

Technical University of Denmark



IEA Bioenergy Task42 Biorefining

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IEA Bioenergy is an international collaboration set-up in 1978 by the International Energy Agency (IEA) to improve international co-operation and information exchange between national bioenergy RD&D programmes. Its Vision is that bioenergy is, and will continue to be a substantial part of the sustainable use of biomass in the BioEconomy. By accelerating the sustainable production and use of biomass, particularly in a Biorefining approach, the economic and environmental impacts will be optimised, resulting in more cost-competitive bioenergy and reduced greenhouse gas emissions. Its Mission is facilitating the commercialisation and market deployment of environmentally sound, socially acceptable, and cost-competitive bioenergy systems and technologies, and to advise policy and industrial decision makers accordingly. Its Strategy is to provide platforms for international collaboration and information exchange, including the development of networks, dissemination of information, and provision of science-based technology analysis, as well as support and advice to policy makers, involvement of industry, and encouragement of membership by countries with a strong bioenergy infrastructure and appropriate policies. Gaps and barriers to deployment will be addressed to successfully promote sustainable bioenergy systems. The purpose of this brochure is to provide an unbiased, authoritative statement on biorefining in general, and of the specific activities dealt with within IEA Bioenergy Task42 on Biorefining, aimed at stakeholders from the agro-sector, industry, SMEs, policy makers, and NGOs.

IEA BIOENERGY Task42 BIOREFINING



**Sustainable and synergetic processing of biomass
into marketable food & feed ingredients, chemicals,
materials and energy (fuels, power, heat)**

IEA Bioenergy

IEA BIOENERGY

Task42 BIOREFINING

Sustainable and synergetic processing of biomass into marketable food & feed ingredients, products (chemicals, materials) and energy (fuels, power, heat)

Wageningen, the Netherlands, August 2014

Prepared by all IEA Bioenergy Task42 country representatives; edited by René van Ree and Alniek van Zeeland - Wageningen UR Food and Biobased Research

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1. Biorefining – Current Status & Future Challenges

Currently, biomass is mainly used for human food, animal feed and the production of fuels, power and/or heat. Within a future BioEconomy, however, biomass will be used for the sustainable and synergetic production of food, feed, bioenergy (power, heat, CHP and biofuels for transport) and bio-based products (chemicals, materials). The relatively scarce raw material availability requires the development and implementation of high-efficient biomass conversion technologies to maximise valorisation and the overall environmental benefits of full biomass supply chains.

It is expected that current biomass supply chain expertise and facilities available in the energy sector will be used as starting point for the development of more sustainable multi-product and multi-stakeholder based biomass implementation strategies. In the short-term this approach potentially could improve the overall economics of business cases in the energy sector by valorisation of currently available agro and process residues to added-value bio-based products (i.e. biofuels for transport potentially could be produced in a market competitive way in case residues are optimally valorised); whereas in the longer-term the energy sector will become an integral part of full biomass refining strategies, i.e. using a variety of primary, secondary and tertiary organic residues as raw materials for energy purposes. The food-versus-fuel debate has shifted the focus on non-food biomass as feedstock not just for biofuels but also for biochemicals and materials. This debate is somehow misleading because the cause of limited access to food is rather complex. The major factor is not the availability of food but unequal purchasing power of consumers in different countries. The restricted use of biomass alone is insufficient to solve that problem. The major challenge for using biomass is that multi-objectives must be fulfilled simultaneously, e.g. ensuring sufficient food availability, maintaining soil fertility but also sufficient biomass availability if the transition to a BioEconomy is the ultimate goal.

Biorefining, i.e. the sustainable processing of biomass into a spectrum of marketable food and feed ingredients, bio-based products (chemicals, materials) and bioenergy (biofuels, power and/or heat) is the main driver for large-scale implementation of biomass within the different market sectors of the global economy.

In a future Circular BioEconomy (Fig. 1) sustainable production and valorisation of biomass to both Food and Non-food applications will be the framework of operation. Sustainably produced biomass (crops, algae, residues) has to be used as efficient as possible – using bio-cascading and biorefining approaches – to meet future demands of food, feed, chemicals, materials, fuels, power, and heat.

Biorefineries are already applied for ages in for example the food industry. Large-scale implementation of biorefineries for non-food (inc. bioenergy) applications, however, is still lacking. Major reasons for this are that: some of the key technologies (fractionation & product separation) being part of integrated biorefinery plants are still not mature enough for commercial market implementation; there is still no level-playing-field for sustainable biomass use for Food and Non-food applications; market sectors that should co-operate (food, feed, agro, chemistry, energy, fuels, logistics, ...) for the development and commercialisation of full sustainable biomass value chains, including high-efficient biorefinery processes, are often still not working together, and there is still lack of knowledge/expertise on the advantages of biorefinery processes for optimal sustainable biomass use at both industrial, SME and (regional) governmental level. Improving the communication/collaboration among different actors from different industrial sectors is paramount for going across the valley-of-death.

Major challenges still to be tackled are: develop industry legitimacy and a level-playing field for sustainable biomass use; multi-sectorial stakeholder involvement in the deployment of sustainable value chains; technology development and biorefinery scale-up using best practices; unlock available expertise energy/fuel, agri/food, material and chemical manufacturing sectors, and develop the necessary human capital by training students and other stakeholders to become the biorefinery experts of today and tomorrow.

To open up the biorefinery application potential, technology and full chain development of multi-stakeholder consortia still is a necessity. Joint international priorities and RD&D-programmes between industry, research institutes, universities, governmental bodies and NGOs are necessary; whereas identification of market introduction strategies together with industry will be inevitably for the creation of a proper RD&D-framework.

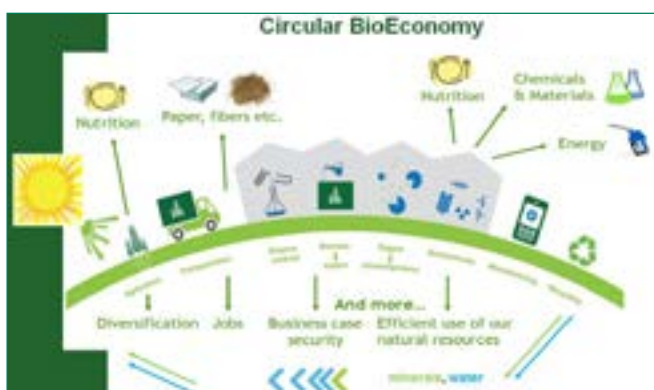


Figure 1. Circular BioEconomy [Wageningen UR]

2. Biorefining – Country Specific Challenges

Australia

Australia is a large country of approximately 7 million square kilometres with over 80% of the country being desert or semi-desert and not suitable for agricultural activities. Despite the large percentage of non-agriculture area, the country is one of the few western world countries that has sufficient natural resources and land to support large scale biorefineries based on food or non-food sources to replace liquid mineral hydrocarbons. There are significant areas in the north of the country such as Queensland and Western Australia that are ideal for the development of large scale projects based on sugar cane or other fast growing sources of biomass. The major challenges for renewable fuels for the country are more political, financial and business related than technical. A recent change in Government has seen proposed policy changes including a scrapping of the carbon tax, elimination of credits for biofuels and the axing of key Government groups responsible for funding bioenergy projects and research. Groups being closed include the Australian Renewable Energy Agency (ARENA) and the Clean Energy Finance Corporation. The Government has also taken the decision to not appoint a Science Minister and significantly reduce funding for Australia's leading Government funded research group, the CSIRO. Australia is a net energy exporter, it is the largest exporter of coal and based on current projections expected to be the largest exporter of gas in the near future. However, the country is a net importer of oil and increasingly lifting its imports of gasoline and diesel. A number of petrochemical refineries are being closed around Australia (NSW and Queensland) with most crude and refined products now coming from offshore. With little prospect of Australia replacing its mineral hydrocarbon liquid fuels from domestic sources, the opportunity for biofuels to replace mineral hydrocarbons is excellent from a macro position. However, unless broad Government policy settings are changed, it is unlikely that Australia will see the development of biorefineries (over and above the 0.3 billion to 0.4 billion litres already produced) to help replace imported liquid mineral hydrocarbons.

Austria

As Austria is a forest country, it has a long industrial tradition of using wood for pulp and paper, wooden products, particle boards, and as bioenergy for power and heat. Biorefining of wood (about $7.5 \cdot 10^6 \text{ m}^3$ per year) in the pulp and paper industry is in place for many centuries. Stimulated by the goals of the Renewable Energy Directive to reach 10% renewable fuels in 2020, a strong Austrian biofuel industry was built up to co-produce biodiesel and bioethanol with animal feed and chemicals. The main raw materials of the current production of transportation biofuels (installed capacity about 850 kt per year) are waste cooking oil, fresh vegetable oil, maize and wheat. In addition to these

commercial industrial biorefining activities, four innovative pilot-scale biorefineries are in operation since several years, viz.: a Green Biorefinery for biorefining of grass into biogas and chemicals (e.g. amino acids) in Utzenaich, a biorefinery for the gasification of wood into syngas to produce SNG, Fischer-Tropsch fuels and chemicals (e.g. hydrogen) in Güssing, a liquid pyrolysis plant integrated in an oil refinery to co-produce biofuels and chemicals in Schwechat, and an algae production plant and biorefining to Omega 3 fatty acids and biofuels. This already existing industrial and logistical infrastructure is now further deployed towards a strong Austrian bio-based industry, in which straw and organic residues will become additional relevant feedstocks. The Austrian R&D-activities are focused on new technologies for the bio-based industry, to further broaden-up the product portfolio (e.g. transportation biofuels) for future commercial application from various biomass feedstocks.

Denmark

Despite the small size of Denmark, the country has a large and intensive agricultural production that contributes significantly to the economy but also holds large potential for production of biomass for bioenergy and biorefineries. More than 60% of the land is used for agriculture whereas forest only covers 12%. Traditional biorefining of agricultural crops and livestock to food and feed is a well-established industry but for many years. Focus has also been on production of energy from biomass. Already by the "Biomass Action Plan" from 1993 the Danish government set specific targets for the use of biomass in the production of heat and power. The law forced the power companies to introduce incineration of wood and co-firing of straw. Today roughly one-fifth of the total available amount of straw is used for heat and power generation. The latest energy plan from 2012 aims at increasing the use of biomass for heat and power and simultaneous increasing the share of bioenergy in the transport sector to 10% by 2020. One challenge is the biomass availability and the allocation between heat and power, and biorefining to liquid biofuels. Another challenge is the expansion of the biogas production to better utilise the large amounts of manure available from the livestock production. The ultimately goal is a complete transition to renewable energy by 2050. Denmark has a number of companies that are active in the area of biorefining. Examples are: Novozymes, a world leading enzyme company producing enzymes for a number of biorefinery applications; DONG Energy, a leading Power company but it has also technologies for biomass pyrolysis (Pyroneer pilot plant); production of cellulosic ethanol (Inbicon demonstration plant) and bioenergy from municipal solid waste (REnescience pilot plant); Biogasol and Estibio, two sister companies developing technologies for biomass pre-treatment and fermentation to ethanol and chemicals (pilot scale); Haldor Topsøe, leading company for production of

catalysts for chemical processes e.g. the TIGAS™ technology to convert waste wood into synthetic gasoline. The development of more complex biorefineries producing also chemicals and materials is to some extent impeded by the lack of a traditional chemical industry in Denmark.

Germany

Germany lies in the centre of Europe and has approximately 80 million inhabitants. Germany has a vibrant biotechnology and chemical industry, both focusing on value-added products rather than the production of basic chemicals. The German Government supports the transition to a bio-based economy by subsidizing bioenergy and fostering the development of regional clusters in order to improve the collaboration between research/education facilities, start-ups and established companies.

Germany has published a Biorefinery Roadmap in 2012 and a number of events with multi-stakeholders have been organised to follow-up the development of biorefineries in Germany since then. In addition there are various activities in the field of biotechnology in Germany; the following link provides generic information: <http://www.biotechnologie.de/BIO/Navigation/EN/root.html>. Also a number of regional biotechnology clusters exist, e.g. in North Rhine Westphalia <http://www.bio.nrw.de/en/home>, in Bavaria <http://www.cluster-bayern.de/cluster/biotechnologie>, and in Baden-Wuerttemberg www.bio-pro.de.

The definition of biorefineries in Germany differs from the definition used by Task42 and the US definition for biorefineries. The German definition requires integrated conversion of biomass, including primary and secondary refining. Installations that are built to produce bioenergy are outside that definition; therefore the 7000 biogas plants in Germany are not considered as biorefineries. Within the biorefinery concept four groups are defined (sugar/starch, vegetable oil/algae, lignocellulose/grass and syngas). The concepts are further distinguished in bottom-up and top-down approaches. Traditional bottom-up biorefineries, such as: sugar/starch, vegetable oil and cellulosic for paper, are fully developed; while top-down biorefineries, such as: algae, grass and syngas even commercially operating, are still in its infancy. In total there are 16 installations that fulfil the German definition of biorefineries, 12 using a bottom-up approach and the remaining are top-down biorefineries.

