas	ethanol	15000	t/y	commercial	planned	2013
LanzaTech – Concord Enviro Systems PVT Lt.	Aurangabad	India	any gas containing carbon monoxide from municipal waste	ethanol, electricity	300	t/y	demo	planned	2013
Lignol Innovations Ltd.	Burnaby	Canada	hardwood & softwood residues	ethanol; lignin	n.s.		pilot	operational	2009
Mascoma Corporation	Rome	United States	wood Chips, Switchgrass and other raw materials	ethanol; lignin	500	t/y	demo	operational	
New Energy and Industrial Development Organization (NEDO)	Hiroshima	Japan	lignocellulosics: wood chips	ethanol	65	t/y	pilot	operational	2011
NREL (National Renewable Energy Laboratory)	Golden, Colorado	United States	dry biomass	ethanol	100	t/y	pilot	operational	1994/ 2011
Petrobras	Rio de Janeiro	Brazil	sugarcane bagasse	ethanol	270	t/y	pilot	operational	2007
Petrobras and Blue Sugars (same plant as Blue Sugars but specific test programm)	Upton, Wyoming	United States	sugarcane dried bagasse	ethanol	700	t/y	demo	operational	2011
POET	Scotland	United States	agricultural residues	ethanol	60	t/y	pilot	operational	2008

Company	**Location**	**Country**	**Input Material**	**Product**	**Output**	**Unit**	**Type**	**Status**	**Start-up**
POET-DSM Advanced Biofuels	Emmetsburg	United States	agricultural residues	ethanol, biogas	75000	t/y	commercial	under construction	2013
PROCETHOL 2G	Pomacle	France	flexible; woody and agricultural by-products, residues, energy crops	ethanol	2700	t/y	pilot	operational	2011
Queensland University of Technology	Mackay	Australia	sugarcane bagasse & other lignocellulosics	ethanol; lignin; various chemicals	n.s.		pilot	operating	2010
SEKAB	Goswinowice	Poland	wheat straw and corn stover	ethanol	50000	t/y	demo	planned	2014
SEKAB/EPAB	Örnsköldsvik	Sweden	primary wood chips; sugarcane bagasse, wheat, corn stover, energy grass, recycled waste etc have been tested.	ethanol	160	t/y	pilot	operational	2004
TNO	Zeist	Netherlands	wheat straw, grass, corn stover, bagasse, wood chips	pretreated biomass	100	t/y	pilot	operational	2002
Weyland AS	Bergen	Norway	lignocellulose – various feedstocks, mostly spruce & pine	ethanol; lignin	158	t/y	pilot	operational	2010
ZeaChem	Boardman	United States	poplar trees, wheat straw	ethanol; various chemicals	75000	t/y	commercial	planned	2014
ZeaChem Inc.	Boardman, Oregon	United States	poplar trees, wheat straw	ethanol; diesel-type hydrocarbons; various chemicals; gasoline-type fuel; jet fuel	750	t/y	demo	operating	2011

Table 2: List of projects applying the biochemical pathway, by alphabetical order of the company name

4.2 Thermochemical Technologies

Company	Location	Country	Input Material	Product	Output	Unit	Type	Status	Start-up
Biomassekraftwerk Güssing	Güssing	Austria	syngas from gasifier	SNG	576	t/y	demo	operational	2008
Chemrec AB	Pitea	Sweden	black liquor gasification	DME;	1800	t/y	pilot	operational	2011
ECN	Petten	Netherlands	lignocellulosics (clean wood and demolition wood)	syngas, SNG (smaller scale or side stream)	346	t/y	pilot	operational	2008
ECN - Consortium Groen Gas 2.0	Alkmaar	Netherlands	lignocellulosics	SNG, heat	6500	t/y	demo	planned	2013
Enerkem	Sherbrooke	Canada	Sorted municipal solid waste (SMSW) from numerous municipalities and more than 25 different feedstocks, including wood chips, treated wood, sludge, petcoke, spent plastics, wheat straw. Feedstocks can be in solid, slurry or liquid form.	ethanol; methanol; various chemicals	n.s.		pilot	operational	2003
Enerkem	Westbury	Canada	treated wood (i.e. decommissioned electricity poles and railway ties), wood waste and MSW	ethanol; methanol; various chemicals	4000	t/y	demo	operational	2009
Enerkem - Varennes Cellulosic Ethanol L.P.	Varennes	Canada	sorted industrial, commercial and institutional waste	ethanol; methanol; various chemicals	30000	t/y	commercial	planned	
Enerkem Alberta Biofuels LP	Edmonton	Canada	sorted municipal solid waste (SMSW)	ethanol; methanol; various chemicals	30000	t/y	commercial	under construction	2013
Enerkem Mississippi Biofuels LLC	Pontotoc	United States	sorted municipal solid waste (SMSW) and wood residues	ethanol; methanol; various chemicals	30000	t/y	commercial	planned	

Company	**Location**	**Country**	**Input Material**	**Product**	**Output**	**Unit**	**Type**	**Status**	**Start-up**
Goteborg Energi AB	Göteborg	Sweden	forest residues, wood pellets, branches and tree tops	SNG, district heating	11200	t/y	demo	under construction	2013
Greasoline GmbH	Oberhausen	Germany	bio-based oils and fats, residues of plant oil processing, free fatty acids, used bio-based oils and fats	diesel-type hydrocarbons	2	t/y	pilot	operational	2011
GTI Gas Technology Institute	Des Plaines	United States	forest residues: tops, bark, hog fuel, stump material	FT-liquids	880	t/y	pilot	operational	2004
GTI Gas Technology Institute	Des Plaines	United States	wood, corn stover, bagasse, algae	FT-liquids; gasoline-type fuel	4,1 (wood) 8 (algae)	t/y	pilot	operational	2012
Iowa State University	Boone	United States	grains, oilseeds, vegetable oils, glycerin	ethanol; FT-liquids;	200	t/y	pilot	operational	2009
Karlsruhe Institute of Technology (KIT)	Karlsruhe	Germany	lignocellulosics	DME; gasoline-type fuel;	608	t/y	pilot	under construction	2013
Licella	Somersby	Australia	radiate pine, banna grass, algae	bio-oil	350	t/y	demo	operational	2008
NREL (National Renewable Energy Laboratory)	Golden, Colorado	United States	dry biomass	various chemicals	50	t/y	pilot	operational	1985, expansion ongoing
Research Triangle Institute	Research Triangle Park	United States	lignocellulosics	FT-liquids; mixed alcohols;	22	t/y	pilot	under construction	
Southern Research Institute	Durham	United States	cellullulosics, Municipal wastes, syngas	FT-liquids; mixed alcohols	n.s.		pilot	operational	2007
Tembec Chemical Group	Temis-caming	Canada	spent sulphite liquor feedstock	ethanol;	13000	t/y	demo	operational	
TUBITAK	Gebze	Turkey	combination of hazelnut shell, olive cake, wood chips and lignite blends	FT-liquids	250	t/y	pilot	under construction	2013

Vienna University of Technology / BIOENERGY 2020+	Güssing	Austria	syngas from gasifier	FT-liquids;	0,2	t/y	pilot	operational	2005
Virent	Madison, Wisconsin	United States	pine residues, sugarcane bagasse and corn stover	diesel-type hydrocarbons	30	t/y	demo	operational	2009

Table 3: List of projects applying the thermochemical pathway, by alphabetical order of the company name

4.3 Chemical Technologies

Company	Location	Country	Input Material	Product	Output	Unit	Type	Status	Start-up Year
AliphaJet Inc.	n.s.	n.s.	triglyceride oils	diesel-type hydrocarbons; jet fuel	230	t/y	pilot	planned	2013
BioMCN	Farmsum	Netherlands	crude glycerine, others	methanol	200000	t/y	commercial	operational	2009
Dynamic Fuels LLC	Geismar	United States	animal fats, used cooking greases	diesel-type hydrocarbons	210000	t/y	commercial	operational	2010
Neste Oil	Porvoo	Finland	oils and fats	diesel-type hydrocarbons	190000	t/y	commercial	operational	2009
Neste Oil	Rotterdam	Netherlands	oils and fats	diesel-type hydrocarbons	800000	t/y	commercial	operational	2011
Neste Oil	Singapore	Singapore	oils and fats	diesel-type hydrocarbons	800000	t/y	commercial	operational	2010
Neste Oil	Porvoo	Finland	palm oil, rapeseed oil and animal fat	diesel-type hydrocarbons	190000	t/y	commercial	operational	2007

Table 4: List of projects applying chemical technologies, by alphabetical order of the company name

4.4 Stopped Projects

Company	Location	Country	Input Material	Product	Output	Unit	Type	Status
BioGasol	Ballerup	Denmark	flexible	ethanol;	n.s.		pilot	stopped
CHEMREC	Örnsköldsvik	Sweden	SSL	DME	95000	t/y	demo	plans put on hold
Coskata	Warrenville	United States	various lignocellulosics	ethanol	n.s.		pilot	idle
Coskata	Madison	United States	wood chips, natural gas	ethanol	120	t/y	demo	Idle
Coskata	Clewiston	United States	sugarcane waste, others	ethanol	300000	t/y	commercial	Plans stopped
Flambeau River Biofuels Inc.	Park Falls	United States	forest residuals, non-merchantable wood	FT-liquids	51000	t/y	demo	plans stopped
Iogen Corporation	Birch Hills	Canada	wheat straw, etc.	ethanol	70000	t/y	commercial	plans stopped
Iogen Biorefinery Partners, LLC	Shelley	United States	agricultural residues: wheat straw, Barley straw, corn stover, switchgrass, rice straw	ethanol	55000	t/y	commercial	plans stopped
Lignol Energy Corporation	Grand Junction	United States	hardwood & softwood residues; agri -residues	ethanol; lignin	7500	t/y	demo	plans stopped
NSE Biofuels Oy, a Neste Oil and Stora Enso JV	Porvoo or Imatra	Finland	forest residues	FT-liquids	100000	t/y	commercial	plans stopped
NSE Biofuels Oy, a Neste Oil and Stora Enso JV	Varkaus	Finland	forest residues	FT-liquids	656	t/y	pilot	operations stopped after successful trials
Pacific Ethanol	Boardman, Oregon	United States	lignocellulosics	ethanol, biogas, lignin	8000	t/y	demo	plans stopped
Petrobras	Rio de Janeiro	Brazil	sugarcane bagasse	ethanol	n.s.		pilot	plans put on hold

Company	Location	Country	Input Material	Product	Output	Unit	Type	Status
Schweighofer Fiber GmbH	Hallein	Austria	sulfite spent liquor from spruce wood pulping	ethanol	12000	t/y	demo	plans put on hold
SEKAB	Örnsköldsvik	Sweden		ethanol	120000	t/y	commercial	plans postponed
SEKAB Industrial Development AB	Örnsköldsvik	Sweden	flexible for wood chips and sugarcane bagasse	ethanol	4500	t/y	demo	plans stopped

Table 5: List of facilities that have been shut down or deactivated

4.5 Closed Companies

Company	Location	Country	Input Material	Product	Output	Unit	Type	Last status
BBI BioVentures LLC	Denver, Colorado	United States	lignocellulosics; pre-collected feedstocks that require little or no pretretment	ethanol	13000	t/y	commercial	planned
BFT Bionic Fuel Technologies AG	Aarhus - odum	Denmark	straw pellets	diesel; hydrocarbons	200	t/y	demo	operational
CHOREN Fuel Freiberg GmbH & Co. KG	Freiberg	Germany	dry wood chips from recycled wood and residual forestry wood;	FT-liquids	13500	t/y	demo	under commissioning
CHOREN Industries GmbH	Schwedt	Germany	dry wood chips from recycled wood; fast growing wood from short-rotation crops	FT-liquids	200000	t/y	commercial	planned
Range Fuels, Inc.	Soperton	United States	wood and wood waste from nearby timber harvesting operations	ethanol; methanol	300000	t/y	commercial	under construction
Range Fuels, Inc.	Denver	United States	Georgia pine and hardwoods and Colorado beetle kill pine	mixed alcohols	n.s.	t/y	pilot	operational

Company	**Location**	**Country**	**Input Material**	**Product**	**Output**	**Unit**	**Type**	**Last status**
Terrabon	Bryan	United States	MSW, sewage sludge, manure, agricultural residues and non-edible energy crops	mixed alcohols	103 - 120	t/y	demo	operational

Table 6: List of companies that have stopped operation

4.6 Company Name Changes

Former	**New**	**Remark**
AE Biofuels	Aemetis	
CTU - Conzepte Technik Umwelt AG	Biomassekraftwerk Güssing	taken over after CTU went bankrupt
DDCE Dupont	DuPont	
KL Energy	Blue Sugars Corporation	
Mossi&Ghisolfi	Beta Renewables	
M-real Hallein AG	Schweighofer Fiber GmbH	project plans put on hold
Verenium	BP Biofuels	take over

Table 7: List of companies that have changed name

4.7 Technology Cooperations

BioGasol	Technical University Denmark (DTU) and Aalborg University Copenhagen	BioGasol is a spinout of the DTU; the Aalborg University; Copenhagen works on the same project BornBiofuel
Biomassekraftwerk Güssing	Vienna University of Technology / BIOENERGY 2020+	run projects in the same gasification facility: BioSNG and FT resp.
Enerkem	Greenfield Ethanol	Varennes Cellulosic Ethanol
Graal Bio	Beta Renewables	GraalBio is planning commercial-scale cellulosic ethanol plants in Brazil using Beta Renewable's PROESA process
Lanza Tech	Boa Steel	LanzaTech BaoSteel New Energy Co., Ltd. In Shanghai / China
Mascoma	J.M. Longyear	FrontierRenewable Sources
Mossi & Ghisolfi Chemtex divison	TPG	Beta Renewables
Petrobras	Blue Sugars	Petrobras runs trials in the Blue Sugar demo plant and Blue Sugars licended their technology to Petrobras.
SEKAB	Technical University of Lulea, University of Umea	EPAP

Table 8: List of company cooperations

5 Data Summary

Overall, data from 71 actively pursued projects for the production of advanced biofuels has been gathered. More projects are cited in the lists of section 4 of this report, but not all of them produce biofuels, and some of the projects are not being actively pursued any more. Even more projects were identified, but not for all of them data was provided by the pursuing companies. In the following graphs and tables, only actively pursued projects for which data was provided from the company are included.

5.1 Technology

Biochemical technologies are clearly dominating over thermochemical technologies. Of the 71 projects for which data was provided, 43 were classified to use a biochemical pathway, 20 use a thermochemical pathway, and 7 use a chemical pathway. One pilot plant is flexible and allows for both biochemical or thermochemical pathway; this project is counted half towards each of these technologies. Output capacities are in the range of <50 t/y through <800 000 t/y, as can be seen in the following graph.

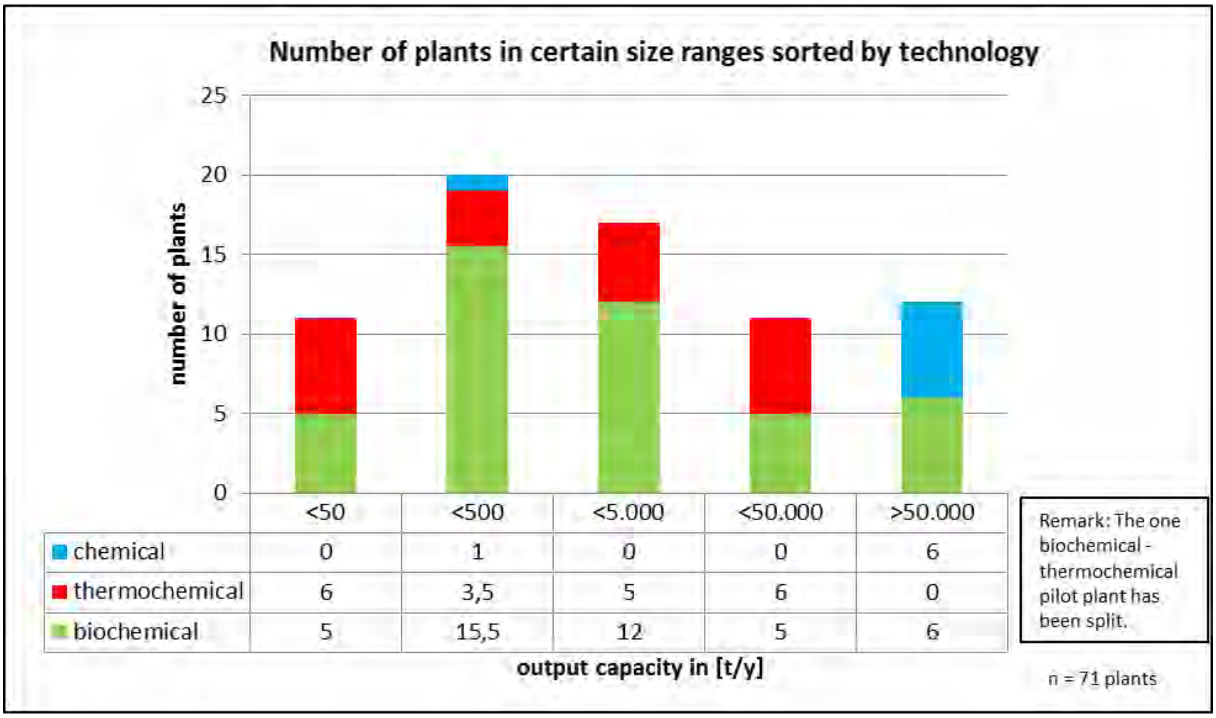


Figure 7: Diagram of projects sorted by technology

5.1.1 Biochemical Pathway

Throughout the 43 projects for which data is available, a variety of lignocellulosic feedstocks are being used, including agricultural residues, wood and wood residues from forestry and forest products, dedicated energy crops, and municipal solid waste. The most frequently cited feedstocks are corn cobs, corn stover, wheat straw and wood waste. Woodchips, sugarcane bagasse and sulphite spent liquor are also applied in some cases. Some technologies utilize gases as feedstock; these gases may be derived from biomass gasification or from other industrial processes. Individual companies pursue specific opportunities.

Most technologies include steam explosion or acids for pretreatment of lignocellulosic, followed by enzymatic hydrolysis and fermentation. Enzymes are often provided by dedicated enzyme producers, but some companies like Iogen and Mascoma produce their own enzymes. Mascoma combines enzyme production, hydrolysis and fermentation in a single step (consolidated bioprocessing).

Integrated production of power and steam (combined heat and power, CHP) is applied in various cases: Some companies separate lignin at the beginning of the process and use it for power and steam generation (Inbicon, Iogen, Lignol Energy Corporation), but the lignin can also be sold as lignin pellets by-product. POET integrates ethanol production from corn cobs into an existing grain ethanol plant and uses part of the collected biomass for power production. Abengoa also couples ethanol production with a biomass CHP. The concept of Schweighofer Fiber (plans postponed) foresees integration of ethanol production into an existing pulp mill with production of ethanol and energy and recycling of chemicals from the sulphite spent liquor (SSL); and Borregaard Industries are successfully producing ethanol from SSL since 1938.

Terrabon uses a completely different approach: a pretreatment with lime and oxygen is followed by microbial conversion into acetic acid; a wide range of products can be derived from this. Acetic acid as an intermediate is also used in ZeaChem´s process: The first step is chemical fractionation of the sugars from the lignin. The sugars are being fermented into acetic acid and then converted into ester, while the lignin is being gasified into a hydrogen-rich gas. The hydrogen from this gas is used to hydrogenate ethanol from the ester, while the remainder of the syngas is burned for steam and power generation.

Another interesting option is the utilization of gases as feedstock. INEOS Bio´s technology combines gasification of the biomass (wood chips) with a microbial conversion of the resulting syngas into ethanol and a combination of distillation and membrane pervaporation for ethanol recovery. Coskata has followed a similar concept, but in the meanwhile stopped these activities. Lanza Tech also converts gaseous feedstock (such as industrial flue gases) into ethanol.

5.1.2 Thermochemical Pathway

While biochemical projects are targeting agricultural residues and herbaceous feedstocks, thermochemical technologies focus on woody feedstock. On the product side a variety of products can be found. Products from the 20 projects using the thermochemical pathway range from Fisher Tropsch (FT)-liquids, synthetic natural gas (SNG), and Di-Methyl-Ether (DME) to ethanol, methanol and mixed alcohols. The type of biofuel produced does not depend on the feedstock in use but on the demand for replacement of either gasoline or diesel fuel in the respective region. Recently, a shift away from the production of FT-liquids to the less costly pathway to mixed alcohols can be observed.

Feedstocks used include wood chips and pellets from forestry and forestry residues, sorted municipal solid waste (SMSW), and sulphite spent liquor (SSL).

Gasification technologies applied quite equally split between fluidised bed gasifiers and entrained flow gasifiers, and within each of these types a variety of different concepts is being pursued. For example, Enerkem applies a bubbling fluidized bed gasifier, while Forschungszentrum Karlsruhe uses fast pyrolysis in front of a high temperature entrained flow gasifier, and Chemrec uses the spent sulphite liquor from the pulping process in its entrained flow gasifier. Generally, fluidised bed gasifiers build smaller than entrained flow gasifiers.

5.1.3 Chemical Pathway

7 projects apply chemical pathways to produce advanced biofuels. Neste Oil (in 4 facilities worldwide) and Dynamic Fuels apply hydrotreatment of oils. Alipha Jet applies catalytic decarboxylation of crude fats. Both technologies produce biofuels of superior quality that can be tailored to meet aviation fuel requirements. BioMCN produces methanol from glycerine residue from biodiesel plants. Methanol can subsequently be converted into various fuels and chemicals.

While the resulting fuels are of high quality, the drawback of these technologies are that they rely on potentially food feedstock such as oils and fats.

5.2 Project Status

By end of 2012 the status of 48 projects is operational, 9 projects are under construction or under commissioning, and 14 projects are planned.

Operational facilities are comparatively small except for chemical facilities. The largest chemical facilities are Neste Oil´s facilities in Rotterdam and Singapore; the largest biochemical facility is that of Borregaard Industries, and the largest thermochemical facility is that of Tembec Chemical Group, both of which produce app. 15 000 t/y of ethanol from spent sulphite liquor.

Two large thermochemical projects have recently failed for economic reasons: CHORENs FT-liquids beta plant in Freiberg, Germany, with a capacity of 15 000 t/y went bankrupt while under commissioning; Range Fuels´ plant in Soperton, USA, with a capacity of 300 000 t/y of ethanol production, stopped operation shortly after its start up for economic reasons. BP Biofuels had earlier announced a large biochemical cellulosic ethanol plant for Florida, but abandoned pursuing this in 2012.

The largest facilities under construction for cellulosic ethanol production include Abengoa´s facility in Hugoton, USA (75 000 t/y), POET-DSM´s facility in Emmetsburg, USA, (75 000 t/y), Beta Renewables´ facility in Crescentino, Italy, (40 000 t/y) and INEOS Bio´s Vero Beach facility (24 000 t/y). Thermochemical facilities under construction include Enerkem´s facility in Edmonton, Canada (30 000 t/y of ethanol) and Göteborg Energi´s facility in Göteborg, Sweden (11 200 t/y SNG).

Planned projects include commercial scale facilities (for those companies that are currently building demoplants), demonstration scale facilities and a few pilot plants. All large projects are dedicated to ethanol production. Many more projects may be planned but have not yet been announced, depending on company policies and the stability and favourability of the political framework.

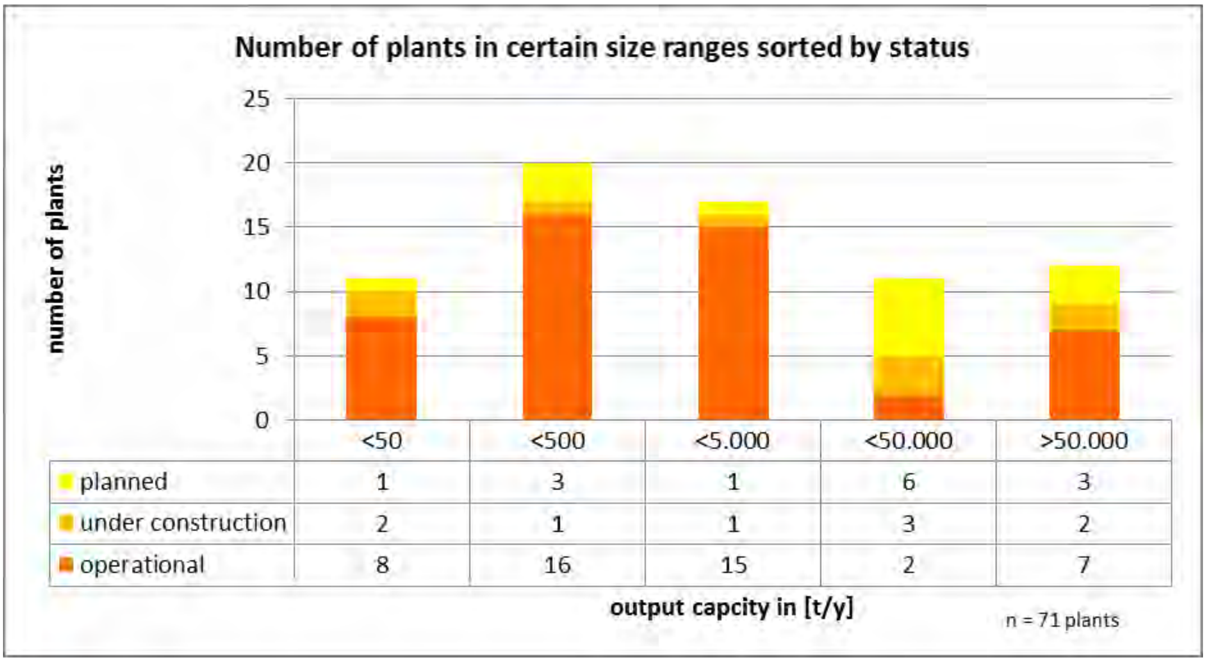


Figure 8: Diagram of projects sorted by status

5.3 Project Type

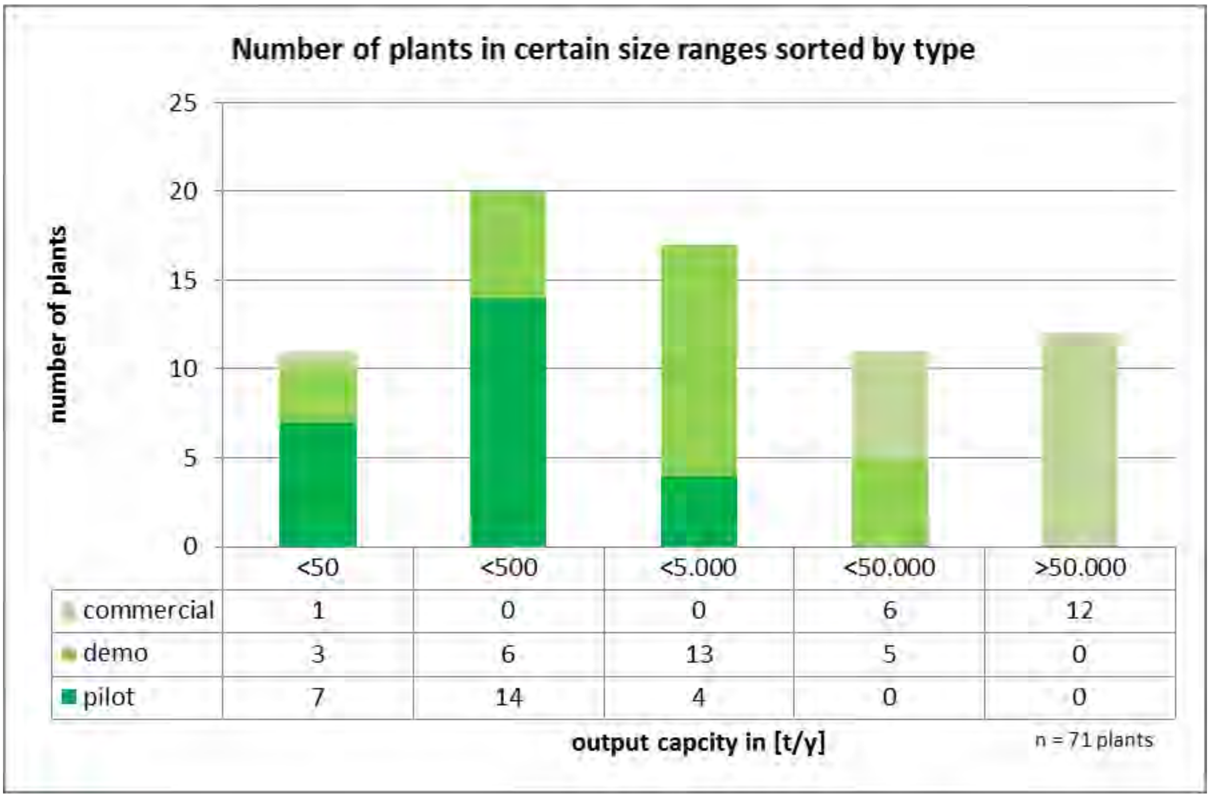


Figure 9: Diagram of projects sorted by type of facility

The graph on the previous page illustrates the number of pilot, demo and commercial scale projects.

25 production facilities are classified by the project owner to be pilot facilities, 27 are demonstration facilities, and 19 are commercial facilities. Generally, pilot facilities have rather small capacities, while most demo facilities range from 5 000 to 50 000 t/y, and commercial facilities have even larger capacities.

Several companies operate a pilot or demo facility while building a commercial facility. Examples include Abengoa, Beta Renewables, Enerkem, Fiberight and POET. The gasification technology developed by the Vienna University of Technology and several partners is being upscaled for Göteborg Energi.

5.4 Project Capacities

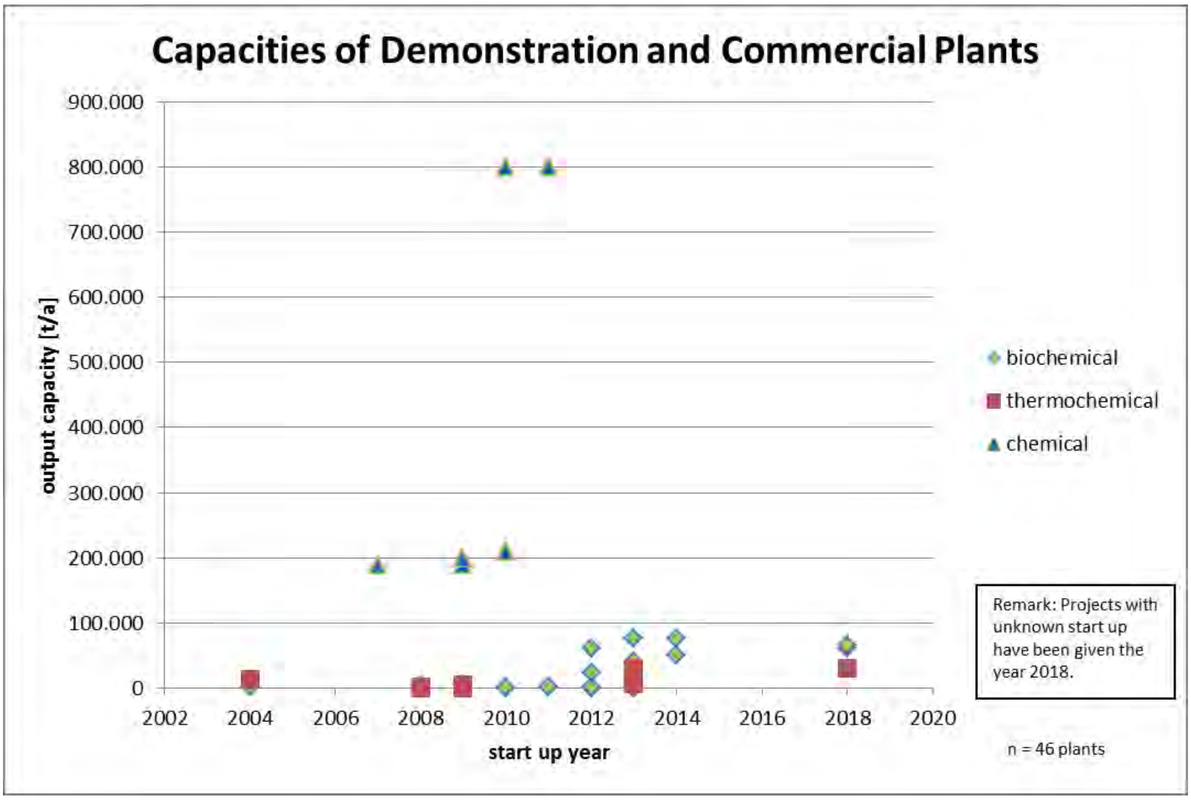


Figure 10: Diagram of project capacities (demo and commercial scale); up to 2012 facilities are operational, after 2012 under construction or planned

The capacities of the demonstration and commercial facilities sorted by technology are depicted over the timeline in the graph below. All facilities depicted up to 2012 are operational, after 2012 they are under construction or planned. Highest capacities are seen with chemical technologies (up to 800 000 t/y). Plans for thermochemical facilities of capacities above 100 000 t/y that were announced earlier have been abandoned or postponed in the meanwhile. Biochemical facilities clearly dominate in construction of further facilities with capacities of up to 100 000 t/y.

5.5 Cumulative Capacities

Summing up the production of all projects for which data was provided, the current production capacity for advanced biofuels equals 2 530 000 t/y of which the largest part (2 390 000 t/y) are produced through chemical technologies. Hydrotreatment of vegetable oils has successfully been deployed and currently contributes 2 190 000 t/y (~2,4%) to the worldwide biofuels production.

The possible development of advanced biofuel production capacities is depicted below. Capacities up to the year 2012 are already existing and operational; after 2012 the picture is based on prospects. Only capacities reported to us by the project owners are depicted. Companies that have not yet provided data are not included.

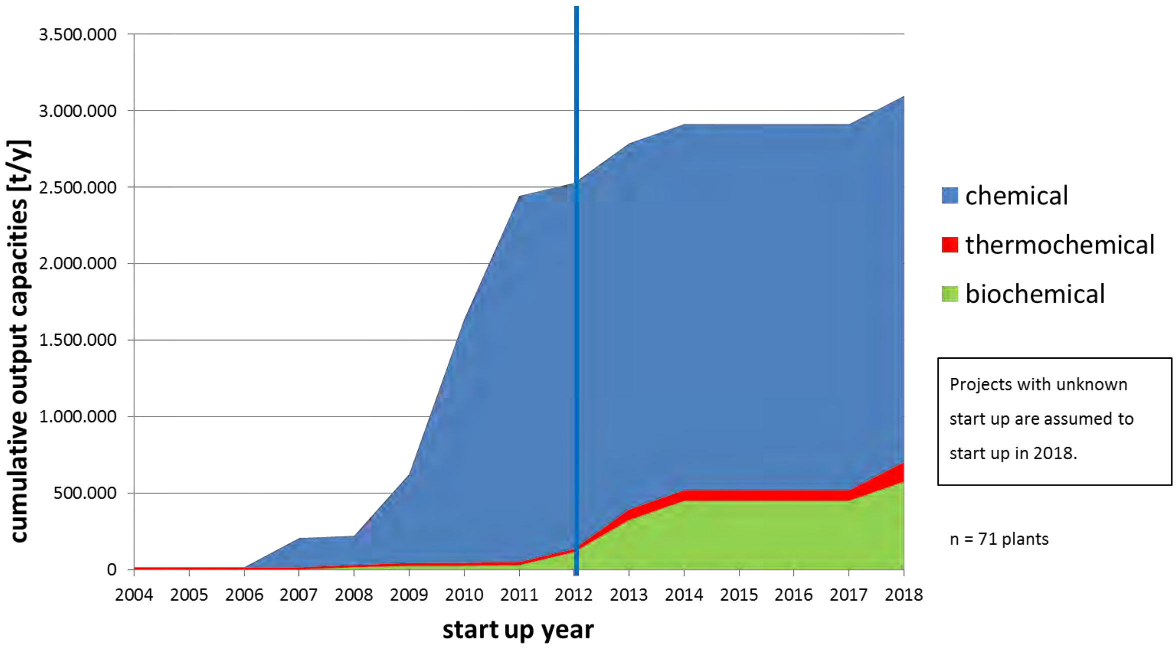


Figure 11: Diagram of cumulative capacities of projects in this overview

For easier comparison with the 2010 edition of this report, in the picture on the next page only data for projects which are based on lignocellulosic feedstock are depicted (55 projects). Moreover, recently, EU policy backs away from biofuels made from crops used for food and feed, so the share of biofuels produced from other (in general lignocellulosic) feedstock is of special interest.