Italy

Over the past 10 years, Italy has had a primary energy demand in the range 180-190 Mtoe. The energetic supply has been strongly based on fossil fuels and on foreign imports although contribution of renewables is increased. According to the European strategy of 20-20-20, Italy will produce at 2020 17% of the final energy uses from renewables and will reduce the CO₂ emissions by 13% with respect to 2005. This target implies a renewable

energy production of 22 Mtoe, 44% of which will be produced from biomass. With respect to these targets, the latest available official statistics indicate that the electricity production and the energy consumption in the heating sector from bioresources have been 0.93 Mtoe and 3.8 Mtep¹ respectively. In this energetic framework, the Italian chemical industry represents the third European producer of chemicals. One driving factor of this sector is the progressive reduction of greenhouse gas emissions and of the energy consumption of industrial processes. Bio-based Economy and green chemistry can bring great systemic and trans-sectorial opportunities in terms of jobs and GDP. For Italy, new biorefineries complexes could offer the opportunities of reconverting some industrial sites facing a severe crisis and promoting the development of locally integrated value chains.

Italy has an overall biomass potential of 540-550 PJ with a contribution of 38-49% of agricultural residues, mainly straws. The number of biomass plants for the production of electricity has grown in the last decade, mainly thanks to installations higher than 10MW. Considering the low availability of domestic biomass and the relevant distribution, these plants could face problems in reliable feedstock supply. Some opportunities to develop bioenergy in the future could derive from an increased use of residual biomass/wastes or low inputs dedicated crops in decentralized applications (1-5 MWe) for which gasification could be of interest.

Concerning the biofuel-driven biorefineries, since 2008 Italy has had a mandatory target for biofuels blending. The quota obligation for 2014 is 4.5%. Despite the availability of an important installed capacity (i.e. biodiesel installed capacity in 2012 was 2.3 million tonnes), the domestic production of biofuels has been limited (only 287,000 tonnes in 2012). New drivers are expected from the production of second generation bioethanol. The Chemtex (M&G) demo plant in Northern Italy with a designed capacity up to 60 kt/y is the largest lignocellulosic plant in the world already in operation. The plant is fed with two main local feedstocks, wheat straw and Giant reed (*Arundo donax*). A joint venture, Beta Renewables, has been created with the scope of exploiting the PROESA technology developed by Chemtex for the production of several biobased products from lignocellulosics.

Concerning bioproduct-driven biorefineries, Novamont leader in the European bioplastics industry is manufacturing Mater-Bi obtained from the complexation of the biomass starch proteins with polyesters. The company is involved in two important initiatives: the conversion of an old industrial plant located in Northern Italy in a new fermentation plant of BDO with a capacity of 20 kt/y; the construction of a biorefinery plant located in Porto Torres (Sardinia) to produce, monomers, rubber additives, lubricants, bio-fillers and bio-plastics from Cardoon. Finally, bio-succinic acid is another biobased building block of interest for Italy. Reverdia, a joint venture established between

¹ data from GSE (2011)

DSM and Roquette, will produce 10 kton/y of bio-succinic acid in Cassano Spinola.

In 2014 Italy has kicked-off some projects of the national cluster on green chemistry (SPRING-Sustainable Processes and Resources for Innovation and National growth). The cluster consists in the aggregation of the main Italian industrial and academic stakeholders in the sector of biobased products. This initiative has inaugurated a new era in which a number of products will be obtained from the barrel of biomass.

Netherlands

In the Netherlands (NL) the Bio(based) Economy has been widely adopted in the last years. The most important motives behind this adoption were: striving for more sustainability (reduction of CO₂-emissions, circular economy), the awareness of the finite nature of fossil fuels, and the economic opportunities offered to Dutch business through the use of renewable biological resources and residues. The NL possesses an agri-food and chemical sector that is on par with global industry leaders. The Netherlands also has a well-developed energy sector. Add to that a large number of innovative small and medium enterprises, international ports linked to a close-knit logistics network, a sizable hinterland, and the availability of high-quality education and knowledge institutes, it is clear that the Netherlands is in a strong position to make the Bio(based) Economy a success. Consequently, the government as well as the business world have made the Bio(based) Economy a main priority.

The NL is the second largest exporter of **agricultural and food products** worldwide. It has 2 million ha of agricultural land. The added-value of the overall agri-complex is about 50 billion Euros (2010) being about 9% of the of the added-value of the Dutch economy. The Dutch production efficiency per ha is still the highest in Europe. Further, the NL is a global player in the breeding of new plant varieties with 8000-10000 employees, and about 300 companies (a.o. Rijk Zwaan, Nunhems, Enza, KeyGene, Syngenta, Novartis).

The processing and upgrading of primary (agricultural) residues is increasingly improving. Part of these residues are currently sold as livestock feed; however, several consortia are currently analysing the opportunities to process protein-rich residues to protein ingredients for human food (a.o. Avebe, Grassa, HarvestaGG). They also explore if enzymes can be extracted that can be used in the chemical industry; whereas also initiatives are analysing the extraction of specific fibre fractions (a.o. NewFoss, Solidpack). In Roosebdaal, Cosun has built a pilot-plant for upgrading beet pulp.

The **horticulture sector** is also actively involved in upgrading of their residues (a.o. tomato box from tomato stalks). In addition this sector is a producer of high-quality and complex extractives for applications in pharmaceuticals and cosmetics; whereas they are also involved in the production of aquatic biomass

(microalgae, duckweed) for proteins, fatty acids, antioxidants, and colouring agents.

Over the past 10 years, the Dutch **chemical sector** has expanded its turnover by 30% by introducing new products in the market, increasing labour productivity by more than 30%, and reducing energy consumption per tonne of product by 25%. The chemical industry has set a target of consuming 50% less fossil fuels within the next 25 years. The substitution of fossil resources with biomass is an important development in the chemical sector. Huge global players, like Shell, DSM and AkzoNobel are based in the NL, and are actively involved in the development and production of bio-based chemicals. Examples of other stakeholders involved are: a.o. BioMCN, Suikerunie, Cosun, Croda, Nuplex Resins, Purac, Avantium, Synbra, Parengo, Rodenburg Biopolymers.

Biomass is currently already being used on a large scale in the **energy sector**. This development is being driven by the European objective of 14% renewable energy (final gross end-use) in 2020, and the raised objective of 16% (about 340 PJ) set by the Dutch government. Biomass is anticipated to contribute significantly to this 2020 objective.

In 2012 about 97 PJ renewable energy was produced in the NL, corresponding to about 4.5% of the national gross end-use. The bioenergy sector is one of the major LC-biomass consumers in the NL. Over 52% (49.8 PJ) of the renewable energy produced in the NL in 2012 was biomass based by combustion of organic materials in domestic waste combustion facilities, direct and indirect co-firing in existing coal-fired power plants, and the use of wood stoves. Mono and co-digestion for the production of power, heat and raw biogas to be upgraded to SNG or CNG/LNG give an additional contribution of about 8% (8.8 PJ).

The use of biomass resources for the production of secondary energy carriers (power, heat, biogas) is currently financially supported by the Dutch government (SDE+: 1.7 billion Euro in 2012, 3 billion Euro in 2013), and probably will also remain being subsidised for the mid and longer term to meet the Dutch part of the European renewable energy policy goal of 20% in 2020 [RED; Richtlijn 2009/28/EG [EU 2009a]]. For the period after 2020, the self-support issue concerning energy will become an even more important issue at European level. Within that framework the production and use of bioenergy will remain an important issue.

Positive aspects of the large-scale use of biomass for bioenergy are that a significant biomass potential has been made available in the recent years, certification systems have been developed that guarantee the sustainability over the full production and valorisation chains, and that chain covering stakeholder consortia are formed that are successful in the market deployment of the full value chains.

A promising near future way to use the available biomass also for higher value Biobased applications (chemicals, materials) is to co-operate with the stakeholders from the energy sector to make use of their expertise and already available infrastructure for biomass sourcing. Options for synergetic co-operation are: i) upstream fractionation of raw biomass resources to separate

added-value bio-based products (proteins, carbohydrates, oils) before energy production from the lignin-rich residue stream, and ii) downstream valorisation of produced secondary (process) residue streams (ash fractions, heat, CO₂, ...). The up-/downstream integration of the energy sector with the agro-food and/or chemical sector creates a win-win situation for both the Dutch government and all the stakeholders involved because biomass valorisation chains are developed and deployed that are technically mature, socio-ecologically acceptable and economically profitable.

The same approach is applicable for digestion processes, however, on a smaller and more regional scale. Without financial governmental support these systems are economically not feasible. Therefore, they require a biorefining approach for creating sustainable business concepts.

In the **transport sector** the use of renewable energy is achieved by requiring fuel suppliers to blend fuels with biofuels. In 2012, the mandatory share of renewable energy in transport amounted 4.5%. This share will continue to expand in the next years. In the NL the transport sector is one of the major sectors concerning biomass use. In 2012 about 15% (14.3 PJ) of the renewable energy used in the NL was for transport purposes (bio-based gasoline and diesel substitutes).

To meet the European policy goal of 10% renewable energy in the transport sector in 2020 also in the coming years the use of biomass in this sector is expected to increase. The ILUC discussion has resulted in the decision at European level that only 50% of the 2020 goal may be met by using conventional biofuels; the other part should come from advanced biofuels produced from non-food crops, incl. residue streams. For the period after 2020 the situation concerning biofuels is much more unclear. Self-supporting in energy, including transportation, will become a major policy defining framework at European level. For biofuels, however, the EC has not defined any specific policy goals for the period after 2020. The application of biofuels will be part of the overall policy framework described in the Transport White Paper (EC, COM(2014)15 which deals more with the greening of the transport sector in general, rather than on the application of alternative fuels, incl. biofuels, alone. The use of biofuels in aviation, shipping and for heavy duty transport is the only alternative to meet specific additional environmental goals within these sectors. Therefore it is expected that necessary technology development, upscaling and implementation trajectories will more and more focussed on these specific types of advanced biofuels. Like the bioenergy sector, also the biofuel sector offers the running train concerning expertise, logistics, certification, and infrastructure that can be used to further realise the Bio(based) Economy. By development and deployment of Biofuel-driven Biorefineries, using existing infrastructure, multi-product facilities can be realised to valorise biomass in the most efficient and sustainable way.

The NL counts a number of public-private joint ventures that conduct targeted research programmes in the **knowledge infrastructure** of the Bio(based) Economy, viz.:

- Regional Clusters with cross-sector cooperation, including provinces, development companies, industry, SMEs, research institutes, universities (BioEconomy Innovation Cluster Eastern Netherlands (BIC ON), Biobased Delta, BioDelta South Wing, Port of Amsterdam, Biobased Limburg, Bio-based Economy North Netherlands, ...).
- Knowledge-based Clusters: Application Centre for Renewable REsources (ACCRES), AlgaeParc, Bioprocess Pilot Facility (BPF), Fresh Biomass Refinery Parc, BioSolar Cells, Green Genetics Centre of Excellence (TGG), Knowledge Centre on Vegetable Substances, Chemelot Institute for Science and Technology (tbe), Shared Research Centre Biobased Aromatics (tbe), ...
- Research Programmes: Catchbio (biocatalysis), BE-Basic (biotechnology), DPI (polymers), BPM (bio-based performance materials), CCC (carbohydrates), BIOcab (agricultural residues valorisation), ISPT (sustainable process technology), AMIMB (bio-based materials, tbe), ...

The **Top Consortium for Knowledge and Innovation (TKI Biobased Economy (BBE))** is one of the seven TKIs within the Top Sector (TS) Chemical Industry. This TS is one of the nine defined TSs in which the NL holds a strong global position. The TKI BBE is directed at the production of biobased innovation across the entire biomass value chain, from field to end-product, including the closing of loops. The TKI BBE is organised around six programme lines: high quality energy carriers (focus on pre-treatment/fractionation of biomass), high percentages of additional and auxiliary co-firing, biorefining, chemical and biotechnological conversion technology, aquatic biomass (micro and macro algae, BioSolar) and Economy, Policy and Sustainability (EBD). The TKI BBE has a network of about 100 companies, research institutes, and non-governmental organisations. Governmental innovation budget 2012: 42 million Euro, supplemented with about 150 million Euro individual contributions.

The information presented in this paragraph on country specific challenges in the Netherlands is mainly taken from a) "The Bio-based Economy in the Netherlands", NL Agency – NL EVD International, The Hague, the Netherlands (www.ianetwerk.nl), May 2013, b) "TKI Biobased Economy" (www.tki-bbe.nl), Top Sector Energy, NL Agency, March 2013, c) "Status Document Bioenergie 2012", NL Agency, Utrecht, the Netherlands, 2013. It is slightly processed by the Dutch representative within IEA Bioenergy Task42 for this specific report.

New Zealand

New Zealand is a small country of 4.5 million people which is geographically isolated from Europe and North America. It has a free market economy which is strongly reliant on international trade and is vulnerable to international commodity prices. The New Zealand government does not have any specific policies to encourage biorefinery deployment. Biofuels are

included in the government's energy strategy, however, currently there are no mandates for their use and only limited incentives. New Zealand has an operational greenhouse gas emissions trading scheme, however, at present the price of carbon is very low, providing little incentive for biofuels. New Zealand's electricity production is 73% renewable, and wood residues are widely used for industrial heat. Hence there are limited market opportunities for heat & power-driven biorefineries. Displacing imported oil with 'drop-in' liquid biofuels and bio-chemicals from wood biomass represents the largest biorefinery opportunity in New Zealand. However suitable technologies are yet to be proven on a commercial scale and the investment risk is high. The high investment capital needed for demonstration facilities drives NZ-grown technology companies to seek investment offshore. Established NZ companies are more likely to adopt a fast-follower approach to technology implementation rather than first-of-its-kind development. So far, the environmental and social benefits of biorefineries are not widely recognised by the New Zealand public.

United States of America

The U.S. Department of Energy (DOE) Bioenergy Technologies program's mission is to catalyze the development of a domestic capability to produce cost-competitive renewable fuels from non-food biomass resources². Biofuels are a major component of a multipronged strategy that addresses energy security, transportation-related greenhouse gas (GHG) emissions, and U.S. job growth. The potential exists to sustainably produce at least 1 billion dry tons of non-food biomass resources by 2030³: this is a sufficient quantity to displace approximately 30 percent of the country's present petroleum consumption without impacting food or feed needs, and to have a positive impact on the environment by significantly reducing GHG emissions.

To deliver on the broad benefits of advanced biofuels and bioenergy technologies, the program works to understand the critical linkages along the supply chain including research, development, demonstration, and deployment (RDD&D) on sustainable feedstock supply, and logistics, cost competitive conversion process including cost-shared scale up and construction of integrated biorefineries that will reduce the risk of this "First of a Kind" technology encouraging further private investment. The program enables the development of technologies that transform the robust, renewable biomass resources of the U.S. into commercially viable, high-performance biofuels, bioproducts, and biopower through targeted RDD&D supported by public-private partnerships. Research is targeted primarily on fuels that have the potential to enter the market and compete directly with petroleum, both in terms of cost and performance.

Cellulosic ethanol was the program's initial focus because it could easily be blended into the gasoline fuel pool, in order to address the need for increased octane content. DOE has made significant progress in the RD&D of cellulosic ethanol in order to enable appreciable market penetration for the foreseeable future. While cellulosic ethanol has the potential to displace up to 38 percent⁴ of crude oil that is used to produce light-duty gasoline, it cannot be blended with diesel or jet fuel or be integrated within the existing refinery system.

Building on the foundation and success of cellulosic ethanol R&D, the program has now shifted toward RDD&D activities focused on drop-in hydrocarbon biofuels, including renewable gasoline, diesel, and jet fuel — as well as chemicals and products. Science and technology have evolved to make drop-in hydrocarbons a highly promising future opportunity that supports the domestic demonstration and deployment of commercial renewable fuels supply. These bio-based hydrocarbon fuels are more compatible with today's engines and fuel delivery infrastructure. Cellulosic ethanol has enjoyed over 10 years of RDD&D which is leading to demonstration of first of a kind cellulosic ethanol producing biorefineries at commercial scale. To address the next wave of technologies to drop-in hydrocarbon fuels, the program is pursuing multiple pathways, including thermochemical-, catalytic-, biochemical- and hybrid-conversion routes of lignocellulosic and algal feedstocks with the goal of achieving \$3/gasoline gallon equivalent (gge) by 2022 with at least 50 percent GHG reduction on a lifecycle basis with several down-selected technologies in order to provide optimal solutions across the nation.

Several key challenges must be addressed for the bioenergy sector to significantly contribute further to our national goals of reducing oil dependency and decreasing GHG emissions:

Scalability — significant quantities of biomass exist today as agricultural and forestry residues and urban wastes. However, it is difficult to economically collect and haul these materials to a central processing facility because they have intrinsically lower bulk and energy densities than crude oil, coal, or corn grain. In addition, first-of-a-kind facilities carry large risks in scaling technologies from bench to commercial scale.

Cost reduction — the significant external advantages to the U.S. economy of domestically produced biofuels and bioproducts are not captured in the market price, so domestic production must be able to compete in the market in order to develop a meaningful industry. A recent survey⁵ indicated that the cost of biofuels has dropped significantly since 2008. The survey found that the largest cost elements for producers in 2012 were project capital expenditure, feedstock, and enzymes. The operating costs of the process have dropped significantly since 2008 due to leaps forward in the technology. For example between 2008 and 2012, the program's 10 year investment of over \$65 million contributed to a 72 percent reduction in the enzyme cost necessary to produce a liter of

2 Source of entire text is the U.S. Department of Energy Bioenergy Technologies Program's FY15 Budget Request

3 http://www1.eere.energy.gov/bioenergy/pdfs/billion_ton_update.pdf.

4 EIA, Annual Energy Review 2012, 85 percent of gasoline stream in total petroleum products.

5 Bloomberg New Energy Finance, "Cellulosic Ethanol Costs: Surveying an Industry" (March 2013).

cellulosic ethanol. Continued investments to achieve these types of cost reductions will be necessary to maintain this same reduction trajectory for the whole value chain.

Private-sector investments — In order to support the emerging advanced biofuels industry through its early development and commercialization, the industry needs to demonstrate the technology thus reducing risk in order to attract future private sector investment in subsequent commercial facilities. For example, continued government support, in partnership with the private sector, to build specialized, first-of-a-kind facilities will help validate performance and economics at a scale necessary to enable confidence from the financial markets for commercializing a robust biofuels industry.

Infrastructure — there is a need to ensure that the transportation supply chain and delivery infrastructure are able to deploy and utilize advanced biofuels as they are produced in significant volumes. Vehicle compatibility will need to be validated for drop-in replacement fuels as well. This work represents a significant opportunity for collaboration between Bioenergy Technologies and Vehicle Technologies, and ensures widespread adoption within the transportation sector.

Within the program's mission, the following activities are directed at overcoming these fundamental challenges:

Conduct research and development (R&D) directed at reducing the cost of producing biofuels, bioproducts, and biopower by improving the efficiencies of feedstock production and delivery, as well as through developing more effective, cost-competitive processes to convert biomass into finished products.

Develop technologies to convert non-food sources of biomass to intermediates — such as low-cost sugars, chemicals, and crude bio-oils — to meet the need for fuels and bioproducts, thus enhancing project economics and environmental sustainability.

Evaluate infrastructure readiness through analysis and testing of advanced biofuels to enable use of existing infrastructure for deployment and utilization, thus reducing the need for capital investments in new infrastructure.

Enable demonstration activities for the manufacturing of biofuels and bioproducts that are critical to proof of performance and lay the groundwork for future commercial deployment.

DOE's biofuels demonstration and deployment activities focus on Integrated Biorefineries. As of July 2014, the Bioenergy Technologies Offices has 20 active biorefinery projects, utilizing a broad spectrum of feedstocks and conversion techniques. An additional six projects have been successfully completed. The objective of these first-of-a-kind technologies at pilot, demonstration, and commercial scales is to validate key technical and economic performance parameters and demonstrate the reduction of technical and logistical risks upon scaling to encourage private investment and increased market share. Importantly, biorefinery efforts include both on cellulosic ethanol and renewable hydrocarbon projects. Roughly half of these biorefinery projects are cellulosic ethanol and half are drop-in biofuels or high-value bio-based chemicals. The first pioneer scale demonstration facility produced its initial product in 2013

(INEOS in Florida, projected 8 MGY capacity). American Process Incorporated, in Michigan, in the spring of 2014 began producing the first RIN-qualifying quantities of cellulosic ethanol from mixed forest residue (894 KGY cellulosic ethanol). Additional facilities utilizing cellulosic feedstocks (Abengoa, Kansas projected capacity 25 MGY; DuPont, Iowa projected capacity 30 MGY; POET, Iowa projected capacity 25 MGY) are expected to begin producing ethanol fuels in 2014.

3. Vision, Mission & Strategy IEA Bioenergy Task42

Biorefineries are already applied for ages in for example the food industry. Large-scale implementation of biorefineries for Non-food (incl. Bioenergy) applications, however, is still lacking. Major reasons for this are that: some of the key technologies (fractionation & product separation) being part of integrated biorefinery plants are still not mature enough for commercial market implementation; there is still no level-playing-field for sustainable biomass use for Food and Non-food applications; market sectors that should co-operate (food, feed, agro, chemistry, energy, fuels, logistics, ...) for the development and commercialisation of full sustainable biomass value chains, including high-efficient biorefinery processes, are often still not working together, and there is still lack of knowledge/expertise on the advantages of biorefinery processes for optimal sustainable biomass use at both industrial, SME and (regional) governmental level. Major challenges still to be tackled are: develop industry legitimacy and a level-playing field for sustainable biomass use; multi-sectorial stakeholder involvement in the deployment of sustainable value chains; technology development and biorefinery scale-up using best practices; unlock available expertise energy/fuel, agri/food, material and chemical manufacturing sectors, and develop the necessary human capital by training students and other stakeholders to become the biorefinery experts of today and tomorrow.

The vision, mission, and strategy statements for IEA Bioenergy Task42 focus on overcoming the environmental, institutional, technological, social, and market challenges to the near- and long-term deployment of biorefinery technologies.

Vision: Biorefining is the most optimal way for large-scale sustainable use of biomass in the BioEconomy. By accelerating the sustainable production and use of biomass, particularly in a biorefinery approach, the socio-economic and environmental impacts will be optimized resulting in more cost-competitive production of food and feed ingredients, bio-based products (chemicals, materials) and bioenergy (fuels, power, heat), reduced greenhouse gas emissions, and efficient use of available resources (raw materials, minerals, water).

Mission: To facilitate the commercialisation and market deployment of environmentally sound, socially acceptable, and cost-competitive biorefinery systems and technologies, and to advise policy and industrial decision makers accordingly.

Strategy: To provide platforms for international collaboration and information exchange in biorefinery research, development, demonstration, and policy analysis. This includes the development of networks, dissemination of information, and provision of science-based technology analysis, as well as support and advice to policy makers, involvement of industry, and encouragement of membership by countries with a strong biorefinery infrastructure and appropriate policies. Gaps and barriers to deployment need to be addressed to successfully promote sustainable biorefinery systems.

The **aim of the Task** is to contribute to the development and implementation of sustainable biorefineries – as part of highly efficient, zero waste value chains – synergistically producing bio-based Food and Non-food Products as base for a global BioEconomy. It will be accomplished by carrying out a number of activities, which will be carried out by the Task42 country representatives as well as by competitively selected contractors.

The information provided can be used by national and international governmental organisations to develop bioenergy-related policies, industrial stakeholders for focusing their RTD and deployment strategies on the most promising (i.e. sustainable) biomass value chains, NGOs to be included into their renewable energy scenarios, and research institutes and universities to focus their applied and strategic research programmes.

4. Definition Biorefining & Classification Biorefineries

Definition

Biorefining is the sustainable synergetic processing of biomass into a spectrum of marketable food & feed ingredients, products (chemicals, materials) and energy (fuels, power, heat) (Fig. 2).

In general, both energy-driven (or fuel-driven) and product driven biorefineries can be distinguished.

In **energy-driven (or biofuel-driven) biorefineries** the main goal is to produce huge volumes of relatively low-value energy (or fuels) out of biomass. The full value chain infrastructure exists, however, their profitability is still questionable, requiring significant financial governmental support or a regulated market to guarantee large-scale market deployment.

In **product-driven (i.e. chemicals, materials) biorefineries** the main goal is to produce smaller amounts of relatively higher value-added biobased products out of biomass; primary (agro) and secondary (process) residues are used to produce energy (power/heat) for internal or external use. Currently, only limited product-driven biorefineries are in operation, mainly because of the fact that some key technologies are still in the R&D, pilot and demo-phase. However, their potential is huge, and it is generally believed that a refocus will take place concerning optimal sustainable biomass use from mainly energy (fuel) applications to chemical/material applications, and – depending on the raw materials used – even to biorefineries that use biomass for both Food and Non-food applications. The current energy/fuel infrastructures, and the expertise to implement full biomass value chains, will be used as starting point in a transition process. However, also on the longer-term bioenergy, incl. biofuels, will be produced in significant amounts from primary (agro), secondary

(process) and tertiary (post-consumer) residues, and therefore will remain the lubricating oil of a future BioEconomy.

Classification

IEA Bioenergy Task42 has developed a classification scheme to describe different biorefineries obviously. The classification of a biorefinery consists of the following features: platforms, products, feedstocks (and processes). With the combination of these features, different biorefinery configurations can be described and named in a consistent manner. The naming of a biorefinery system consists of the following elements: number and name of the platform(s), product(s), feedstock(s), and optionally the processes involved (Fig. 3).

In Fig. 4 a generic classification scheme of a biorefinery is shown on the left hand side, and an example of the biorefining of oilseed crops into biodiesel, glycerine and animal feed on the right hand side.

The most important feature is the platform. Platforms (Fig. 5) might be: intermediate products from biomass feedstocks towards biorefinery's products, linkages between different biorefinery concepts or final products of a biorefinery.

The platforms might represent mixtures of compounds (C6&lignin, C5&C6 sugars) or more isolated compounds. For the platform "electricity & heat" in the different biorefinery concepts, it is important to define if electricity and heat are produced from process residues, directly from biomass feedstock, fossil fuels or other form of renewable energy, e.g. wind, solar. Further, electricity & heat can be produced within the biorefinery plant e.g. from process residues or can be covered by external supply.

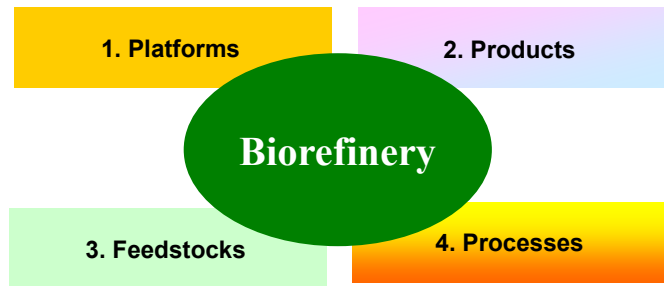
The classification scheme is used for the description (naming) of selected biorefinery facilities in this report. For simplification in most of the cases electricity and heat are combined into one platform "electricity&heat".