Current production capacity of biofuels from lignocellulosic raw materials sums up to 137 000 t/y. While this only represents 0,15 % of the current total production of biofuels worldwide (91 300 000 t/y in 2011), it is a threefold increase as compared to the capacity calculated for 2010 in the previous edition of this report. Yet, the deployment of biofuels from lignocellulosics has not been as rapid as depicted in the 2010 report: the cumulative capacity of all projects under construction or planned in mid 2010 had summed up to 680 000 t/y for 2012. This is in line with the failure of several larger projects that could be observed in this period.

Taking into account those projects that are currently under construction as well as those that have been announced, the further development of lignocellulosic biofuels production capacities might sum up to 620 000 t/y by 2018.

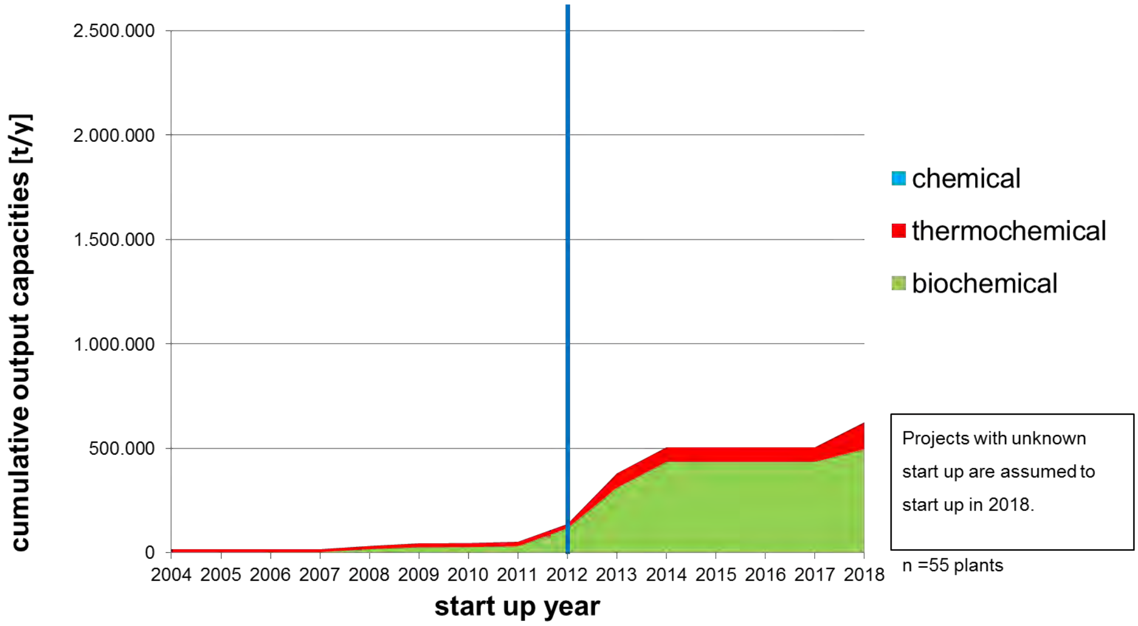


Figure 12: Diagram of cumulative capacities of projects based on lignocellulosic feedstocks

6 Detailed Descriptions

The descriptions below originate from the companies / institutions listed. Wherever possible, data has been verified by experts of IEA Bioenergy Task 39 and other biofuels experts. Yet, the level of independent verification of the data provided varies.

Descriptions are ordered alphabetically by company name.

6.1 Aalborg University Copenhagen

AALBORG UNIVERSITY
COPENHAGEN

The Section for Sustainable Biotechnology (SSB) at Aalborg University Copenhagen (AAU-Cph) is one of the five sections of the Department of Biotechnology, Chemistry and Environmental Engineering of Aalborg University. SSB's integrated research approach is combining fundamental biotechnology with bioprocess engineering. The overall aim is to develop biomass conversion systems for the sustainable production of chemicals, fuels and materials (including feed and food). Research is mainly focused on the biochemical conversion of biomass into bioenergy, biofuels and valuable by-products in biorefinery systems. SSB offers both Bachelor and Master Programmes in Sustainable Biotechnology and Ph.D. Courses in Biorefineries and Anaerobic Digestion.

SSB is involved in a number of research projects for the development of biorefinery concepts for the conversion of biomass into feed, food, fuel and chemicals. Within the biofuels area, SSB is currently leading two applied projects concerning (1) the integrated production of bioethanol and biogas from lignocellulosic biomass (BornBiofuel optimization) and (2) a new concept for increasing the biogas yield of manure-based biogas plants by integration of fiber separation, pretreatment and re-circulation (FiberMaxBiogas). Together with different project partners the improved treatment concepts will be tested in pilot-scale (BornBiofuel optimization) and demo-scale (FiberMaxBiogas), respectively.

BornBiofuel optimization

Copenhagen/Bornholm, Denmark

BornBiofuel Optimization involves the further optimization of the 2nd generation bioethanol concept behind the BornBiofuel demo-scale plant projected for the island of Bornholm by the company Biogasol. Optimization includes increasing the yield of bioethanol, biogas and hydrogen, reducing the input of energy and external enzymes, and improving the process robustness of the whole biorefinery scheme. Pilot testing will be performed on an optimized process integration including modified pretreatment and hydrolysis, on-site enzyme production, and with improved and adapted fermentation strains. New process configurations will be tested on potential biomass resources, relevant for the BornBiofuel project.

Project Owner	Aalborg University Copenhagen
Project Name	BornBiofuel optimization
Location	Copenhagen and Bornholm, Denmark
Technology	biochemical
Raw Material	lignocellulosics
Project Input	wheat straw, cocksfoot grass
Input Capacity	0.5 t/h
Product(s)	ethanol; biogas
Output Capacity	11 t/y; 40 L/d
Facility Type	Pilot
Investment	11 692 000 DKK
Project Funding	6 814 000 DKK
Status	operational
Start-up Year	2009
Contact Person	Hinrich Uellendahl, hu@bio.aau.dk, +45 9940 2585
Web	www.sustainablebiotechnology.aau.dk

Table 9: Aalborg – pilot plant in Copenhagen and Bomholm, Denmark

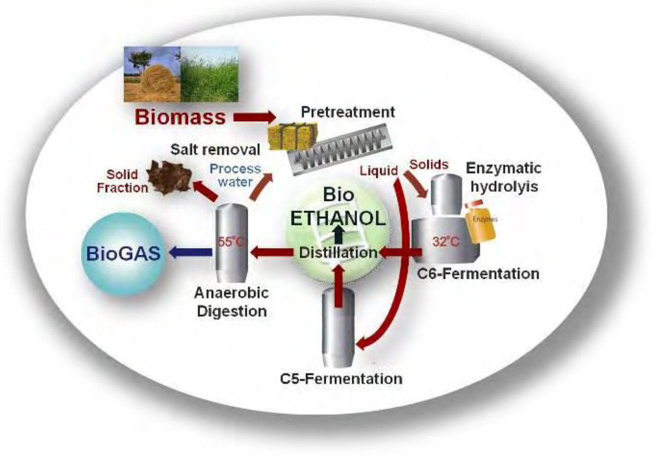


Figure 13: Aalborg – flow chart

6.2 Abengoa Bioenergía

Abengoa Bioenergía is a global biotech ethanol company, and a leader in the development of new technologies for the production of biofuels and chemical bioproducts from renewable feedstocks including lignocellulosic materials. The company's activities can be grouped under under six areas:

Procurement of raw materials (cereal grains and lignocellulosic biomass)
Bioethanol origination (from third parties)
Production (ethanol, biodiesel, DDGS)
Marketing of bioethanol, DGS, and sugar
Co-generation of electricity
New Technologies Development (advanced biofuels and chemical bioproducts)

Abengoa Bioenergía has production facilities in Europe, United States, and Brazil. The production capacities include:

Bioethanol:	782 million gallon/year
Biodiesel:	60 million gallon/year
DDGS:	1,845,000 ton/yr
Sugar:	645,000 ton/year
Glycerine:	18,500 ton/yr
Electricity:	1.236 GWh

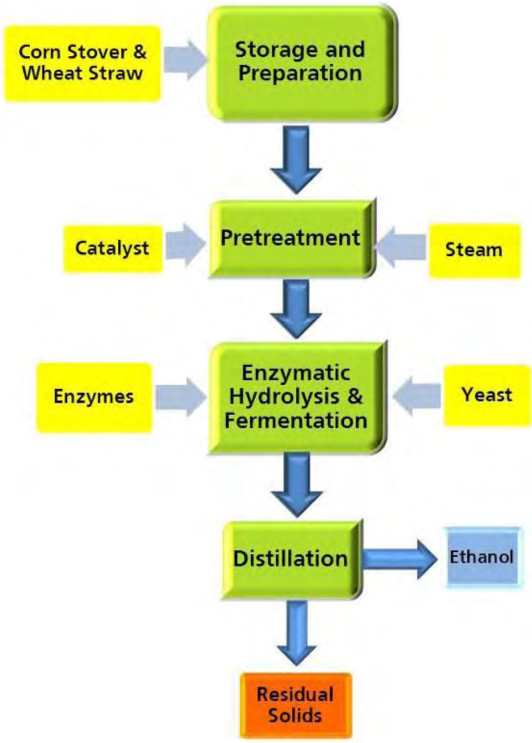


Figure 14: Abengoa – flow chart

In 2011, the revenues reached 2.225 billion €, and the EBITDA was 152 million €.

The combination of international marketing and cellulosic conversion technology capabilities of Abengoa Bioenergía, with agricultural, production and local marketing capacities gives rise to very important synergies that allow Abengoa to achieve significant growth in the global bioethanol market. Abengoa collaborates with many industrial partners, universities and research organizations to develop cost competitive technologies.

Abengoa´s first commercial cellulosic ethanol facility, located in Hugoton, KS, U.S.A., is currently under construction. The conversion process, as shown in the following simplfied block flow diagram, is based on steam explosion pretreatment followed by enzymatic cellulose hydrolysis and ethanol fermentation.

Pilot

York, Nebraska, United States

This integrated and flexible pilot plant allows scientists and engineers to scale up and integrate processes developed at bench scale. New unit operations can be tested in the plant.

Project Owner	Abengoa Bioenergy New Technologies
Project Name	pilot
Location	York, United States
Technology	biochemical
Raw Material	lignocellulosics
Project Input	corn stover
Input Capacity	330 t/y
Product(s)	ethanol
Output Capacity	75 t/y; 0.02 mmgy
Facility Type	pilot
Project Funding	35 500 000 USD
Status	operational
Start-up Year	2007
Contact Person	Quang Nguyen; qnguyen@bioenergy.abengoa.com
Web	www.abengoabioenergy.com

Table 10: Abengoa – pilot plant in York, United States

Figure 15: Abengoa – picture of pilot plant in York, United States

Demo

Babilafuente, Salamanca, Spain

This fully integrated plant which includes feedstock preparation and wastewater treatment has generated valuable operation experience and design data for the commercial plant. The plant has successfully processed corn stover and wheat straw.

Project Owner	Abengoa Bioenergy
Project Name	demo
Location	Babilafuente, Salamanca, Spain
Technology	biochemical
Raw Material	lignocellulosics
Project Input	cereal straw (mostly barley and wheat)
Input Capacity	35 000 t/y
Product(s)	ethanol
Output Capacity	4000 t/y; 5 Ml/y
Facility Type	demo
Project Funding	50 000 000 EUR
Status	operational
Start-up Year	2008
Contact Person	Pablo Gutierrez Gomez, pablo.gutierrez@bioenergy.abengoa.com
Web	www.abengoabioenergy.com

Table 11: Abengoa – demo plant in Babilafuente, Spain

Figure 16: Abengoa – picture of demo plant in Babilafuente, Spain

Abengoa Arance EC demonstration

Arance, France

This project involves a feasibility study of colocation of cellulosic ethanol production facility with an existing cereal grain ethanol plant. The study was completed.

Project Owner	Abengoa Bioenergy, S.A.
Project Name	Abengoa Arance EC demonstration
Location	Arance, France
Technology	biochemical
Raw Material	lignocellulosics
Project Input	agricultural and forest residues
Product(s)	ethanol
Output Capacity	40 000 t/y; 50 000 m3/a
Facility Type	demo
Investment	10 466 737.4 EUR
Project Funding	8 632 722 (EU funded; LED) EUR
Status	planned
Start-up Year	June 2013
Contact Person	Ricardo Arjona; ricardo.arjona@bioenergy.abengoa.com
Web	www.abengoabioenergy.com

Table 12: Abengoa – demo plant in Arance, France

Commercial

Hugoton, Kansas, United States

Abengoa's first cellulosic ethanol commercial plant. The lignin residue is combusted to generate process steam and electricity.

Project Owner	Abengoa Bioenergy Biomass of Kansas, LLC
Project Name	commercial
Location	Hugoton, United States
Technology	biochemical
Raw Material	lignocellulosics
Project Input	corn stover, wheat straw, switch grass
Input Capacity	320 000 t/y
Product(s)	ethanol; power
Output Capacity	75 000 t/y; 25 mmgy
Facility Type	commercial
Project Funding	76 000 000 USD
Status	under construction
Start-up Year	Q4 2013
Contact Person	Gerson Santos-Léon; gerson.santos@bioenergy.abengoa.com
Web	www.abengoabioenergy.com

Table 13: Abengoa – commercial plant in Hugoton, United States

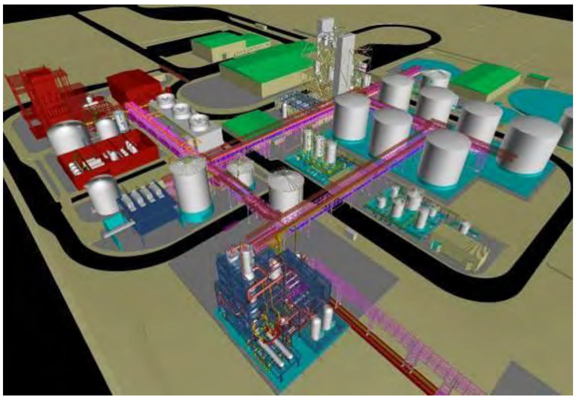


Figure 17: Abengoa - 3D model of the commercial plant in Hugoton, United States

Figure 18: Abengoa – picture of commercial plant in Hugoton, United States (June 12, 2012)

6.3 Aemetis

Pilot

Butte, United States

Technology: Ambient Temperature Starch/ Cellulose Hydrolysis (ATSCH)

Project Owner	Aemetis
Project Name	pilot
Location	Butte, United States
Technology	biochemical
Raw Material	lignocellulosics
Project Input	switchgrass, grass seed, grass straw and corn stalks
Product(s)	ethanol
Output Capacity	500 t/y; 0.16 mmgy
Facility Type	pilot
Status	operational
Start-up Year	2008
Contact Person	Andy Foster; afoster@aemetis.com
Web	www.aemetis.com

Table 14: Aemetis – pilot plant in Butte, United States

6.4 Alipha Jet

AliphaJet's proprietary catalytic deoxygenation ("decarboxylation") technology converts any renewable oils and fats (such as waste vegetable oil, tallow, algal oil, and non-food oil crops like pennycress, camelina, jatropha, and pongamia), into true "drop-in" hydrocarbon fuels including diesel (F-76), jet fuel (Jet-A, JP-5, JP-8), and high-octane gasoline. It does this by catalytically removing the oxygen from the fatty acids contained in triglyceride oils, producing hydrocarbons and glycerine as the sole products. Analysis shows that AliphaJet's decarboxylation technology will prove to be the lowest cost method of producing drop-in hydrocarbon fuels with the lowest environmental impact. AliphaJet has produced both diesel and jet fuel that meet ASTM specifications based on tests performed by an independent lab. The next step is to build a fully-integrated pilot plant with capacity of 1 ton per day of oil feedstock able to produce 80,000 gallons/year of hydrocarbon fuels.

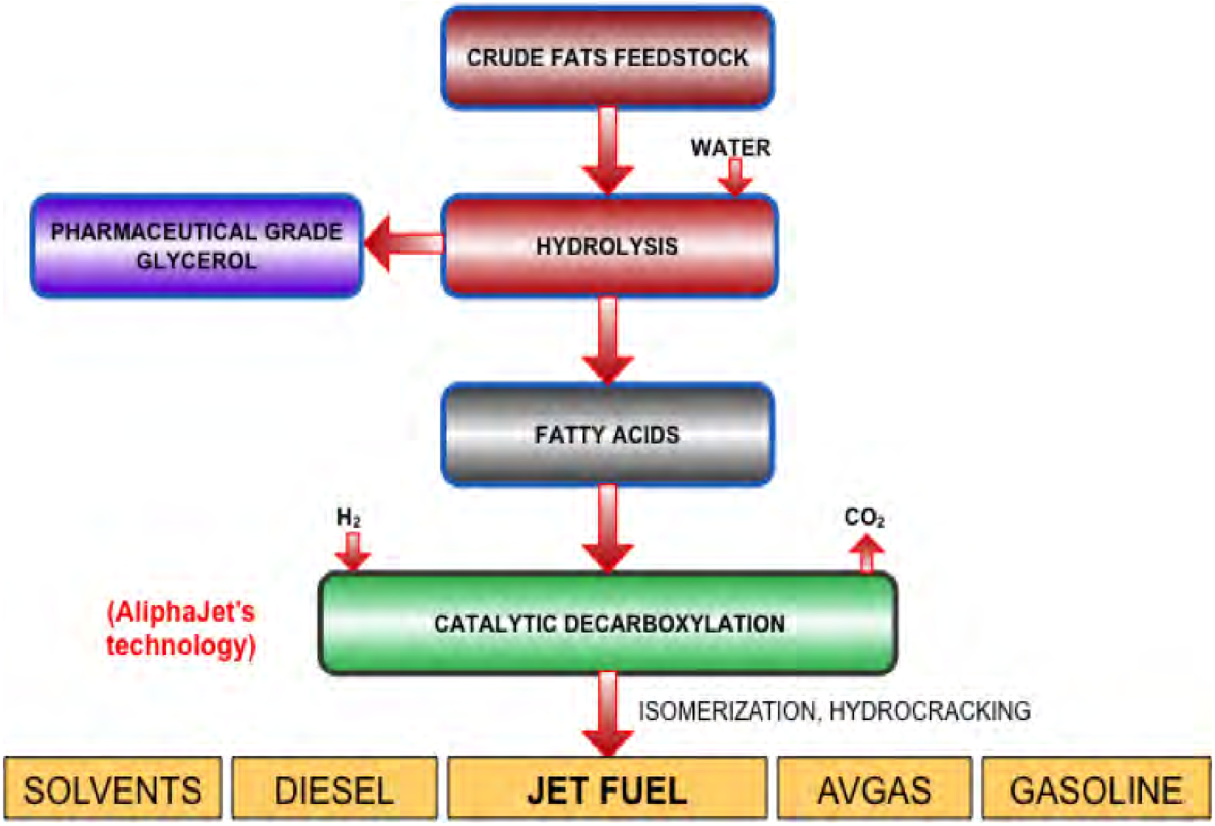


Figure 19: Alipha Jet – flow chart

AliphaJet Pilot Plant

San Francisco, United States

Project Owner	AliphaJet Inc.
Project Name	AliphaJet Pilot Plant
Location	n/a
Technology	Catalytic decarboxylation
Raw Material	Triglyceride oils
Project Input	Oils from soy, beef tallow, waste veg. oil, and oil crops such as camelina, jatropha, pennycress, and pongamia
Input Capacity	1 ton per day
Product(s)	diesel-type hydocarbons; jet fuel
Output Capacity	230 t/y; 80 000 gallons/year;
Facility Type	pilot
Project Funding	$4.5M
Status	planned
Start-up Year	2013
Contact Person	Sanjay Wagle AliphaJet Inc. 310 Green Street San Francisco, CA 94133 +1 510.517.8742 sjwagle@aliphajet.com
Web	www.aliphajet.com

Table 15: AliphaJet – pilot plant in San Francisco, United States

6.5 Amyris

Amyris Pilot & Demonstration Plant

Campinas, Brazil

Project Owner	Amyris, Inc.
Project Name	Amyris Pilot & Demonstration Plant
Location	Campinas, Brazil
Technology	biochemical
Raw Material	fermentable sugars
Project Input	sugarcane
Product(s)	diesel-type hydrocarbons
Output Capacity	n.s.
Facility Type	demo
Status	operational
Start-up Year	2009
Contact Person	Joel Velasco; info@amyris.com
Web	www.amyris.com

Table 16: Amyris – demo plant in Campinas, Brazil

Amyris USA

Emeryville, United States

Project Owner	Amyris, Inc.
Project Name	Amyris USA
Location	Emeryville, United States
Technology	biochemical
Raw Material	fermentable sugars
Project Input	sugarcane
Product(s)	diesel-type hydrocarbons
Output Capacity	n.s.
Facility Type	pilot
Status	operational
Start-up Year	2008
Contact Person	Joel Velasco; info@amyris.com
Web	www.amyris.com

Table 17: Amyris – pilot plant in Emeryville, United States

Amyris Biomin

Piracicaba, Brazil

Project Owner	Amyris, Inc.
Project Name	Amyris Biomin
Location	Piracicaba, Brazil
Technology	biochemical
Raw Material	fermentable sugars
Project Input	sugarcane
Product(s)	diesel-type hydrocarbons
Output Capacity	n.s.
Facility Type	commercial
Status	operational
Start-up Year	2010
Contact Person	Joel Velasco; info@amyris.com
Web	www.amyris.com

Table 18: Amyris – commercial plant in Pirocicaba, Brazil

Amyris Paraiso

Brotas, Brazil

Project Owner	Amyris, Inc.
Project Name	Amyris Paraiso
Location	Brotas, Brazil
Technology	biochemical
Raw Material	fermentable sugars
Project Input	sugarcane
Product(s)	diesel-type hydrocarbons
Output Capacity	n.s.
Facility Type	commercial
Status	operational
Start-up Year	2012
Contact Person	Joel Velasco; info@amyris.com
Web	www.amyris.com

Table 19: Amyris – commercial plant in Brotas, Brazil

Amyris São Martinho

Pradópolis, Brazil

Project Owner	Amyris, Inc.
Project Name	Amyris São Martinho
Location	Pradópolis, Brazil
Technology	biochemical
Raw Material	fermentable sugars
Project Input	sugarcane
Product(s)	diesel-type hydrocarbons
Output Capacity	n.s.
Facility Type	commercial
Status	planned
Start-up Year	2013
Contact Person	Joel Velasco; info@amyris.com
Web	www.amyris.com

Table 20: Amyris – commercial plant in Pradópolis, Brazil

Amyris Tate & Lyle

Decatur, United States

Project Owner	Amyris, Inc.
Project Name	Amyris Tate & Lyle
Location	Decatur, United States
Technology	biochemical
Raw Material	fermentable sugars
Project Input	corn dextrose
Product(s)	diesel-type hydrocarbons
Output Capacity	n.s.
Facility Type	commercial
Status	operational
Start-up Year	2011
Contact Person	Joel Velasco; info@amyris.com
Web	www.amyris.com

Table 21: Amyris – commercial plant in Decatur, United States

Amyris Antibioticos

Leon, Spain

Project Owner	Amyris, Inc.
Project Name	Amyris Antibioticos
Location	Leon, Spain
Technology	biochemical
Raw Material	fermentable sugars
Project Input	sugar beet; dextrose
Product(s)	diesel-type hydrocarbons
Output Capacity	n.s.
Facility Type	commercial
Status	operational
Start-up Year	2011
Contact Person	Joel Velasco; info@amyris.com
Web	www.amyris.com

Table 22: Amyris – commercial plant in Leon, Spain

6.6 Beta Renewables

Beta Renewables is the leader in making non-food cellulosic biomass practical and cost-competitive for the production of advanced biofuels and biochemicals. Beta Renewables is a unique $350 million (€250M) joint venture formed from the Chemtex division of Gruppo Mossi & Ghisolfi and TPG. The company has over 60 years of success in process development and commercializing hundreds of plants worldwide.

Beta Renewables has invested over $200 million (€140M) in the development of the PROESA™ process. PROESA takes inedible biomass, like energy crops (such as giant reed, miscanthus or switchgrass) or agricultural waste (such as sugarcane bagasse and straws) and turns them into high-quality, low-cost, fermentable C5 and C6 sugars. PROESA combines an enzymatic pretreatment process with fermentation, runs faster than other enzymatic hydrolysis approaches, is acid- and alkali-free and has minimal byproducts. Lignin may be used to generate power to run the plant.

Beta is currently building the world's first commercial-scale cellulosic ethanol facility in Crescentino, Italy, expected to start operations in the fall of 2012.

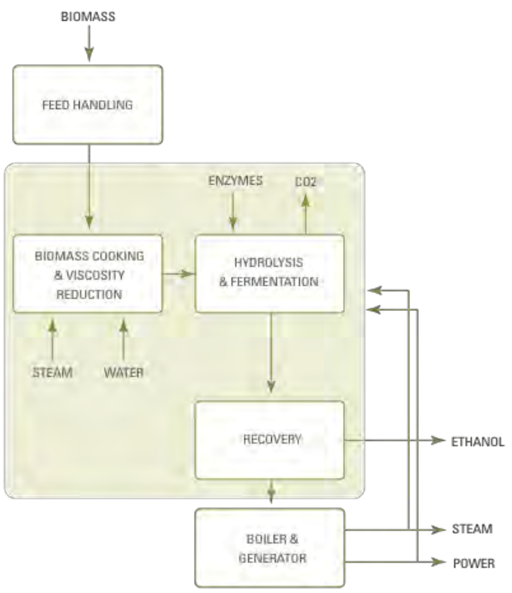


Figure 20: Beta Renewables – flow chart of PROESA technology

PROESA™ advantages

- Industrial-scale
- Sugars, 10 cents/lb (cash cost)
- Ethanol, <$1.50/gal (cash cost)
- Agronomically sustainable
- Flexible inputs and outputs
- Up to 80% reduction in greenhouse gas emissions

Beta will license PROESA as part of a complete technology package, from biomass to ethanol, along with EPC services and key equipment from Chemtex and performance guarantees. To date, GraalBio and Colbiocel have announced plans to use PROESA for cellulosic ethanol plants. Genomatica and Codexis will use PROESA for renewable fuels and chemicals from biomass.

Pilot

Rivalta Scrivia, Italy

Project Owner	Beta Renewables (joint venture, Mossi & Ghisolfi Chemtex divison, with TPG)
Project Name	Pilot
Location	Rivalta Scrivia, Italy
Technology	Biochemical
Raw Material	Lignocellulosics
Project Input	corn stover, straw, husk, energy crops (Giant Reed), woody biomass
Input Capacity	250 t/y (dry)
Product(s)	Ethanol, various chemicals
Output Capacity	50 t/y
Facility Type	Pilot
Project Funding	Self-funded
Status	Operational
Start-up Year	2009
Contact Person	Dario Giordano; dario.giordano@betarenewables.com
Web	www.betarenewables.com

Table 23: Beta Renewables – pilot plant in Rivalta Scrivia, Italy

IBP – Italian Bio Products

Crescentino (VC), Italy

The world's first commercial-scale cellulosic ethanol plant: expected to start operations, fall 2012. Uses the PROESA process from Beta Renewables.

Project Owner	Beta Renewables (joint venture, Mossi & Ghisolfi Chemtex divison, with TPG)
Project Name	IBP – Italian Bio Products
Location	Crescentino (VC), Italy
Technology	Biochemical
Raw Material	Lignocellulosics: Straw, energy crops (giant reed)
Input Capacity	270 000 t/y (dry)
Product(s)	Ethanol
Output Capacity	60 000 t/y
Facility Type	Commercial
Project Funding	Self-funded
Status	operational
Start-up Year	2012
Contact Person	Dario Giordano; dario.giordano@betarenewables.com
Web	www.betarenewables.com

Table 24: Beta Renewables – commercial plant in Crescentino, Italy

GraalBio plants

Brazil

In May 2012, GraalBio announced plans to build at least five commercial-scale cellulosic ethanol plants in Brazil using Beta Renewable's PROESA process and Chemtex services.

Project Owner	GraalBio
Location	Brazil
Technology	Biochemical
Raw Material	Sugarcane bagasse and straw
Product(s)	ethanol
Output Capacity	65 000 t/y (first plant)
Facility Type	Commercial
Status	Planned
Start-up Year	2013 (first plant)
Contact Person	Dario Giordano; dario.giordano@betarenewables.com
Web	www.betarenewables.com

Table 25: GraalBio – commercial plant example in Brazil

6.7 BioGasol

BioGasol ApS is a Danish biotechnology company founded in January 2006 as a spinout from the Technical University of Denmark, DTU. Among other biological renewable energy technologies, the company develops, manufactures and licenses pretreatment solutions – the Carbofrac™ series - now at a commercial stage. The Carbofrac™ process is based upon extensive research and development work at DTU since 1994. BioGasols C5 fermentation development activities have led to the proprietary high-yield pentose/hexose co-fermentation technology Pentoferm™ utilizing the unique Petocrobe™ thermophilic microorganism in a continuous process. Biogasol has just over 30 employees and has since 2006 demonstrated its equipment in a series of successfully up-scaled pilot and demo plants.

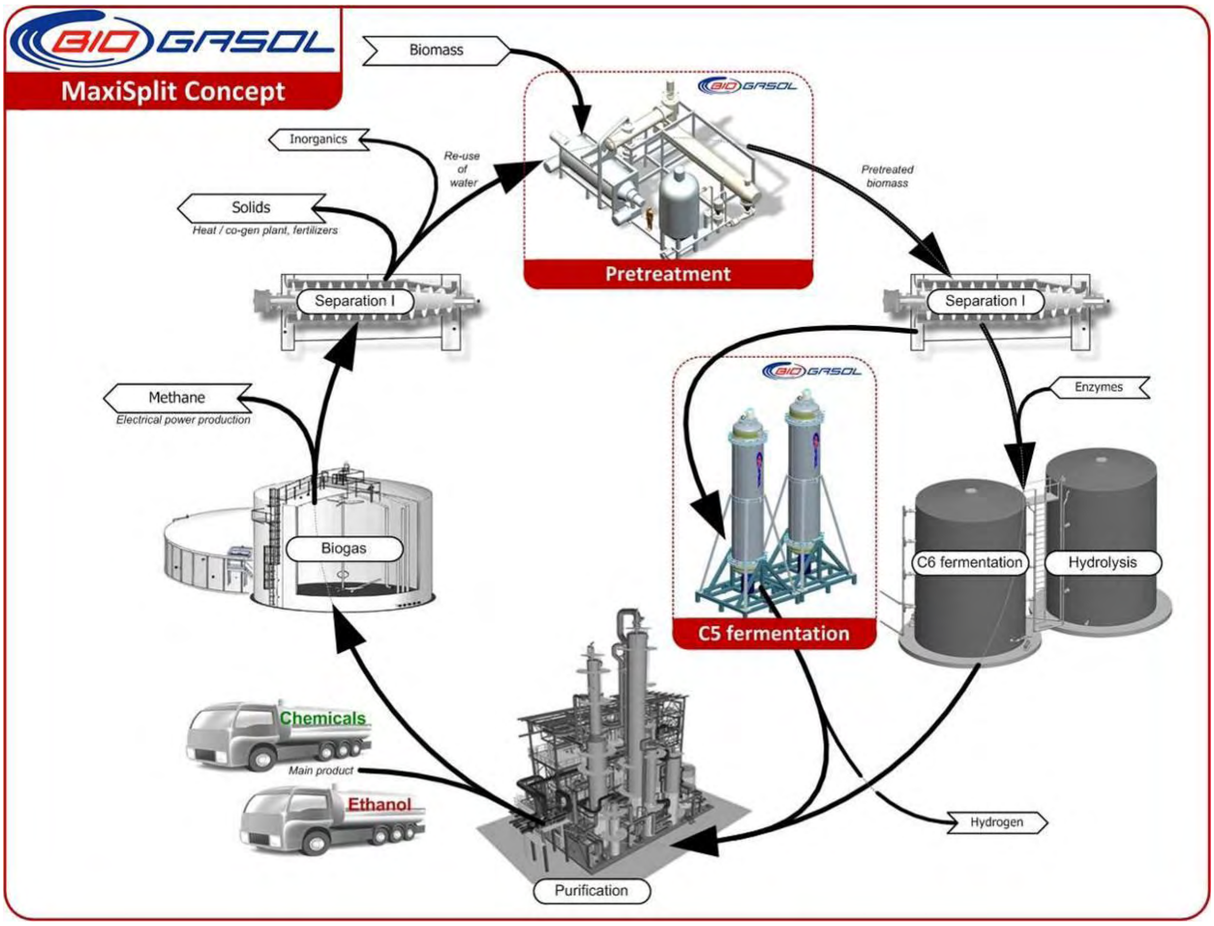


Figure 21: BioGasol – MaxiSplit Concept

BornBioFuel 1

Ballerup, Denmark

The project ended in 2010 and during the course of the project the two core technologies were developed at various scale. The Pretreatment technology was developed and materialised as a 50 kg/h pilot pretreatment and a 1 t/h demonstration unit respectively, both based on the continuous Carbofrac™ concept. The C5 fermentation was demonstrated using the Pentoferm™ organism at 250L and 2.5m³ active reactor volume.

Project Owner	BioGasol
Project Name	BornBioFuel 1
Location	Ballerup, Denmark
Technology	biochemical
Raw Material	lignocellulosics
Project Input	flexible
Input Capacity	50kg/h + 1t/h
Product(s)	Pretreated biomass, Xylose fermentation to ethanol
Output Capacity	n.a.
Facility Type	Pilot / technology demonstrator
Investment	57 000 000 DKK
Project Funding	27.500.000 DKK
Status	idle
Start-up Year	2008
Contact Person	Rune Skovgaard-Petersen; rsp@biogasol.com
Web	www.biogasol.com

Table 26: BioGasol – pilot plant in Ballerup, Denmark

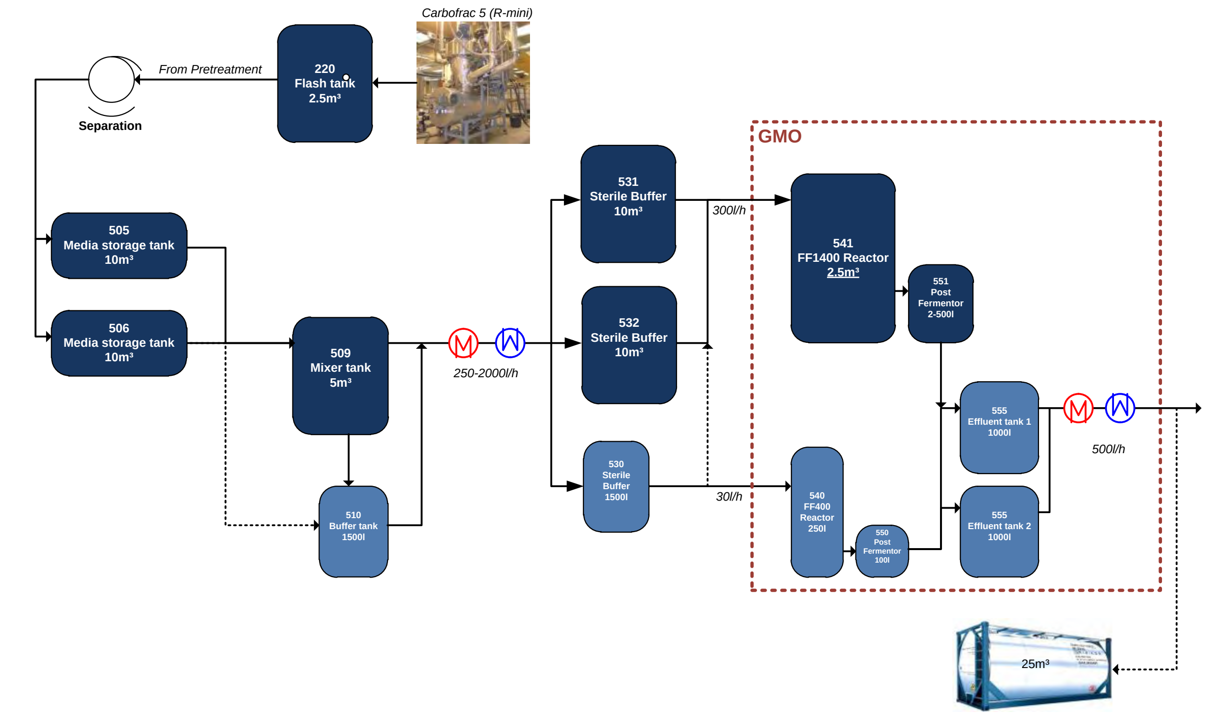


Figure 22: BioGasol – flow chart

Figure 23: BioGasol – picture of the Carbofrac™ 100 pretreatment technology demonstrator (1 t/h)

BornBioFuel 2

Aakirkeby, Bornholm, Denmark

The project is an extension of BornBioFuel 1 with the primary objective to establish a fully integrated biomass-to-ethanol demonstration plant, based on BioGasols process concept and core technologies; pretreatment and C5 fermentation.