For more information

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Figure 2. Spectrum of marketable bio-based "products" [IEA Bioenergy Task42]



Naming:

- Number platforms (Name of platforms)/Feedstock/Products/Processes
- e.g. 2-platform (electricity&heat, syngas) biorefinery/wood chips/FT-biofuels, electricity, heat, waxes/steam gasification

Figure 3. The features to characterise a biorefinery system [IEA Bioenergy Task42]

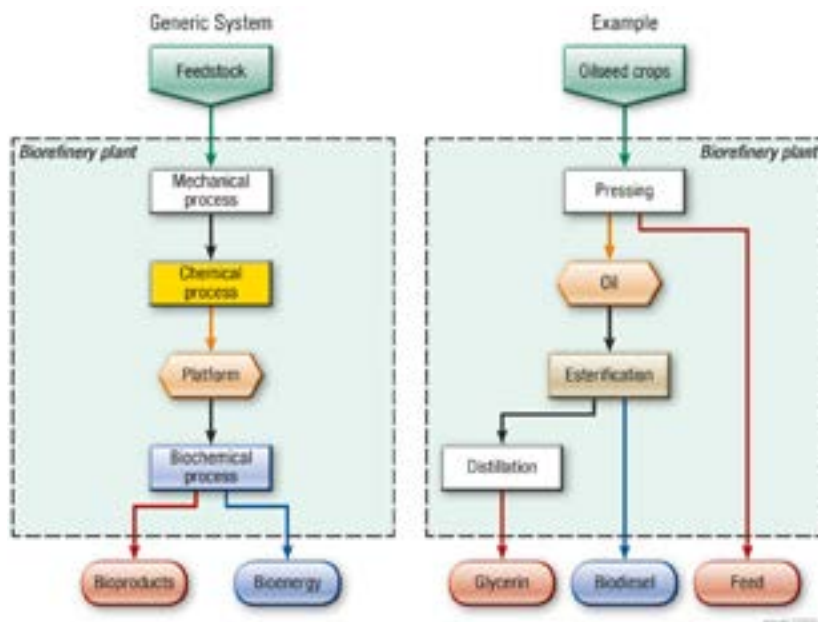


Figure 4. Classification scheme of a biorefinery: generic scheme (left), example (right) "1-platform (oil) biorefinery producing biodiesel, glycerine and feed from oilseed crops (via pressing, esterification and distillation)" [IEA Bioenergy Task42]

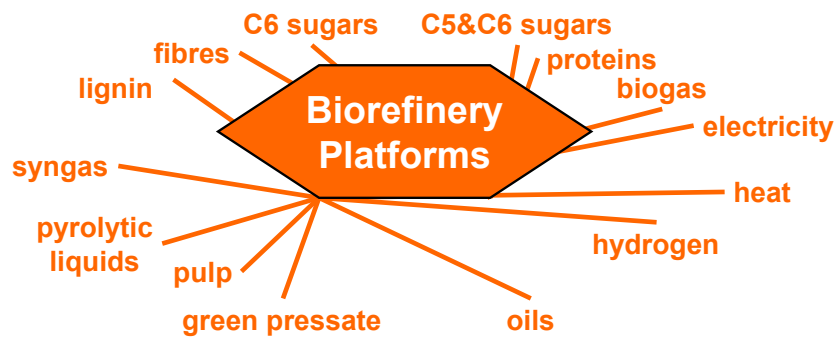


Figure 5. Examples for possible platforms in a biorefinery system [IEA Bioenergy Task42]

5. Sustainability Issues Biofuel-driven Biorefineries

Sustainability is deemed to be a core attribute of biorefineries. In fact, it is the first term in the Task42 biorefining definition. It refers to the biomass feedstock, the conversion or transformation of biomass feedstock, and the products and co-products that are produced from a biorefinery.

Biorefineries, if appropriately designed and operated, should contribute to sustainable innovation. Renewability is one of its distinguishing features as biorefineries transform renewable resources in a clean and efficient way into a variety of products that can be recycled or reused as a material or energy. Being part of the cyclical economy is how biorefineries contribute to today's and future generations.

Measuring sustainability is not an easy task for several reasons. First, there are differing definitions, and second, the definitions encompass many parameters. Most would agree that the concept addresses three broad dimensions of development - economic, environmental and social dimensions. In business, this is expressed as triple bottom line (TBL) reporting. Numerous frameworks have emerged to define the indicators for each of the three dimensions that are relevant to the operation or business, and the context in which it functions. Not surprisingly, the sustainability indicators are generally very similar but not always identical. Nowadays a fourth dimension of sustainability is discussed: Good Governance. The development of Good Governance indicators and the implementation of them in a broader sustainability framework is still in its infancy.

In the case of biorefineries, sustainability assessment should reflect the important renewability attribute in addition to showing how biorefineries contribute to social, environmental and economic well-being (or people, planet and profit). As much as possible assessments should be carried out on a lifecycle basis, starting from biomass feedstock and extending to the end-of-life of the products derived from its biomass feedstocks. This is more easily carried out for Biofuel-driven biorefineries, as fuels have relatively short value chains. Bio-based chemicals and materials are typically intermediate products that are further transformed and become part of considerably longer, more complex value chains. Consequently, assessments of Product-driven biorefineries are often partial evaluations that are limited by the amount of available data.

Another complicating factor is that biorefineries are highly diverse in form and are just emerging, that is, the data are not yet available. The examples included in this brochure illustrate the wide range in design configurations and product mixes. That being said, biorefinery sustainability needs to be addressed. As a first step, greenhouse gas (GHG) emissions should be quantified on a lifecycle basis and relative to a reference system. While GHG emissions represent only one indicator of sustainability, this

indicator provides information on environmental benefits, energy consumption as well as the renewability of a bio-based system.

Standards are under development for sustainability assessment of bioenergy and bio-based products at international, continental and national level. ISO is currently developing a standard for "Sustainability criteria for bioenergy" (ISO 13065); the Global Bioenergy Partnership (GBEP) has developed a sustainability framework; in Europe CEN/TC411 is developing standards for "Life Cycle Assessment of bio-based products", and for "Sustainability criteria for bio-based products".

At national level various activities in the field of sustainability assessment and sustainability metrics development take place. Canada has been developing a sustainability framework called LEEAFF to communicate the Land use, Environmental, Employment, Acceptability, Feedstock and Financial attributes of biorefineries. At this early stage of development, qualitative and quantitative information will be used to describe the contribution of biorefineries to sustainable development. For more information on this Canadian framework, or to become involved in testing its application, please contact: Maria Wellisch, Agriculture and Agri-Food Canada.

In Germany the German Association of German Engineers has produced a guidance document for classifying and assessing biorefineries. The Greenprint was presented in May 2014. In addition the Federal Ministry of Food and Agriculture has initiated a project "Initiative Sustainable Supply of Raw Materials for the Industrial Use of Biomass" – www.inro-biomasse.de). The aim of project is to reach an agreement with industrial companies on the voluntary certification of renewable raw materials to the point of their first processing. For more information on these activities, please contact: Heinz Stichnothe, Thuenen Institute of Agricultural Technology, Germany.

In Austria a hotspot assessment tool covering economic and ecological aspects of biorefineries is under development in collaboration with Task42. More details are provided in Chapter 6.

Ultimately, sustainability can only be achieved on a global scale, across all sectors, over very long time frames. But it is important to recognize progress in the field of sustainable biorefineries towards this ultimate goal.

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6. Factsheets Biorefinery Facilities

In spite of the fact that biorefining is very promising for the sustainable valorisation of biomass to both food and feed ingredients, bio-based products and bioenergy, the whole biorefinery area is very broad, the concepts involved are often very complicated, and data on their (potential) technical, socio-economic and ecological performance are often very difficult to understand. To help the market deployment of biorefineries one important critical success factor is clear knowledge dissemination to all stakeholders involved, so that they are finally able to speak the same language, and to raise some public support for implementation.

To facilitate the implementation trajectory, IEA Bioenergy Task42 is developing a so called "Biorefinery Fact Sheet", for the uniform description of the key facts & figures of different biorefineries. Based on a technical description and the classification scheme, the mass and energy balance is calculated for the most reasonable production capacity. Then the three dimensions – economic, environmental and social – of sustainability are assessed and documented in a compact form, i.e. the "Biorefinery Fact Sheet". Based on these sheets an easy comparison of the different biorefinery systems is possible.

The "Biorefinery Fact Sheet" consists of three parts (Fig. 6): Part A: Biorefinery plant, Part B: Value chain assessment, and Annex: Methodology and data sustainability assessment.

In Part A the key characteristics of the biorefinery plant are described by giving compact information on: classification scheme, description of the biorefinery, mass and energy balance, share of costs and revenues. In Part B the sustainability assessment based on the whole value chain of the biorefinery plant are described by giving compact information on: system boundaries, reference system, cumulated primary energy demand, greenhouse gas emissions and costs and revenues. In the Annex of the "Biorefinery Fact Sheet" the methodology and data for the sustainability assessment are documented. In the near future this Annex potentially will be expanded with a qualitative description of other sustainability indicators (see chapter 5).

One important aspect for the sustainability assessment is the choice of the reference system to produce the same portfolio of products as the biorefinery plant (Fig. 7), and the basics of comparing a biorefinery to the reference system (Fig. 8).

"Biorefinery Fact Sheets" will be made for the 15 most interesting biorefinery concepts identified by the members of IEA Bioenergy Task42.

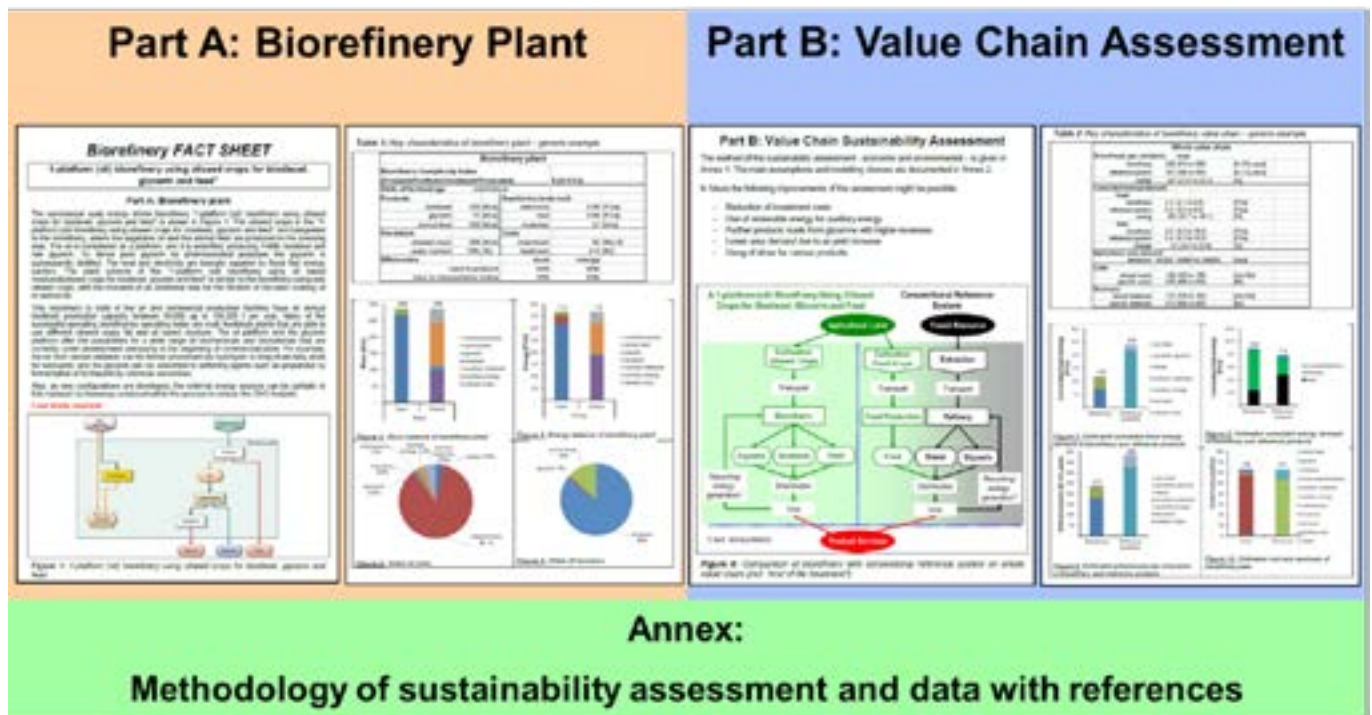


Figure 6. The three parts of the "Biorefinery Fact Sheet" [IEA Bioenergy Task42]

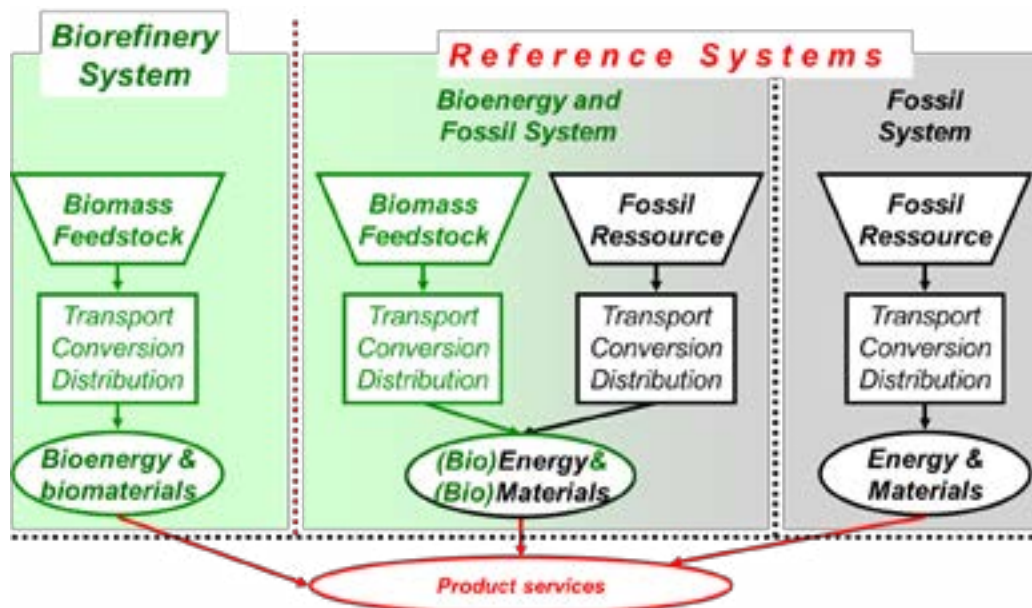


Figure 7. Choice and definition of the reference system for the sustainability assessment in the "Biorefinery Fact Sheet" [IEA Bioenergy Task42]