The first phase is to design, manufacture, install and operate a 4t/h pretreatment unit based on the Carbofrac™ concept. Second phase includes installation and operation of fermentation reactors including the Pentoferm™ and distillation capability.

Project Owner	BioGasol
Project Name	BornBioFuel 2
Location	Aakirkeby, Bornholm, Denmark
Technology	biochemical
Raw Material	lignocellulosics
Project Input	straw, various grasses, garden waste
Input Capacity	2.5 t/h
Product(s)	ethanol; biogas; lignin; hydrogen
Output Capacity	4000 t/y; 5 Ml/y
Facility Type	demo
Investment	27 500 000 EUR
Project Funding	10 400 000 EUR
Status	planned
Start-up Year	2013 (Phase 1), 2014 (Phase 2)
Contact Person	Rune Skovgaard-Petersen; rsp@biogasol.com
Web	www.biogasol.com

Table 27: BioGasol – demo plant in Aakirkeby, Denmark

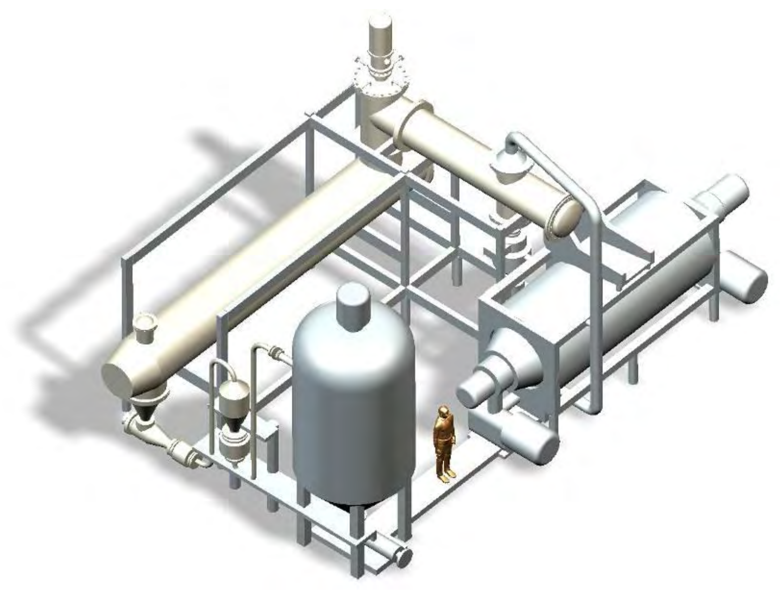


Figure 24: BioGasol – 3D model of the Carbofrac™ 400 Demonstration pretreatment unit

6.8 Biomassekraftwerk Güssing

SNG demo

Güssing, Austria

After lab testing in a scale of 10 kW during the last few years, the pilot and demonstration unit (PDU) with an output of 1 MW of SNG was inaugurated in June 2009. The plant uses a side stream of the existing Güssing gasifier. The syngas is further purifed before entering the catalysis reactor, where the conversion to methane takes place.

The plant has been designed to work in a fairly wide pressure (1-10 bar) and temperature range (300-360°C) in order to optimize the efficiency of the system. SNG upgrading downstream of the reactor is focussed at reaching H-Gas quality in order to meet the feed in conditions for natural gas pipelines. Achieved performance of the plant is above expectation and the CNG filling station has been supplied with high quality H-gas. CNG cars have been run successfully with the gas produced.

The technology was developed in cooperation with Vienna University of Technology. The former project owner was CTU - Conzepte Technik Umwelt AG. The facility has recently been taken over by Biomassekraftwerk Güssing.

Project Owner	Biomassekraftwerk Güssing
Project Name	SNG demo
Location	Güssing, Austria
Technology	thermochemical
Raw Material	lignocellulosics; syngas from gasifier
Input	350 Nm3/h
Product	SNG;
Output Capacity	576 t/y; 100 Nm3/h
Facility Type	demo
Partners	Vienna University of Technology, Austria; Paul Scherrer Institute, Switzerland; Repotec, Austria
Status	operational
Start-up Year	2008
Contact Person	Reinhard Koch, r.koch@eee-info.net
Web	www.eee-info.net

Table 28: Biomassekraftwerk Güssing – demo plant in Güssing, Austria

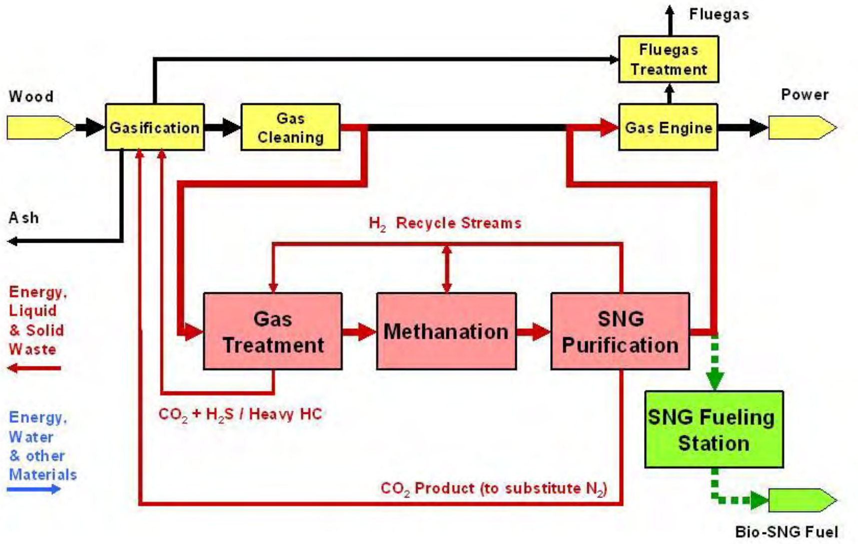


Figure 25: Biomassekraftwerk Güssing – flow chart

Figure 26: Biomassekraftwerk Güssing – picture of demo plant in Güssing, Austria

6.9 BioMCN

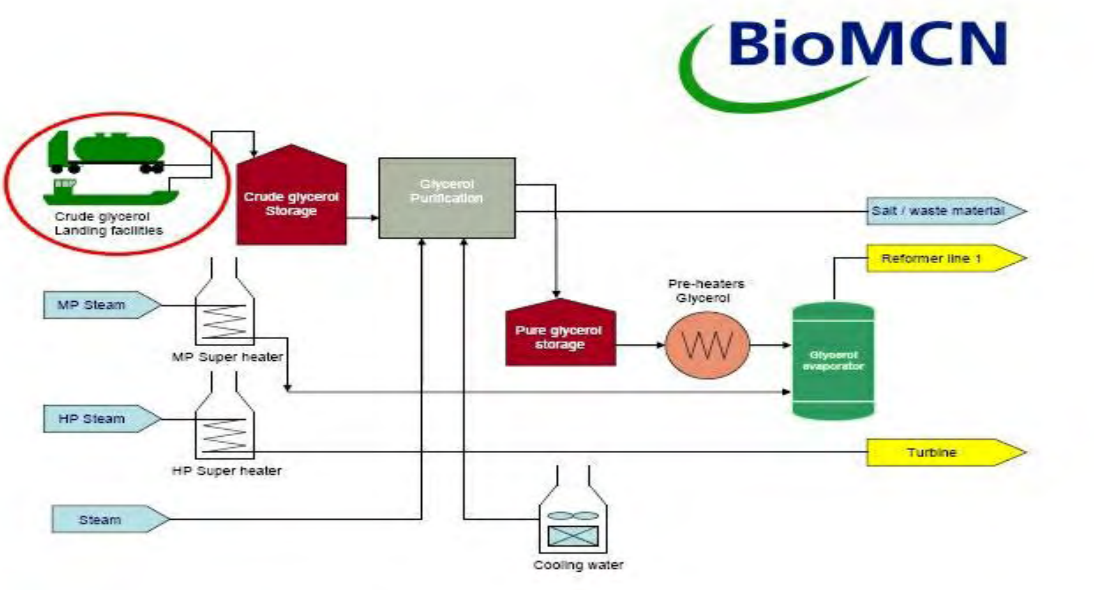


Figure 27: BioMCN – flow chart

BioMCN commercial

Farmsum, Netherlands

Project Owner	BioMCN
Project Name	BioMCN commercial
Location	Farmsum, Netherlands
Technology	chemical
Raw Material	glycerine
Project Input	crude glycerine, others
Product(s)	methanol
Output Capacity	200 000 t/y
Facility Type	commercial
Status	operational
Start-up Year	2009
Contact Person	info@biomcn.eu
Web	www.biomcn.eu

Table 29: BioMCN – commercial plant in Farmsum, Netherlands

Figure 28: BioMCN – picture of commercial plant in Farmsum, Netherlands

6.10 Blue Sugars Corporation (formerly KL Energy)

Rapid City – SD and Upton - WY, United States
São Paulo – SP, Brazil

Converting sugarcane bagasse into lignin

Blue Sugars is now commercializing its process technology to companies in the global sugarcane industry. In April 2012, Blue Sugars licensed its technology to Petrobras SA, Brazil's largest company and one of the world's ten largest companies by market capitalization, for exclusive use in Petrobras sugarcane mills.

- Blue Sugars offers the following products to the market:
- Project development
- EPC select services and turnkey solutions
- Technology license
- Structured financing including co-investments
- Start-up and operating management

Strategic partner Petrobras

Since August 2010, Blue Sugars has developed its technology in partnership with Petrobras for the use of sugarcane bagasse feedstock in commercial plants embedded in Petrobras' sugarcane assets. In April 2012, Blue Sugars licensed the technology to Petrobras for the deployment in all of Petrobras sugarcane mills.

Petrobras announced the construction and start-up of its first commercial cellulosic ethanol plant for the year 2015. Petrobras is a major integrated oil, gas, and energy company operating in the following segments of the industry: exploration and production, downstream, marketing, transportation and petrochemicals, distribution, natural gas, energy and biofuels. http://www.petrobras.com.br

Process technology

Blue Sugars has developed a continuous process technology consisting of:

- Biomass handling
- Biomass low acid impregnation
- Thermal-mechanical pre-treatment
- Enzymatic hydrolysis
- Solids separation
- Co-fermentation of C5 and C6 sugars
- Yeast propagation
- Distillation and evaporation
- Dehydration

Blue Sugars' process technology is robust and adjustable to the feedstock and industrial requirements of Blue Sugars' partners.

Blue Sugars

Demonstration plant

Project Owner	Blue Sugars Corporation (formerly KL Energy)
Project Name	Blue Sugars
Location	Upton, United States
Technology	Biochemical
Raw Material	Lignocellulosic biomass
Project Input	Sugarcane bagasse and other biomass
Input Capacity	1.0 – 2.0 BDMT of biomass/ hour
Product(s)	Ethanol; lignin
Output Capacity	4500 t/y
Facility Type	Demonstration plant
Investment	Confidential
Project Funding	Petrobras, other industrial partners and investors
Status	Operational
Start-up Year	2008
Contact Person	Peter Gross; pg@bluesugars.com
Web	www.bluesugars.com

Table 30: Blue Sugars Corporation – demo plant in Upton, United States

Since 2009, Blue Sugars has been operating its demonstration plant in Upton – WY. The plant allows for the processing of various types of biomass feedstock at a capacity of 1.0 – 2.0 dry tons/ hour. This capacity allows for safe scale-up to commercial plants at industry typical factors of 10-15.

The plant is equipped with the following capabilities:

- Biomass storage, handling and preparation
- Biomass low acid impregnation
- Biomass thermal-mechanical pre-treatment
- Enzymatic multiple-stage hydrolysis
- Enzyme recycle
- Solid separation
- On-site enzyme production
- Clear mash and mash co-fermentation of C5 and C6 sugars
- Yeast propagation
- Distillation and evaporation
- Dehydration
- Ethanol storage

Environmental Health & Safety standards, automation and instrumentation all meet the high requirements of Blue Sugars' petrochemical partners. The plant allows for remote live-stream data sharing with the development partners.

Blue Sugars' demonstration plant is primarily designed for the validation of customized process designs and equipment and other test programs. The plant is highly adjustable to new feedstocks and process changes.

But more than being a mere demonstration plant, it allows for industrial scale production of ethanol.

Blue Sugars processes several hundred dry tons of biomass feedstock in each of its industrial validation campaigns.

Blue Sugars produces fuel spec ethanol eligible for RINs. The ethanol is predominantly shipped to Blue Sugars' partners. The lignin by-product is used for sampling and development of value-added applications.

Figure 29: Blue Sugars Corporations – picture of demo plant in Upton, United States

Figure 30: Blue Sugars Corporation – picture of demonstration of the ethanol fleet at the Rio+20 event in 2012

6.11 Borregaard

Borregaard owns and operates the world's most advanced biorefinery. By using natural, sustainable raw materials, the company produces advanced and environmentally friendly bio chemicals, biomaterials and bioethanol that can replace oil-based products. The company has developed a unique process to produce bioethanol and lignin speciality chemicals from bagasse and other biomasses, and is currently scaling up the process in a dedicated demonstration facility

In their Sarpsborg Biorefinery, spruce chips is treated with acidic calcium bisulfite cooking liquor. Hemicellulose is hydrolyzed to various sugars during the cooking process. After concentration of the SSL, the sugars are fermented and ethanol is distilled off in several steps. A part of the 96% ethanol is dehydrated to get absolute ethanol.

Figure 31: Borregaard – bird view of demo plant in Sarpsborg, Norway

BALI Biorefinery Demonstration Plant

Sarpsborg, Norway

Project Owner	Borregaard AS
Project Name	BALI Biorefinery Demo
Location	Sarpsborg, Norway
Technology	Chemical/biochemical
Raw Material	lignocellulosics
Project Input	Feedstock agnostic process: sugarcane bagasse, straw, wood, energy crops, other lignocellulosics
Input Capacity	1 t dry substance/day
Product(s)	ethanol; lignin; various chemicals
Output Capacity	110 t/y of ethanol or 220 t/y C5/C6 sugars and 110 t/y lignin specialty chemicals
Facility Type	demo
Investment	16 000 000 EUR
Project Funding	7 000 000 EUR
Status	operational
Start-up Year	2012
Contact Person	Gisle Lohre Johansen, gisle.l.johansen@borregaard.com
Web	www.borregaard.com

Table 31: Borregaard – demo plant in Sarpsborg, Norway

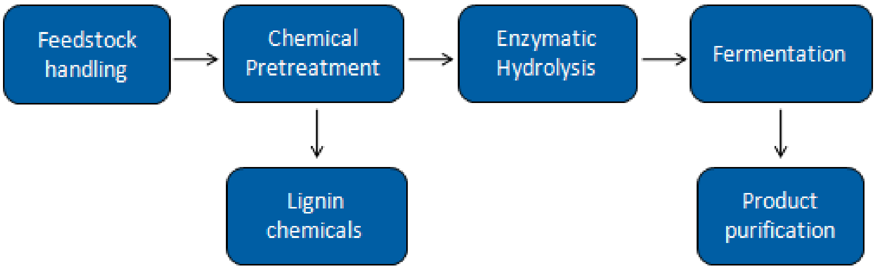


Figure 32: Borregaard – flow chart of demo plant in Sarpsborg, Norway

Figure 33: Borregard – picture of demo plant in Sarpsborg, Norway

ChemCell Ethanol Production Plant

Sarpsborg, Norway

Project Owner	Borregaard AS
Project Name	ChemCell Ethanol
Location	Sarpsborg, Norway
Technology	Chemical/biochemical
Raw Material	Lignocellulosics (Norwegian spruce)
Project Input	sulfite spent liquor (SSL, 33% dry content) from spruce wood pulping
Input Capacity	400 000 t DS (spruce)/a
Product(s)	ethanol
Output Capacity	15 800 t/y; 20 Ml/y
Facility Type	commercial
Status	operational
Start-up Year	1938
Contact Person	Gisle Lohre Johansen, Senior Vice President NBD and R&D, gisle.l.johansen@borregaard.com
Web	www.borregaard.com

Table 32: Borregaard – commercial plant in Sarpsborg, Norway

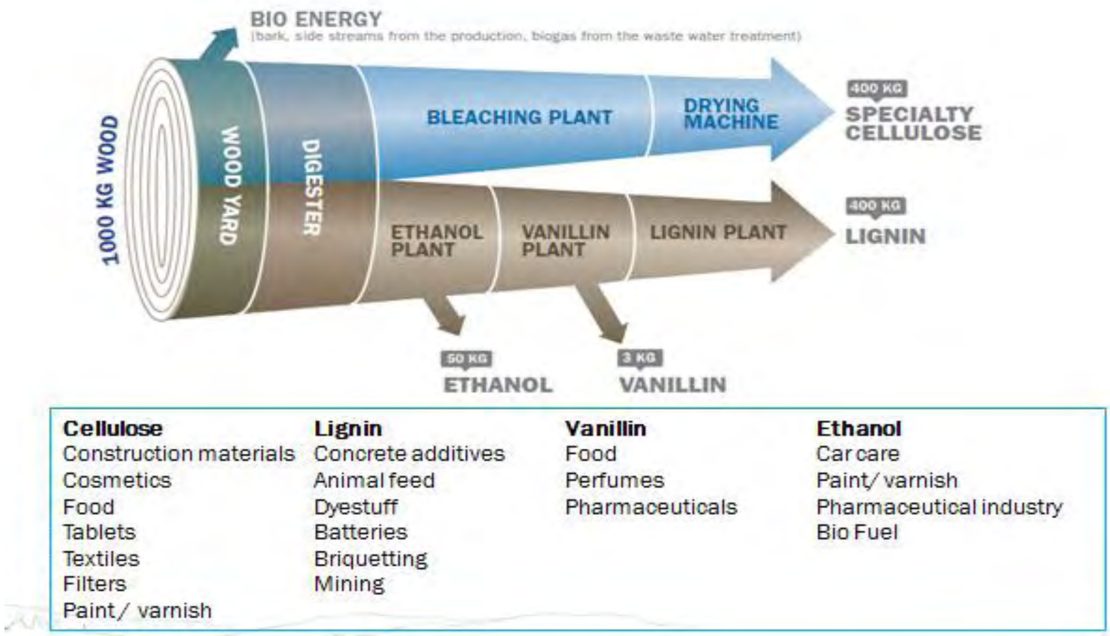


Figure 34: Borregard – chart of products

6.12 BP Biofuels

BP is committed to building a large-scale biofuels production business based on the conversion of the sugars in cellulosic biomass using proprietary technologies. BP will use sustainable low-cost feedstocks, including 'for-purpose' energy grasses such as energy cane and other similar grasses. Today in the US, BP has biofuels research and development activities and a cellulosic demonstration facility. BP has already begun to invest in its first cellulosic operational facility.

A significant strand of the company's strategy is building an industry-leading cellulosic ethanol business in the US including the development of proprietary biomass-to-ethanol conversion technology, a world class Global Technology Center and a large scale biofuels demonstration facility necessary to advance the company's cellulosic biofuels strategy. This capability will initially be focused on supporting BP's strategic goal to build its US cellulosic ethanol business, and will enable BP to integrate other proprietary biofuel technologies through R&D and scale-up in the future.

BP is one of very few global biofuels companies with a fully integrated end-to-end capability, from bioscience and R&D through capital project commercialization to finished fuel blending and distribution.

Jennings Demonstration Facility

Jennings, United States

Project Owner	BP Biofuels
Project Name	Jennings Demonstration Facility
Location	Jennings, United States
Technology	biochemical
Raw Material	lignocellulosics
Project Input	dedicated energy crops
Product(s)	ethanol
Output Capacity	4200 t/y; 1.4 mmgy
Facility Type	demo
Investment	79 000 000 USD
Status	operational
Start-up Year	2009
Contact Person	BP Biofuels Communications; BPBIOFUELS@uk.bp.com
Web	www.bp.com/biofuels

Table 33: BP Biofuels – demo plant in Jennings, United States

6.13 Chempolis

Chempolis core products are the two patented biorefining technologies:

1) formicobio for the production of cellulosic ethanol and biochemicals from non-food biomasses,

2) formicofib for the production of papermaking fibers (i.e. pulp) and biochemicals from non-wood biomasses.

These two technologies share a common technology platform that enables selective fractionation of various biomasses with a novel biosolvent, full recovery of biosolvent and co-production of biochemicals. Chempolis technologies enable highly profitable and environmentally sustainable biorefining deriving from higher revenues and reduced operating costs while CO2 emissions and other pollution to atmosphere and waterways can be eliminated practically completely.

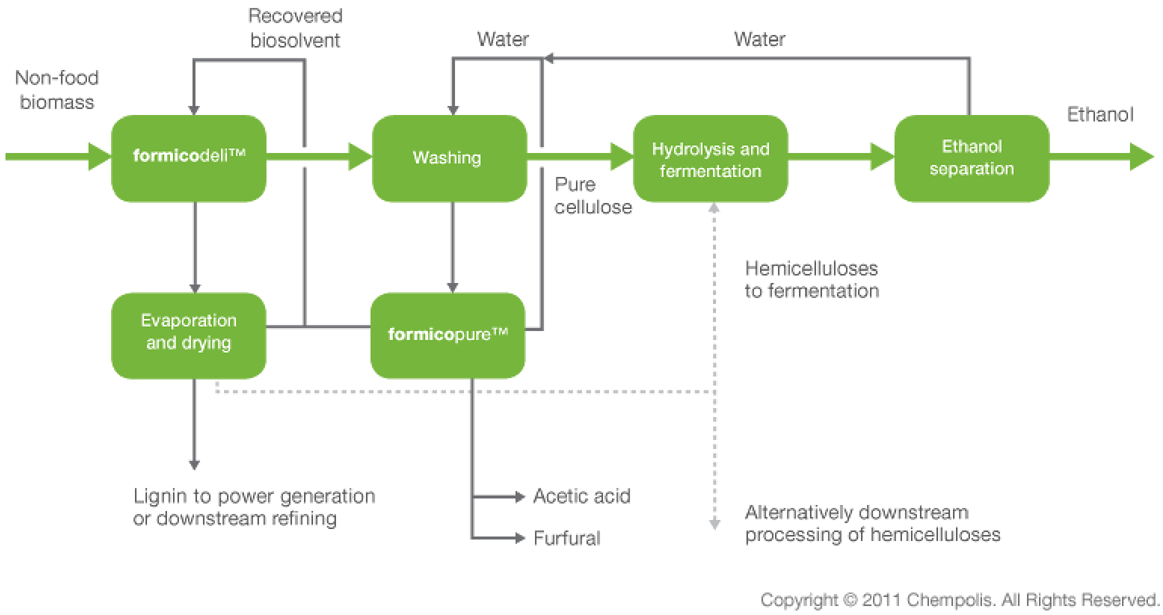


Figure 35: Chempolis – flow chart

Chempolis Biorefining Plant

Oulu, Finland

Project Owner	Chempolis Ltd.
Project Name	Chempolis Biorefining Plant
Location	Oulu, Finland
Technology	biochemical
Raw Material	lignocellulosics
Project Input	non-wood and non-food lignocellulosic biomass such as straw, reed, empty fruit bunch, bagasse, corn stalks, as well as wood residues
Input Capacity	25 000 t/y
Product(s)	ethanol; various chemicals
Output Capacity	5000 t/y
Facility Type	demo
Investment	20 000 000 EUR
Status	operational
Start-up Year	2008
Contact Person	Dr. Juha Anttila, phone: +358 10 387 6666
Web	www.chempolis.com

Table 34: Chempolis – demo plant in Oulu, Finland

Figure 36: Chempolis – picture of demo plant in Oulu, Finland

6.14 Chemrec

CHEMREC

Chemrec is a technology provider in the field of gasification. Chemrec specializes in the gasification of black liquor, a liquid and very reactive biomass feedstock that is available in large quantities as a by-product from the wood pulp industry. Chemrec provides technology licenses, key equipment and services for black liquor gasification included in biofuels and combined-cycle power plants. The technology provides advantages in terms of very high overall energy conversion efficiency and reduced investment costs. The thermochemical process applied provides a high product flexibility including a range of biofuels and bio-chemicals.

In industrial inplementation the recovery boiler in the pulp mill is replaced or supplemented by a gasification-based biofuels plant with simultaneous recovery of pulp mill cooking chemicals.

The BioDME pilot is an integrated part of heavy DME fuelled vehicle fleet trials.

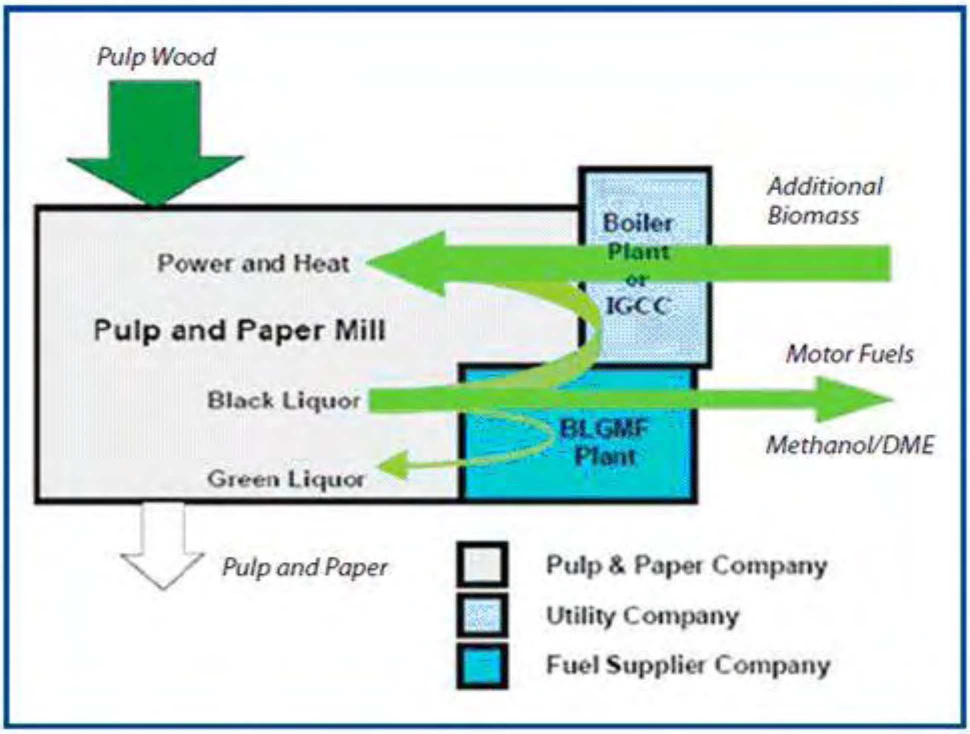


Figure 37: Chemrec – flow chart

BioDME

Pitea, Sweden

The BioDME project is a pan-European collaboration where the role of Chemrec has been to build and now operate the BioDME production plant. The product from this plant is used in a fleet test with DME-fuelled heavy Volvo trucks.

Project Owner	Chemrec AB
Project Name	BioDME
Location	Pitea, Sweden
Technology	thermochemical
Raw Material	lignocellulosics
Project Input	Black liquor gasification
Input Capacity	20 t/d
Product(s)	DME
Output Capacity	1800 t/y
Facility Type	pilot
Investment	28 500 000 EUR (Total BioDME propject)
Status	operational
Start-up Year	2011
Contact Person	Patrik Lownertz; patrik.lownertz@chemrec.se
Web	www.chemrec.se

Table 35: Chemrec – pilot plant in Pitea, Sweden

Figure 38: Chemrec – picture of DME plant with DME-fuelled log truck

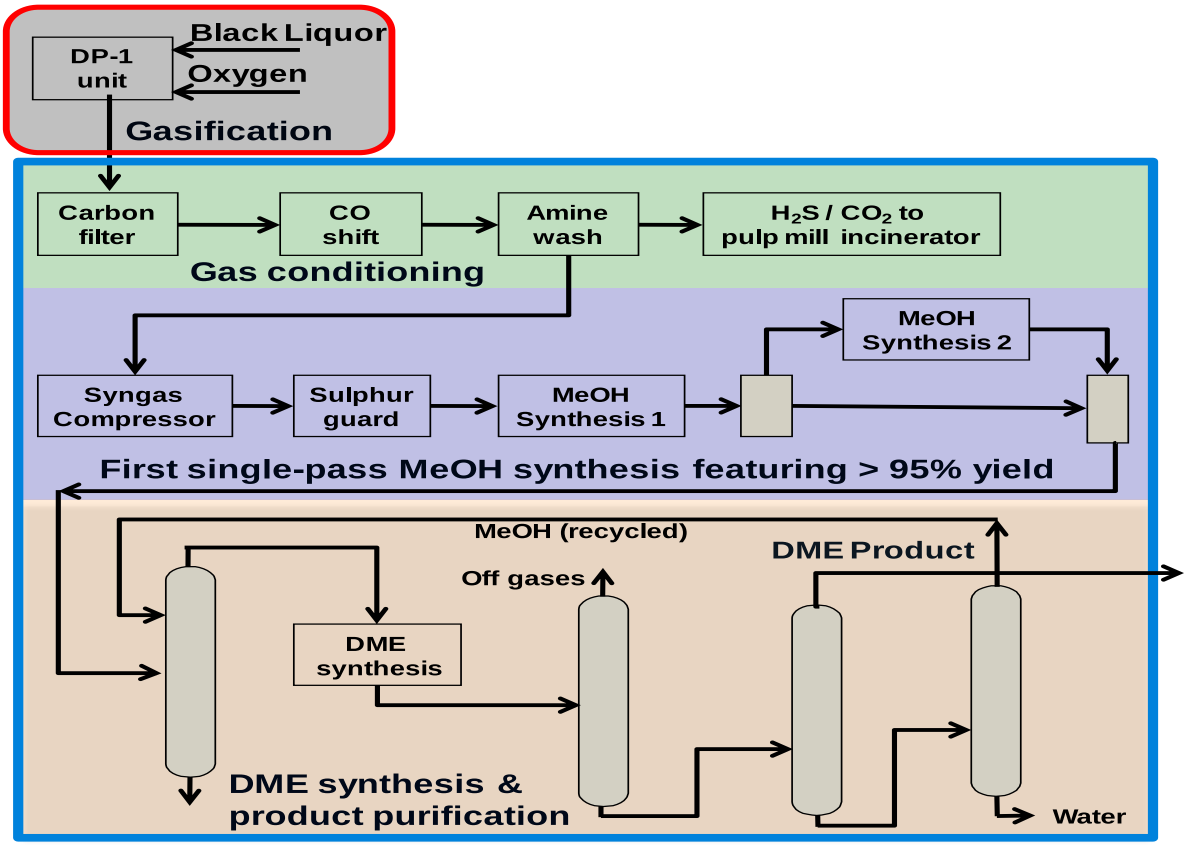
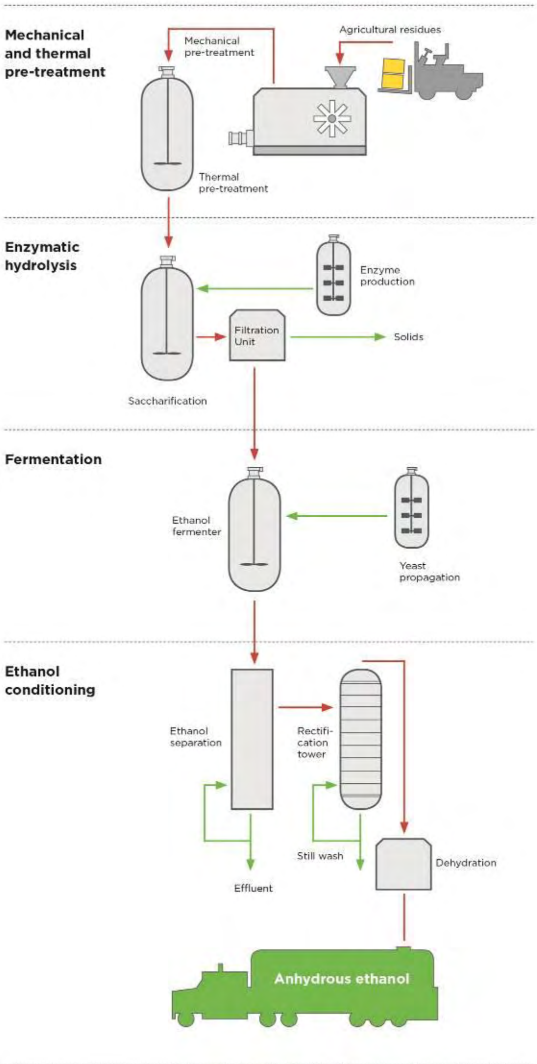


Figure 39: Chemrec – flow chart of DP-1 gasifier and DME biofuels synthesis plant

6.15 Clariant

CLARIANT

As one of the world's leading specialty chemical companies, Clariant contributes to value creation with innovative and sustainable solutions for customers from many industries. The portfolio is designed to meet very specific needs with as much precision as possible. At the same time, Clariant's research and development is focused on addressing the key trends of our time. These include energy efficiency, renewable raw materials, emission-free mobility, and conserving finite resources. The business units are divided into six market segments: Consumer Care, Industrial Applications, Plastics & Coatings, Energy, Resources, and Biotechnology.



In the financial year 2011, Clariant produced a turnover of CHF 7.4 billion. Clariant is represented by more than 100 Group companies and employs more than 22,000 people globally. Clariant focuses on creating value by investing in future profitable and sustainable growth, which is based on four strategic pillars: Improving profitability, innovation as well as research and development, dynamic growth in emerging markets, and optimizing the portfolio through complementary acquisitions or divestments.

Biotechnology and sunliquid®

Clariant's Biotech & Renewables Center (BRC) revolves entirely around industrial biotechnology. Focus is on progress and innovation based on the sustainable use of renewable resources. Thus, the BRC creates solutions for biocatalysis and biorefining. The innovative focus is on energy and resource-efficient development and production of bio-based chemicals and biofuels.

Clariant has developed the sunliquid® process for the conversion of lignocellulose to cellulosic ethanol, using its expertise in strain development and optimization, biocatalysis and bioprocessing, and applying its fully automated ultra-high throughput screening method as well as its know-how in downstream processing and process design.

Clariant's sunliquid® technology offers an efficient and economic process for the production of cellulosic ethanol. It overcomes the main challenges of competitive conversion of lignocellulosic feedstock into cellulosic sugars for fermentation to cellulosic ethanol. First, the pretreated feedstock undergoes efficient hydrolysis. The feedstock and process specific enzymes used in this step are produced process-integrated, minimizing enzyme production costs. Hydrolysis is followed by simultaneous C5 and C6 fermentation, resulting in a 50% increase in ethanol output and an energy saving ethanol separation. Thus, a high process yield of 20-25% can be achieved and cellulosic ethanol production becomes competitive to first generation ethanol. The process itself is energy self-sufficient, yielding cellulosic ethanol with about 95% of CO2 emission reductions. However, the process is flexible for use of different feedstock and different production plant concepts.

Key facts of the process:

- Highly efficient: 4-5 tons of lignocellulosic material to 1 ton of cellulosic ethanol
- Patented feedstock and process specific enzymes
- Low enzyme cost due to fully integrated enzyme production (pretreated feedstock as substrate)
- Simultaneous one-pot fermentation of both C5 and C6 sugars to ethanol
- Energy saving ethanol separation on the basis of an adsoption-process (up to 50% less energy demand compared to standard distillation)
- Energy self-sufficient process – all energy derived from byproducts (mainly lignin)
- Low water consumption due to maximum recycling
- Recovery of minerals as fertilizer
- Flexible for different lignocellulosic feedstock
- Cellulosic ethanol reaches 95% CO2 emission savings compared to fossil fuels
- Competitive to first generation processes

Demonstration plant

Straubing, Germany

At the beginning of 2009, Clariant (back then still Süd-Chemie) commissioned a pilot plant with an annual capacity of up to two tons of cellulosic ethanol at its research centre in Munich. In July 2010, a decision was subsequently taken to construct a demonstration plant located in the Bavarian town of Straubing. The plant officially started into operation in July 2012, using about 4,500 tons of wheat straw, corn stover or other lignocellulosic material to produce around 1,000 tons of cellulosic ethanol each year. This proves the high maturity reached by sunliquid® technology and represents an interim stage necessary prior to erecting production plants with annual capacities of between 50,000 and 150,000 tons of ethanol which will operate at the highest levels of efficiency while achieving optimal savings in CO2 emissions. Clariant intends to realize a first reference plant together with partners in 2013/2014 and subsequently license out this technology.

Project Owner	Clariant
Project Name	sunliquid
Location	Straubing, Germany
Technology	biochemical
Raw Material	Wheat straw and other agricultural residues
Product	ethanol
Output Capacity	1000 t/y
Facility Type	demo
Investment	28 000 000 EUR
Status	operational
Start-up Year	2012
Contact Person	sunliquid@clariant.com
Web	www.sunliquid.com

Table 36: Clariant – demo plant in Straubing, Germany

Figure 40: The sunliquid® demo plant in Straubing, Germany

6.16 DuPont

DuPont has been bringing world-class science and engineering to the global marketplace in the form of innovative products, materials, and services since 1802. The company believes that by collaborating with customers, governments, NGOs, and thought leaders it can help find solutions to such global challenges as providing enough healthy food for people everywhere, decreasing dependence on fossil fuels, and protecting life and the environment.

DuPont Cellulosic Ethanol operates as a business group within DuPont Industrial Biosciences, which was formed through the 2011 acquisition of Danisco. In the last decade DuPont and Danisco have invested more than $100 million toward the advancement of cellulosic ethanol technology.

Bringing together the expertise from Danisco, Genencor and DuPont has yielded a unique combination of strengths in enzyme technology, materials science and bioprocessing. It is called DuPont™ Genencor® Science, and it's what powers the innovations to help solve some of the world's greatest challenges.

Energy security is one of DuPont's greatest challenges, particularly developing more sustainable advanced biofuels from renewable, non-food feedstocks.

Collaboration is key to success

At DuPont, it is believed that it's going to take many different solutions to meet the global demand for renewable energy. As a global leader in advanced biofuels production, DuPont is looking for innovators who can contribute to — and benefit from — the integrated technology program and commercial vision. These opportunities could include:

- Establishing new cellulosic ethanol production sites
- Participating in the cellulosic ethanol supply chain
- Sharing management skills and knowledge
- Design and delivery of production equipment and systems

The DuPont advantage: turnkey solutions for the advanced biorefinery

DuPont believes no other company can offer the end-to-end expertise DuPont brings to the emerging advanced biofuels industry. Through the broad range of competencies, it is advancing the commercialization of cellulosic ethanol production in three critical areas of feedstock, conversion, and licensing, production and delivery.

The licensing model is based on a fully optimized package from supply chain to finished product. This turnkey biorefinery solution contains all the design/technical elements necessary from the receipt of biomass to the output of fuel grade ethanol, including all the proprietary conversion processes, operational information and licensing for full-scale production.

DuPont Cellulosic Ethanol demonstration plant

Vonore, Tennessee

DuPont Cellulosic Ethanol is operating a demonstration plant in Vonore, Tennessee, to optimize and develop cost-effective production technology of advanced biofuels, in preparation for scale up to commercial operations. The 74,000-square-foot facility can produce up to 250,000 gallons of ethanol per year from agricultural residues, such as corn stover and corn cobs, and other potential feedstocks such as switchgrass.

Every part of the plant is powered by DuPont™ Genencor® Science. It includes a pretreatment technology that opens the cellulose polymers in the biomass, allowing greater access for DuPont-engineered enzymes to break down the plant materials into sugars. During fermentation, DuPont-developed technology converts the sugars into ethanol.

Project Owner	DuPont
Project Name	DuPont Cellulosic Ethanol Demonstration plant
Location	Vonore, Tennessee, United States
Technology	Enzymatic hydrolysis
Raw Material	Lignocellulosics: corn stover, switchgrass
Product(s)	ethanol
Output Capacity	750 t/y; 250 000 gallons of ethanol per year
Facility Type	Demonstration
Status	Operational
Start-up Year	2010
Contact Person	Rene Molina, info.cellulosicethanol@dupont.com
Web	www.dupont.com

Table 37: DuPont – demo plant in Vonore, United States

Figure 41: DuPont – picture of demo plant in Vonore, United States

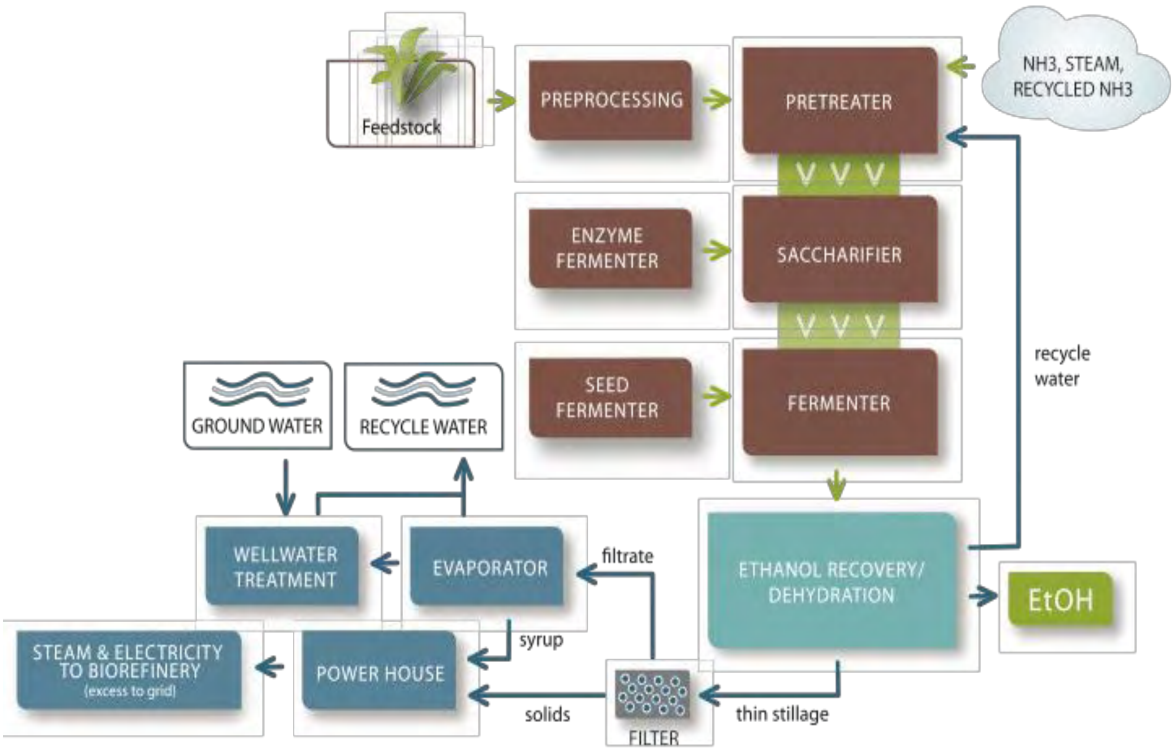


Figure 42: DuPont – flow chart of demo plant in Vonore, Unites States

6.17 Dynamic Fuels LLC

Hydroprocessing of animal fats, used cooking greases and the like, into renewable synthetic diesel meeting the US ASTM D975 diesel spec.

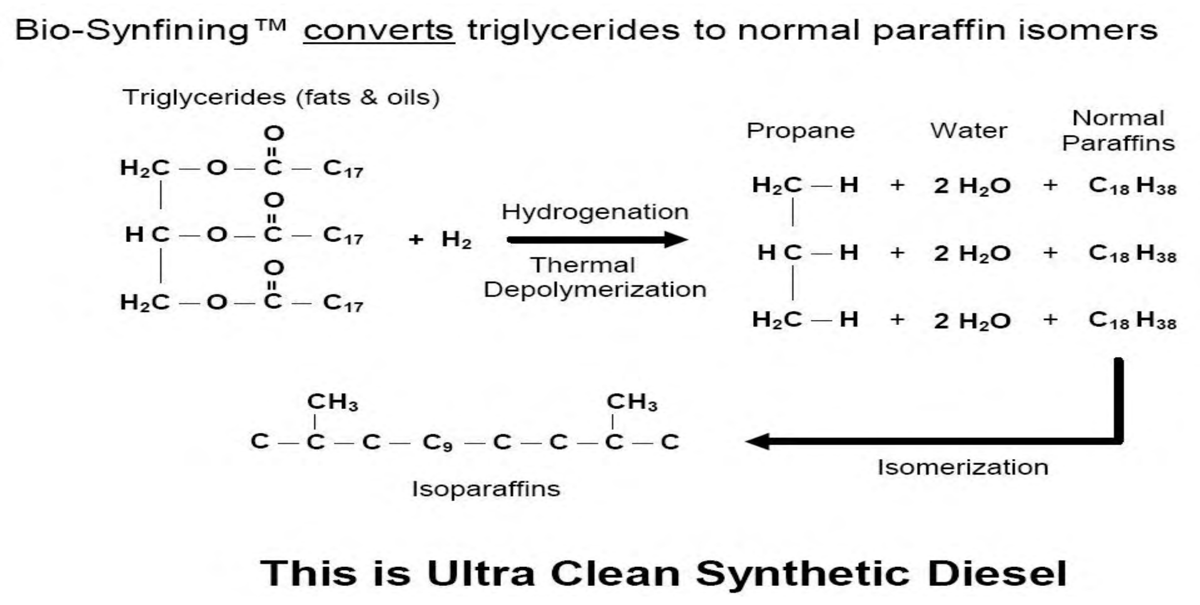


Figure 43: Dynamic Fuels – flow chart

Geismar Project

Geismar, United States

Project Owner	Dynamic Fuels LLC
Project Name	Geismar Project
Location	Geismar, United States
Technology	chemical
Raw Material	oils, fats
Project Input	hydrotreatment of animal fats, used cooking greases
Product(s)	diesel-tpye hydrocarbons
Output Capacity	210 000 t/y; 75 mmgy
Facility Type	commercial
Investment	138 000 000 USD
Status	operational
Start-up Year	2010
Contact Person	Jeff Bigger; jbigger@dynamicfuelsllc.com
Web	www.dynamicfuelsllc.com

Table 38: Dynamic Fuels – commercial plant in Geismar, United States

Figure 44: Dynamic Fuels – picture of commercial plant in Geismar, United States

6.18 ECN

The Energy Research Center of the Netherlands, ECN, consists of over 500 highly skilled energy technologists.With and for the market, ECN develops knowledge and technology that enable a transition to a sustainable energy system. ECN focusses on solar PV, off-shore wind, bio-energy, energy efficiency in industry, and energy policy studies.

In the field of Biomass gasification, ECN has developed gasification and gas cleaning technologies and executes R&D contracts for companies. The ECN CFB gasifier is marketed by HOST (www.host.nl) and the tar removal technology, Olga, by Royal Dahlman (www.dahlman.nl). The plants described below have as the heart the Milena indirect gasification technology. Milena has high efficiency, can take a large range of fuels, produces carbon-free ash and a producer gas with a very high calorific value. ECN owns and operates a 5 kW input lab-scale Milena and a 800 kW input pilot plant. A simplified scheme of the Milena indirect gasifier is shown below.

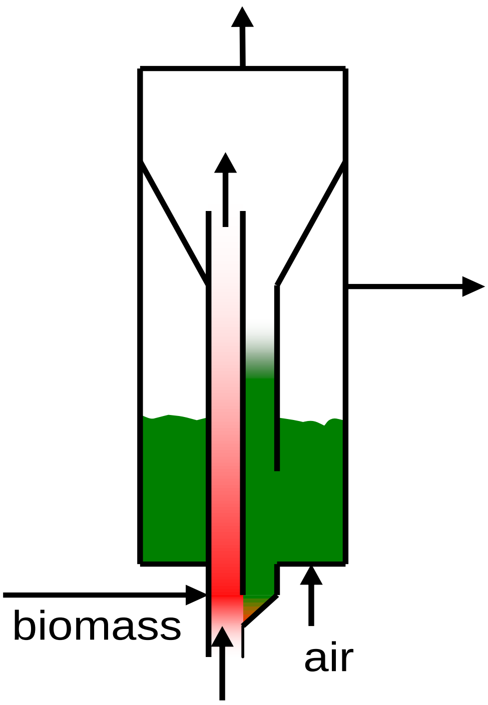


Figure 45: ECN – flow chart of gasifier

Pilot

Milena gasifier, Petten, Netherlands

ECN operates the 800 kW input MILENA indirect gasifier, feeding wood chips, demolition wood and other fuels. The produced gas is fed to the OLGA tar removal technology, which is commercially available under license at Royal Dahlman (www.dahlman.nl). SNG is produced using a smaller-scale Milena and OLGA installation also available in Petten.

Project Owner	ECN
Project Name	pilot
Location	Petten, Netherlands
Technology	thermochemical
Raw Material	Lignocellulosics (clean wood and demolition wood)
Input Capacity	1800 t/y
Product(s)	SNG (smaller scale or side stream)
Output Capacity	346 t/y; 60 Nm3/h
Facility Type	pilot
Status	operational
Start-up Year	2008
Contact Person	Bert Rietveld, g.rietveld@ecn.nl
Web	www.ecn.nl

Table 39: ECN – pilot plant in Petten, Netherlands

Figure 46: ECN – picture of pilot plant in Petten, Netherlands

Demo

Groen Gas 2.0, Alkmaar, Netherlands

A consortium containing of HVC, Gasunie, Royal Dahlman, ECN, local, regional and national government are developing a demonstration project in Alkmaar. The project consists of a 11.6 MWth Milena gasifier and an Olga tar removal unit. A side stream will be fed to a SNG production unit. Final Investment Decision is expected in Q3 2012, construction to start in 2013.

Project Owner	Consortium Groen Gas 2.0 (ECN, HVC, Gasunie, Royal Dahlman, Province North-Holland)
Project Name	demo
Location	Alkmaar, Netherlands
Technology	Thermochemical
Raw Material	Lignocellulosics
Product(s)	SNG
Output Capacity	6500 t/y; 11.6 MWth
Facility Type	demo
Status	planned
Start-up Year	2013
Contact Person	Bert Rietveld, g.rietveld@ecn.nl
Web	www.ecn.nl

Table 40: ECN – demo plant in Alkmaar, Netherlands

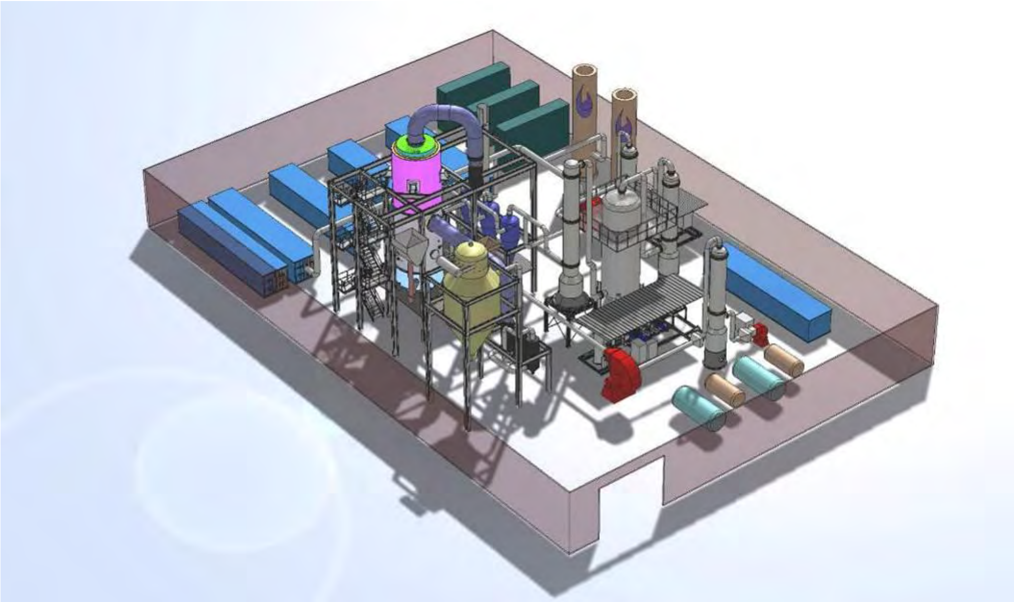


Figure 47: ECN – model of demo plant in Alkmaar, Netherlands

6.19 Enerkem

Enerkem develops renewable biofuels and chemicals from waste.

Through the combination of a proprietary thermochemical technology platform and community-based advanced facilities, Enerkem addresses the challenges of oil dependence and waste disposal.

Enerkem has validated its proprietary technology over a period of 11 years using solid waste from numerous municipalities and other types of feedstock. The company's process uses relatively low temperatures and pressures, which reduces energy requirements and costs. Its process and business model are designed to profitably produce cellulosic ethanol from a large municipal solid waste supply.

Enerkem's clean technology platform is a 4-step thermochemical process that consists of:

1. feedstock preparation
2. gasification
3. cleaning and conditioning of syngas
4. catalytic synthesis

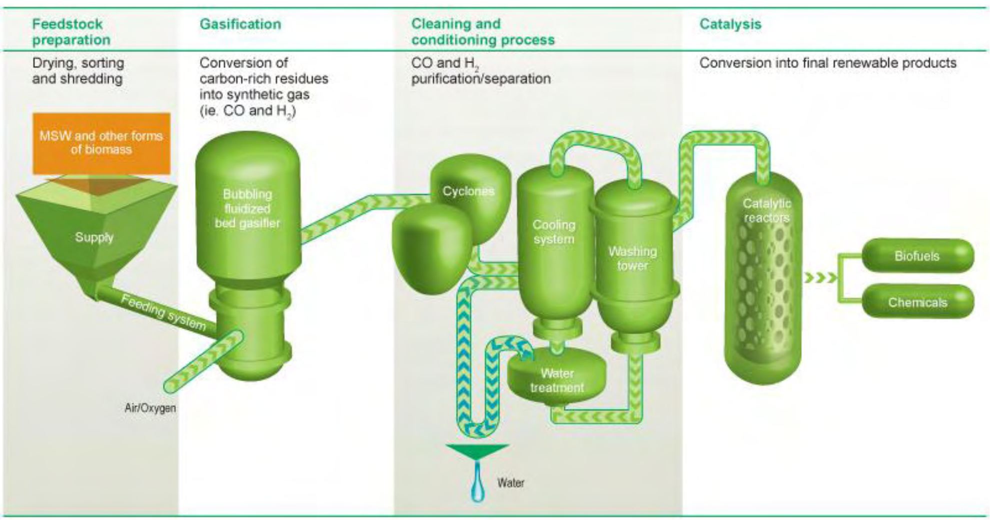


Figure 48: Enerkem – flow chart.

Enerkem converts mixed waste and residues into a pure synthesis gas (or syngas) which is suitable for the production of biofuels and chemicals using proven, well-established and commercially available catalysts. With its proprietary technology platform, the company is able to chemically recycle the carbon molecules from non recyclable waste into a number of products.

Enerkem's primary focus is the commercial production of cellulosic ethanol. Its exclusive process first requires the production of methanol as a chemical building block for the production of ethanol. Enerkem can also sell its methanol as an end-product, or use it as a key intermediate to produce other renewable chemicals.

Enerkem's green chemistry provides a source of clean energy as well as a sustainable alternative to landfill and incineration.

Sherbrooke pilot plant and research centre

Sherbrooke, Canada

Enerkem has been operating its pilot plant in Sherbrooke, Quebec since 2003. This pilot plant produces small quantities of syngas, methanol, acetates and second-generation ethanol. It is equipped with various sampling ports for data collection. It is well instrumented and automated for testing and reporting.

It can feed solid materials, slurries, and liquids. To date, over 25 different types of feedstocks have been used to test and validate the technology, and for engineering design purposes. These feedstocks include municipal solid waste, wood chips, treated wood, sludge, petcoke, spent plastics and wheat straw. Enerkem works in close relationship with the University of Sherbrooke.

Project Owner	Enerkem
Project Name	Sherbrooke pilot plant and research centre
Location	Sherbrooke, Canada
Technology	Thermochemical
Raw Material	Sorted municipal solid waste (SMSW) from numerous municipalities and more than 25 different feedstocks, including wood chips, treated wood, sludge, petcoke, spent plastics, wheat straw. Feedstocks can be in solid, slurry or liquid form.
Project Input	See above
Input Capacity	4.8 metric tons per day
Product(s)	ethanol; methanol; various chemicals
Output Capacity	n/a
Facility Type	Pilot
Status	Operational
Start-up Year	2003
Contact Person	David Lynch; dlynch@enerkem.com
Web	http://www.enerkem.com/en/facilities/innovation-centers/sherbrooke-quebec-canada.html

Table 41: Enerkem – pilot plant in Sherbrooke, Canada

Figure 49: Enerkem – picture of pilot plant in Sherbrooke, Canada

Westbury commercial demonstration facility

Westbury, Canada

Enerkem's Westbury facility is the company's first commercial biofuels and biochemicals facility. This demonstration-scale facility is among the world's first ethanol and biochemicals plant to use negative-cost and unconventional materials, such as treated wood from used electricity poles, as feedstock.

Operations started in 2009 with the production of conditioned syngas. Methanol production has been underway at the Westbury facility since 2011, and cellulosic ethanol since spring 2012.

The plant is located in a rural area, near a sawmill that recycles used electricity and telephone poles. Enerkem employs the non-usable portion of these poles and creates value from it.

Project Owner	Enerkem
Project Name	Westbury commercial demonstration facility
Location	Westbury, Canada
Technology	Thermochemical
Raw Material	Treated wood (i.e. decommissioned electricity poles and railway ties), wood waste and MSW
Project Input	See above
Input Capacity	48 metric tons per day
Product(s)	ethanol; methanol; various chemicals
Output Capacity	4000 t/y (5 million litres per year; 1.3 million gallons per year) (waste-to-methanol equipment)
Facility Type	Commercial demonstration
Status	Operational
Start-up Year	2009
Contact Person	Nathalie Morin; nmorin@enerkem.com
Web	http://www.enerkem.com/en/facilities/plants/westbury-quebec-canada.html

Table 42: Enerkem – demo plant in Westbury, Canada

Figure 50: Enerkem – picture of demo plant in Westbury, Canada

Edmonton Waste-to-Biofuels Project (first full-scale commercial facility)

Edmonton, Canada

Enerkem, through its affiliate Enerkem Alberta Biofuels, has signed a 25-year agreement with the City of Edmonton to build and operate a plant that will produce and sell next-generation biofuels from non recyclable and non compostable municipal solid waste (MSW). It is expected to be one of the first major collaborations between a metropolitan centre and a waste-to-biofuels producer to turn municipal waste into methanol and ethanol.

As part of the agreement, the City of Edmonton will supply 100,000 dry metric tons of sorted MSW per year. The sorted MSW to be used is the ultimate residue after recycling and composting, which is saved from being landfilled. The project was granted a permit, under the Environmental Protection and Enhancement Act of the Province of Alberta, to commence construction and operation of the commercial facility. Construction started during summer 2010. Operations are scheduled to start in 2013.

Enerkem's project partners, the City of Edmonton and Alberta Innovates – Energy and Environment Solutions, contributed $20 million to the project. The project has been selected by Alberta Energy to receive $3.35 million in funding, as part of the Biorefining Commercialization and Market Development Program. This program is designed to stimulate investment in Alberta's bio-energy sector. In addition, Waste Management and EB Investments are investing $15 million for a minority equity interest in the project. This facility, which is part of a comprehensive municipal waste-to-biofuels initiative (www.edmontonbiofuels.ca), in partnership with the City of Edmonton and Alberta Innovates, will enable the City of Edmonton to increase its residential waste diversion rate to 90 percent.

Project Owner	Enerkem Alberta Biofuels LP
Project Name	Edmonton Waste-to-Biofuels Project
Location	Edmonton, Canada
Technology	Thermochemical
Raw Material	Post-sorted municipal solid waste (MSW)
Project Input	See above
Input Capacity	350 metric tons per day
Product(s)	ethanol; methanol; various chemicals
Output Capacity	30 000 t/y (38 million litres per year; 10 million gallons per year)
Facility Type	Commercial
Project Funding	Enerkem Inc., City of Edmonton via Alberta Innovates – Energy and Environmental Solutions, Alberta Energy, Waste Management Corporation of Canada, EB Investments ULC
Status	Under construction
Start-up Year	2013
Contact Person	Marie-Helene Labrie; mlabrie@enerkem.com
Web	www.edmontonbiofuels.ca

Table 43: Enerkem – commercial plant in Edmonton, Canada

Figure 51: Enerkem – picture of commercial plant in Edmonton, Canada (under construction, May 2012)

Mississippi commercial facility

Pontotoc, United States

Enerkem plans to build and operate a waste-to-biofuels plant in Pontotoc, Mississippi, under its U.S. affiliate, Enerkem Mississippi Biofuels LLC.

The company has signed an agreement with the Three Rivers Solid Waste Management Authority of Mississippi (TRSWMA) for the supply of municipal solid waste (MSW) per year. The facility will be located on the Three Rivers' landfill site. A portion of the waste will be recycled and the other portion will be converted into ethanol.

The project has been selected to receive an award of up to US$ 50 million from the U.S. Department of Energy (DOE). It has also received strong support from local politicians and partners. This landmark project obtained a conditional commitment in January of 2011 for an US $80 million loan guarantee by the U.S. Department of Agriculture (USDA).

The plant under development has successfully met the federal environmental assessment requirements and is now finalizing the process to obtain other permits required to build and operate the facility.

Project Owner	Enerkem Mississippi Biofuels LLC
Project Name	Enerkem Mississippi Biofuels
Location	Pontotoc, United States
Technology	thermochemical
Raw Material	Sorted municipal solid waste and wood residues
Project Input	See above
Input Capacity	350 metric tons per day
Product(s)	ethanol; methanol; various chemicals
Output Capacity	30 000 t/y (38 million litres per year; 10 million gallons per year)
Facility Type	Commercial
Status	Under development
Contact Person	Marie-Helene Labrie; mlabrie@enerkem.com
Web	http://www.enerkem.com/en/facilities/plants/pontotoc-mississippi.html

Table 44: Enerkem – commercial plant in Pontotoc, United States

Figure 52: Enerkem – 3D model of commercial plant in Edmonton, Canada

Varennes commercial facility

Varennes, Canada

Enerkem and GreenField Ethanol are planning to build Québec's first full-scale cellulosic ethanol facility.

The facility will be built and operated by Varennes Cellulosic Ethanol L.P., a joint venture formed by Enerkem Inc. and GreenField Ethanol Inc. It will be located in Varennes, Québec (near Montréal), next to GreenField Ethanol's current first-generation biofuels facility.

The Varennes facility will use Enerkem's proprietary technology to produce cellulosic ethanol from non-recyclable waste from institutional, commercial and industrial sectors as well as construction and demolition debris.

The Government of Québec plans to inject $27 million in this project through the Ministry of Natural Resources and Wildlife and Investissement Québec.

Project Owner	Varennes Cellulosic Ethanol L.P.
Project Name	Varennes Cellulosic Ethanol
Location	Varennes, Canada
Technology	Thermochemical
Raw Material	Sorted industrial, commercial and institutional waste
Project Input	See above
Input Capacity	350 metric tons per day
Product(s)	ethanol; methanol; various chemicals
Output Capacity	30 000 t/y (38 million litres per year; 10 million gallons per year)
Facility Type	Commercial
Status	planned
Contact Person	Marie-Helene Labrie; mlabrie@enerkem.com
Web	http://www.enerkem.com/en/facilities/plants/varennes-quebec-canada.html

Table 45: Enerkem – commercial plant in Varennes, Canada

Figure 53: Enerkem – 3D model of commercial plant in Varennes, Canada

6.20 Fiberight

Fiberight has successfully developed a biomass conversion process that produces commercially viable quantities of renewable biofuel and other valuable biochemicals from municipal solid waste (MSW). Fiberight's innovative technology efficiently fractionates the organic components of MSW such as contaminated paper, food wastes, yard discards and other degradables for the production of cellulose and hemicellulose into fuel grade ethanol and other sugar platform biochemicals using enzymatic hydrolysis and fermentation. The plastic fraction and methane collected from Fiberight's processes may also used to create co-generation electricity to power its plant facilities for zero energy input. Fiberight's proprietary extraction, pulping and digestion processes have the potential to unlock over 5 billion gallons of renewable biofuel contained in the 175 million tons of non-recyclable Municipal Solid Waste (MSW) generated each year in the US.

Fiberight's intention is to build, own and operate hub and spoke biorefineries that will solve two pressing environmental challenges: 1) Fiberight has developed a cost effective means to divert formerly unusable trash from traditional landfill or incineration disposal for sustainable waste processing into valuable end-products; and 2) Fiberight converts municipal solid waste into cellulosic ethanol to meet EPA RFS2 renewable biofuel targets to reduce the country's dependence upon foreign energy. Fiberight's facilities operate at low temperatures in a closed-loop system resulting in nominal levels of emissions or effluents. Fiberight's process has distinct competitive advantages over other waste to energy methods that use high cost arc gasification/ syngas or acid hydrolysis methods, because of low cost and high levels of recycling or conversion.

Fiberight's technology capitalizes on the ability to reduce MSW costs for communities with declining landfill space or stranded trash costs. Fiberight is one of the first companies in the US to achieve actual production of cellulosic ethanol at industrial scale. Fiberight has operated a pilot plant in Lawrenceville, VA since 2007 and recently upgraded it to be a fully integrated demonstration facility. Fiberight also controls a commercial scale plant in Blairstown, Iowa, which plant will be upgraded for cellulosic ethanol production in 2013, the project was recently awarded a $25M federal Loan Guarantee.

Fiberight integrated demonstration plant

Lawrenceville, VA

Project Owner	Fiberight LLC
Project Name	Integrated Demonstration Plant
Location	Lawrenceville, VA USA
Technology	Biochemical
Raw Material	Municipal Solid Waste
Input Capacity	75 t/d
Product(s)	ethanol; power
Output Capacity	To 1M GPY ethanol; 3 t/y
Facility Type	Demonstration
Project Funding	Private equity
Status	Operational
Start-up Year	2012
Contact Person	Craig Stuart-Paul
Web	info@fiberight.com

Table 46: Fiberight – demo plant in Lawrenceville, United States

Figure 54: Fiberight – pictures of demo plant in Lawrenceville, United States

Commercial Plant

Blairstown, Iowa USA

Project Owner	Fiberight LLC
Project Name	Commercial Plant
Location	Blairstown, IA USA
Technology	Biochemical
Raw Material	Municipal Solid Waste
Input Capacity	500 t/d
Product(s)	ethanol; power
Output Capacity	To 6M GPY ethanol; 18 t/y
Facility Type	Commercial
Project Funding	Private equity, USDA Loan $25M, State Grant $2.9M
Status	Idle while under reconstruction
Start-up Year	2013
Contact Person	Craig Stuart-Paul
Web	info@fiberight.com

Table 47: Fiberight – commercial plant in Blairstown, United States

Figure 55: Fiberight – picture of commercial plant in Blairstown, United States

6.21 Frontier Renewable Resources

Kinross Plant 1

Kincheloe, Michigan, United States

The unique technology developed by Mascoma Corporation uses yeast and bacteria that are engineered to produce large quantities of the enzymes necessary to break down the cellulose and ferment the resulting sugars into ethanol. Combining these two steps (enzymatic digestion and fermentation) significantly reduces costs by eliminating the need for enzyme produced in a separate refinery. This process, called Consolidated Bioprocessing or "CBP", will ultimately enable the conversion of the solar energy contained in plants to ethanol in just a few days.

Frontier Renewable Resources is a joint venture of J.M. Longyear and Mascoma (see 4.33 Mascoma).

Project Owner	Frontier Renewable Resources
Project Name	Kinross Plant 1
Location	Kincheloe, Michigan, United States
Technology	biochemical
Raw Material	lignocellulosics; wood chip
Input	700 t/d
Product	ethanol; lignin
Output Capacity	60 000 t/y; 20 mmgy
Facility Type	commercial
Partners	Mascoma Corporation J.M. Longyear
Status	planned
Contact Person	Frontier Renewable Resources
Web	www.frontier-renewable.com

Table 48: Frontier Renewable Resources – commercial plant in Kincheloe, United States

6.22 Göteborg Energi

Göteborg Energi is Western Sweden's leading energy company, providing its customers with energy services, district heating, electricity, natural gas, cooling, natural gas and electricity supply network and broadband. The company is fully owned by the city of Gothenburg with 300,000 costumers, 1200 employees and an annual turnover of approximately 800 M€.

The company aims to create energy solutions that are sustainable in the long term. Therefore research and development has played an important role in creating the solutions now used. Examples are production and distribution of district heating, biogas production and injection in the existing natural gas grid. Efficient energy provision is one of the most important building blocks of a well functioning society. To achieve this goal, Göteborg Energi has developed into a versatile energy company, offering services and products that make life easier for both companies and private individuals.

One of the greatest challenges in the future is to supply the transport sector with renewable energy. Today there are more than 15 million natural gas vehicles in the world. Therefore is it important to develop the second generation of biofuels to increase the production capacity of renewable gas. Göteborg Energi is in the construction phase of the first plant in the world to produce biomethane (SNG) through gasification of forest residues, the GoBiGas-project. The gas will be of such quality that it can be injected directly into the existing gas grid. The company has also several plants for anaerobic digestion using different feedstocks and also one of the first plants to liquefy biogas.

The GoBiGas-project is using indirect gasification technology from Repotec supplied by Metso Power and fixed bed methanation with technology from Haldor Topsoe. The process is aiming for a yield of SNG from biomass and also a high overall energy efficiency, thus by e.g. utilizing excess heat for district heating. The aim of the project is to show that SNG can be produced continuously through gasification of forest residues and to take a step to commercialisation of the technology.

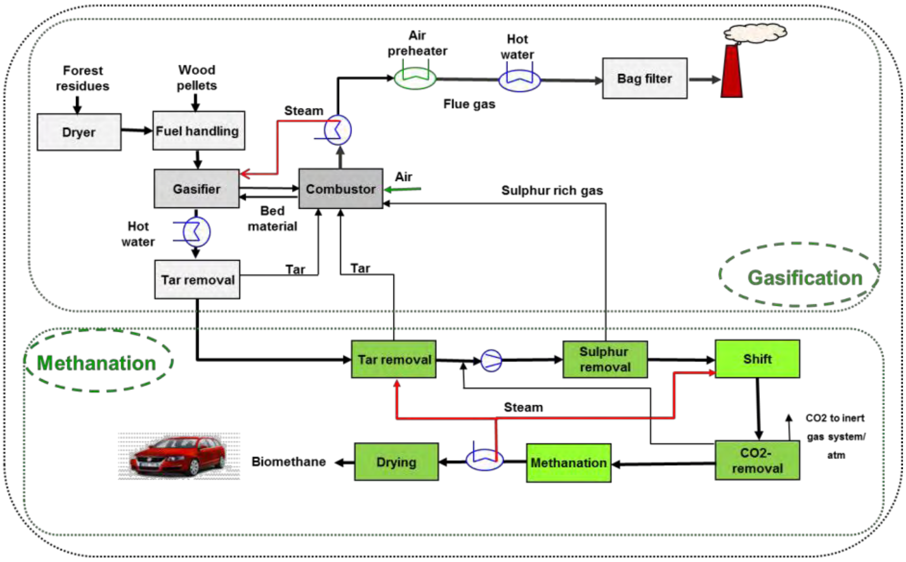


Figure 56: Göteborg Energi – flow chart

GoBiGas Plant – Phase 1

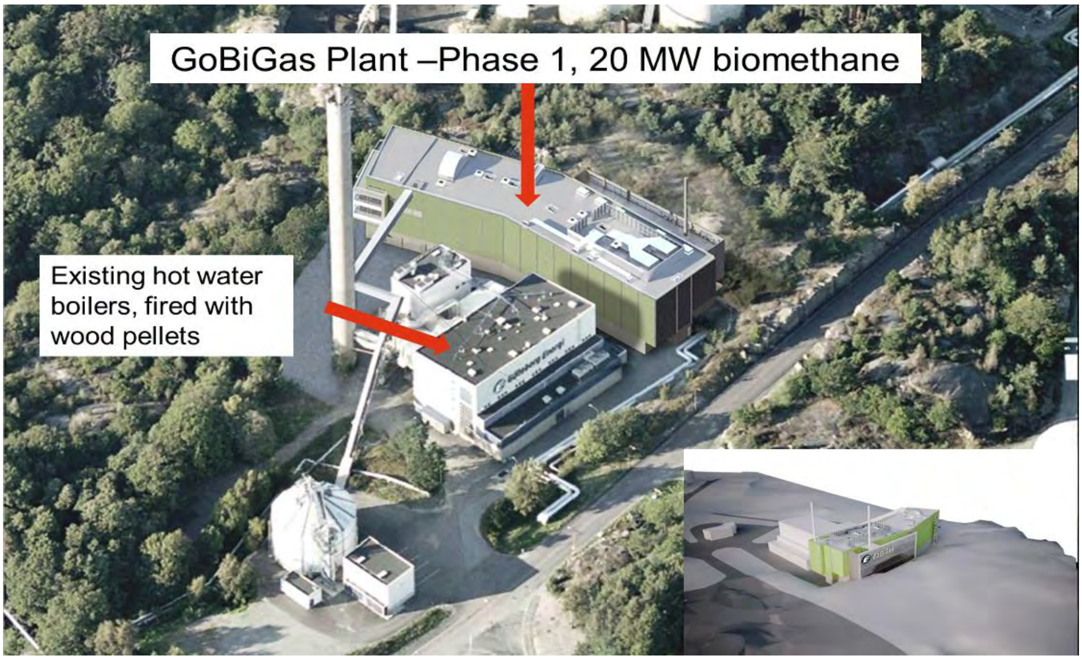
Gothenburg, Sweden

The GoBiGas-project was started 2005-2006 and has after pre-studies been divided into two phases where the first phase is a demonstration plant, partly funded by the Swedish energy Agency, and the second phase to be a 4-5 times larger commercial installation.