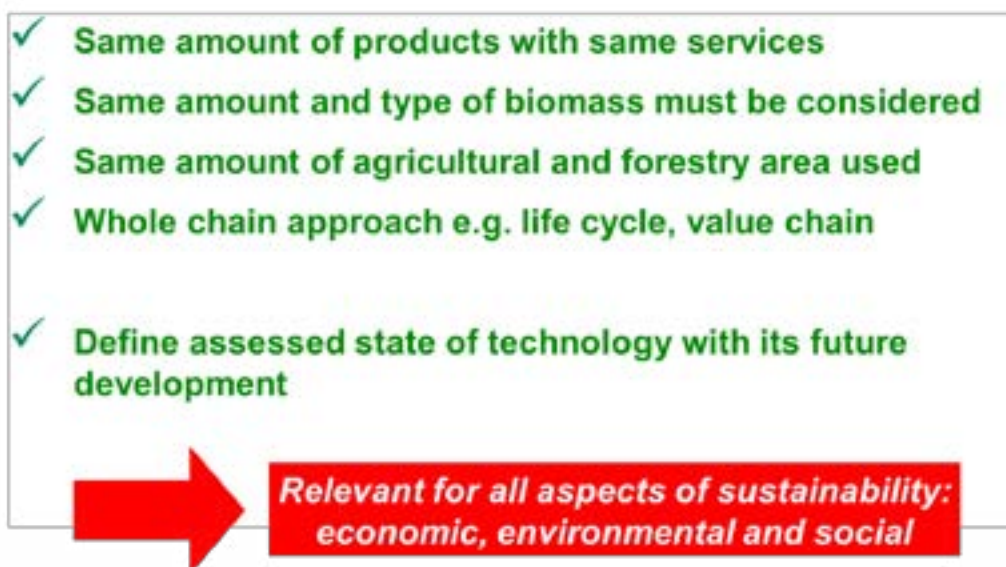


Figure 8. Basics for the consistent comparison of biorefineries to reference systems [IEA T42]

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Proteins for Food and Non-food Applications

In 2014, IEA Bioenergy Task42 will publish the report Proteins for Food and Non-food Applications – Value Added Products from Biorefineries. The main goal of this report is to give stakeholders of the BioEconomy a better insight in 1) the potential economic optimisation of biofuel production processes by giving higher added-value to the protein fraction of the biomass sources used (bio transportation fuel sector), and 2) the refinery options to synergistically and sustainably process protein-rich biomass sources to food/feed ingredients, bio-based products for non-food technical applications, and energy (fuels, power and/or heat).

The report will deal with: the role of proteins within a future BioEconomy, current and future protein sources and markets, biorefining of protein containing biomass, protein-driven biorefining initiatives in some of the participating countries, sustainability assessment of protein-driven biorefineries, and stakeholders involved in the valorisation of proteins to Food and Non-food. This 2014-report will be published in Q4 2014, and will then be downloadable from the Task42-website.

For more information

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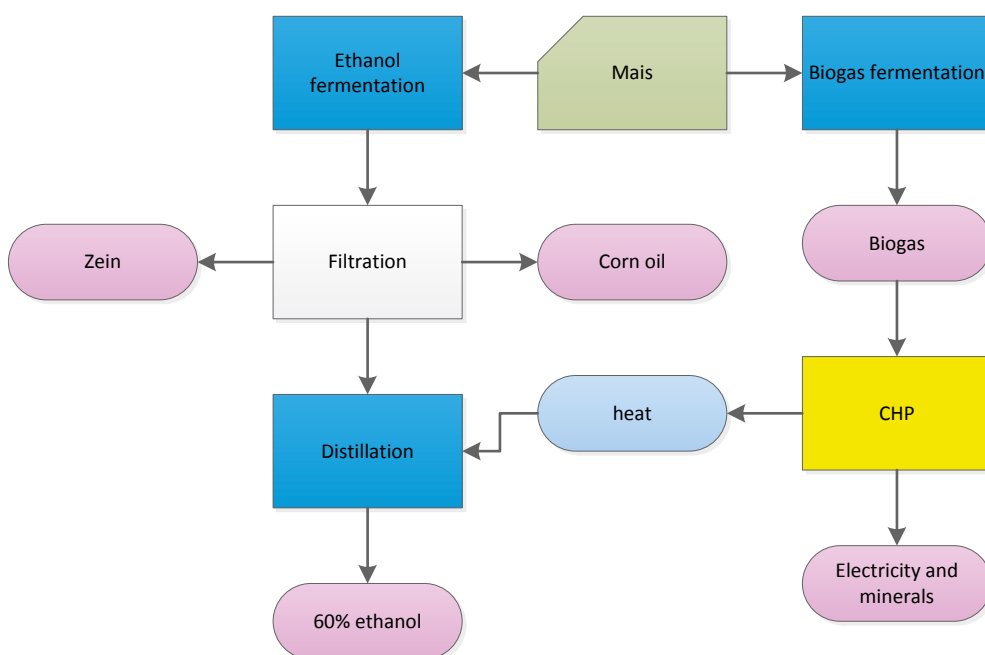


Figure 11.1 Maize refining to Zein (protein for non-food applications), ethanol and biogas (CHP) [Wageningen UR]

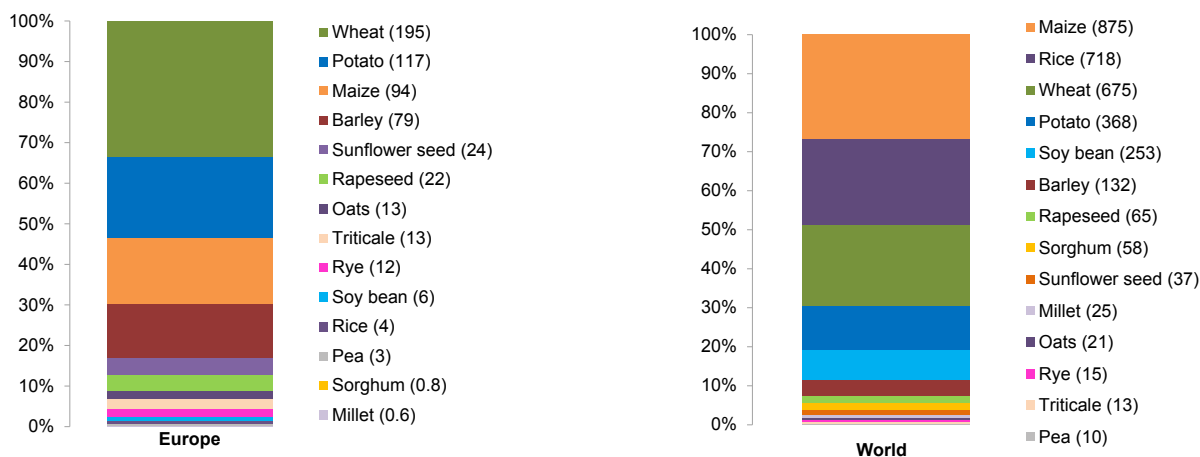


Figure 11.2 Types and volumes protein rich crops in Europe and the world [Wageningen UR]

8. Training Activities

IEA Bioenergy Task42 on Biorefining together with INRA (F), Wageningen UR (NL) and NTUA (GR) have developed and implemented a M.Sc.-level Biorefinery Training (Summer) Course to familiarise both students and other interested stakeholders with the concept of biorefining and the underpinning logic.

A first ½--day course was organised as part of the 5th International Conference on Renewable Resources & Biorefineries RRB5, Ghent, Belgium, 12 June 2009. A second full-day course was organised as part of an International Biomass Valorisation Congress in Amsterdam, the Netherlands on 13 September 2010. With about 70 Participants this event was very successful. A 4-days Training Course "1st European Training Course on Biorefining Principles and Technologies" was successfully (about 120 participants) given in Paris, France, 28 August-1 September

2011. The 2nd European Training Course was successfully (about 75 participants) given in Wageningen, the Netherlands, 3-6 June 2012. The 3rd European Training Course was successfully organised in close co-operation with the European Climate-KIC Programme in Budapest, Hungary, 7-10 July 2014. The goal of IEA Bioenergy Task42 is to co-organise a Training Course minimally once every triennium. Stakeholders/countries that are interested to host a Training Course are asked to get in contact with the Task42 representative.

For more information

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9. Website

In 2013 IEA Bioenergy Task42 has set-up a new Task-website. It consists of an open internet-site www.IEA-Bioenergy.Task42-Biorefineries.com (Fig. 12), and a password protected intranet-site for internal document sharing and management between Task42 partners.

In the vertical left-site navigation information can be found on the specific Task42 activities in the running triennium (2013-2015) (see chapter 10.). In the horizontal top-site navigation major Task42 deliverables, such as: biorefinery fact sheets, biorefinery descriptions, links to biorefinery stakeholders in participating

countries, Task42 partnering countries and country representatives, publications and country reports, can be found. In the factsheets both descriptions and results of the sustainability assessments of some specific biorefineries are presented (see chapter 6). In the country reports – that will be prepared minimally once per triennium – the following info is provided: country specific energy consumption, biomass use for energy and non-energetic applications, biomass related (national) policy issues, biomass related sustainability aspects, running commercial biorefineries, biorefinery demonstration and pilot plants, major R&D projects, and major national stakeholders involved in the field of biorefining.

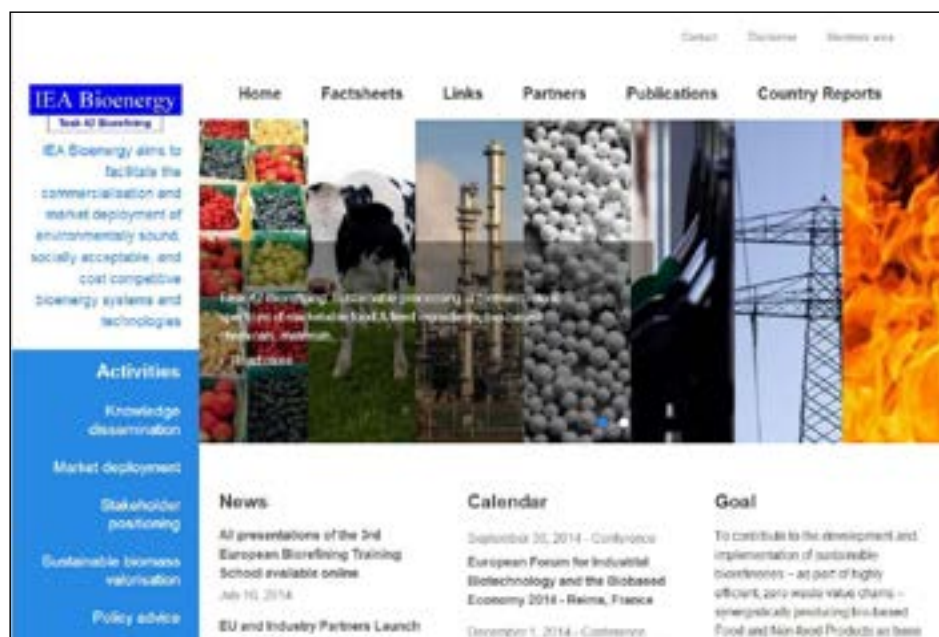


Figure 12. Homepage IEA Bioenergy Task42 internet-site [IEA Bioenergy Task42]

10. IEA Bioenergy Task42 Work Programme 2013-2015

The 2013-2015 work programme of the Task is based on a prioritisation of objectives and activities agreed upon by the participating countries, and is as follows [coordinating country]:

1. To assess the market deployment potential of integrated biorefineries
 - Technical and non-technical critical success factors [U.S.]
 - Disruptive/game changing technologies [NL]
 - Biorefinery-Complexity-Index (BCI) [AT]
2. To support industrial/SME stakeholders finding their position in a future BioEconomy
 - Role involved market sectors in the transition to a BioEconomy [DEN]
 - Upgrading strategies existing industrial infrastructures [AT]
 - Factsheets major biorefineries/national case studies [AT]
 - Updating of bio-chemicals report, and set-up proteins report [NL]
3. To analyse optimal sustainable biomass valorisation options using the market-pull approach
 - Sustainability assessment toolbox [CAN]
 - Mobilising sustainable bioenergy supply chains [D]
 - Future market demand biomass from a BioEconomy perspective [D]
 - BioEconomy Strategies in IEA Bioenergy Implement Agreement participating countries [AT, IT, NL]
4. To advise policy makers on current status, future potential and priority needs
 - Roadmap biorefinery [-]
 - Biorefinery (related) policies in participating countries [NL]
 - Country reporting [NL]
5. To disseminate knowledge on biorefining
 - Bi-annual task and stakeholder meetings, incl. excursions [All]
 - Annual task meetings at national level [All]
 - Task website (public internet and closed members area) [NL]
 - Task newsletters [AT]
 - Glossy task brochure, poster, leaflet [NL]
 - International workshops and conferences [All]
6. To initiate and contribute to biorefinery training activities
 - Triennial training school on biorefining [NL]

Examples Biorefinery Facilities in participating Countries

Low Grade Animal Fats and Vegetable Oils to Biodiesel (Victoria, Australia)

State-of-the-art: Commercial Scale

Type of biorefinery: A 2-platform (oil, biogas) biorefinery for the production of biodiesel, biogas, burner fuel, glycerine and sulphated potash from animal fat and vegetable oil

Location: Barnawartha, Victoria, Australia

Owner: Australian Renewable Fuels Ltd, Melbourne, Victoria, Australia

Feedstocks: Low grade animal fats and waste vegetable oils

Outputs: Biodiesel, technical-grade glycerine, sulphated potash, liquid burner fuel, biogas

Description: Australian Renewable Fuels Ltd owns and operates three plants within Australia in Victoria, South Australia and Western Australia with a combined output of 150 10⁶ litres per annum. The Victorian plant with capacity of 60 10⁶ litres per annum, converts low-grade animal fats (tallow), used cooking oils, and other waste vegetable oils to biodiesel, glycerine, potassium sulphate, burner fuel and biogas, utilising a multi-feedstock technology sourced from BDI – BioEnergy International AG.