For the first plant, the investment decision was taken in December 2010 and the project is now in the construction phase. The plant is planned to be in operation late 2013.

Project Owner	Göteborg Energi AB
Project Name	GoBiGas Plant – Phase 1
Location	Göteborg, Sweden
Technology	Thermochemical; thermal gasification and methanation
Raw Material	Forest residues, wood pellets, branches and tree tops
Product(s)	SNG
Output Capacity	11 200 t/y (20 MW)
Facility Type	Demonstration
Investment	Approx. 150 M€
Project Funding	Project Owner, partly funded by the Swedish Energy Agency
Status	Under construction
Start-up Year	2013
Contact Person	Åsa Burman, Project director; info.gobigas@goteborgenergi.se
Web	www.goteborgenergi.se, www.gobigas.se

Table 49: Göteborg Energi – demo plant in Göteborg, Sweden



Picture 1: GoBiGas Phase1

6.23 Greasoline

Greasoline® is a process for the production of high-quality biofuels, developed by the Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT and now exclusively commercialized by the start-up company Greasoline GmbH. The greasoline® biofuel technology permits the catalytic cracking of bio-based fats, oils, waste oils and oil residues into diesel, kerosene and gasoline fuels. The technology is world-wide protected by four patent families.

Greasoline GmbH was founded in August 2011 with Fraunhofer Society as one of the shareholders. It is a license-oriented start-up which provides technology licenses, technology and raw material support towards production companies, forward-integration-focused raw material suppliers and established oil engineering & construction companies.

Catalytic cracking of bio-based oils and fats primarily produces diesel and kerosene fuel-range hydrocarbons. Preferred catalysts are activated carbons and inorganic catalysts. Variation in process conditions, catalysts and input material lead to renewable chemicals like bio-based naphtha, alkenes and LPG.

greasoline® products are almost chemically identical to fossil fuels, i.e. they are non-corrosive, non-hygroscopic, and not sensitive to oxidation. They can even be used as upgrading fuel additives (cetane number booster) or jet-fuel additives (bio-based alkylated benzenes).

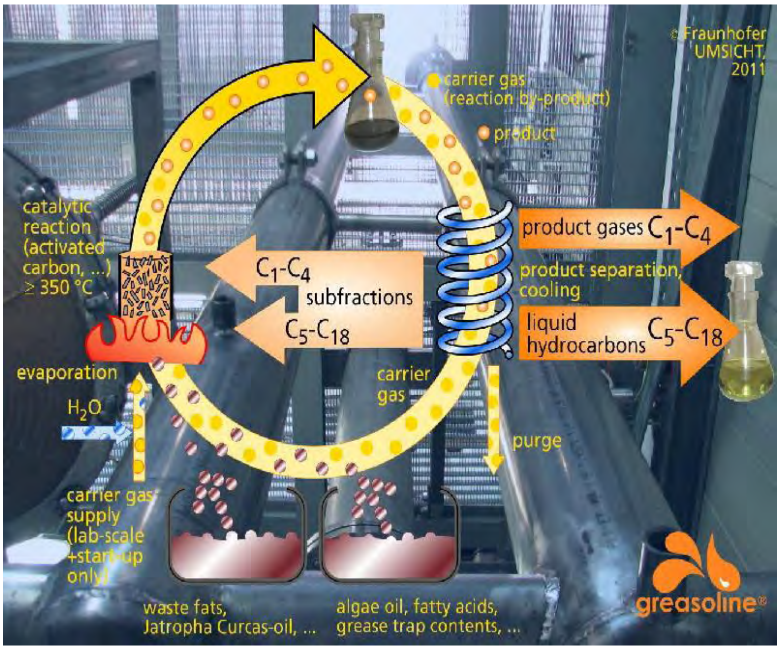


Figure 57: Greasoline – flow chart of the greasoline® process

The greasoline® process offers significant advantages because it

- uses currently available non-food raw materials and is therefore not in competition with nutrition of an increasing number of human beings worldwide,
- can also use raw materials and residues that are not suited for alternative technologies due to water content or impurities like solid compounds or inorganic salts,
- is an ideal conversion process for future optimized feedstock like micro algae oils,
- doesn't need additional hydrogen for the de-oxygenation and
- it can be implemented into existing oil refinery assets, lowering investment cost and enabling oil refineries to produce bio-based products instead of being forced to blend stand-alone biofuels like biodiesel and bioethanol.

sts-plant

Oberhausen, Germany

Since 2008 more than € 3 million have been invested into the pilot plant at Oberhausen. Scaling-up from lab to pilot plant has successfully demonstrated technical proof of concept for the technology. The pilot plant converts 3 kg bio-based fats and oils per hour into 3 l biofuels. It consists of a biofuel synthesis section, a dedicated distillation unit and a catalyst regeneration centre. Main purpose of the plant is process optimization re different types of feedstock, production of quantities for engine tests and measurement of process flow and energy data.

Project Owner	Greasoline GmbH
Project Name	sts-plant
Location	Oberhausen, Germany
Technology	thermochemical
Raw Material	oils, fats
Project Input	bio-based oils and fats, residues of plant oil processing, free fatty acids, used bio-based oils and fats
Input Capacity	3 kg/h
Product(s)	diesel-type hydrocarbons
Output Capacity	2 t/y
Facility Type	Pilot
Investment	3 000 000 EUR
Status	Operational
Start-up Year	2011
Contact Person	Dr. Peter Haug, contact@greasoline.com; +49 0208 8598 0
Web	www.greasoline.com

Table 50: Greasoline – pilot plant in Oberhausen, Germany

Figure 58: Greasoline – picture of pilot plant in Oberhausen, Germany

6.24 GTI – Gas Technology Institute

Figure 59: GTI – picture of the Energy and Environmental Technology Center

Gas Technology Institute (GTI) has been involved in energy research and development for over 70 years with the primary focus of moving new technology solutions into the marketplace. GTI has extensive experience in the design, construction, and operation of lab- and bench-scale energy conversion test systems as well as pilot- and commercial demonstration-scale plants. GTI's staff and its advanced research facilities provide the necessary resources for the evaluation and testing of all types of gasification, gas cleaning and conditioning, pyrolysis and related processes. GTI works with clients and partners in one-on-one and collaborative projects to assess application- and technology-specific information needed to design experimental and commercial biomass plants for a wide range of applications: power, liquid transportation fuels, chemicals production, hydrogen production, and pipeline-quality methane.

Three years of testing of integrated biomass gasification and syngas production and conditioning systems were completed in 2011 in GTI's pilot test facilities (Figure 58) in Des Plaines, Illinois. This testing provided ANDRITZ Carbona and their client UPM-Kymmene with performance data for their biomass-to-liquids process designs for future 300 MW_{th} commercial plants in Finland and France. The BTL system will use the ANDRITZ Carbona gasifier, based on GTI fluidized bed technology, to produce synthesis gas that will feed a Fischer-Tropsch second generation biodiesel production facility. This collaborative project team also included Haldor Topsøe for the syngas tar reformer catalysts and design. The team was also joined by E.ON, a global energy production and distribution company to develop design basis information for renewable natural gas projects from 250 – 600 MW_{th} in Sweden.

A gasification-based wood to "green" gasoline development project, funded by the U.S. Department of Energy under it's biorefinery program, is now underway in Des Plaines. The project will fully integrate the pilot-scale gasification and syngas cleanup pilot plants with a new catalytic syngas conversion pilot in the FFTF and AGTF. The GTI-based ANDRITZ Carbona biomass gasifier with a downstream tar reformer will perform the gasification process. The GTI Morphysorb® process will be used for acid gas cleanup, and the Haldor Topsøe TIGAS process will convert the cleaned and compressed syngas into gasoline. The project team includes Haldor Topsøe, ANDRITZ Carbona, UPM-Kymmene and Phillips 66.

Figure 60: GTI – picture of the Flex-Fuel Test Facility (FFTF) and the Advanced Gasification Test Facility (AGTF) in Des Plaines, Illinois

GTI is also developing the IH^2 process, which is a unique thermochemical conversion technology using catalytic hydropyrolysis and hydroconversion to convert a broad range of biomass feedstocks directly into drop-in gasoline, diesel and jet fuel. GTI's development partner in the IH^2 technology is CRI Catalyst, a wholly owned subsidiary of Shell. CRI Catalyst's IH^2 business goal is to widely license the IH^2 technology for conversion of multiple biomass feeds and supply catalyst for the IH^2 process. The near term goal is to work with an industry partner to build a demonstration scale unit as a bridge to commercialization.

Flex-Fuel and Advanced Gasification Test Facilities

Des Plaines, United States

GTI has been operating its Des Plaines test facility since 2004. The facility's primary purpose is to generate process performance data and evaluate plant design and integration strategies at a scale sufficient to support commercial-scale, first-of-a-kind demonstration plant designs. The overall facility comprises a fuel-flexible, configurable technology development platform suitable for a wide range of solid fuels, including all ranks of coal and all types of biomass, as well as petcoke and solid wastes. It is operated by an experienced team of engineers and technicians in round-the-clock test campaigns of from 5 to 30 days in length.

Two gasification platforms including fluidized-bed and entrained-bed technologies are available for air- or oxygen-blown syngas production at pressures up to 400 psig (28.6 bara). In addition to hot, high pressure cyclones for syngas fines removal, full-stream hot gas filters with metal or ceramic filter elements are available along with a catalytic syngas tar reformer, a wet scrubber and syngas compression capability to 1000 psig (70 bara). A full-stream acid gas removal system suitable for use with physical or chemical solvents is available for CO2 and H2S removal, rendering the clean syngas suitable for use in catalytic synthesis processes for liquids or chemicals production. A full-stream pilot version of this type of synthesis process is being installed in the facility during the 3rd quarter of 2012. The new TIGAS pilot from Haldor Topsøe will provide catalytic conversion of clean syngas to gasoline as part of an ongoing U.S. DOE Biorefinery project. A block flow diagram of the plant configuration for this project is shown in Figure 61.

Project Owner	GTI, Gas Technology Institute
Project Name	Flex-Fuel and Advanced Gasification Test Facilities, Wood to Gasoline
Location	Des Plaines, Illinois, United States
Technology	Thermochemical
Raw Material	Biomass, Coal, Petcoke, Wastes
Project Input	Forest residues: tops, bark, hog fuel, stump material
Input Capacity	21 metric tons per day
Product(s)	FT-Liquids
Output Capacity	880 t/y (23 bbl/d)
Facility Type	Pilot
Status	Operational
Start-up Year	2004
Contact Person	Bruce Bryan; Bruce.bryan@gastechnology.org
Web	www.gastechnology.org

Table 51: GTI – pilot plant in Des Plaines, United States

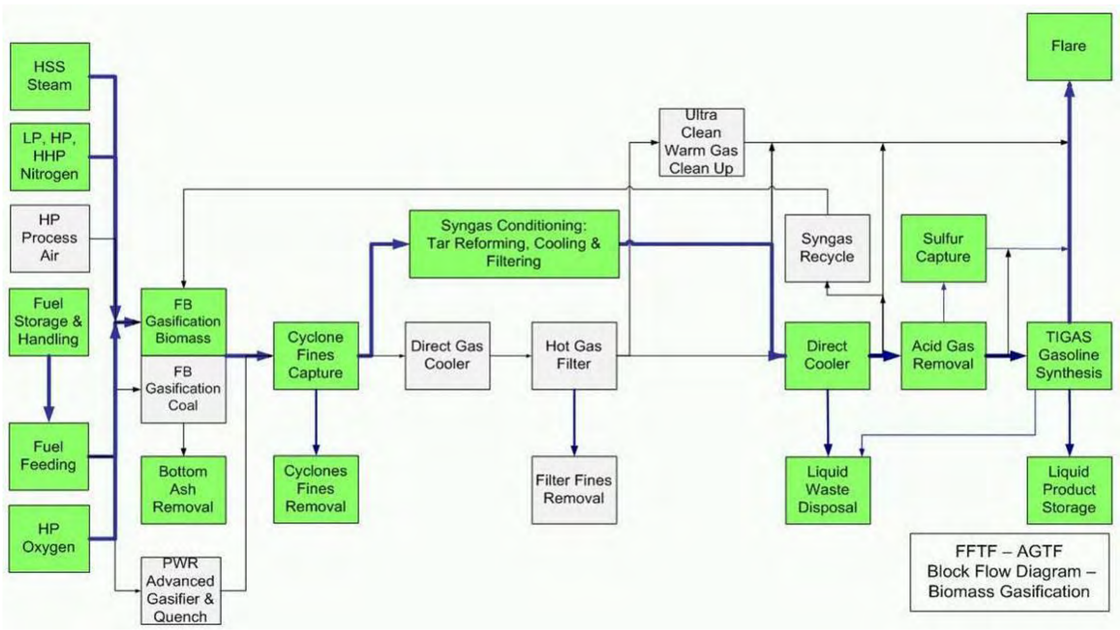


Figure 61: GTI – flow chart of pilot plant in Des Plaines, United States

IH2–50 Biomass to Gasoline and Diesel Pilot Facility

Des Plaines, United States

The IH2 technology directly converts a wide variety of biomass, including wood, cornstover, lemna, and algae directly into high quality, drop in, gasoline and diesel. The process is able to produce gasoline and diesel at less than $2.00/gallon on a commercial scale. The LCA for IH2 is excellent, with a greenhouse gas reduction of over 90%. The IH2 process makes its own hydrogen from C1-C3 produced in the process and requires no external hydrogen. The overall process is shown in Figure 62.

The IH2 pilot plant contains a first stage fluidized bed catalytic hydropyrolysis reactor, and a second stage hydroconversion reactor. Hydrogen produced in the process is continuously recycled. The biomass is continuously fed while liquid, gas, and char products are continuously removed. The pilot plant operates 24 hours a day in test campaigns lasting 30 days or longer.

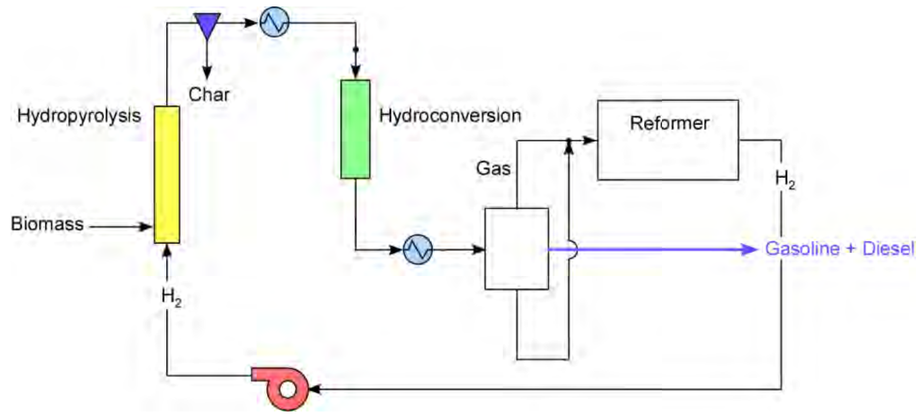


Figure 62: GTI – flow chart of IH^2 process for direct replacement fuels from biomass

Project Owner	GTI, Gas Technology Institute
Project Name	IH2 – 50 Continuous Pilot Plant
Location	Des Plaines, Illinois, United States
Technology	Thermochemical-Hydropyrolysis and Hydroconversion
Raw Material	Lingnocellulosics
Raw Material details	Wood, Corn-stover, Bagasse, Algae
Input Capacity	50 kg/d of biomass
Product(s)	FT-Liquids; gasoline-type fuel
Output Capacity	Wood: 4.1 t/y (4.1gal/d) of gasoline+diesel, Algae: 8.0 t/y (7.9gal/d) of gasoline+diesel
Facility Type	Pilot
Status	Operational
Start-up Year	2012
Contact Person	Terry Marker, terry.marker@gastechnology.org
Web	www.gastechnology.org

Table 52: GTI – pilot plant in Des Plaines, United States

Figure 63: GTI – picture of pilot plant in Des Plaines, United States

6.25 Inbicon (DONG Energy)

Pilot 1

Fredericia, Denmark

Hydrothermal pre-treatment, high gravity hydrolysis, yeast fermentation

Project Owner	Inbicon (DONG Energy)
Project Name	pilot 1
Location	Fredericia, Denmark
Technology	biochemical
Raw Material	lignocellulosics; straw
Input	0.1 t/h
Product	ethanol; c5 molasses
Facility Type	pilot
Investment	5 000 000 EUR
Funding	2 500 000 EUR
Status	operational
Start-up Year	2003
Contact Person	Ms. Lykke Mulvad Jeppesen, info@inbicon.com
Web	www.inbicon.com

Table 53: Inbicon – pilot 1 plant in Fredericia, Denmark

Figure 64: Inbicon – picture of pilot 1 plant in Fredericia, Denmark

Pilot 2

Fredericia, Denmark

Hydrothermal pre-treatment, high gravity hydrolysis, yeast fermentation

Project Owner	Inbicon (DONG Energy)
Project Name	pilot 2
Location	Fredericia, Denmark
Technology	biochemical
Raw Material	lignocellulosics
Input	1 t/h
Product	ethanol; c5 molasses
Output Capacity	several t/h
Facility Type	pilot
Investment	15 000 000 EUR
Funding	5 000 000 EUR
Status	operational
Start-up Year	2005
Contact Person	Ms. Lykke Mulvad Jeppesen, info@inbicon.com
Web	www.inbicon.com

Table 54: Inbicon – pilot 2 plant in Fredericia, Denmark

Figure 65: Inbicon – picture of pilot 2 plant in Fredericia, Denmark

Demo

Kalundborg, Denmark

Output: 4300 tonnes ethanol per year 13.100 tonnes of lignin pellets per year 11.250 tonnes of C5-molasses (70% DM).

Project Owner	Inbicon (DONG Energy)
Project Name	demo
Location	Kalundborg, Denmark
Technology	biochemical
Raw Material	lignocellulosics; wheat straw
Input	30 000 t/y
Product	ethanol; c5 molasses
Output Capacity	4300 t/y; 1.5 mmgy
Facility Type	demo
Investment	50 000 000 EUR
Funding	10 000 000 EUR
Status	operational
Start-up Year	2009
Contact Person	Ms. Lykke Mulvad Jeppesen, info@inbicon.com
Web	www.inbicon.com

Table 55: Inbicon – demo plant in Kalundborg, Denmark

Figure 66: Inbicon – picture of demo plant in Kalundborg, Denmark

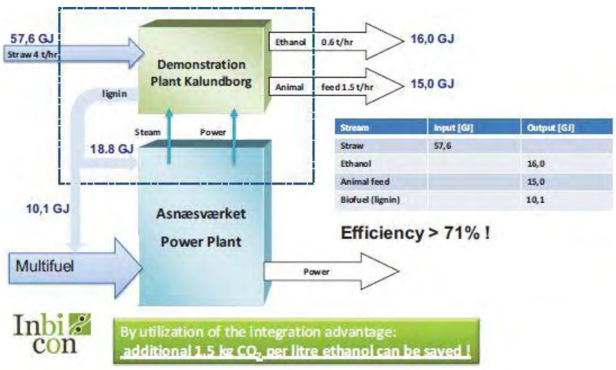


Figure 67: Inbicon – flow chart of demo plant in Kalundborg, Denmark

6.26 INEOS Bio

INEOS Bio is part of INEOS. A young and ambitious organization, INEOS has grown to become one of the world's largest chemical companies. INEOS Bio develops and brings to market green process technology for global use. INEOS Bio is the owner and developer of the INEOS Bio Bioenergy process – a highly innovative thermochemical and bio-chemical technology for the production of renewable biofuels and renewable power from waste materials such as Municipal Waste, green waste and a wide range of other low-cost carbon materials.

INEOS Bio's focus is providing sustainable solutions for waste to local communities while serving the global renewable transport fuels market and the renewable energy market. The INEOS Bio technology aims to address key needs of society such as combating climate change, utilizing waste as a resource, creating skilled local jobs and providing increased energy security and diversity. The first commercial advanced BioEnergy facility is currently being commissioned, with start of production expected early in the third quarter of 2012 at the Vero Beach, FL location. The project has been supported by the US Department of Energy, the US Department of Agriculture and the State of Florida.

The INEOS Bio Bioenergy process technology combines advanced bioethanol production, involving gasification, fermentation and distillation, with renewable power generation. The thermochemical gasification step provides feedstock flexibility, converting all types of biomass, including waste, into carbon monoxide and hydrogen gases. The bio-chemical fermentation step is a highly selective and high yield synthesis of ethanol from these gases at low temperature and pressure. The continuous process is also rapid, taking less than ten minutes to convert waste into ethanol. The Bioenergy process technology is energy-efficient and environmentally safe. The technology has been fully developed and tested since 2003 at integrated pilot scale on a broad range of waste feedstocks.

The INEOS Bio Bioenergy process technology can be described through the following steps:

1. Feed reception and drying
2. Gasification
3. Syngas heat recovery (to generate renewable power) and gas clean up
4. Fermentation (bioethanol production from syngas through biological process)
5. Filtration, distillation and dehydration (bioethanol recovery and purification)
6. Renewable power generation

In addition to the main steps described above, the plant includes ancillary systems such as the process sewer and chemical additives systems, culture storage, handling equipment and intermediate tankage.

The entire process is simple and well defined and energy costs are minimized. The combination of gasification and fermentation processes overcomes the significant challenges faced by other lignocellulosic ethanol processes (such as pretreatment of the lignocellulose feedstock, hydrolysis to fermentable sugars and fermentation of pentose sugars) by breaking complex molecules into CO, H2 and CO2, and then building them back efficiently into a single product, ethanol. Heat integration usefully employs the heat energy generated during gasification for the distillation step and power generation while the rapid synthesis of ethanol at the ambient temperature and low pressure of the fermentation step overcomes one of the primary disadvantages of most biological processes, which is a slow fermentation rate.

As the feedstock used is predominately biomass rather than fossil carbon, the carbon dioxide released from the process is mostly biogenic and does not contribute to global warming. The commercial INEOS Bio plants are designed to be safe, simple, robust, reliable and scalable.

Indian River County Facility

Vero Beach, United States

The INEOS Bio project facility will produce eight million gallons of third generation bioethanol per year from renewable biomass including yard, wood and vegetative wastes. The facility will also generate clean renewable power for export to the Florida market. The export of power is expected to be 1-2 megawatts, enough to power 1400 homes in the local area.

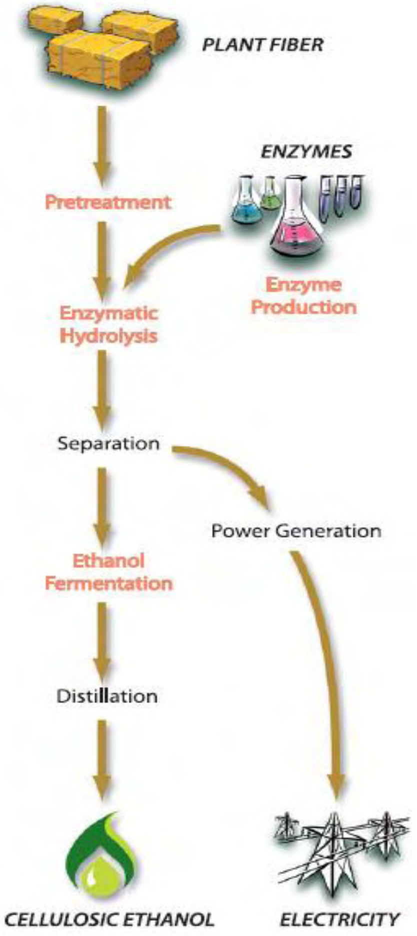
Project Owner	INEOS Bio
Project Name	Indian River County Facility
Location	Vero Beach, United States
Technology	biochemical
Raw Material	lignocellulosics
Project Input	Vegetative Waste, Waste wood, Garden Waste
Product(s)	ethanol; power
Output Capacity	24 000 t/y; 8 mmgy
Facility Type	commercial
Investment	132 000 000 USD
Project Funding	DOE share 50 000 000; owner's share 83 000 000 USD
Status	commissioning
Start-up Year	2013
Contact Person	biopress@ineos.com
Web	www.ineosbio.com

Table 56: INEOS Bio – commercial plant in Vero Beach, United States

Figure 68: INEOS Bio – picture of commercial plant in Vero Beach, United States (photo: April 2012)

6.27 Iogen

Established in the 1970s, Iogen Corporation has become one of Canada's leading biotechnology firms. Iogen is a world leader in technology to produce cellulosic ethanol, a fully renewable, advanced biofuel that can be used in today's cars. Iogen is also a manufacturer and marketer of enzyme products for application in processes that modify or hydrolyze natural fiber, including, for example, the pulp and paper, grain processing, brewing, textile and animal feed industries.



Iogen technology makes it economically feasible to convert biomass into cellulosic ethanol using a combination of thermal, chemical and biochemical techniques. The lignin in the plant fibre is used to drive the process by generating steam and electricity, thus eliminating the need for fossil CO_2 sources such as coal or natural gas.

<u>Pretreatment</u>: Iogen developed an efficient pretreatment method to increase the surface area and "accessibility" of the plant fibre to enzymes. This is achieved through a modified steam explosion process. This improves ethanol yields, increases pretreatment efficiency, and reduces overall cost.

<u>Enzyme Production</u>: Iogen has new, highly potent and efficient sulphite enzyme systems tailored to the specific pretreated feedstock. Iogen already has a worldwide business making enzymes for the pulp and paper, textiles and animal feed industries.

<u>Enzymatic Hydrolysis</u>: Iogen developed reactor systems that feature high productivity and high conversion of cellulose to glucose. This is accomplished through separate hydrolysis and fermentation using a multi-stage hydrolysis process.

<u>Ethanol Fermentation</u>: 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.

<u>Process Integration</u>: Large-scale process designs include energy efficient heat integration, water recycling, and co-product production that make the overall process efficient and economical. Iogen has successfully validated these improvements within its demonstration scale cellulosic ethanol facility.

Iogen Corporation's Ottawa Demonstration Facility

Ottawa, Canada

Iogen operates the world's first demonstration facility, opened in 2004, where clean-burning cellulosic ethanol fuel is made from agricultural residues. The demonstration plant, located at 300 Hunt Club Rd. East in Ottawa, is designed to prove the feasibility of Iogen's cellulosic ethanol process by validating equipment performance and identifying and overcoming production problems prior to the construction of larger plants. The plant can handle all functions involved in the production of cellulosic ethanol, including: receipt and pretreatment of up to 30 tonnes per day of feedstock; conversion of cellulose fibre into C6 and C5 sugars; C6 and C5 sugar fermentation; and distillation. Raw materials such as wheat, oat and barley straw, corn stover, sugar cane bagasse and other agricultural residues can be processed.

Since 2004, Iogen has produced over 2,000,000 litres of cellulosic ethanol, which has been used in a variety of real world applications around the world. In 2009, Iogen became the first cellulosic ethanol producer to sell its advanced biofuel at a retail service station.

Project Owner	Iogen Corporation
Project Name	Iogen Corporation's Ottawa Demonstration Facility
Location	Ottawa, Canada
Technology	Biochemical
Raw Material	Lignocellulosics
Project Input	Wheat/oat/barley straw, corn stover, sugar cane bagasse and other agricultural residues
Input Capacity	20-30 tonnes/day
Product(s)	Ethanol
Output Capacity	1600 t/y; 5000-6000 litres/day
Facility Type	Demonstration
Status	Operational
Start-up Year	2004
Contact Person	info@iogen.ca
Web	www.iogen.ca

Table 57 Iogen – demo plant in Ottawa, Canada

Figure 69: Iogen – pictures of demo plant in Ottawa, Canada

6.28 Iowa State University

The Iowa State University BioCentury Research Farm is an integrated research and demonstration facility dedicated to biomass production and processing. Activities at the Farm include cultivar development and testing; biomass harvest, storage, and transportation; biomass processing; and byproduct disposal.

The bioprocessing facility will offer three different lines for processing ground and pretreated biomass: a biochemical train, a thermochemical train, and a bioprocessing train (hybrid technologies). The products can be fuels and other biobased products. Byproduct recycling to the field shall be optimized.

BioCentury Research Farm

Boone, Iowa, United States

Project Owner	Iowa State University
Project Name	BioCentury Research Farm
Location	Boone, Iowa, United States
Technology	Three lines: biochemical, thermochemical and bioprocessing
Raw Material	lignocellulosics; grains, oilseeds, vegetable oils, glycerin
Input	5 t/d
Product	ethanol; FT-liquids
Output Capacity	200 t/y; 5 t/d
Facility Type	pilot
Investment	18 000 000 USD
Funding	2 500 000 USD
Status	operational
Start-up Year	2009
Contact Person	Lawrence Johnson; ljohnson@iastate.edu
Web	www.biocenturyresearchfarm.iastate.edu

Table 58: Iowa State University – pilot plant in Boone, United States

Figure 70: Iowa State University – picture of pilot plant in Boone, United States

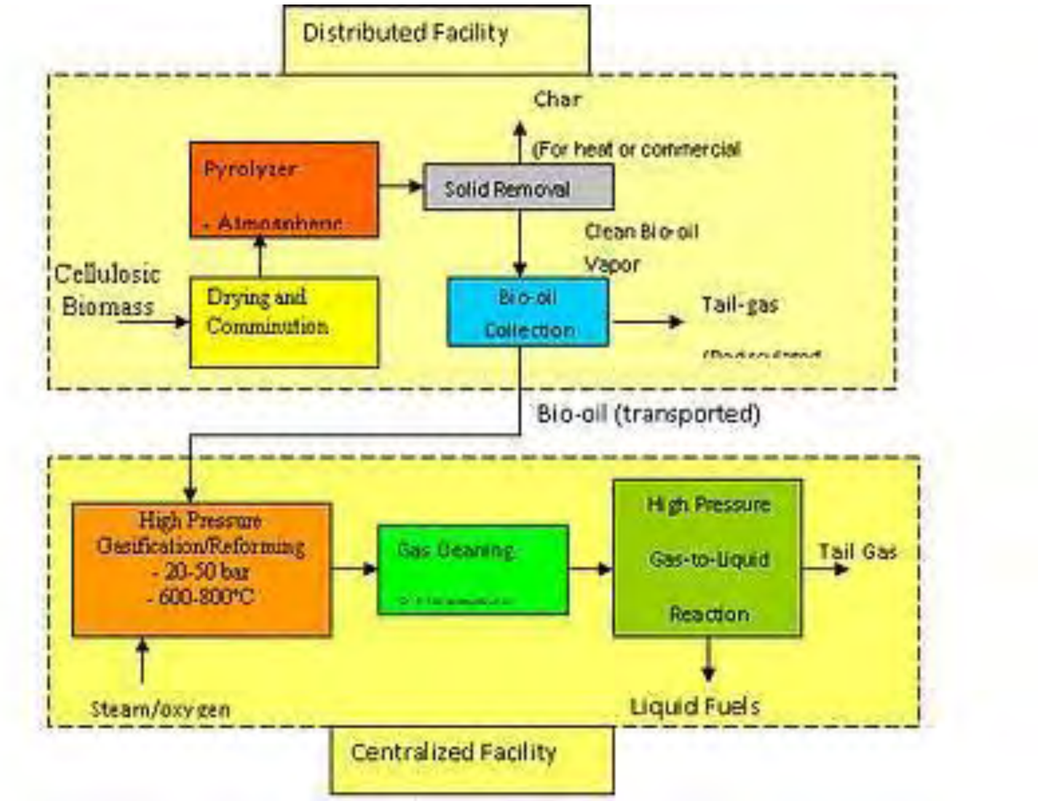


Figure 71: Iowa State University – flow chart of pilot plant in Boone, United States

6.29 Karlsruhe Institute of Technology (KIT)

In 2009, the Karlsruhe Institute of Technology (KIT) was founded by a merger of Forschungszentrum Karlsruhe and Universität Karlsruhe. KIT bundles the missions of both precursory institutions: A university of the state of Baden-Wuerttemberg with teaching and research tasks and a large-scale research institution of the Helmholtz Association conducting program-oriented provident research on behalf of the Federal Republic of Germany. Within these missions, KIT is operating along the three strategic fields of action of research, teaching, and innovation.

The Karlsruhe bioliq Process

The bioliq® pilot plant under construction will cover the process chain required for producing customized fuels from residual biomass. Being mainly synthesized from dry straw or wood, the BtL fuels offer environmental and climatic benefits through clean combustion. The integrative process chain, moreover, enables production of synthesis gas and chemicals.

bioliq® intends to mainly convert large local quantities of residual biomass by densifying energy. To save carbon dioxide and reduce routes of transport to refineries, the Karlsruhe BtL concept combines decentralized production of energy-rich bioliqSynCrude® by means of rapid pyrolysis and central processing with final industrial-scale refinement. Since the energy density of bioliqSynCrude® is by more than one order of magnitude higher relative to the volume of dry straw, it is evident that the method’s efficiency is enhanced by decentralized energy densification and that such densification ensures that biomass can be fully exploited and put to use in substance and in energy.

Figure 72: Karlsruhe Institute of Technology (KIT) – some pictures

bioliq

Karlsruhe, Germany

Project Owner	Karlsruhe Institute of Technology (KIT)
Project Name	bioliq
Location	Karlsruhe, Germany
Technology	thermochemical
Raw Material	lignocellulosics
Input Capacity	0.5 t/h
Product(s)	DME; gasoline-type fuel
Output Capacity	608 t/y; 100 l/h
Facility Type	pilot
Status	In commissioning
Start-up Year	mid 2013
Contact Person	Nicolaus Dahmen nicolaus.dahmen@kit.edu
Web	http://www.bioliq.de

Table 59: Karlsruhe Institute of Technology (KIT) – pilot plant in Karlsruhe, Germany

By early 2013, the fast pyrolysis part of the plant was in operation. Mechanical completion was achieved for gasification, gas cleaning, DME- and gasoline synthesis plants in 2012.

Figure 73: Karlsruhe Institute of Technology (KIT) – picture of pilot plant in Karlsruhe, Germany

6.30 LanzaTech New Zealand Ltd

Waste Flue Gas CO to Innovative Biofuel Production

LanzaTech, founded in 2005 in New Zealand, offers a fully integrated sustainable fuels and chemicals platform that uses local, available, abundant waste and low cost resources to produce fuels such as ethanol and chemicals such as 2.3Butanediol (2,3BDO) at high selectivities and yields.

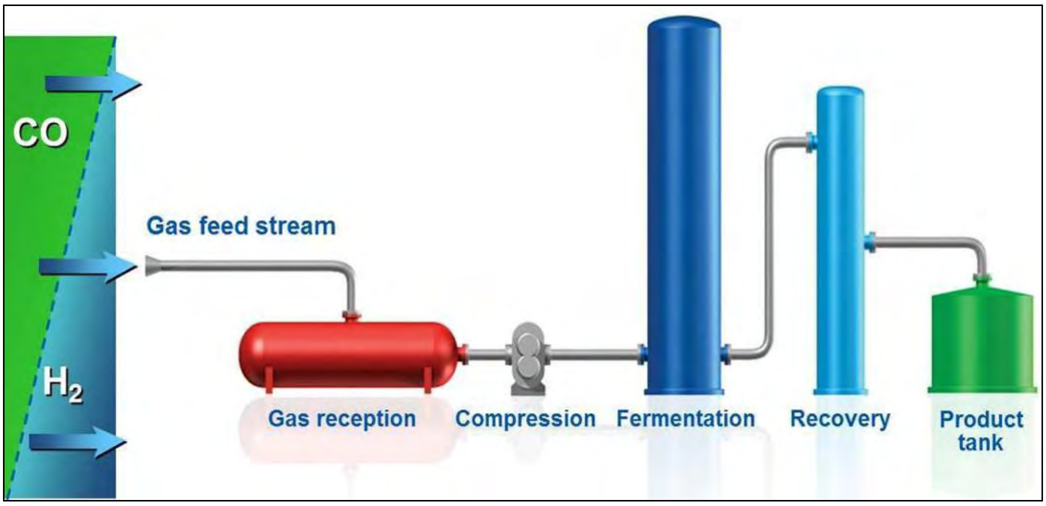


Figure 74: Lanza Tech – flow chart

The patented process uses a robust, feedstock-flexible microbe to convert CO-rich gases into fuels and chemicals. A wide range of input gas streams are suitable for the process; industrial flue gases from steel mills and processing plants, typically flared or used as a source of fuel; syngas generated from any biomass resource (such as municipal biowaste, organic industrial waste, and agricultural waste); coal derived syngas; and reformed natural gas are good examples. The LanzaTech technology is operating at demonstration scale and is being scaled up for commercial production.

LanzaTech's proprietary microbe, the company's unique bioreactor design, and novel gas introduction methods enable a suite of fermentation products and maximize product yields.

LanzaTech's gas fermentation process can use gas streams with flexible CO and H2 input gas ratios. While both CO and H2 are utilized in the LanzaTech process, LanzaTech's proprietary microbes are also able to consume hydrogen-free CO-only gas streams, due to a highly efficient biological water gas shift reaction within its proprietary bacteria.

The low temperature, low pressure gas fermentation route benefits from tolerance to several impurities, and the ability to utilize a flexible H2/CO ratio feed gas eliminates the need for extensive gas clean-up or conditioning. The microbes used in the gas fermentation process can convert nearly all of the carbon to fuels or chemicals at high selectivity compared to the conventional chemical syntheses routes. The result is higher overall fuel and thermal efficiency.

Life cycle analysis demonstrates that due to higher carbon to fuel conversion efficiency, the gas fermentation route reduces carbon emissions making it an overall ‘greener’ process compared with conventional petroleum products. Of critical importance, the LanzaTech process’ products can be produced at the scale needed to satisfy energy demands, using feed-stocks that do not compete with the food value chain.

LanzaTech estimates that 65% of steel mills worldwide use technology that could be retrofitted to include the LanzaTech Process. The process, which has been demonstrated at pilot scale since 2008 at the NZ Steel mill in Glenbrook, New Zealand, could potentially be utilized to produce nearly 11 billion gallons of ethanol from steel mill off gases in China alone. Worldwide, nearly 30 billion gallons of ethanol could be produced annually through steel mill waste gases using LanzaTech’s process, with the potential to significantly impact the global fuel pool. This same ethanol could alternatively be used to make 15B gallons of alternative aviation fuel (about 19% of the current world aviation fuel demand).

Lanzatech is now operating a demonstration facility in Shanghai, China in partnership with BaoSteel (the world’s second largest steel producer). It will produce 100,000 gallons ethanol per year. The first full scale commercial production facility in Shanghai will produce 30 million gallons ethanol per year by 2014. China produces 50% of the world’s steel and consumes 90% of that domestically. It also has ethanol mandates across many provinces, and so is an ideal first market for LanzaTech’s technology. Additional demonstration plants across a variety of geographies are scheduled for 2012. These include a second steel waste gas plant with Capital Steel in China, a facility using municipal solid waste-derived syngas with Concord Enviro in India and in the USA, a plant using biomass syngas derived from forestry residues.

Waste Gas to Fuel

Parnell, New Zealand

Project Owner	LanzaTech New Zealand Ltd.
Project Name	Waste gas to fuel
Location	Glenbrook, New Zealand
Technology	biochemical
Raw Material	Any gas containing Carbon Monoxide
Project Input	Industrial flue gasses
Product(s)	Ethanol
Output Capacity	90 t/y
Facility Type	Pilot
Status	Operational
Start-up Year	2008
Contact Person	Sean Simpson
Web	www.lanzatech.com

Table 60: Lanza Tech – pilot plant in Glenbrook, New Zealand

Figure 75: Lanza Tech – picture of pilot plant in Glenbrook, New Zealand

Waste Gas to Fuel

Shanghai, China

Project Owner	LanzaTech BaoSteel New Energy Co., Ltd.
Location	Shanghai, China
Technology	biochemical
Raw Material	Any gas containing carbon monoxide
Project Input	Industrial flue gasses
Product(s)	Ethanol
Output Capacity	300 t/y
Facility Type	Demonstration
Status	Operational
Start-up Year	2012
Contact Person	Jennifer Holmgren
Web	www.lanzatech.com

Table 61: Lanza Tech – demo plant in Shanghai, China

Figure 76: Lanza Tech – picture of demo plant in Shanghai, China

Biomass Syngas to Fuel

Soperton, Georgia

Project Owner	LanzaTech, Inc.
Project Name	LanzaTech Freedom Pines Biorefinery
Location	Georgia, USA
Technology	biochemical
Raw Material	Woody biomass
Project Input	Biomass syngas
Input Capacity	125 ton/day dry wood residues
Product(s)	Ethanol
Output Capacity	15 000 t/y
Facility Type	Commercial
Status	Evaluation and design
Start-up Year	2013 (planned)
Contact Person	John Burgess
Web	www.lanzatech.com

Table 62: Lanza Tech – commercial plant in Georgia, United States

Figure 77: Lanza Tech – picture of commercial plant in Georgia, United States

Waste Gas to Fuel

Beijing, China

Project Owner	Beijing Shougang LanzaTech New Energy Technology Co., Ltd.
Location	Beijing, China
Technology	biochemical
Raw Material	Any gas containing carbon monoxide
Project Input	Industrial off gas
Product(s)	Ethanol
Output Capacity	300 t/y
Facility Type	Demonstration
Status	Construction
Start-up Year	2013
Contact Person	Jennifer Holmgren
Web	www.lanzatech.com

Table 63: LanzaTech Beijing Shougang – demo plant in Beijing, China

MSW Syngas to Electricity and Fuel

Aurangabad, India

Project Owner	Concord Enviro Systems PVT Ltd.
Location	Aurangabad, India
Technology	biochemical
Raw Material	Any gas containing carbon monoxide
Project Input	Municipal solid waste
Product(s)	Ethanol, electricity
Output Capacity	300 t/y
Facility Type	Demonstration
Status	Design
Start-up Year	2013
Contact Person	Prabhakar Nair
Web	www.lanzatech.com

Table 64: Lanza Tech Concord Enviro Systems – demo plant in Aurangabad, India

6.31 Licella

Licella has developed a unique process to convert biomass into a stable Bio-Crude oil, which can be refined into various “drop in” fuels. Using Licella´s proprietary Catalytic Hydrothermal Technology (Cat-HTR), Licella can use any form of lignocellulosic biomass feedstock to produce its Bio-Crude oil

Licella’s process can in one step produce a high energy density (34-36 MJ//Kg) Bio-Crude within 30 minutes, that can be blended with traditional fossil crude and dropped in to existing refineries to make the same range of fuels e.g. petrol, diesel and jet and chemical feedstocks.

Licella’s pilot plant, near Sydney, has been operating successfully for 3 years on various feedstocks, laying the foundation for the Commercial Demonstration facility, which was officially opened by the Minister for Resource, Energy and Tourism, on the 14th of December 2011. Licella has recently scaled the reactors a further 10 times to deliver a capacity 100 times that of the pilot plant.

Licella’s technology has been validated by Boeing, GE, Lockheed Martin and others resulting in Virgin Australia and Air New Zealand signing MOU’s to pursue the commercialisation of the products produced from the new Demonstration Plant.

Licella is partnering with appropriate feedstock supplier and forming JV companies to ensure adequate supply of feedstock and capital to built plants. Licella’s Cat-HTR plants are expected to be co-located at feedstock sites, reducing transport costs and leveraging the partner’s capital infrastructure

Licella aims to commercialise globally its Bio-Crude by 2016. The construction of the first commercial plant is due to start late 2014

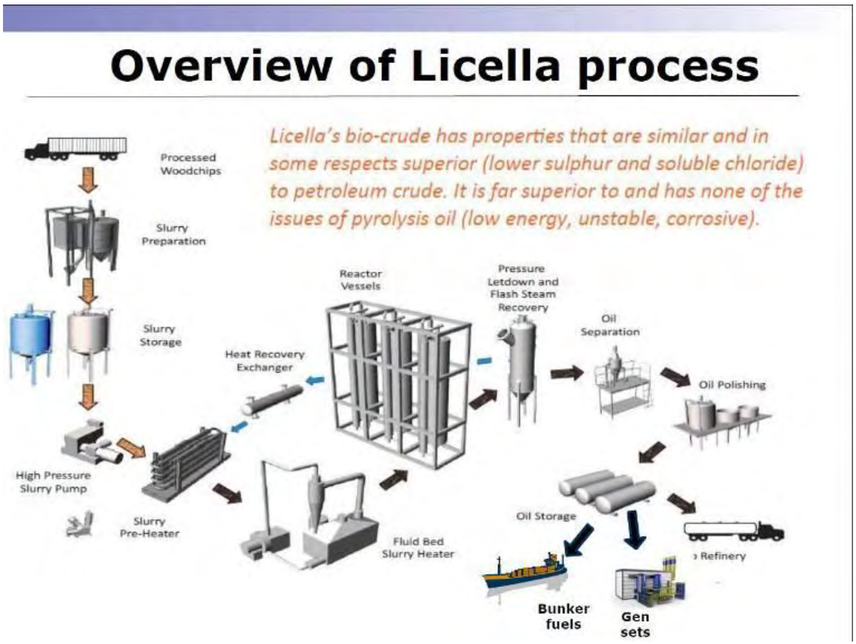


Figure 78: Licella – flow chart of commercial demo plant in Somersby, Australia

Commercial Demonstration Plant

Somersby, located one hour north of Sydney, NSW, Australia

Project Owner	Licella
Project Name	Biomass to Bio-Crude
Location	Near Sydney in Somersby, NSW, Australia
Technology	Catalytic Hydro-Thermal upgrading
Raw Material	Radiata Pine, Banna Grass, Algae
Input Capacity	1000 odt
Product(s)	Bio-oil
Output Capacity	2500 barrels pa; 350 t/y
Facility Type	Demonstration Plant
Investment	AU$ 10 000 000
Project Funding	Government and Private
Status	Operational
Start-up Year	2008
Contact Person	Info@licella.com.au
Web	www.licella.com.au

Table 65: Licella – demo plant in Somersby, Australia

Figure 79: Licella – picture of commercial demo plant in Somersby, Australia

6.32 Lignol

Lignol Innovations, a wholly owned subsidiary of Lignol Energy Corp (LEC-TSXV), is a British Columbia-based technology company that is developing patented biorefining technology to produce renewable fuels, chemicals and biomaterials from lignocellulosic feedstocks. Lignol's solvent-based pre-treatment process allows for the efficient fractionation of a wide variety of biomass into streams of cellulose, hemicellulose and lignin. The process allows for the conversion of cellulose to sugars for fermentation to ethanol, or other advanced biofuels, as well as the production of value-added biochemical co-products, including a suite of high purity lignin based products (HP-L™ Lignin) for which advanced applications are being developed in the chemical and materials industry.

Lignol's technology, which originated in the pulp and paper industry, has been adapted to produce sugars, renewable fuels and chemicals of interest to the biofuels, chemicals, polymers and materials industry. Differentiating Lignol from other companies in the biorefining sector is the broad suite of products that can be produced, notably the unique, proprietary HP-L Lignin products for which Lignol has developed partnerships with several leading companies to develop applications. Lignol's process also has the flexibility to produce high-value cellulose materials of interest to the textiles industry and several others. Lignol's technology is widely protected with 90 patents cases in various stages of prosecution and 9 awarded patents.

Lignol's process been extensively demonstrated in its integrated pilot-scale biorefinery in Burnaby, BC and is now ready for commercial deployment. Project development is underway with commercial arrangements and off-take agreements being developed.

Pilot Plant

Burnaby, Canada

Lignol operates its Biorefining Technology Development Centre near Vancouver, BC, where it employs a highly skilled staff of scientists, engineers and technologists. This facility is one of only a few worldwide capable of producing fuels and chemicals from biomass in a continuous, fully integrated operation. Coupled with advanced R&D laboratories, Lignol operates its pilot scale biorefinery in multi-day campaigns using fermenters up to 2500 litre scale. The operational data is used to develop and validate engineering designs for commercial facilities being planned for deployment in Canada and other parts of North America.

Project Owner	Lignol Innovations Ltd.
Project Name	Integrated Pilot-scale Biorefinery
Location	Burnaby, BC, Canada
Technology	Organosolv pretreament with bioconversion
Raw Material	lignocellulosics
Project Input	hardwood & softwood residues
Input Capacity	Up to 1 t/d
Product(s)	Ethanol, lignin
Facility Type	Integrated process pilot plant
Investment	20 000 000 CAD including infrastructure
Project Funding	Shareholder equity plus government support
Status	Operates in campaigns 24 hours per day from several days to several weeks.
Start-up Year	2009
Contact Person	Michael Rushton, COO – mrushton@lignol.ca
Web	www.lignol.ca

Table 66: Lignol – pilot plant in Burnaby, Canada

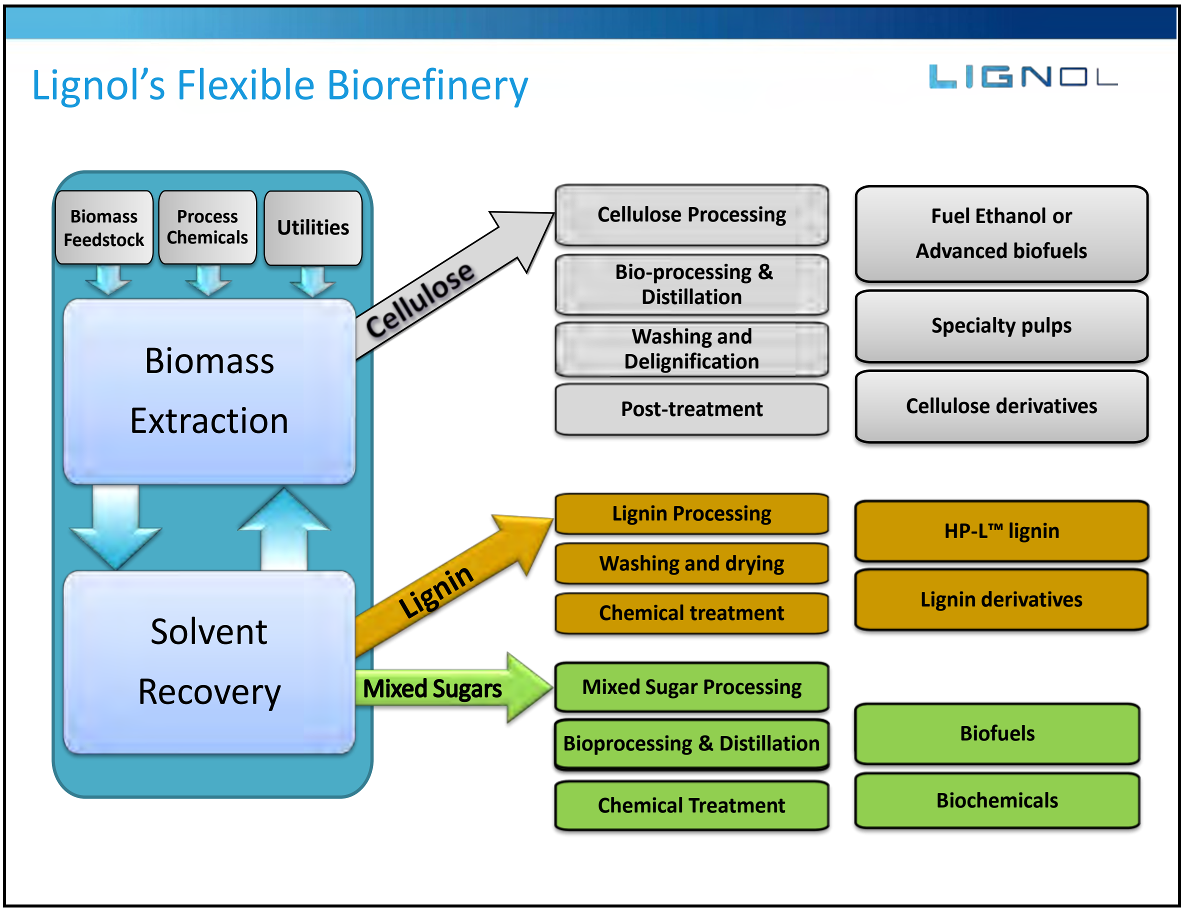


Figure 80: Lignol – flow chart

6.33 Mascoma

The unique technology developed by Mascoma Corporation uses yeast and bacteria that are engineered to produce large quantities of the enzymes necessary to break down the cellulose and ferment the resulting sugars into ethanol. Combining these two steps (enzymatic digestion and fermentation) significantly reduces costs by eliminating the need for enzyme produced in a separate refinery. This process, called Consolidated Bioprocessing or "CBP", will ultimately enable the conversion of the solar energy contained in plants to ethanol in just a few days.

Mascoma also runs a joint venture with J.M. Longyear, the Frontier Renewable Resources, planning a commercial facility (see 4.21 Frontier Renewable Resources).

Demonstration plant

Rome, NY, United States

Project Owner	Mascoma Corporation
Project Name	Demonstration Plant
Location	Rome, NY, United States
Technology	biochemical
Raw Material	lignocellulosics; Wood Chips, Switchgrass and other raw materials
Input	5 t/d
Product	ethanol; lignin
Output Capacity	500 t/y; 0.125 mmgy
Facility Type	demo
Partners	Marathon Oil Chevron Technology Ventures General Motors State of New York
Status	operational
Start-up Year	2003
Contact Person	Nathan Margolis Mascoma Corporation 67 Etna Road Lebanon, NH. 03766
Web	www.mascoma.com

Table 67: Mascoma – demo plant in Rome, United States

6.34 Neste Oil

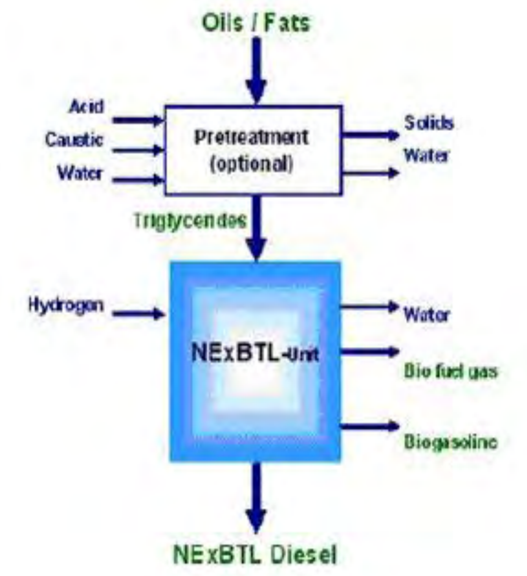


Figure 81: Neste Oil – flow chart

The CFPP of hydrotreated vegetable oil (HVO) lies at -25°C and therefore below that of FAME biodiesel. In the USA HVO is called renewable diesel. In this report the product is referred to as diesel-type hydrocarbon.

Porvoo 1

Porvoo, Finland

Project Owner	Neste Oil
Project Name	Porvoo 1
Location	Porvoo, Finland
Technology	chemical
Raw Material	oils, fats
Project Input	hydrotreatment of palm oil, rapeseed oil and animal fat
Product(s)	diesel-type hydrocarbons
Output Capacity	190000 t/y
Facility Type	commercial
Status	operational
Start-up Year	2007
Contact Person	renewablefuels@nesteoil.com; raimo.linnaila@nesteoil.com
Web	www.nesteoil.com

Table 68: Neste Oil - commercial plant 1 in Porvoo, Finland

Figure 82: Neste Oil – picture of commercial plant 1 in Porvoo, Finland

Porvoo 2

Porvoo, Finland

Project Owner	Neste Oil
Project Name	Porvoo 2
Location	Porvoo, Finland
Technology	chemical
Raw Material	oils, fats
Project Input	hydrotreatment of oils and fats
Product(s)	diesel-type hydrocarbons
Output Capacity	190 000 t/y
Facility Type	commercial
Status	operational
Start-up Year	2009
Contact Person	renewablefuels@nesteoil.com; raimo.linnaila@nesteoil.com
Web	www.nesteoil.com

Table 69: Neste Oil – commercial plant 2 in Porvoo, Finland

Rotterdam

Rotterdam, Netherlands

Project Owner	Neste Oil
Project Name	Rotterdam
Location	Rotterdam, Netherlands
Technology	chemical
Raw Material	oils, fats
Project Input	hydrotreatment of oils and fats
Product(s)	diesel-type hydrocarbons
Output Capacity	800 000 t/y
Facility Type	commercial
Status	operational
Start-up Year	2011
Contact Person	renewablefuels@nesteoil.com; raimo.linnaila@nesteoil.com
Web	www.nesteoil.com

Table 70: Neste Oil – commercial plant in Rotterdam, Netherlands

Figure 83: Neste Oil – picture of commercial plant in Rotterdam, Netherlands

Singapore

Singapore, Singapore

Project Owner	Neste Oil
Project Name	Singapore
Location	Singapore, Singapore
Technology	chemical
Raw Material	oils, fats
Project Input	hydrotreatment of oils and fats
Product(s)	diesel-type hydrocarbons
Output Capacity	800 000 t/y
Facility Type	commercial
Investment	550 000 000 EUR
Status	operational
Start-up Year	2010
Contact Person	renewablefuels@nesteoil.com; raimo.linnaila@nesteoil.com
Web	www.nesteoil.com

Table 71: Neste Oil – commercial plant in Singapore

Figure 84: Neste Oil – picture of commercial plant in Singapore

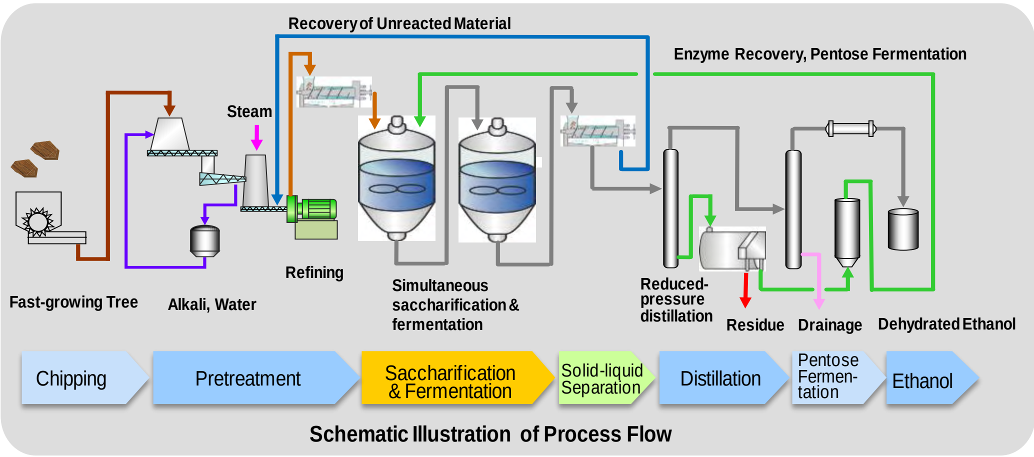
6.35 New Energy and Industrial Technology Development Organization (NEDO)

Oji Holdings Corporation (OJI) is a Japan's paper manufacturer founded in 1873. OJI is the 6th-largest paper manufacturing company in the world in terms of revenue. OJI has progressively implemented forestation projects worldwide. OJI actively seek to promote structural changes in business portfolio through the discovery of new possibilities in paper, forests and trees.

Nippon Steel & Sumikin Engineering Co., Ltd (NSENGI) is an engineering company and one of core subsidiaries of Nippon Steel & Sumitomo Metal Corporation. NSENGI entered the bioethanol field in 2005 with an R&D project for bioethanol derived from food waste. In 2008, NSENGI participated in a technology development project to produce ethanol from pomace generated during the production process of orange juice. A commercial plant was constructed at an orange juice factory in Japan.

The National Institute of Advanced Industrial Science and Technology (AIST) was founded in 2001 as an independent administrative institution funded by the Japanese government to a large extent. AIST and its predecessor organizations have been contributing to advancement in industrial science and technologies since 1882. AIST established research units for biofuels in 2003, and the present "Biomass Refinery Research Center" covers wide spectrum of biomass utilization; fuels, chemicals, and materials.

Since 2009, OJI, NSENGI and AIST have been entrusted to a Japanese national project of cellulosic ethanol development financed by New Energy and Industrial Technology Development Organization (NEDO). A Mechanochemical Pulping Process for conversion of cellulose to ethanol has been developed. The project's goal is to develop a coherent bioethanol production system from biomass plantation to ethanol production. The targeted cellulosic biomass in the project is wood from eucalyptus. The development includes basic studies on raw material production, pretreatment using pulping technology, simultaneous saccharification and fermentation using thermal and acid tolerant yeast, and saving energy technology with self-heat recuperation.



By reference to "NEDO: Development of an Innovative and Comprehensive Production System for Cellulosic Bioethanol"

Figure 85: NEDO – flow chart

Pilot Plant

Kure, Hiroshima, JAPAN

Project Owner	New Energy and Industrial Technology Development Organization (NEDO)
Project Name	Development of an Innovative and Comprehensive Production System for Cellulosic Bioethanol
Location	Hiroshima, Japan
Technology	Biochemical
Raw Material	lignocellulosics: wood chips
Input Capacity	1 Metric ton per day
Product(s)	Ethanol
Output Capacity	65 t/y; 50 litres per day
Facility Type	Pilot
Partners	Oji Holdings Nippon Steel & Sumikin Engineering The National Institute of Advanced Industrial Science and Technology (AIST)
Status	Operational
Start-up Year	2011
Contact Person	Oji Holdings: Jun SUGIURA sugiura212jun@oji-gr.com Nippon Steel & Sumikin Engineering: Yoichi ISHIBASHI ishibashi.yohichi@eng.nssmc.com AIST: Shinichi YANO s-yano@aist.go.jp
Web	Oji Holdings: http://www.ojiholdings.co.jp/ Nippon Steel & Sumikin Engineering: http://www.eng.nssmc.com AIST: http://www.aist.go.jp/

Table 72: NEDO – pilot plant in Hiroshima, Japan.

Figure 86: NEDO – picture of pilot plant in Hiroshima, Japan.

6.36 NREL – National Renewable Energy Laboratory

The National Renewable Energy Laboratory (NREL) is the only national laboratory in the U.S. solely dedicated to advancing renewable energy and energy efficiency technologies from concept to commercial application. For 35 years, NREL innovations, analysis, and expertise have catalysed and enabled the emergence of a U.S. clean energy industry and led to numerous success stories from across the laboratory. NREL's 327-acre main campus in Golden, Colorado, is a living model of sustainable energy. The laboratory also operates the National Wind Technology Center on 305 acres located 13 miles north of its main campus.

NREL develops renewable energy and energy efficiency technologies and practices, advances related science and engineering, and transfers knowledge and innovations to address the nation's energy and environmental goals.

NREL's research and development achievements have helped shape clean-energy alternatives for powering homes and businesses, and the nation's transportation infrastructure. The laboratory's research and analysis activities span the full spectrum of innovation, from fundamental science and market-relevant research to process development, systems integration, testing and validation.

Integrated Biorefinery Research Facility (IBRF)

Golden, Colorado, United States

The Integrated Biorefinery Research Facility contains the following equipment and related capabilities:

Pretreatment

- Bench- and pilot-scale biomass chemical impregnation and dewatering systems (screw presses)
- 1-L high-solids stirred batch reactor
- 4-L steam-injected batch reactor
- 130-L steam-jacketed and steam-injected batch paddle-type mixed reactor limited to <160°C
- Continuous horizontal screw-type reactor, 100-200 kg per day (dry basis) capacity (140°-210°C and 5-30 min residence times)

- Continuous horizontal screw-type reactor, 0.5-1.0 ton biomass per day (dry basis) capacity (140°-210°C and 3-120 min residence times)
- Continuous vertical reactor, 0.7-1.0 ton biomass per day (dry basis) capacity (140°-200°C and 1-60 min residence times)
- Continuous vertical reactor, 0.5-1.0 ton biomass per day (dry basis) capacity (140°-210°C and 10-40 min residence times), with an in-line secondary reactor for optional treatment at lower temperatures
- All reactor systems have multiple options for pretreatment catalysts.

Enzymatic hydrolysis

- High-solids bench-scale tumbling reactors (up to 10 L)
- 1900-L hot-water jacketed paddle reactor for high solids slurries
- Four 4000-L hot-water jacketed paddle reactors for semi-continuous processing at total solids loadings greater than 20% (w/w).

Fermentation

Multiple stand-alone sterilize-in-place fermentation systems from 15-L to 100-L scale

- Pilot plant fermentation train consisting of two 160-L seed production vessels, two 1500-L seed production vessels, and four main 9,000-L fermentation vessels
- All vessels can be operated in either batch, fed-batch, or continuous mode of operation
- Continuous high-temperature, short residence time sterilizer
- Bench-scale fermentation laboratories housing a number of traditional bench-top fermentors, ranging in size from 500 Ml to 5 L, and one high-solids bioreactor.

Product separation and recovery

- Solid-liquid separation systems, solid-bowl and perforated-bowl centrifuges
- Semi-continuous pressure belt filter
- Forced-recirculation evaporator
- 19-sieve tray distillation column.
- Process-related capabilities
- Wet chemistry-based and spectroscopy-based compositional analysis

Process engineering and economic analysis

- Molecular biology
- Microscopy analysis
- Rheology and particle size characterization
- High throughput pretreatment and enzymatic hydrolysis processing and analysis

While using the IBRF, industry partners have access to NREL's world-renowned experts, process equipment, and systems that can be used to develop and evaluate commercial to NREL's state-of-the-art molecular biology, biochemistry, and biomass compositional analysis laboratories. Advanced biofuels produced in the IBRF can be tested and analyzed in NREL's fuel testing laboratories, and data generated in the IBRF can be incorporated into technoeconomic and life cycle analysis models to estimate the feasibility and sustainability of commercial-scale production.

Project Owner	NREL (National Renewable Energy Laboratory)
Project Name	Integrated Biorefinery Research Facility (IBRF)
Location	Golden, Colorado, United States
Technology	biochemical
Raw Material	lignocellulosic
Input Capacity	450–900 kg (0.5–1 ton) per day of dry biomass
Product(s)	ethanol
Output Capacity	Up to 100 t/y (100 000 L/a)
Facility Type	pilot
Investment	US $50 million (cumulative)
Project Funding	government and industry
Status	operational
Start-up Year	1994 (expansion completed 2011)
Contact Person	John Ashworth, john.ashworth@nrel.gov Rich Bolin, richard.bolin@nrel.gov
Web	www.nrel.gov/biomass

Table 73: National Renewable Energy Laboratory (NREL) – Integrated Biorefinery Research Facility in Golden, United States

Figure 87: National Renewable Energy Laboratory (NREL) – picture of Integrated Biorefinery Research Facility in Golden, United States

Thermochemical Users Facility (TCUF)

Golden, Colorado, United States

The Thermochemical Users Facility comprises the following laboratories and capabilities:

- **Thermochemical Process Development Unit.** The heart of the TCUF is the 0.5-metric-ton-per-day Thermochemical Process Development Unit (TCPDU), which can be operated in either a pyrolysis or gasification mode. The main unit operations in the TCPDU include 8-inch diameter fluidized bed reactor; 1.5-inch diameter by 100-ft-long tubular entrained flow reactor; cyclonic particulate separation; fluidized bed catalytic reformer; and wet scrubber system. A variety of particulate removal, secondary catalytic conversion, and condensation equipment is also available.

- **Catalytic Fuel-Synthesis Reactors**. The TCUF includes a full-stream, catalytic-fuel-synthesis system capable of converting the full syngas stream from the TCPDU to liquid fuels. Three independent reactors can use the TCPDU syngas stream to test multiple synthesis catalysts or reactor conditions for comparative fuel synthesis studies.

- **Fuel Synthesis Catalyst Test Facility**. NREL's Fuel Synthesis Catalysis Laboratory provides a wide range of capabilities in high-pressure heterogeneous catalyst testing. Current research areas of emphasis are mixed alcohol and hydrocarbon synthesis from biomass-derived syngas. Many other catalyst systems can be studied by making minor system modifications. This state-of-the-art reactor laboratory consists of three bench-scale reactors and a custom gas analysis system. The reactors are designed for isothermal testing of gas-to-liquids catalysts using synthesis gas. All reactors are fully integrated with the TCPDU so researchers can evaluate catalyst performance with "real-world" biomass-derived syngas. A full-stream, catalytic fuel synthesis system capable of converting the full syngas stream from the TCPDU to liquid fuels is under construction.

- **Bench-Scale Biomass Conversion System**. This 2-in.-diameter fluidized bed reactor system can be used for small-scale studies of biomass and bio-oil gasification, pyrolysis, catalytic reforming of pyrolysis liquids or vapors, or raw syngas conditioning.

- **Biomass Catalyst Characterization Laboratory**. Houses instrumentation to comprehensively characterize catalysts and materials and test their performance. Material characterization capabilities span a range of physical and chemical techniques. Physical characterization capabilities include: Rapid thermal analysis; surface area, particle size, and pore size distribution; and adsorption and chemisorption. Chemical characterization capabilities include: Elemental composition; surface analysis; ultimate and proximate analysis; surface chemistry; crystal structure; fuel analysis. Catalyst screening capabilities include: Fully automated, real-time screening of catalyst performance, lifetime, and regenerability; fuel synthesis catalyst screening in batch or flow through mode with online analytical instrumentation; and kinetic studies of catalytic reactions.

- **Magnetic Resonance Facility**. NREL scientists analyze solid and liquid samples on three nuclear magnetic resonance (NMR) spectrometers as well as an electron paramagnetic resonance (EPR) spectrometer.

- **Molecular Beam Mass Spectrometry.** NREL has six molecular beam mass spectrometers (MBMS): two stationary systems; two field-deployable systems, customized for use in industrial environments; and two additional high-throughput stationary systems with autosamplers. MBMS applications include: Plant cell wall chemistry characterization by analytical pyrolysis, which provides rapid estimates of plant cell wall constituents and lignin structure that complements time consuming and expensive traditional wet chemical analysis methods; onsite monitoring of thermochemical processes using transportable MBMS for real-time, continuous monitoring with near-universal detection of chemical compounds, which through direct, robust sampling preserves condensable/ reactive species in high-temperature, high-pressure, wet, and particulate-laden gases and vapors; catalyst characterization using real pyrolysis and gasification process streams for rapid screening of heterogeneous catalysts and product yield estimates; generation of dynamic data to support fundamental and empirical studies of thermochemical reactions and kinetics, including modeling of catalyst deactivation, identification of thermal degradation pathways, investigation of pyrolysis and gasification mechanisms and kinetics and reaction parameter screening for engineering scale-up.

The TCUF facility and associated laboratories are unique in their ability to ulphit products online over a wide spectrum of chemical compositions. A variety of dedicated analytical instruments are available to connect to processes to enable special sampling and analysis methods. The analytical equipment used throughout the TCUF includes:

- Molecular beam mass spectrometers
- Rapid cycle gas chromatographs
- Non-dispersive infrared sensors
- Thermal conductivity detectors
- Paramagnetic O2 sensor
- Residual gas analyzers.

The TCUF's analytical capability can also be taken on the road to provide on-line sampling at a customer's site.

The TCUF capabilities, facilities, technologies, and expertise are available to outside researchers and developers interested in cooperative research and development agreements, work-for others agreements, licenses, and other collaborative business arrangements.

Project Owner	NREL (National Renewable Energy Laboratory)
Project Name	Thermochemical Users Facility (TCUF)
Location	Golden, Colorado, United States
Technology	Thermochemical (gasification and pyrolysis)
Raw Material	lignocellulosic
Input Capacity	450 kg (0.5 ton) per day dry biomass
Product(s)	transportation fuels and chemicals
Output Capacity	Up to 50 t/y (50 000 L/a)
Facility Type	pilot
Investment	US $30 million (cumulative)
Project Funding	Government and industry
Status	Operational
Start-up Year	1985 (expansion in progress)
Contact Person	Rich Bolin, richard.bolin@nrel.gov
Web	www.nrel.gov/biomass

Table 74: National Renewable Energy Laboratory (NREL) – Thermochemical Users Facility in Golden, United States

Figure 88: National Renewable Energy Laboratory (NREL) – picture of Thermochemical Users Facility in Golden, United States

6.37 Petrobras

PETROBRAS

An integrated energy company

Petrobras is driven by the challenge of supplying the energy that can propel development and ensure the future of the society with competency, ethics, cordiality, and respect for diversity.