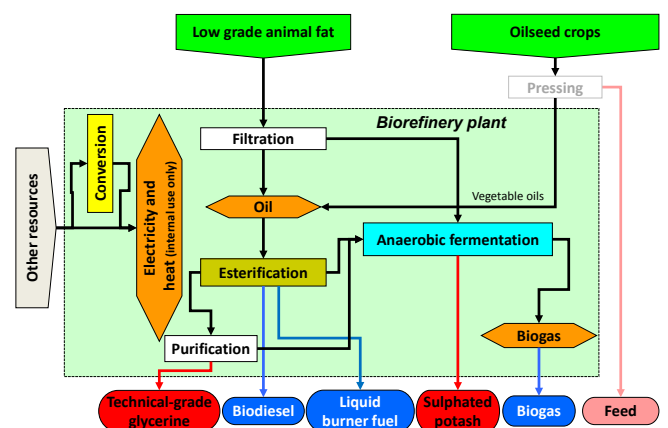
The proprietary process uses acid esterification, base-catalysed trans-esterification and distillation to convert high-FFA feedstocks into high-purity biodiesel. By-products of crude glycerine and spend catalysts are refined and reformulated to produce a high-purity technical-grade (98.5%) glycerine and a granular potassium sulphate. Waste water from the biodiesel process, and the on-site rendering operation, is treated to an irrigation standard producing a usable stream of methane-rich biogas.

The plant construction was completed in 2007 and commissioned in 2008. The majority of the biofuel produced is consumed in Victorian and New South Wales road transport both at retail and through wholesale to high volume haulage fleets.

Contact: Chris Attwood, Chief Operating Officer, Australian Renewable Fuels Ltd, phone: +61-260428400, e-mail: info@arfuels.com.au, web: arfuels.com.au



Figure 12. Victorian plant (2008) [AR-Fuels]



Microbiogen: Lignocellulosic “Fuel and Feed” Bio-refinery (Sydney, Australia)

State-of-the-art: Pilot Plant

Type of biorefinery: A 2-platform (lignin, C5&C6 sugars) biorefinery using wood chips to produce bioethanol, green coal and yeast

Location: Sydney, Australia (Industrial Park in West Lane Cove)

Owner: Microbiogen Pty Ltd

Feedstocks: A range of biomass feedstocks with focus to date on sugar cane bagasse and corn stover

Outputs: Ethanol, dry yeast (active or inactive), and green coal

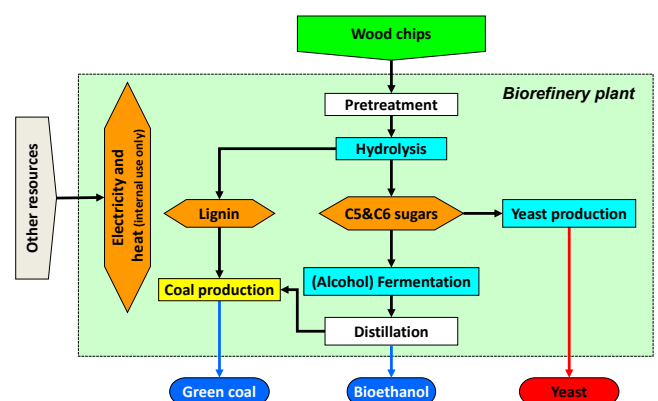
Description: After a 10 year research program, Microbiogen has developed a unique organism and fermentation process that allows lignocellulosic biorefineries to maximise efficiency, yield and product-value. Product yields are estimated to increase from 70% to 85%+ along with unit product revenues. The company recently completed a 2 year US\$5M pilot-program to demonstrate the viability and economics of a “fuel and feed” biorefinery. The pilot-program was funded in part through the Australian Government’s Gen II Biofuels program, and was conducted in conjunction with the US National Renewable Energy Laboratories in Golden Colorado.

The yeast strain developed has several enhanced capabilities that allows the process to operate. Some of these characteristics include: efficient growth on xylose, hydrolyzate resistance, an ability to grow on its own glycerol and organic acid waste streams, fast C6 sugar fermentation, and retaining its non-GM and food grade status. By using the yeast to propagate on its own waste streams, including the less favourable sugar xylose, the MBG “fuel and feed” biorefinery produces two key co-products, ethanol and yeast. The two products enhance yields, revenues and project sustainability. NREL engineering and econometric models (based on pilot-plant studies) estimate that ethanol can be produced at a cash cost US\$0.40/liter and yeast at US\$0.58/liter with minor “green coal” by-product credits. Microbiogen is currently in the process of licensing its technology to a leading global player in the lignocellulosic industry.

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Figure 13. Pilot-facility Sydney (2014) [Microbiogen]



Bomaderry Plant (Australia)

State-of-the-art: Commercial Scale

Type of biorefinery: A 1-platform (C5/C6-sugars) biorefinery for the production of wheat gluten, wheat starch, glucose, ethanol and stock feed from wheat and wheat flower

Location: Bomaderry, New South Wales, Australia

Owner: Manildra Group

Feedstocks: Wheat and Wheat Flour

Outputs: Wheat Gluten, Wheat Starch, Glucose, Ethanol, Stock Feed

Description: The Manildra Group operates a wheat starch, gluten, glucose and ethanol plant situated in Bomaderry, 2 hours drive south of Sydney Australia. The plant processes wheat flour into vital wheat gluten, starch, glucose, ethanol and stock feed products. The gluten and starch are extracted from the flour and are processed and dried. These products are sold domestically, and also exported to the USA and Asia. Some of the starch is also converted into liquid glucose which is sold domestically into

the local confectionary industry. The remaining waste starch is converted into ethanol via a fermentation and distillation process. About 90% of the ethanol produced is used for fuel, and the remainder is used in industrial, pharmaceutical, and beverage applications. The ethanol plant has been accredited to the Round Table of Sustainable Biofuels. The plant is capable of producing up to 300 10⁶ litres p.a.

The waste products from the ethanol process are concentrated into liquid and solid stock feed products. All of the waste process water in the plant gets treated in an anaerobic digester which produces methane, which provides about 6% of the plant's thermal energy requirements. The water is then purified in a reverse osmosis plant which can produce up to 70% of the plant's fresh water requirement.

Contact: Debbie Forster, e-mail:

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Figure 14. Bomaderry Plant, New South Wales, Australia (Dec 2011) [Manildra Group]

BDI bioCRACK Pilot Plant (Austria)

State-of-the-art: Pilot Plant

Type of biorefinery: A one-platform (pyrolysis oil) refinery for the production of diesel fuel, pyrolysis-oil and bio-char from solid biomass

Location: OMV refinery Schwechat/Vienna, Austria

Owner: BDI – Bioenergy International AG

Feedstocks: Lignocellulosic biomass (wood chips, straw)

Outputs: Raw diesel fuel, pyrolysis-oil, char

Description: BDI – BioEnergy International AG is market and technology leader in the construction of customised BioDiesel plants using the Multi-Feedstock Technology. In 2007 BDI started its research activities in the Biomass-to-liquid area. The developed so called **bioCRACK** technology produces mineral diesel with renewable shares that can be easily upgraded to EN590 quality within existing refinery units. This concept fulfils two fundamental tasks: producing diesel to meet the growing demand, while simultaneously increasing the biogenic share.

Pyrolysis-oil and bio-char are valuable by-products of this unique conversion process.

OMV and BDI – BioEnergy International AG – have been jointly involved in the innovative bioCRACK pilot-plant project since 2009, with support from BMVIT (the Austrian Federal Ministry for Transport, Innovation and Technology) and Kilmafonds (the Austrian Climate and Energy Fund). The bioCRACK pilot-plant at the OMV refinery Schwechat is the first of its kind worldwide and converts solid biomass (2.4 t/d input capacity) – such as wood chips and straw – directly into raw diesel fuel (5 t/a). It is fully integrated into the existing plant and uses a refining by-product as heat carrier oil for the underlying in the refinery liquid phase pyrolysis process.

Contact: BDI - Bioenergy International AG,
 e-mail: office@bdi-bioenergy.com,
 web: http://www.bdi-bioenergy.com/de-biomass_to_liquid-24.html

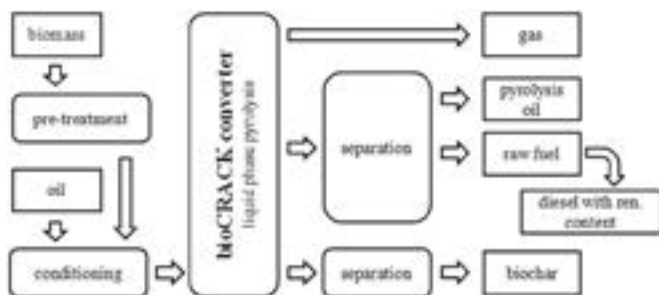
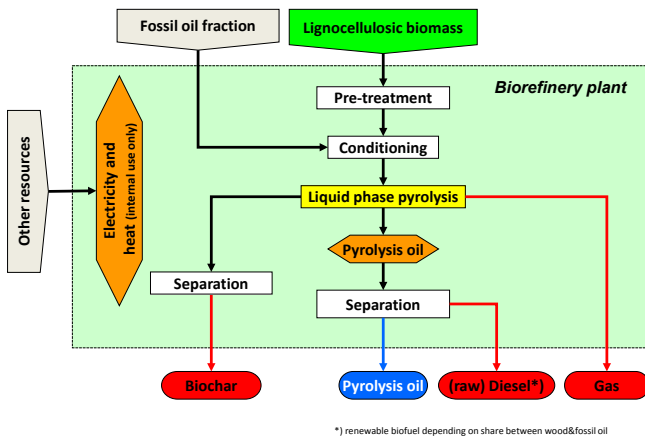


Figure 15. Process Block Diagram of bioCRACK Plant [Bioenergy International AG]

AGRANA Biorefinery Pischelsdorf (Austria)

State-of-the-art: Commercial Scale

Type of biorefinery: Two platform (starch, C5/C6 sugars) biorefinery for the production of bioethanol, wheat starch and gluten, and CO₂ from agrarian raw materials by integration wheat starch processing into existing bioethanol facility

Location: Pischelsdorf, Austria

Owner: AGRANA Bioethanol GmbH

Feedstocks: Agrarian raw materials

Outputs: Bioethanol, wheat starch and gluten, CO₂

Description: The biorefinery project of the AGRANA Bioethanol GmbH in Pischelsdorf, Lower Austria, represents the holistic concept of a complete and sustainable utilisation of the used agrarian raw materials. The since 2007 existing bioethanol production plant is updated with a new wheat starch and gluten production facility that is in operation since autumn 2013. In addition, the largest and most modern CO₂-recuperation plant currently in existence in Austria successfully started operating in early 2012.

Within the **wheat starch facility** 250,000 tons of wheat is processed to: 107,000 t of wheat starch, 23,500 t of wheat

gluten and 55,000 t of wheat bran every year. Those elements of the wheat that cannot be utilised in the first production cycle are afterwards used for bioethanol production. Those will amount to roughly 70,000 p.a. Wheat starch and gluten are essential intermediate products that are used in the food and drinks industry as well as for technical applications i.e.: the paper industry. The used grain is certified after the ISCC-standard² sustainability criteria. In the **bioethanol production** segment of the biorefinery the agrarian raw material – wheat from the wheat starch production plant and additional grains – about 500,000 t of grains are processed to 210,000 m³ of bioethanol and 175,000 t of high quality, GMO free protein animal feed **ActiProt** that reduces Austria's dependency on soy imports from abroad.

To complete the holistic system of the biorefinery the **CO₂-recuperation plant**, operated by the AGRANA partner Air Liquide, captures 100,000 tons of CO₂ per year. This high quality CO₂, which is a by-product of the ethanol production process (fermentation), is used in the food and drinks industry that would otherwise have to be extracted from fossil sources.

The AGRANA biorefinery in Pischelsdorf makes optimal use of the agrarian raw material. First, the grain is used in the wheat starch production plant from there residuals are, with additional grains, further processed in the bioethanol production facility. The CO₂ that incurs during the fermentation process is recuperated for the food and drinks industry. In addition to bioethanol high quality, GMO free protein animal feed (DDGS) is produced. Hence, the optimal use of the raw material is warranted.