Petrobras is a publicly traded corporation, the majority stockholder of which is the Government of Brazil, and it performs as an energy company in the following sectors: exploration and production, refining, oil and natural gas trade and transportation, petrochemicals, and derivatives, electric energy, biofuel and other renewable energy source distribution.

A leader in the Brazilian oil industry, Petrobras has expanded operations aiming to be among the top five integrated energy companies in the world by 2020. Petrobras has a presence in 27 countries. The 2011-2015 business plan foresees investments in the order of $224.7 billion.

Biofuels produced from renewable sources

The investments Petrobras has made in biofuels reassert its commitment to attain development associated to social and environmental responsibility. It is the goal of Petrobras to create and improve technologies that ensure global leadership in the production of biofuels.

In 2008, Petrobras incorporated its wholly owned subsidiary Petrobras Biocombustível, which produces ethanol and biodiesel. Present in all regions of the country, the Company aims to produce biofuels in Brazil and abroad in a safe, profitable manner and with social and environmental sustainability, thus contributing to reducing greenhouse gas emissions and driving development in the countries where has operations.

In the ethanol segment, Petrobras Biocombustível has signed on partnerships to produce the biofuel. The bagasse of the sugarcane used to produce ethanol is reused to generate electric power. Part of that energy energizes the plants, while the rest is sold. Petrobras Biocombustível is also working to have its first industrial plant of ethanol from sugarcane bagasse.

Petrobras Biocombustível operates in both production and marketing in the biodiesel business. The company also trades subproducts derived from biodiesel production, such as fatty acid, gum, castor oil, soybean meal, castor bean cake, sunflower meal and sunflower oil.

Ethanol

Brazil is world renowned for its pioneering work in introducing a biofuel produced from sugarcane in its energy matrix: ethanol.

Since the late 1970's, when the "Proálcool" program was rolled out, ethanol gained great momentum and became definitively an important source of energy for the Country.

Petrobras Biocombustível invests in technological innovations to increase not only the productivity, but also the sustainability of this biofuel production chain, as is the case of second-generation ethanol, which is obtained from sugarcane bagasse.

Biodiesel

Since 2010, all of the diesel marketed in Brazil contains a mixture of 5% biodiesel, which is a fuel produced from oilseed crops grown in Brazil, such as soybeans, cotton, palm, castor beans, sunflower and canola, as well as animal fat and frying oil waste.

Petrobras Biocombustível owns three biodiesel plants, in Candeias (state of Bahia), Quixadá (state of Ceará) and Montes Claros (state of Minas Gerais), and two more in partnerships, one of which in Marialva (state of Paraná) and the other in Passo Fundo (state of Rio Grande do Sul).

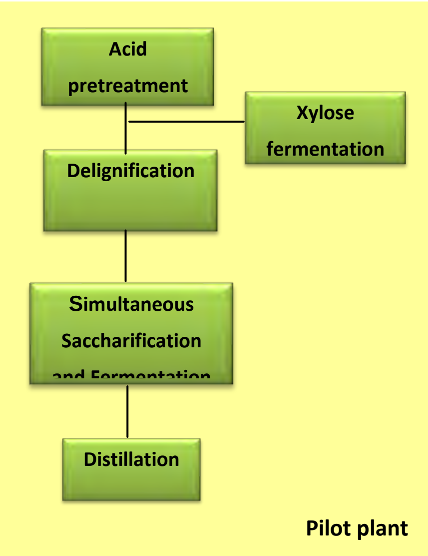
All plants hold the Social Fuel Seal, awarded by the Ministry of Agrarian Development to biodiesel producers that promote social inclusion and regional development.

Technology development

Petrobras started in 2004 in partnership with Brazilian universities studies for utilization of sugar cane bagasse and in 2006 patented the process of conversion of sugarcane bagasse to ethanol via enzymatic route. The pilot scale operation started in 2007 at the Research Center of Petrobras in Rio de Janeiro (CENPES). The first step of the conversion process uses acid pretreatment under mild conditions. This step takes advantage of xylose formation which could suffer an alcoholic fermentation using Pichia stiptis yeast. The treated bagasse is submitted to partial alkaline wash to remove the lignin and thus is submitted to enzymatic hydrolysis to obtain glucose. The strategy of simultaneous saccharification and fermentation (SSF) is used with the Saccharomyces cerevisiae yeast. Alternatively this route could be changed with the delignification step in order to increase the process yield.

In 2010 Petrobras began a partnership with the company Blue Sugar (formerly KL Energy) to accelerate the development of the production process of ethanol 2G from sugarcane bagasse, adapting the existing demonstration plant. The first step uses the acid-catalyzed thermal pretreatment, followed by the enzymatic hydrolysis. The sugar fermentation is carried out using a genetically modified microorganism to convert glucose and xylose into ethanol.

Block diagrams



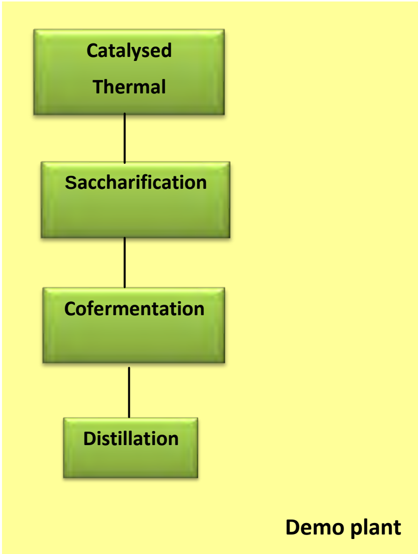


Figure 89: Petrobras – flow chart

Bioethanol pilot plant

Rio de Janeiro, Brazil

Project Owner	Petrobras
Project Name	pilot
Location	Rio de Janeiro, Brazil
Technology	biochemical
Raw Material	sugarcane bagasse
Input Capacity	10 kg/d
Product(s)	ethanol
Output Capacity	Yield = 270 litres of ethanol/ ton of dried bagasse
Facility Type	pilot
Status	operational
Start-up Year	2007
Contact Person	lidia@petrobras.com.br palombo@petrobras.com.br

Table 75: Petrobras – pilot plant in Rio de Janeiro, Brazil

Figure 90: Petrobras – picture of pilot plant in Rio de Janeiro, Brazil

Bioethanol demonstration plant

Upton, Wyoming, USA

Project Owner	Petrobras and Blue Sugars
Project Name	Second generation ethanol demo plant
Location	Upton, Wyoming, USA
Technology	biochemical
Raw Material	sugarcane dried bagasse
Input Capacity	60 ton of bagasse/week
Product(s)	ethanol
Output Capacity	700 ton of ethanol/year
Facility Type	Demonstration
Project Funding	Petrobras
Status	operational
Start-up Year	2011
Contact Person	palombo@petrobras.com.br

Table 76: Petrobras – demo plant in Upton, United States

Please note that under 4.10 Blue Sugar, you will find a fact sheet of the same demo plant but with different input and output figures. The fact sheet on this page shows the numbers of the specific Petrobras test programme in Upton whereas the fact sheet under Blue Sugars features the name plate capacity of the same plant.

Figure 91: Petrobras – picture of demo plant in Upton, United States

6.38 POET-DSM Advanced Biofuels

POET-DSM Advanced Biofuels is a joint venture between POET and Royal DSM aimed at making cellulosic bioethanol competitive with grain ethanol, the most competitive renewable liquid transportation fuel on the market today.

POET-DSM Advanced Biofuels intends to globally license an integrated technology package that converts corn crop residue to cellulosic bioethanol to third parties, as well as the other 26 existing corn ethanol plants in POET's network.

The process makes use of corn stover that passes through the combine during harvest. It uses approximately 25% of the material, leaving about 75% on the ground for erosion control, nutrient replacement and other important farm management practices.

It all starts with Project LIBERTY, a fully funded facility that is under construction today in Emmetsburg, Iowa. Project LIBERTY is expected to be POET-DSM Advanced Biofuel's first commercial–scale, cellulosic ethanol plant. Scheduled to begin operations in Iowa in 2013, the plant is designed to use enzymatic hydrolysis to produce 20 million gallons per year, growing to approximately 25 million gallon per year.

The plant will share infrastructure with the adjacent POET Biorefining – Emmetsburg. Roads, land and other features will be shared, and the co-product from the cellulosic ethanol process will be biogas, which will meet a significant portion of the adjacent grain ethanol plant's power needs.

The United States EPA modeled 7.8 billion gallons of cellulosic ethanol coming from corn crop residue by 2022. The U.S. Departments of Energy and Agriculture have estimated that more than one billion tons of biomass is available in America that could produce enough cellulosic bioethanol to replace a third of the country's gasoline use.

POET and DSM are well positioned to lead commercial development in this area with the combined capabilities to handle supply chain; from acquiring corn crop residue, efficiently handling bioconversion with world class processes, to the ability to move cellulosic bioethanol into the fuel market.

POET-DSM Advanced Biofuels plans to expand cellulosic ethanol production within the POET network and license the technology to other ethanol producers in America and around the world.

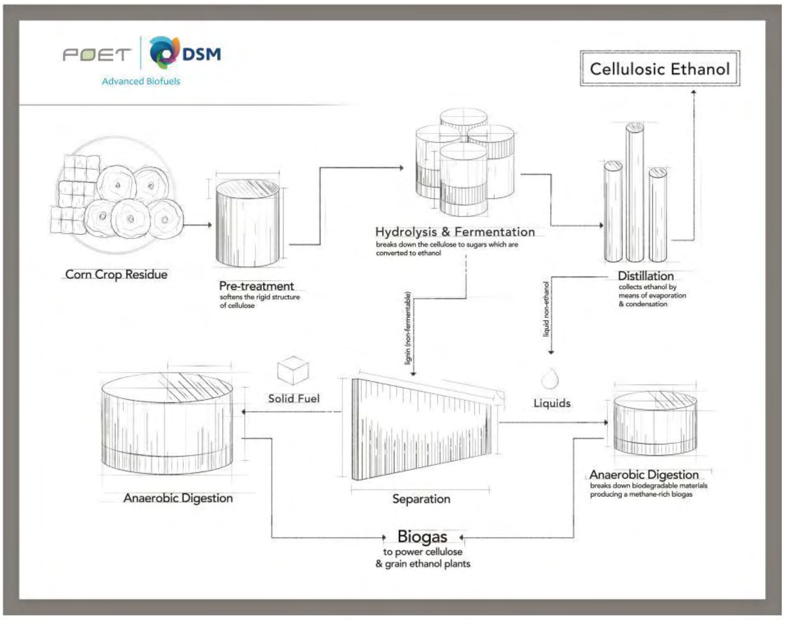


Figure 92: POET – flow chart

Project LIBERTY

Emmetsburg, United States

Project LIBERTY is under construction today, with start-up scheduled for Q4 2013. The biomass stackyard is scheduled to accept 85,000 tons of crop residues from area farmers this fall, the latest step-up in feedstock procurement. Once operational, the biorefinery will use approximately 285,000 tons of biomass per year.

Project Owner	POET-DSM Advanced Biofuels
Project Name	Project LIBERTY
Location	Emmetsburg, United States
Technology	biochemical
Raw Material	lignocellulosics
Project Input	agricultural residues
Product(s)	ethanol; biogas
Output Capacity	75 000 t/y; 20 mmgy
Facility Type	commercial
Investment	250 000 000 USD
Status	Under construction
Start-up Year	2013
Contact Person	Matt Merritt; matt.merritt@poet.com
Web	http://www.projectliberty.com/

Table 77: POET-DSM Advanced Biofuels – commercial plant in Emmetsburg, United States

Figure 93: POET-DSM Advanced Biofuels – picture of commercial plant in Emmetsburg, United States

POET Research Center

Scotland, United States

Project LIBERTY is under construction today thanks in large part to the process breakthroughs made possible by POET's pilot cellulosic ethanol plant in Scotland, S.D. The plant, which started operating in 2008, has gone through multiple redesigns as POET has refined the process to make it more efficient and more cost-competitive in the fuel market.

Project Owner	POET
Project Name	Scotland
Location	Scotland, United States
Technology	biochemical
Raw Material	lignocellulosics
Project Input	agricultural residues
Product(s)	ethanol
Output Capacity	60 t/y; 0.02 mmgy
Facility Type	pilot
Investment	9 000 000 USD
Status	operational
Start-up Year	2008
Contact Person	Matt Merritt; matt.merritt@poet.com
Web	www.poet.com

Table 78: POET – pilot plant in Scotland, United States

Figure 94: POET – picture of pilot plant in Scotland, United States

Feedstock sustainability

The most recent soil data from Emmetsburg, Iowa continues to demonstrate that harvesting crop residue can be a responsible part of good farm management.

For the last four years, Project LIBERTY has commissioned soil sustainability work from researchers with Iowa State University and the U.S. Department of Agriculture. They have studied six different harvest methods in an effort to provide area farmers with data to help them make decisions about biomass harvesting.

The most recent data is consistent with previous years.

“Basically, at the removal level that POET-DSM recommends, there is no reduction in yield, and removal rates are well within the sustainability limits,” said Dr. Stuart Birrell with Iowa State University. Birrell and Dr. Douglas Karlen of USDA-ARS lead the research.

POET-DSM contracts for about 1 ton of biomass per acre with participating farmers. That’s less than 25% of the available above-ground biomass. They are contracting for 85,000 tons this year, and once operational, Project LIBERTY will require about 285,000 tons per year.

“From the beginning we’ve said we would pay close attention to the data in determining our contracts with farmers,” said Larry Ward, Senior Vice President of Project Development at POET. “We’re clearly well within the limits of what the research says is responsible biomass harvesting.”

"As the new entrant to this project we are pleased to embark on all previous work done by POET, Iowa State University, and the USDA already. This work seamlessly fits in our belief that we need to approach this new era of agricultural developments in a responsible way. Sustainable soil fertility will be the source to success in a bio-economy," said Steve Hartig, vice-president Bio-Energy for DSM.

Birrell said nutrient replacement is minimal, with no evidence of a need to replace nitrogen. Based on the research, POET-DSM recommends to farmers the addition of 10-15 pounds of potash when soil tests indicate it is needed.

The effects of biomass harvesting on soil carbon have also proven to be minimal according to measurements of soil organic carbon, Birrell said, more an effect of yield and tillage intensity than biomass removal.

6.39 Procethol 2G

The Project

What makes this project so unique is its objective of developing a sustainable process that integrates a wide range of raw materials and is adaptable not only to the different geographic areas in which it will be used (territory, climate) but also to the different seasons. Labelled by the ulphi "Industrie Agro Ressources" (IAR) competitive cluster, the FUTUROL PROJECT will require investments of a total of 76.4 million Euros. It has received a grant of 29.9 million Euros from OSEO (a French agency that promotes innovation in industry).

The FUTUROL PROJECT will last for eight years and includes a pilot phase followed by a prototype phase. The pilot plant has been built at the agro-industrial site of Pomacle-Bazancourt (Marne-FRANCE); it is now fully operational since 2011.

Figure 95: Procethol 2G – picture of European Biorefinery of Pomacle-Bazancourt (Marne – FRANCE) © CANON PROCETHOL 2G

The objectives of the project are to bring to market a process, technologies and products (enzymes and yeasts) that can be used :

- to produce bioethanol at a competitive price thanks to diversified raw materials (agricultural byproducts, forest biomass, dedicated crops, etc.);
- to develop the most suitable cellulose extraction techniques, select the enzymes and yeasts required and to develop the hydrolysis and fermentation processes best suited to each raw material configuration;

- to obtain the best possible energy and greenhouse gas balance throughout the entire production process;
- to ensure that these biofuels meet the requirements of long-term sustainable development, throughout the whole field-to-wheel process.

The development of 2nd generation biofuels from lignocellulosic biomass (agricultural and forest residue, green urban waste, dedicated plants, etc.) is a major global challenge. The possibility of using all components of a plant will help to sustain the balance with food crops. By committing themselves to this ambitious project, the partners (some of which have been involved in the production of biofuels for many years), are tackling a major challenge for the 21st century, with the perspective of first industrial realizations around 2015 to 2020. Work will be based in particular on the experience acquired from the current production of so-called 1st generation bioethanol, which will be complemented by the new generation biofuel as it emerges.

The members of the PROCETHOL 2G consortium: Agro industrie Recherches et Développements (ARD), Confédération Générale des Betteraviers (CGB), VIVESCIA, Crédit Agricole du Nord-Est, IFP New energies, Institut National de la Recherche Agronomique (INRA), Lesaffre, Office National des Forêts (ONF), Tereos, Total and Unigrains.

Futurol Project

POMACLE, France

The aim of the pilot plant is to integrate in the same place all unit innovation block from research and development partners.

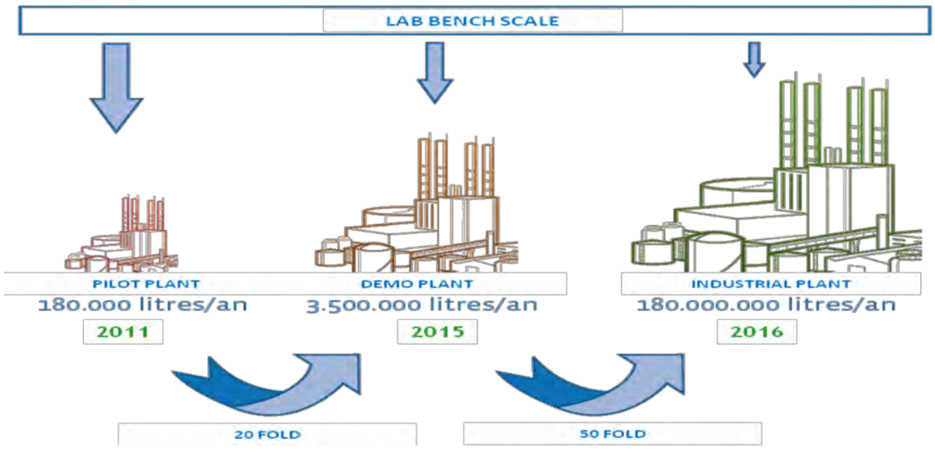


Figure 96: Procethol 2G – plans for upscaling

The pilot plant is a flexible process (multi feedstocks), make choice a priority, and to integrate the advances on the production of all kind of lignocellulosic resources. This plant is a really like a small scale industrial plant : each day, the unit is able to transform 1 tonne of feedstock into 350-450 litres of ethanol.

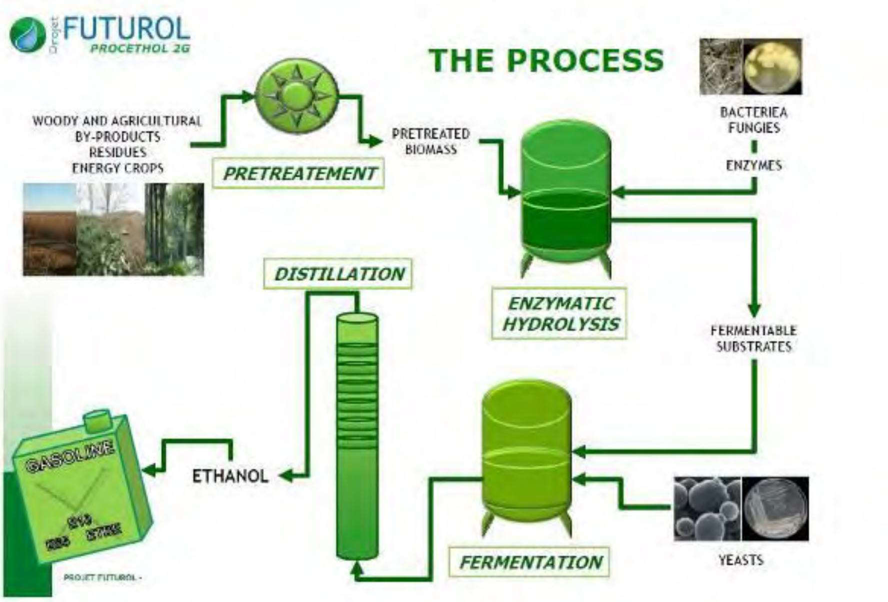


Figure 97: Procethol 2G – flow chart

Project Owner	PROCETHOL 2G
Project Name	Futurol Project
Location	Pomacle, France
Technology	biochemical
Raw Material	lignocellulosics
Project Input	flexible; woody and agricultural by-products, residues, energy crops
Product(s)	ethanol
Output Capacity	2700 t/y; 3.5 Ml/y
Facility Type	pilot
Investment	76 400 000 EUR
Status	operational
Start-up Year	2011
Contact Person	Benoit TREMEAU General Secretary +33 3 26 05 42 80 b.tremeau@projet-futurol.com
Web	www.projet-futurol.com

Table 79: Procethol 2G – pilot plant in Pomacle, France

Figure 98: Procethol 2G – picture (outside view) of pilot plant in Pomacle, France; © CANON PROCETHOL 2G

Figure 99: Procethol 2G – picture (inside view) of pilot plant in Pomacle, France; © JOLYOT- PROCETHOL 2G

Figure 100: Procethol 2G – picture of pilot plant in Pomacle, France; © JOLYOT- PROCETHOL 2G

6.40 Queensland University of Technology

QUT Queensland University of Technology
Brisbane Australia

Queensland University of Technology (QUT) is a leading university in Australia focused on applied research addressing the needs of industry and the community. QUT through the Centre for Tropical Crops and Biocommodities has a major research program on value adding to tropical agriculture through novel plant and industrial biotechnologies.

The QUT Mackay Renewable Biocommodities Pilot Plant is unique publicly available pilot scale research and development infrastructure for the conversion of cellulosic biomass into renewable transport fuels (bioethanol) and high value biocommodities in an integrated biorefinery. The facility aims to link innovations in product and process development with the assessment of commercial viability to enhance the uptake of this technology in Australia.

The Mackay Pilot Plant has been funded by the Australian Government through NCRIS Capability 5.5 – Biotechnology Products, the Queensland Government Department of Employment, Economic Development and Innovation and QUT. The facility is being hosted by Mackay Sugar Limited, one of Australia´s leading sugar manufacturers, on the site of the Racecourse Mill in Mackay, Queensland. In addition to sugarcane bagasse and trash which is readily available from the sugar factory, the facility is also capable of processing a wide range of biomass feedstocks with many of these feedstocks able to be sourced from partners throughout Australia.

Prospective users of the facility can access the NCRIS facility in Mackay and the considerable biomass harvesting, transportation, storage, processing and analytical expertise available through QUT. Full-time employees are based at the Mackay Pilot Plant to assist users with the set–up and operation of the facility and analysis of samples generated.

Facilities available include:

- Pretreatment reactor

The pretreatment reactor is unique equipment constructed from corrosion resistant alloys enabling pretreatment and fractionation with a wide variety of physical and chemical processes including steam explosion, single and two–stage mild acid treatments, alkali and solvent based processes.

- Carbohydrate saccharification and fermentation

Saccharification and fermentation can be undertaken in bioreactors of varying sizes including 1L, 5L, 10L, 100L, 1000L and 10,000L vessels. Fermentation up to 1000L is undertaken inside a PC2 compliant facility enabling the use of yeast, fungal and bacterial hexose and pentose fermenting organisms and both sequential and simultaneous saccharification and fermentation.

- Product recovery

Distillation columns, centrifuges, membrane filtration, spray drying and other bioprocessing equipment is available for product concentration and recovery.

- Other products

A wide variety of products can be produced on–site from the biomass, depending upon the requirements of the user. Sugarcane juice and molasses can be processed into a variety of fermentation products.

Mackay Renewable Biocommodities Pilot Plant

Mackay, Australia

Project Owner	Queensland University of Technology
Project Name	Mackay Renewable Biocommodities Pilot Plant
Location	Mackay, Australia
Technology	biochemical – pretreatment, enzyme hydrolysis, product separation
Raw Material	Lignocellulosics including sugarcane bagasse, corn stover, forestry products
Project Input	Sugarcane bagasse & other lignocellulosics
Input Capacity	0.02 t/h
Product(s)	ethanol, lignin, various chemicals
Output Capacity	N/A
Facility Type	pilot
Investment	10 000 000 AUD
Status	Operating
Start-up Year	2010
Contact Person	Ian O'Hara i.ohara@qut.edu.au
Web	www.ctcb.qut.edu.au

Table 80: Queensland University of Technology – pilot plant in Mackay, Australia

Figure 94: Pictures of Queensland University of Technology pilot plant in Mackay, Australia

6.41 Research Triangle Institute

RTI International is an independent, nonprofit institute that provides research, development, and technical services to government and commercial clients worldwide. RTI International is one of the world's leading research institutes, dedicated to improving the human condition by turning knowledge into practice. RTI staff of more than 2800 provides research and technical expertise to governments and businesses in more than 40 countries in the areas of health and pharmaceuticals, education and training, surveys and statistics, advanced technology, international development, economic and social policy, energy and the environment, and laboratory and chemistry services.

"Biomass-derived syngas will be generated in the University of Utah's pilot-scale gasification system from woody biomass and a combination of wood and lignin-rich hydrolysis residues generated at NCSU. RTI will integrate their dual fluidized bed reactor system called the "therminator" into the gasification process. The "therminator" which operates between 600 – 700ºC (1112 – 1292ºF) with a novel attrition-resistant triple function catalyst system, to simultaneously reform, crack, or remove tar, ammonia (NH3), and hydrogen sulfide (H2S) down to ppm levels. The catalyst is circulated between coupled fluidized-bed reactors to continuously regenerate the deactivated catalyst. The gas leaving the therminator will be cooled and filtered before it enters the second (polishing) stage, consisting of a fixed-bed of a mixed-metal oxide-sorbent catalyst, to further reduce the tar, NH3, H2S, and heavy metals to less than 100 ppb each so that the syngas can be directly used in a downstream process for synthesis of liquid transportation fuels. Once installed in the University of Utah gasification facility, therminator gas cleanup performance will be validated during for 300 hours of operation in Phase 1 of the project. The results from these Phase I trials will be used as input for gasification process models that will also be developed during Phase I. The results from the gasification trials, and the process and economic modeling will then be used to guide the Phase 2 work. In particular these results, in consultation from DOE and industry, will be used to direct the selection of the gas to liquids catalyst towards a Fischer-Tropsch catalyst system for hydrocarbon production or a molybdenum sulfide - based catalyst system for mixed alcohol synthesis. Phase 2 will follow the successful demonstration of the gas cleanup technology to produce a clean syngas that is suitable for a fuel synthesis process. The targeted tar, ulphit, chloride, and nitrogen impurity concentrations will meet or exceed the levels required for the projected 5-year operation of a Fischer-Tropsch catalyst system for hydrocarbon production or a molybdenum-based catalyst system for mixed alcohol synthesis. RTI will design and build a slurry bubble column reactor system to convert the clean syngas into a liquid transportation fuel. This unit operation will be installed in the University of Utah gasification facility downstream of the therminator and operated for 500 hours (at least 100 hours continuously) in an integrated biomass gasification/gas cleanup and conditioning/fuel synthesis process. RTI will be the prime contractor and will be responsible for the overall project. The project will be managed within the Center for Energy Technology (CET) and Dr. David C. Dayton will serve as the overall project manager. The NCSU team will be led by Dr. Steven Kelley and include four faculty, two from Wood and Paper Science and two from Chemical Engineering. Dr. Kevin Whitty will lead the University of Utah team in the Institute for Clean and Secure Energy that will be responsible for the operation of the gasification facility. Successful validation of these integrated gas cleanup and fuel synthesis operations will provide invaluable data and operating experience to reduce the risk of scale-up and commercialization of these technologies and contribute to the development of a robust biofuels industry."

Synfuel production

Research Triangle Park, United States

Project Owner	Research Triangle Institute
Project Name	Synfuel production
Location	3041 Cornwallis Road, Research Triangle Park, 27709, North Carolina, United States
Technology	thermochemical
Raw Material	lignocellulosics
Input Capacity	0,5 t/d
Product(s)	FT-liquids; mixed alcohols;
Output Capacity	22 t/y; 0.0075 mmgy
Facility Type	pilot
Investment	3 000 000 USD
Project Funding	2 000 000 USD
Status	Under construction
Start-up Year	n/a
Contact Person	David Dayton ddayton@rti.org
Web	www.rti.org/process

Table 81: Research Triangle Institute – pilot plant in Research Triangle Park, United States

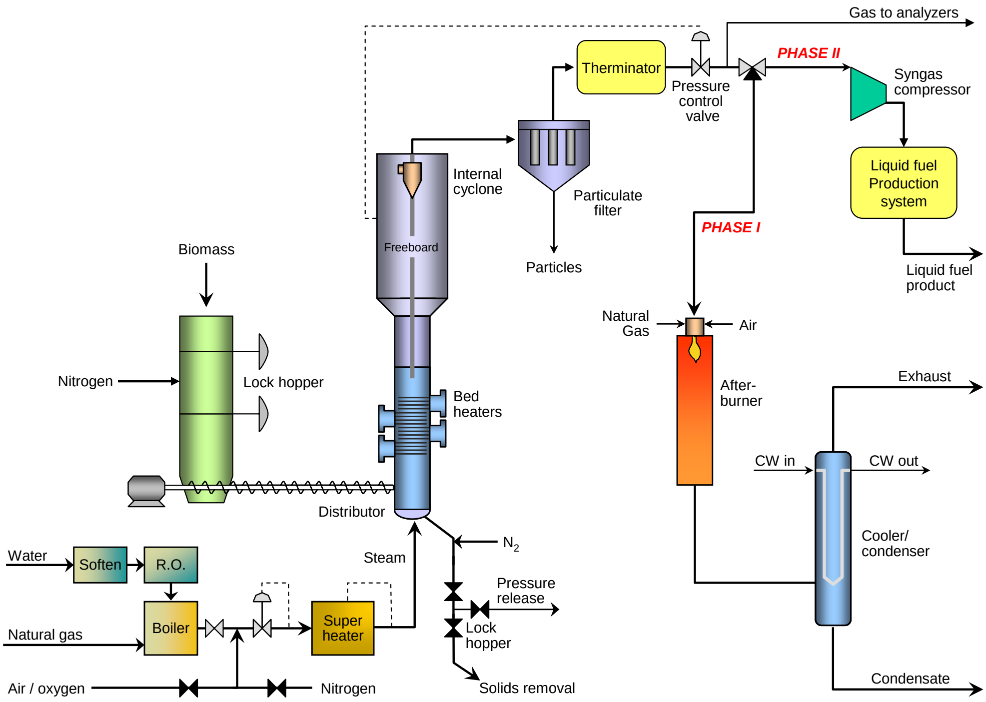


Figure 101: Research Triangle Institute – flow chart

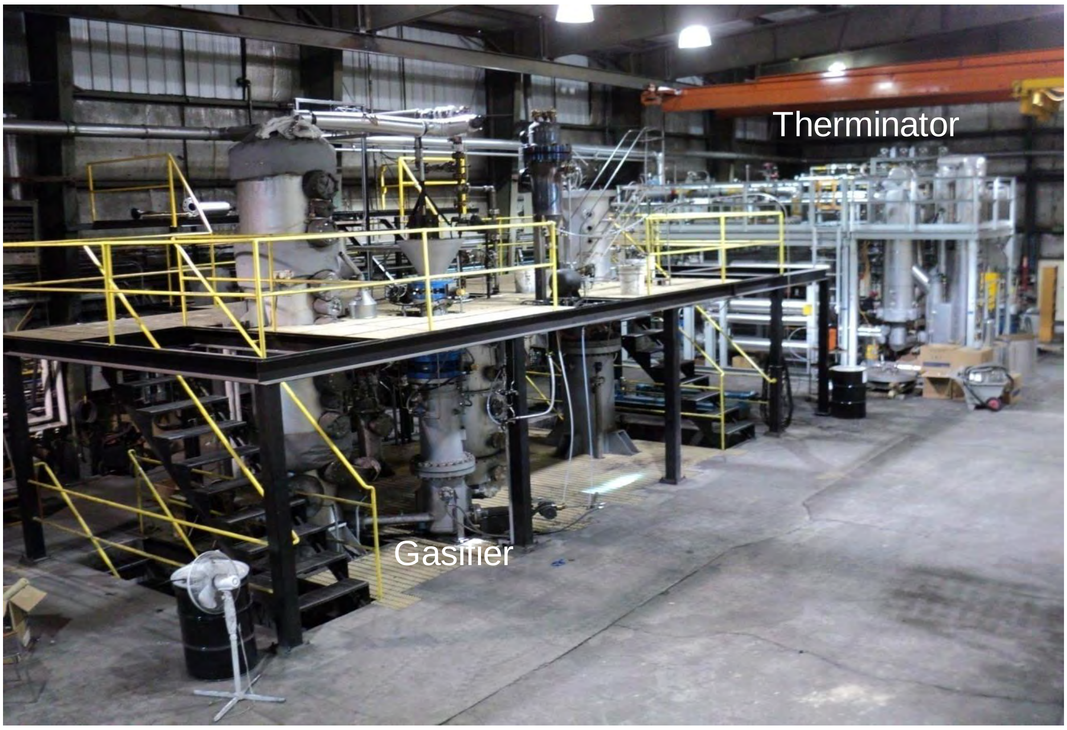


Figure 102: Research Triangle Institute – picture of pilot plant in Research Triangle Park, United States

6.42 SEKAB

Demo plant

Örnsköldsvik, Sweden

Enzymes with pretreatment of diluted acid in one step.

Project Owner	SEKAB/EPAB
Project Name	demo plant
Location	Örnsköldsvik, Sweden
Technology	biochemical
Raw Material	lignocellulosics
Project Input	primary wood chips; sugarcane bagasse, wheat, corn stover, energy grass, recycled waste etc have been tested.
Input Capacity	2 t/d
Product(s)	ethanol
Output Capacity	160 t/y; 600 l/d
Facility Type	pilot
Investment	2 000 000 SEK
Status	operational
Start-up Year	2004
Contact Person	info@sekab.com +46 660 758 00
Web	www.sekab.com

Table 82: SEKAB/EPAB – pilot plant in Ömsköldsvik, Sweden

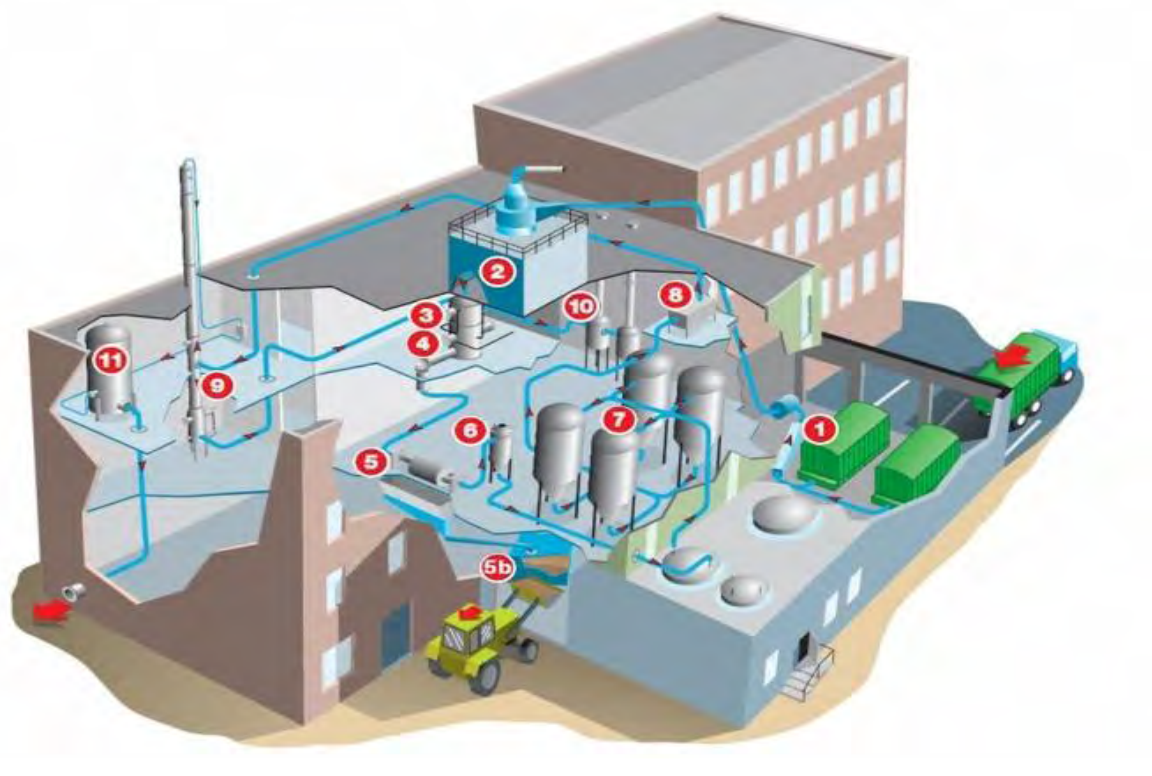


Figure 103: SEKAB/EPAB – scheme of demo plant in Örnsköldsvik, Sweden

Figure 104: SEKAB/EPAB – picture of demo plant in Örnsköldsvik, Sweden

planned demo plant

Goswinowice, Poland

Project Owner	SEKAB
Project Name	planned demo plant
Location	Goswinowice, Poland
Technology	biochemical
Raw Material	lignocellulosics
Project Input	Wheat straw and corn stover
Input Capacity	225 000 t DM/a
Product(s)	ethanol
Output Capacity	50 000 t/y; 60 Ml/y
Facility Type	demo
Investment	1 500 000 000 SEK
Status	planned
Start-up Year	2014
Contact Person	info@sekab.com +46 660 758 00
Web	www.sekab.com

Table 83: SEKAB – demo plant in Goswinowice, Poland

6.43 Southern Research Institute

Southern Research Institute (Southern Research), established in 1941 as a private, not-for-profit research corporation, develops technology and provides contract research services to public and private sector clients in pharmaceutical sciences, life sciences, homeland security, engineering, and the environment and energy industries. The Advanced Energy and Transportation Technologies (AE&TT) Center located in Durham, North Carolina is a unique engineering, laboratory and pilot-plant facility (Figure 105) that allows Southern Research to develop their own technology from conceptual /laboratory stage through bench and pilot-stage. Using this facility, Southern Research also helps its clients to develop, validate, optimize and commercialize advanced biofuel technologies and collaborate with new partners and clients. The Center also helps Government and commercial end users to verify performance and environmental targets of novel energy technologies, including landfill gas to energy, advanced combined heat and power systems, fuel cells, micro-turbines, alternative fuels, clean transportation systems, renewable energy systems, and low-grade waste heat conversion. Over 30 million dollars have been invested by Southern Research and its partners to implement new infrastructure and pilot facilities, including 42 000 square feet of high bay pilot plant space, supporting utilities, analytical laboratories, and office facilities to demonstrate advanced biofuel technologies at the AE&TT Center. The Center offers experienced engineers, scientists and technicians to support PDU design, fabrication, assembly, 24-7 operation, and testing.

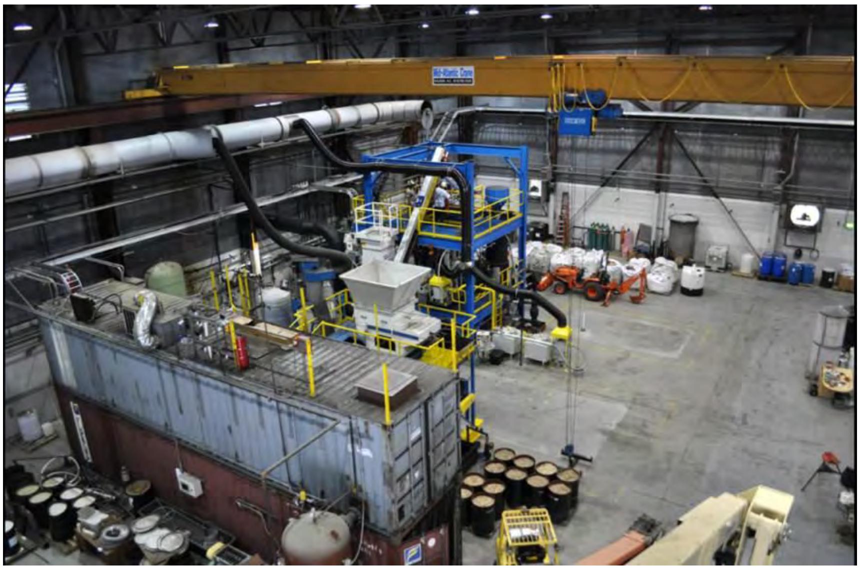


Figure 105: Picture of Southern Research Biofuels Pilot Plant Facility

Currently, the AE&TT Center has several biofuel pilot plants in various stages of development including design, construction, commissioning and shakedown, and operation. Recent client pilot-scale projects have included extensive operation of a:

- ton/day integrated bio-refinery with a fluidized-bed biomass gasifier coupled to a high pressure Fischer-Tropsch synthesis reactor
- High pressure catalytic reactor system for converting syngas to mixed alcohols
- 250 lb/h piston pump for feeding dry coal-biomass mixtures into entrained flow gasifiers
- Concentrated hydrochloric acid hydrolysis system for extraction of sugars from biomass

Southern Research is also presently developing a distributed-scale (1 to 200 ton/day) gasification-based integrated process (Figure 106) for converting waste biomass and municipal solid waste (MSW) to power and liquid drop-in biofuels without using purchased hydrogen. A 3 ton per day system has been installed and is being operated at the AE&TT pilot plant facility.

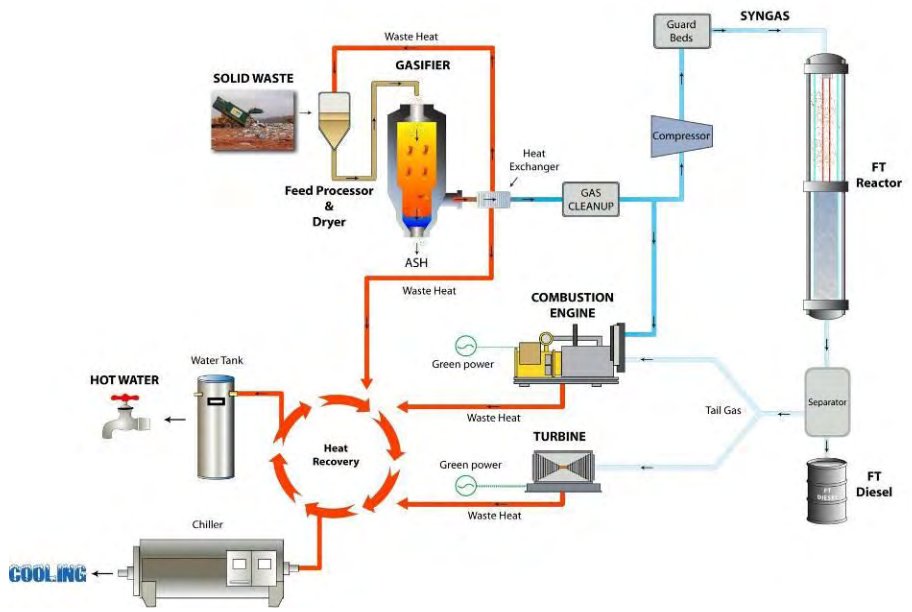


Figure 106: Southern Research Distributed-Scale Process

Specific market segments being targeted by Southern Research's process include:

- US DOD forward operating bases and other small generators (1 to 3 ton/day)
- US DOD domestic bases, landfills, colleges and hospitals (10 to 50 ton/day)
- Rural communities and MSW recycling facilities (50-200 ton/day)

The features of Southern Research's process include:

- Minimal feedstock preparation/sorting
- Proven and scalable gasification system capable of processing low density feeds
- Very low tar in syngas
- Dry integrated syngas cleaning system that produces minimal waste
- Integrated low-cost water purification system that minimizes waste
- Gas to liquid conversion that produces drop in fuels with no off site upgrading requirement

The benefits of Southern Research's process include:

- Reduced transportation infrastructure for feed
- Local direct delivery of products
- Reduces emissions and wastes while producing clean power and/or biofuels
- Attractive payback for systems 30 ton/day or larger
- Based on proven core technologies designed for long-term use
- Automated system requiring minimal labor
- Modular construction allows quick deployment

Technology development laboratory and pilot plant – thermochemical

Durham, United States

Coordinating Organisation/Company	Southern Research Institute
Project Name	technology development laboratory and pilot plant – thermochemical
Location	Durham, United States
Technology	thermochemical
Raw Material	lignocellulosics
Project Input	Cellullulosics, Municipal wastes, syngas
Input Capacity	2 to 4 ton/day gasifiers
Product(s)	FT-liquids; mixed alcohols
Output Capacity	various
Facility Type	pilot
Investment	30 000 000+ USD in facility and infrastructure
Project Funding	20 000 000+ USD since inception
Status	operational
Start-up Year	2007
Contact Person	Tim Hansen; hansen@southernresearch.org
Web	www.southernresearch.org

Table 84: Southern Research – pilot plant in Durham, United States

6.44 Tembec

Demo

Temiscaming, Quebec, Canada

Project Owner	Tembec Chemical Group
Project Name	demo
Location	Temiscaming, Quebec, Canada
Technology	thermochemical
Raw Material	lignocellulosics; spent sulphite liquor feedstock
Product	ethanol
Output Capacity	13 000 t/y; 17 Ml/y
Facility Type	demo
Status	operational
Start-up Year	2003
Contact Person	Jean-Luc Carrière; jean-luc.carriere@tembec.com
Web	www.tembec.com

Table 85: Tembec Chemical Group – demo plant in Temiscaming, Canada

6.45 TNO

TNO is the Netherlands Organization for Applied Scientific Research, a contract research organization established by law in 1932. TNO connects people and knowledge to create innovations that boost the sustainable competitiveness of industry and well-being of society. It has about 4000 employees.

TNO is active in 7 themes: healthy living, industrial innovation, defence, safety and security, energy, transport and mobility, built environment and information society. The core activities are development, application and exploitation of knowledge in the form of consultancy, contract research, testing and certification, licences and performing statutory assignments.

One of the subjects within the proposition ‘Biobased Economy’ within the theme ‘Industrial Innovation’ is the production of fermentation products, such as bioethanol from lignocellulosic biomass. TNO has two proprietary lignocellulose pretreatment technologies: (1) dilute acid in combination with superheated steam (SHS), and (2) concentrated acid pretreament. The pilot plant described below concerns pretreatment using SHS. The business model with respect to SHS treatment is contract research and licencing to companies in the fermentation industry and other industries.

It is known that the lignocellulosic complex can be broken under acidic and high temperature conditions (150-180°C). The way TNO heats the biomass is unique: in a reactor a continuous flow of SHS passes through a heap of grass or straw, in contrast with the usual stagnant and saturated steam. By using SHS the heat is not transferred by condensation but by convection. This avoids dilution of the acid catalysts in the outer regions of the biomass particles and allows to work with high dry matter concentrations. The initial dry matter contents can be 20-45% w/w and probably higher. Such high dry matter content decreases the use of thermal energy since a lower amount of mass is heated. Moreover, as a result of lower water content less acid catalyst is required to reach the effective concentrations and by evaporation of water a desired increase in acid concentration can be created. High dry matter concentrations are important for the economy of fermentation and downstream processing, as higher substrate concentrations lead to higher product concentrations, which makes recovery more cost-effective. The fast temperature increase and decrease within a few seconds allows a better process control. By evaporation of water the final dry matter content can be increased to values between 30% and 60% w/w. The amount of water evaporation can be adjusted by the pressure in combination with the superheating temperature. Flexibility in acid concentration has been observed as well. The user can choose between less acid and longer reaction times or more acid and shorter times. In addition, the user can choose between various inorganic and organic acids. The process can be carried out within a few minutes and a temperature of 160°C already is effective, which can be placed within the fastest and coldest existing thermal mild acid pretreatment processes, which adds to a favourable economy of the process. After SHS pretreatment a conversion of more than 95% of cellulose and hemicellulose after enzymatic hydrolysis can be reached, which can be regarded as high. Samples have been successfully subjected to ethanol fermentation at 38% DM. The pretreatment step can be carried out in TNO's superheated steam pilot plant. SHS dryers are already on the market at the sizes required for lignocellulose biorefineries / cellulosic ethanol production, although they should be adapted to shorter residence times and higher pressures. This guarantees fast implementation. The current 13 kg/h pilot plant works in batch mode. TNO is preparing for the construction of a 100 kg/h pilot plant for continuous operation.

Superheated steam pilot plant at TNO

Zeist, the Netherlands

The current pilot plant is operated in batch using loads of acid impregnated straw and grass

Project Owner	TNO
Project Name	Superheated steam pilot plant
Location	Zeist, the Netherlands
Technology	Biochemical
Raw Material	Wheat straw, grass, corn stover, bagasse, wood chips
Input Capacity	13 kg per hour
Product(s)	Pretreated biomass
Output Capacity	50 kg per hour; approximately 100 t/y
Facility Type	Pilot
Status	Operational
Start-up Year	2002
Contact Person	Johan van Groenestijn (johan.vangroenestijn@tno.nl)
Web	www.tno.nl

Table 86: TNO – pilot plant in Zeist, The Netherlands

Figure 107: TNO – picture of pilot plant in Zeist, The Netherlands

6.46 TUBITAK

The aim of the project is to develop and demonstrate the technologies for liquid fuel production from biomass and/or biomass-coal blends at the laboratory and pilot scale systems. The technological areas within the scope of the project are gasification, gas clean-up, gas conditioning, CO2 separation and liquid fuel production via Fischer-Tropsch (FT) synthesis. Activities related to the technological research areas consist of the pre-design of the units, laboratory tests, detailed design, engineering, manufacturing, commissioning and testing at pilot scale.

In the gasification step, two types of gasifiers circulating fluidized bed gasifier and pressurised fluidized bed gasifier have been studied in laboratory scale (150 kWth). 1.1 MWth capacity pressurised fluidized bed gasifier have been designed for pilot scale. The aim of the gas cleaning step is to remove impurities from raw gas of gasifier. Both hot and cold gas clean-up technologies have been used in laboratory scale experiments. Hybride hot and cold gas clean-up pilot system has been designed. The third step of project is gas conditioning. The aim of this step is to adjust H2/CO ratio in syngas and capture CO2. H2/CO ratio in syngas will be adjusted in a water gas shift (WGS) reactor and CO2 will be captured by chemical absorption technique.

One of the main work packages of the project is the production of liquid fuels via Fischer-Tropsch synthesis since the activities related to both FT catalyst development and fixed bed and slurry phase reactor applications have been performed in this work package. Low temperature FT process with multi tubular fixed bed reactor will be used to produce synthetic diesel in pilot plant. Iron based FT catalyst has been developed to convert syngas into hydrocarbon chains. All units of the pilot scale system are under construction currently.

Figure 108: TUBITAK – 150 kWth Circulating Fluidized Bed Gasifier

TRIJEN (Liquid Fuel Production From Biomass and Coal Blends)

Gebze, Turkey

Project Owner	TUBITAK
Project Name	TRIJEN (Liquid Fuel Production From Biomass and Coal Blends)
Location	Gebze, Turkey
Technology	thermochemical
Raw Material	biomass /biomass coal blends
Project Input	combination of hazelnut shell, olive cake, wood chips and lignite blends
Input Capacity	0.25 t/h
Product(s)	FT-liquids
Output Capacity	250 t/y
Facility Type	pilot
Project Funding	8 500 000 EUR
Status	Under construction
Start-up Year	2013
Contact Person	Assoc.Prof.Dr. Fehmi AKGUN fehmi.akgun@tubitak.gov.tr Yeliz DURAK CETIN, yeliz.durak@tubitak.gov.tr
Web	http://trijen.mam.gov.tr/

Table 87: TUBITAK – pilot plant in Gebze, Turkey

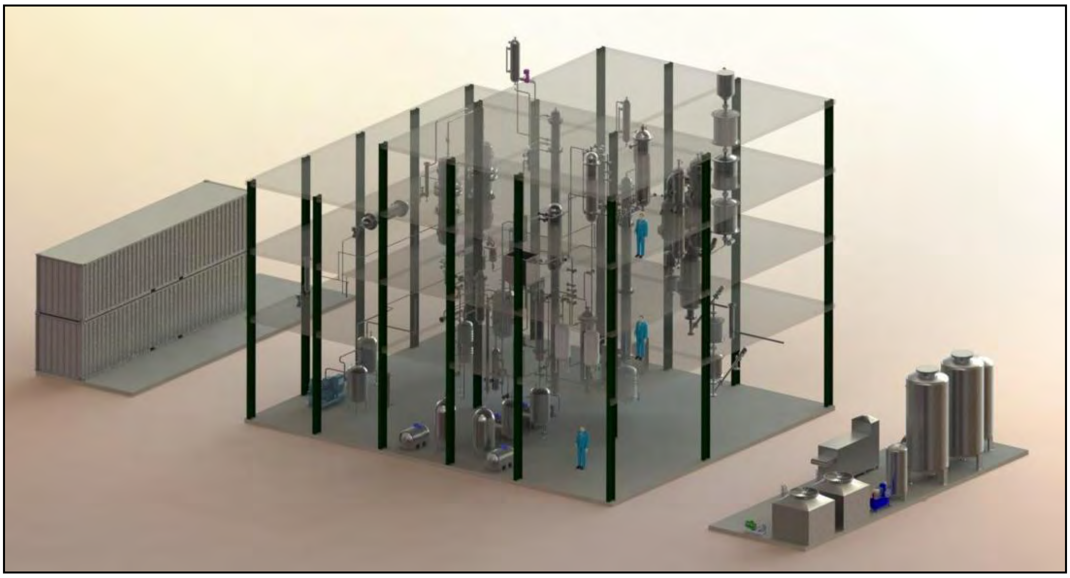


Figure 109: TUBITAK – 1.1 MWth Capacity Indirect Coal to Liquid Pilot System

6.47 Vienna University of Technology / BIOENERGY 2020+

Aim of the work is to convert the product gas (PG) of the Biomass gasification plant with a Fischer-Tropsch (FT) process to liquid fuels, especially to diesel. A FT-PDU (process development unit) is operated, which converts about 7 Nm3/h PG at 25bar in a Slurry reactor to FT-products.

The gas cleaning of the raw PG consists of several steps. First a RME-scrubber is used to dry the gas. After the compression step, chlorine is separated with a sodium aluminate fixed bed. Organic sulphur components are hydrated with a HDS-catalyst and the H2S is chemically separated with Zinc oxide. Both is realised in fixed bed reactors. In alternative to the HDS also activated carbon filter can be used for gas cleaning. As catalyst in the slurry reactor, iron and cobalt based catalyst are used. The results from a Cobalt catalysts give mainly an n-alkan distribution from C1 to compounds higher than C60 n-alkanes. The iron based catalysts give more alkenes and oxygenated compounds. The analyses of the diesel fraction from the distillation of the FT-raw product show that the obtained diesel from the Cobalt catalyst has cetan-numbers of about 80 and is free of sulphur and aromatics.

The plant uses a side stream of the existing Güssing gasifier as does the Biomassekraftwerk Güssing (see 4.7).

FT pilot

Güssing, Austria

Project Owner	Vienna University of Technology
Project Name	FT pilot
Location	Güssing, Austria
Technology	thermochemical
Raw Material	lignocellulosics; syngas from gasifier
Input	7 Nm3/h
Product	FT-liquids
Output Capacity	0.2 t/y; 0.5 kg/h
Facility Type	pilot
Partners	Repotec, Biomassekraftwerk Güssing
Status	operational
Start-up Year	2005
Contact Person	Reinhard Rauch; reinhard.rauch@tuwien.ac.at
Web	http://www.ficfb.at

Table 88: Vienna University of Technology – pilot plant in Güssing, Austria

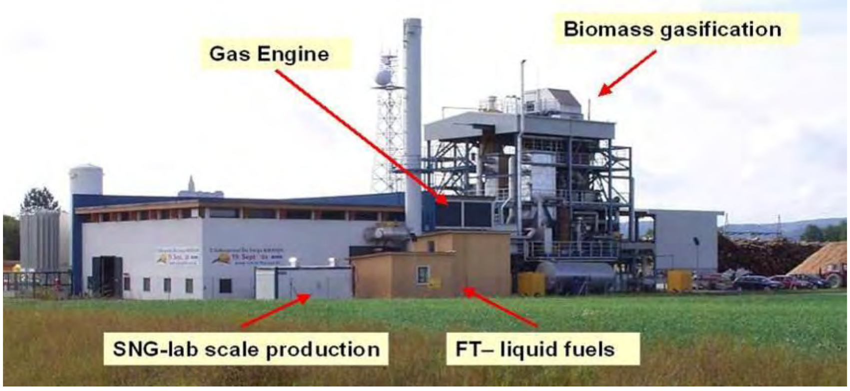


Figure 110: Vienna University of Technology – picture of pilot plant in Güssing, Austria

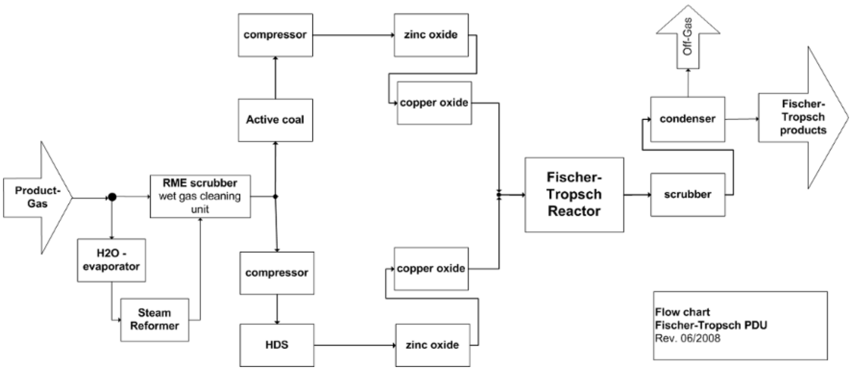


Figure 111: Vienna University of Technology – flow chart of pilot plant in Güssing, Austria

6.48 Virent

Virent creates the fuels and chemicals the world demands from a wide range of naturally occurring, renewable resources. Using patented catalytic chemistry, Virent converts soluble biomass-derived sugars into products molecularly identical to those made with petroleum, including gasoline, diesel, jet fuel, and chemicals used for plastics and fibers. The company has key strategic relationships in place with Royal Dutch Shell, Cargill, the Coca-Cola Company and Honda which are accelerating commercialization of its technology.

Virent's BioForming® platform is based on a novel combination of Aqueous Phase Reforming (APR) technology with modified conventional catalytic processing. The APR technology was discovered at the University of Wisconsin in 2001 by Virent's co-founders. The BioForming platform expands the utility of the APR process by combining APR with catalysts and reactor systems similar to those found in standard petroleum oil refineries and petrochemical complexes.

The BioForming process converts aqueous carbohydrate solutions into mixtures of "drop-in" hydrocarbons. The process has been demonstrated with conventional sugars obtained from existing sugar sources (corn wet mills, sugarcane mills, etc.) as well as a wide variety of cellulosic biomass from various sources. A key advantage to the BioForming process is the ability to produce hydrogen in-situ from the carbohydrate feedstock or utilize other sources of hydrogen such as natural gas for higher yields and lower costs.

The product from the APR step is a mixture of chemical intermediates including alcohols, ketones, acids, furans, paraffins and other oxygenated hydrocarbons. Once these intermediate compounds are formed they can undergo further catalytic processing to generate a cost-effective mixture of nonoxygenated hydrocarbons. Depending on the process route selected the hydrocarbons produced can be a high aromatic mixture similar to petroleum-derived reformate or a distillate-range stream suitable for diesel and jet fuel.

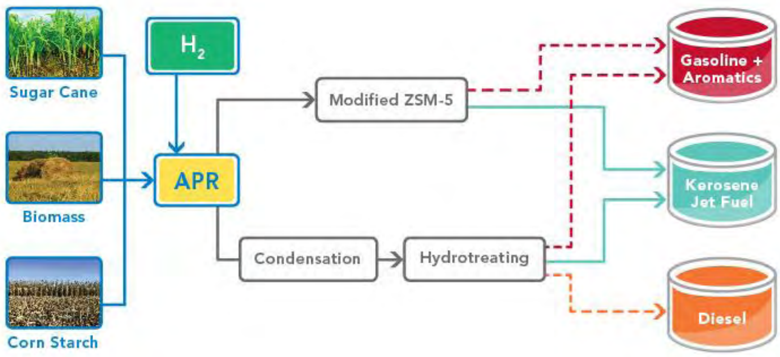


Figure 112: Virent – flow chart of demo plant in Madison, United States.

Eagle Demonstration Plant

Madison, Wisconsin, USA

Virent has over twenty small-scale pilot plants and a larger demonstration-scale plant at its technical facility in Madison, Wisconsin. The demonstration plant was commissioned in November 2009 and produces bio-gasoline and bio-aromatics.

Project Owner	Virent, Inc.
Project Name	Eagle Demonstration Plant
Location	Madison, Wisconsin, USA
Technology	Thermochemical
Raw Material	Cane sugar, beet sugar, corn syrup, hydrolysates from cellulosic biomass including pine residues, sugarcane bagasse and corn stover
Product(s)	diesel-type hydrocarbons
Output Capacity	30 t/y
Facility Type	Demo
Status	Operational
Start-up Year	2009
Contact Person	aaron_imrie@virent.com
Web	www.virent.com

Table 89: Virent – demo plant in Madison, United States

Figure 113: Virent – picture of demo plant in Madison, United States.

6.49 Weyland

Weyland technology has its roots in research conducted at Bergen University College. The breakthrough was a unique acid recovery technology which addresses the economic challenges associated with the use of strong acid hydrolysis of lignocellulose. Since that time the team at Weyland has further developed and patented the process – which is now being tested and demonstrated at pilot scale.

The core technology produces high yield, fermentable sugars and lignin from almost any lignocellulose material. This may be employed as an add-on process, utilising by-products from existing facilities (pulp mills, bio-refineries, sugar production facilities etc.), or for dedicated upstream sugar production for subsequent conversion to biofuels or biochemicals.

Weyland's business model is to sell licenses for its core technology to project developers and to provide key hardware components. Before this, Weyland will perform feedstock and feasibility evaluations. With Weyland's support, engineering partners will then perform the engineering for full scale projects.

The combined use of strong mineral acids and Weyland´s own patented recovery techniques provides a purely chemical route to sugar production from cellulose. The process is characterised by:

- high feedstock flexibility
- low temperatures and pressures throughout
- short residence times
- use of standard chemical process unit operations
- the process can be run on waste heat (LP steam and hot water)
- use of bulk industrial chemicals
- high recovery efficiencies
- low levels of inhibitors in sugars
- saleable lignin

The result is a process with very competitive capex and opex, freedom from single source suppliers and good energy integration potential with existing industry.

Figure 114: Weyland – picture of pilot plant in Bergen, Norway

Weyland Pilot Plant

Bergen, Norway

The pilot plant in Bergen is used for demonstration of Weyland's technology and as a platform for process development, component trials and feedstock evaluations. The core technology produces fermentable sugars and lignin. However, ethanol production facilities are integrated in the pilot plant to demonstrate product quality for a typical downstream application.

Project Owner	Weyland AS
Project Name	Weyland Pilot Plant
Location	Bergen, Norway
Technology	biochemical
Raw Material	Lignocellulose – various feedstocks, mostly spruce & pine
Input Capacity	75 kg/h
Product(s)	ethanol, lignin
Output Capacity	158 t/y (ethanol)
Facility Type	pilot
Investment	6 500 000 EUR
Status	operational
Start-up Year	2010
Contact Person	Petter Bartz Johannessen; pbj@weyland.no
Web	www.weyland.no

Table 90: Weyland – pilot plant in Bergen, Norway

Figure 115: Weyland – picture of pilot plant in Bergen, Norway

6.50 ZeaChem

ZeaChem builds biorefineries to convert low-cost biomass into a range of fuel and chemical products. ZeaChem biorefineries can use any type of non-food biomass, including woody biomass and agricultural residues, which are globally available. The company's "grow where you go" approach locates production facilities in the markets it serves and minimizes transportation logistics and environmental costs. The feedstock model employed is to use dedicated, locally-grown energy crops secured through long-term contracts as the primary supply and then supplement with locally available agricultural residues.

The conversion process uses naturally-occurring organisms and proven, industrial equipment in order to reduce scale-up risk. Non-GMO bacteria ferment cellulosic sugars with nearly 100% carbon efficiency and the combination of biological and thermochemical processes deliver a 40% yield advantage compared to other processes. Like a petrochemical refinery, ZeaChem biorefineries can make multiple fuels and chemicals, shifting production to the highest margin products. Fuel products include ethanol, jet fuel, diesel and gasoline; chemical products include acetic acid, ethyl acetate, ethylene and propylene.

Incorporated in 2002, ZeaChem is headquartered in Lakewood, Colorado, operates a research and development laboratory facility in Menlo Park, California, and a 250 000 gallon per year demonstration biorefinery in Boardman, Oregon.

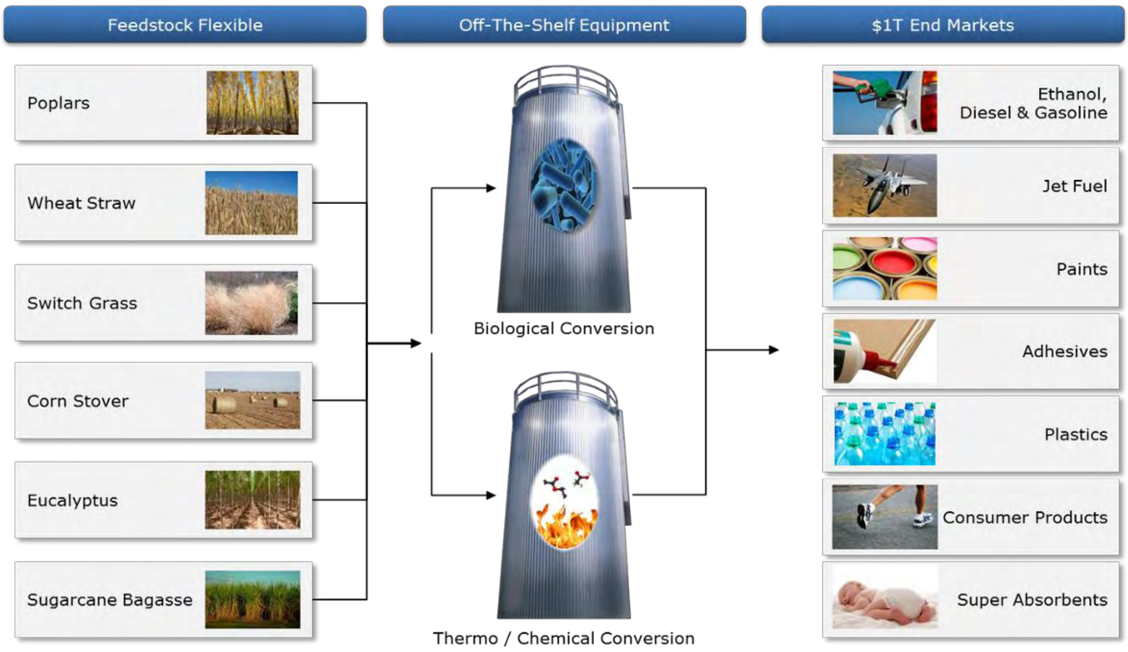


Figure 116: Zeachem – flow chart

Demonstration scale biorefinery

Boardman, Oregon, United States

ZeaChem's demonstration scale production facility began operation in 2011 in Boardman, Oregon. Located at the Port of Morrow, the site has access to barge, rail and interstate highway transportation and is approximately 10 miles from ZeaChem's primary feedstock provider, GreenWood Resources, a worldwide leader in poplar tree management. The facility has capacity to convert 10 tons per day of wood chips, wheat straw and other cellulosic feedstocks into acetic acid, ethyl acetate and ethanol. In 2013, additional process modules will enable the production of bio-based jet and diesel fuels.

Project Owner	ZeaChem Inc.
Project Name	Demonstration scale biorefinery
Location	Boardman, Oregon, United States
Technology	biochemical
Raw Material	lignocellulosics
Project Input	poplar trees, wheat straw
Input Capacity	10 bone dry ton/day
Product(s)	Ethanol, diesel-type hydrocarbons, various chemicals, gasoline-type fuel, jet fuel
Output Capacity	750 t/y; 0.25 mmgy
Facility Type	demonstration
Status	operational
Start-up Year	2011
Contact Person	Carrie Atiyeh catiyeh@zeachem.com
Web	www.zeachem.com

Table 91: ZeaChem – pilot plant in Boardman, United States

Figure 117: ZeaChem – picture of pilot plant in Boardman, United States

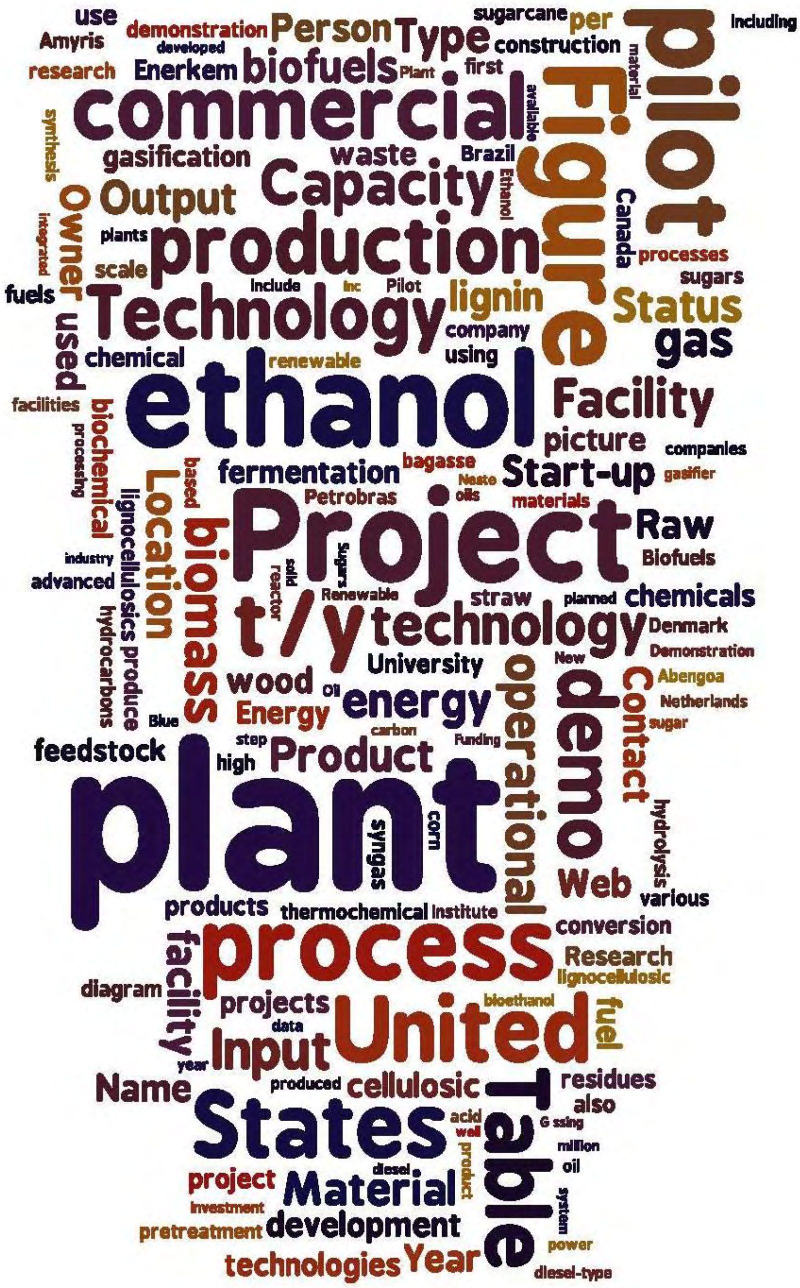
Commercial Scale Biorefinery

Boardman, Oregon, United States

ZeaChem is under development of its first commercial scale cellulosic biorefinery. The facility will be located next to the demonstration biorefinery in Boardman, Oregon. ZeaChem has secured 100% of the feedstock supply through its primary feedstock partner, GreenWood Resources, and locally available wheat straw which will be used as supplemental feedstock. In January 2012, the U.S. Department of Agriculture (USDA) announced a conditional loan guarantee of $232.5M to support the financing of the facility.

Project Owner	ZeaChem Inc.
Project Name	Commercial scale biorefinery
Location	Boardman, Oregon, United States
Technology	biochemical
Raw Material	lignocellulosics
Project Input	poplar trees, wheat straw
Input Capacity	625 bone dry ton/day
Product(s)	Ethanol, various chemicals
Output Capacity	25 mmgy; 75 000 t/y
Facility Type	Commercial
Project Funding	$232.5M conditional loan guarantee from U.S. Department of Agriculture
Status	Under development
Start-up Year	Projected online in late 2014
Contact Person	Carrie Atiyeh; catiyeh@zeachem.com
Web	www.zeachem.com

Table 92: ZeaChem – commercial plant in Boardman, United States



Authors note: If you wish to add your company´s project to the database or to have your data updated, please contact dina.bacovsky@bioenergy2020.eu.