Contact: AGRANA Bioethanol GmbH,
phone: +43-2277-90303-13112, web: www.agrana.com

2 International Sustainability and Carbon Certification

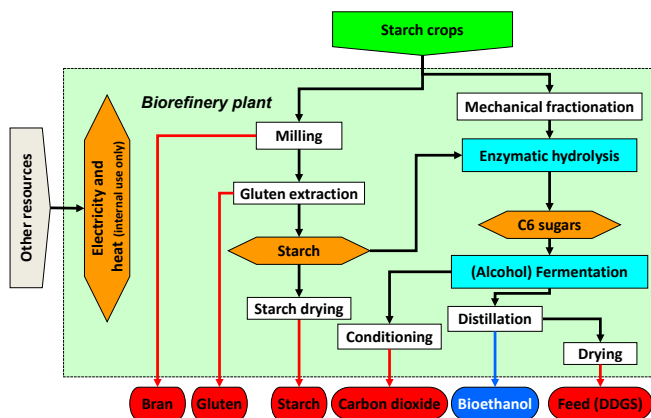


Figure 16. Agrarian raw materials biorefinery facility Pischelsdorf, Austria [AGRANA]

Ecoduna Algae Biorefinery (Austria)

State-of-the-art: Demonstration Plant

Type of biorefinery: 3-platform biorefinery producing biofuels, electricity & heat, omega-3/6 fatty acids and fertilizer from microalgae

Location: Bruck an der Leitha, Austria

Owner: Ecoduna produktions-GmbH

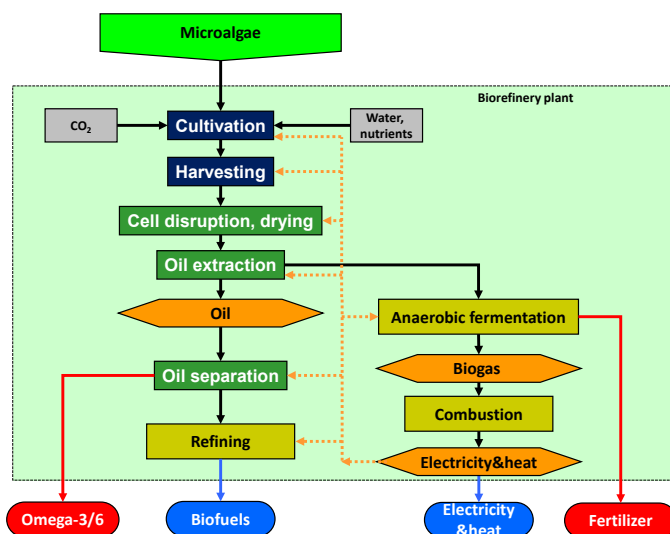
Feedstocks: Microalgae

Outputs: Biofuels, electricity & heat, omega-3/6 fatty acids and fertilizer

Description: Ecoduna is the worldwide technological leader in the construction of cultivation systems for algae. The unique and patented technology enables the production of biomass on an industrial scale under economic criteria (return-on-investment: 6-7 years). Furthermore the system is highly sustainable and conserves natural resources. The technology of "hanging gardens" is based on an unique combination of: exceedingly enlargement of surface to allow photosynthesis with 100% photo active volume, continuous support of micro-organism with nutrients light

without any loss of efficiency, specific control and sensor systems (low costs of labour and energy) , closed production circuit that preserves resources and suspends contamination, hydrostatic transport of biomass that avoids growth limiting stress to the algae, and biological and technical know-how, to manage and control each stage of development of protozoon. Only this combination allows an economic continuous production process 365 days per year. "Hanging gardens" is a well-engineered and worldwide patented technology to grow biomass in an industrial scale. It results in the highest output per hectare per year (> 200 tons/ha.yr) compared to all other existing biomass production technologies.

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 phone: +43 664 88 41 02 02, e-mail: gruen@ecoduna.com,
 web: www.ecoduna.com



Pöls-Biorefinery (Austria)

State-of-the-art: Commercial Scale

Type of biorefinery: 3-platform biorefinery producing pulp, paper, tall oil, turpentine, bark and electricity & heat from wood

Location: Pöls, Austria

Owner: Zellstoff Pöls AG, Heinzel Holding GmbH, EMACS Foundation

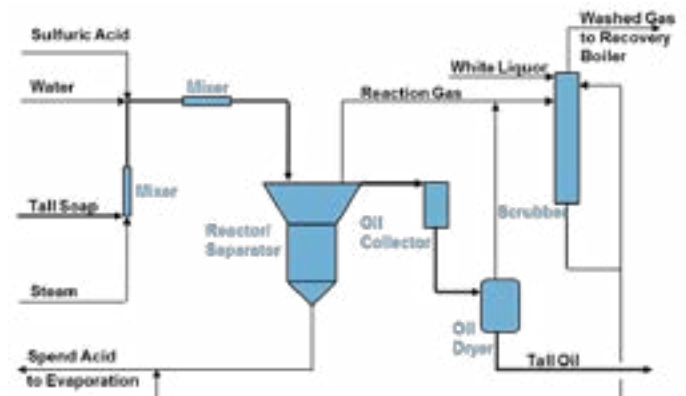
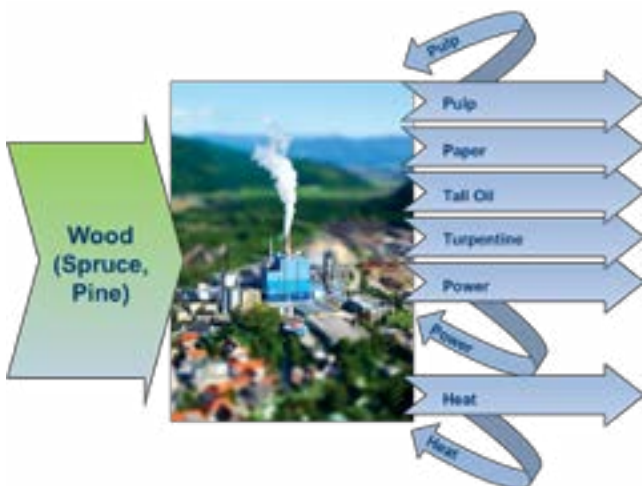
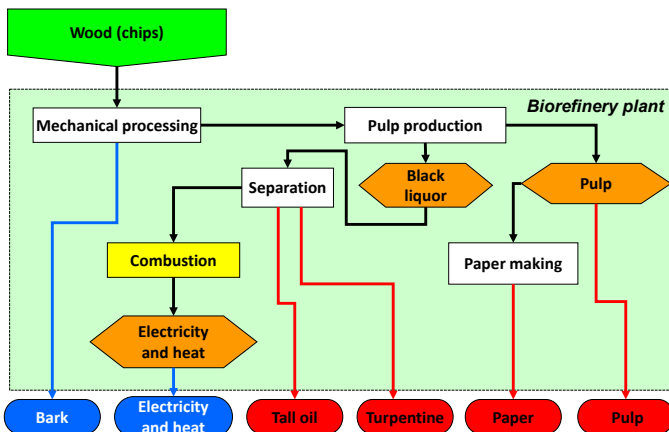
Feedstocks: Wood

Outputs: Pulp, paper, tall oil, turpentine, bark and electricity & heat

Description: The major product from the Kraft pulping process in Pöls is market pulp. A part of the pulp is directly converted to packaging paper grades. The black liquor from the pulping process contains the dissolved organic biomass from the wood. The black liquor is burned in the recovery boiler after evaporation of water. Evaporation is essential to maximize the energy efficiency at incineration of the liquor. Power and heat are

generated for internal and external usage and process chemicals are recovered from the black liquor. Pöls supplies 15000 households with heat in the local area, and is able to supply 35000 households with electricity. Besides pulp, paper, heat and power, Zellstoff Pöls is producing tall oil and turpentine oil. These are interesting raw materials, from which a large variety of chemicals can be produced. Tall oil and turpentine oil products are used for example in tires, asphalt, perfumes, adhesives, paints etc. The quality of the chemicals from tall oil and turpentine oil cannot be reached with synthetic generated products made from petro oil.

Contact: Klaus Eibinger, Zellstoff Pöls AG, Dr. Luigi-Angeli
 Straße 9, A-8761 Pöls, AUSTRIA, phone: +43 (0)3579 8181-222, e-mail: k.eibinger@zellstoff-poels.at,
 web: www.zellstoff-poels.at



Alberta Pacific Forest Industries (Alberta, Canada)

State-of-the-art: Commercial Scale

Type of biorefinery: 3-platform (pulp, stripper off-gas, electricity & heat) biorefinery for the production of Kraft pulp, heat and electricity and bio-methanol from wood chips

Location: Alberta, Canada

Owner: Alpac Forest Products Incorporated

Feedstocks: Wood (aspen, poplar, spruce, pine) certified by Forest Stewardship Council

Outputs: Kraft pulp, bio-methanol, heat and power

Description: Alberta Pacific Forest Industries' (Alpac) Boyle AB mill is the largest bleached Kraft pulp mill in North America producing both hardwood and softwood pulp. Built in 1992 with a pulp capacity of 665,000 tons per year, the mill produces and exports over 80 GWh of green electricity per year. Now, the mill is again expanding its product offerings and implementing the biorefinery concept by investing in green biochemical production. The conventional Kraft pulp mill process used at the mill generates a waste gas stream (steam stripper off-gas, which can contain as much as 70% methanol. This waste gas is incinerated in the lime kiln, as until now it has not been possible to separate out the methanol from the other impurities. With a new investment in its Methanol Purification Project, Alpac will become the first mill in the world to separate and purify commercial grade methanol from the waste gas. The goal of this \$10M investment is to produce nearly 3,000 tonnes of 99.85% methanol a year

– the highest purity ever before produced by a Kraft mill. The purification project distills the waste gas using a novel process developed by the Canadian company A.H. Lundberg Systems Limited. This innovative system, implemented by Alpac with support from the Government of Canada, will lead to the world-first demonstration of IMPCA bio-methanol production. Presently, purchased methanol is used for the on-site production of chlorine dioxide, used in the company's pulp whitening operations. The new bio-methanol will completely meet the mill's internal needs, with the surplus available for sale to external industries for use as a solvent, antifreeze, fuel, or for formaldehyde production. In addition to the project's economic benefits (methanol as a product has a value of over four times that of fuel), there are significant environmental and process benefits. "Alberta-Pacific is here for the long-term and this project makes our goal of becoming a more diversified manufacturer a reality." Al Ward, Al-Pac's president and COO. "New technologies are helping mills create innovative products and reduce their environmental footprint. These are important steps to ensuring the long-term viability of the forest industry," Member of Parliament Brian Jean.

Contact: Alpac Forest Products Incorporated,
 PO Box 8000 Boyle, Alberta, Canada, phone: +1-780-525-8000,
 e-mail: info@alpac.ca, web: www.alpac.ca

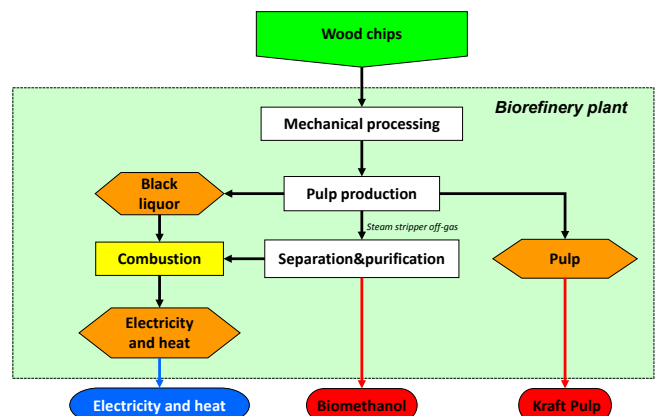


Figure 17. Alberta Pacific Forest Industries' Boyle AB mill [Alpac]

GreenField Specialty Alcohols 2G Ethanol Pilot Plant (Ontario, Canada)

State-of-the-art: Pilot Plant

Type of biorefinery: 2-platform (lignin, C5&C6 sugars) biorefinery producing bioethanol, acetic acid and CO₂ from lignocellulosic biomass

Location: Chatham, Ontario (next to 1G corn ethanol facility)

Owner: GreenField Specialty Alcohols Inc.

Feedstocks: Agricultural crop residues, forestry residues, dedicated energy crops

Outputs: Cellulosic ethanol, distillers grains, CO₂, acetic acid and lignin that is used for process energy

Description: In 2007, GreenField Specialty Alcohols Inc. (GFSA), Canada's largest producer of fuel ethanol and industrial alcohol, created an advanced biochemistry group ("Team") of over 20 experienced senior executives and technical experts. Their mandate was to develop a second generation process technology to meet the demand for increased ethanol produced from a variety of low to high lignin feedstocks, including agricultural residues (e.g. corn stover and cobs), wood residues and energy crops (e.g. switch grass, prairie tall grass, etc.). In 2008, GFSA built, and has continuously operated, its one-tonne/day pilot and full laboratory facilities at its Centre of Excellence in Chatham, Ontario. GFSA's Team has succeeded in developing both proprietary process and equipment technologies that can: efficiently deliver clean, highly digestible cellulose and hemicellulose sugars for downstream hydrolysis and fermentation, and consistently achieve an average of 309L/MTDM cellulosic ethanol. At the core of its world-class process technology is GFSA's Modified Twin Screw Extruder Technology which allows single-stage or two-stage continuous percolation/hot water/steam explosion pre-treatment with: fewer pieces of equipment and no acid – thus reducing the capital cost; less enzyme, yeast,

and a positive energy balance – thus reducing the operating cost, and an energy consumption and water use similar to 1G corn-based ethanol plants. In 2012-13, GFSA's Team demonstrated and validated its proprietary continuous process and equipment technologies at pilot-scale. In 2014, GFSA's Team is demonstrating its proprietary process and equipment technologies on a pre-commercial continuous scale.

Contact: Barry S. Wortzman, Q.C., Vice President Business Development, GreenField Specialty Alcohols Inc., 20 Toronto Street, Suite 1400, Toronto, ON M5C 2B8, phone: +416-304-1700-8420, e-mail: b.wortzman@greenfieldethanol.com, web: www.greenfieldethanol.com

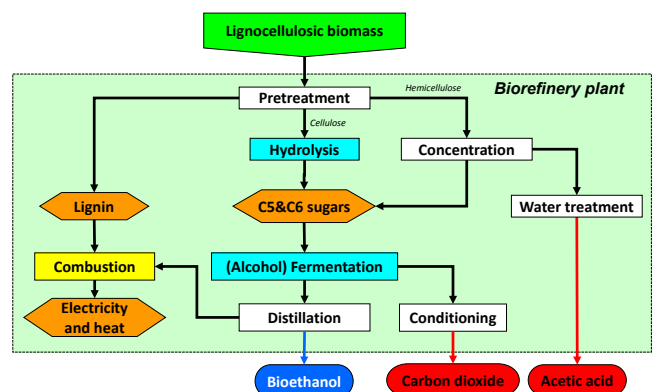


Figure 18. a) Continuous pilot plant (left) and b) 2G ethanol process (right) [GFSA]

Enerkem Waste-to-Biofuels facility (Alberta, Canada)

State-of-the-art: Commercial Scale, under commissioning

Type of biorefinery: 1-platform (syngas) biorefinery producing biofuels, chemicals and bioenergy from municipal solid waste

Location: Edmonton, Alberta (on the integrated waste management site of the City of Edmonton)

Owner: Enerkem Alberta Biofuels L.P.

Feedstocks: Municipal solid waste from the City of Edmonton (population: 817,000)

Outputs: Ethanol, methanol and energy used to meet process needs

Description: 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 38 10⁶ litres per year of next-generation biofuels from non-recyclable and non-compostable municipal solid waste (MSW). The proprietary thermochemical process includes the stages of feedstock preparation, gasification, syngas cleaning and catalytic conversion. The ethanol will be sold for transportation use and the methanol for chemical applications. As part of the

agreement, the City of Edmonton will supply 100,000 dry tonnes of sorted MSW per year. The sorted MSW to be used is the residue after recycling and composting, which would otherwise be landfilled. This facility is part of a comprehensive municipal waste-to-biofuels initiative in partnership with the City of Edmonton and Alberta Innovates. In addition to contributing to the Renewable Fuels Standard, this waste-to-biofuels facility will enable the City of Edmonton to increase its residential waste diversion rate to 90 percent. Plant construction was started in 2010, and the Waste-to-Biofuels facility is scheduled to start up in 2014. The facility is expected to be the world's first major collaboration between a metropolitan centre and a waste-to-biofuels producer to convert municipal waste into methanol and ethanol.

Contact: Enerkem Alberta Biofuels L.P., Marie-Hélène Labrie, Vice President, Government Affairs and Communications, phone: +514-875-0284, x. 231, e-mail: mlabrie@enerkem.com, web: www.enerkem.com/www.edmontonbiofuels.ca;

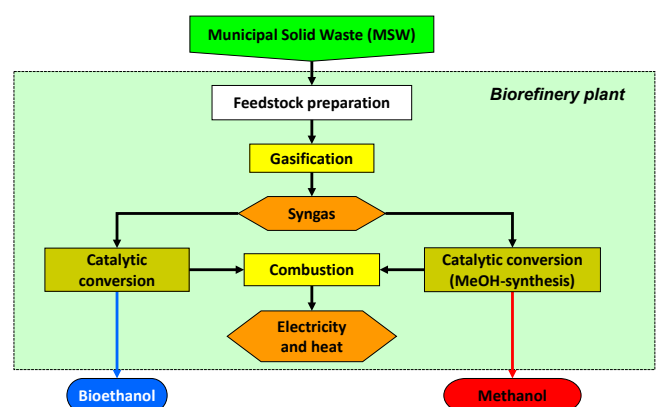


Figure 19. Waste-to-Biofuels facility (January 2014) [Enerkem]

BioGasol/Estibio (Denmark)

State-of-the-art: Pilot Plant; an integrated, continuous pilot-plant, based on pre-treatment (BioGasol) and C5 fermentation technology (Estibio). Pre-treatment demonstrated at 1t/h, and commercial deployment of a 4t/h pre-treatment unit.

Type of biorefinery: A 3-platform (C5&C6 sugar, lignin and biogas) biorefinery for the production of bio-methane, bioethanol, solid fuel and fertilizer from straw or agricultural residues

Location: Ballerup, Denmark

Owner: Biogasol ApS (Estibio was founded in 2012 as a spin out of BioGasol ApS)

Feedstocks: Straw, agricultural residues

Outputs: Bio-methane, bioethanol, solid fuel, fertilizer

Description: The pilot-plant focusses on the development and demonstration of BioGasol's Carbofrac® pre-treatment and Estibio's Pentoferm™ fermentation. These two process steps are crucial for achieving economically viable commercial plants. The demo-project is seen as a stepping stone towards larger cellulosic ethanol production plants, which can be based on the BioGasol process concept, but not necessarily, as the two enabling

technologies can be used in many other biochemical conversion plants. The Carbofrac® pre-treatment, together with enzyme technology forms a complete sugar platform, for liberation of all ligno-cellulosic sugars thus forming the first stage of a biorefinery with biofuels as the main product. However, the hemicellulosic sugars can be released without enzymes, which can provide a low-cost sugar stream suitable for biochemical processing of e.g. xylose and mannose to chemical building blocks. Estibio's VHTP (very high temperature processing) fermentation platform harnesses the key metabolic pathways of Pentocrobe®, an in-house genetically modified microorganism, derived from the thermophilic species *Thermoanaerobacter italicus*, which enables simultaneous conversion of simple sugars as well as combined C5/C6 biomass sugars into bioethanol at elevated temperatures (~70° Celsius).

Contact: BioGasol ApS, Lautrupvang 2A, DK-2750 Ballerup, Denmark, Rune Skovgaard-Petersen, phone: +45-5122 6112, e-mail: rsp@biogasol.com, web: www.biogasol.dk

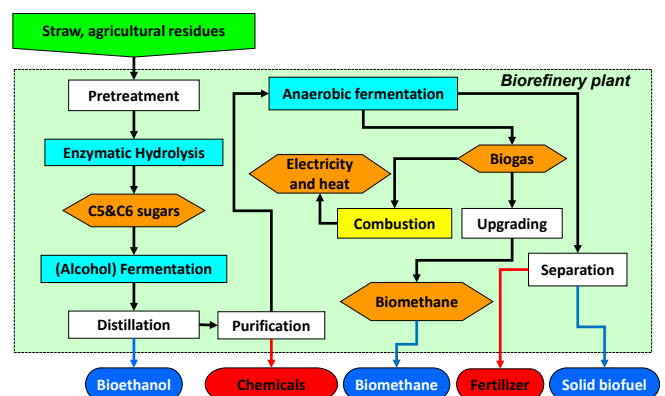
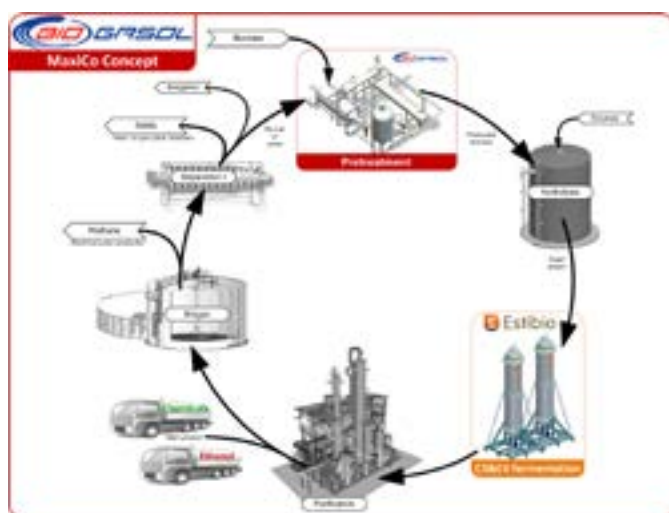


Figure 20. Process diagram showing the BioGasol MaxiCo concept [BioGasol]

Maabjerg Energy (Denmark)

State-of-the-art: Commercial Scale (project)

Type of biorefinery: A 5-platform (C5&C6 sugar, lignin, biogas, bio-methane, electricity&heat) biorefinery for the production of bio-methane, bioethanol, fertilizer, electricity and heat from wood chips, straw, manure, sewage sludge and MSW

Location: Maabjerg, Denmark

Owner: Vestforsyning A/S, Struer Forsyning A/S, Nomi I/S, DONG Energy A/S, Novozymes A/S

Feedstocks: Wood chips, straw, manure, sewage sludge and MSW

Outputs: Bio-methane, bioethanol, fertilizer, electricity and heat

Description: The Maabjerg Bioenergy Concept is currently under development and is based on adding a bioethanol facility onto an already existing biomass fired power plant (Maabjergværket) and the newly inaugurated biogas plant (Maabjerg BioEnergy), thereby creating a commercial-scale fully integrated biorefinery. The Maabjerg BioEnergy biogas plant is currently operated on manure, sewage sludge and whey (production 18 10⁶ m³ biogas annually).

The expansion will include an ethanol plant, which will use 300,000 tons of straw and other annual plants to produce 2nd generation bioethanol, molasses (for biogas) and lignin (for combustion). The liquid part is degassed in the biogas plant, and the energy of the solid part is used in the cogeneration plant. Excess heat from the power plant will be used internally in e.g. pre-treatment, heat treatment and distillation. The ethanol plant will be based on Inbicon technology. The integrated biorefinery will annually be able to process 300,000 tons of straw, 520,000 tons of manure, 280,000 tons of various types of bio-waste, and 100,000 tons of MSW into 80,000 m³ bioethanol, 50 10⁶ m³ biogas, 36,000 tons lignin, and heat and power corresponding to 25,000 households.

Contact: Maabjerg Energy Concept, Nupark 51, DK-7500 Holstebro, Denmark, phone: +45-9612-7300, e-mail: info@maabjergenergyconcept.dk, web: <http://www.maabjergenergyconcept.eu/>

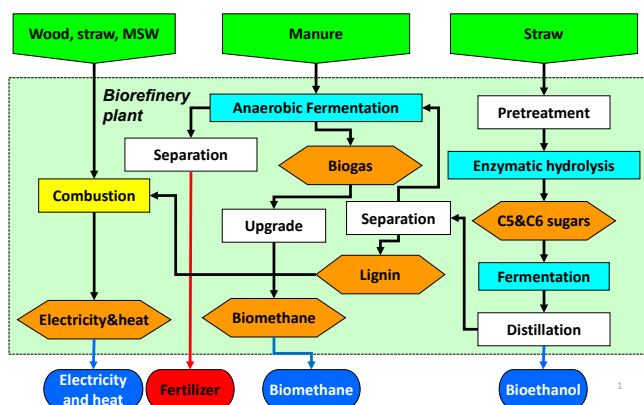


Figure 21. Maabjerg Energy Concept when fully developed [Illustration COWI A/S]

INBICON (Denmark)

State-of-the-art: Demonstration Plant

Type of biorefinery: A 5-platform (C6 sugars, C5 sugars, lignin, electricity and heat) biorefinery producing bioethanol, electricity, heat and feed from straw, corn stover, bagasse and EFB

Location: Kalundborg, Denmark

Owner: Inbicon A/S (subsidiary of DONG Energy A/S)

Feedstocks: Straw, corn stover, bagasse and EFB

Outputs: Bioethanol, electricity, heat and feed

Description: Inbicon's core technology, proven in pilot plants since the beginning of 2003, is a three-stage continuous process: mechanical conditioning of the biomass, hydrothermal pre-treatment, and enzymatic hydrolysis. The process releases the building blocks of the plant material – cellulose, hemicellulose, and lignin – and converts them to useful purposes. The Inbicon pre-treatment technology is based on a continuously operated one-step hydrothermal pre-treatment at 180-200°C. Key to it is that only steam is used, and that no acids or other chemicals are added. After the pre-treatment, the C5-sugars are separated into a liquid fraction, which is concentrated to C5 molasses

for biogas production, and a solid fibre fraction consisting of C6 sugars for enzymatic hydrolysis and C6-fermentation. Alternatively, C5 sugars can be led to enzymatic hydrolysis and used for C5+C6 mixed sugar fermentation, co-producing vinasse to be used for biogas production. Key to the Inbicon technology is the ability to operate at high dry matter concentration (up to 30% DM), which results in a much higher final concentration of ethanol, which is important to reduce the production costs. After distillation, the lignin is dried and pelletized to produce a solid fuel with high heating value and good storage properties. The demonstration plant has been in operation since 2009, and the annual production is about 5.4 10⁶ liter of cellulosic ethanol, 11,400 metric tons of lignin pellets, and 13,900 metric tons of C5 molasses. With a newly modification of the plant, which allows for C5+C6 mixed sugar fermentation, ethanol yield has been increased 40-45%.

Contact: Inbicon, Kraftværksvej 53, DK-7000 Fredericia, Denmark, e-mail: Info@Inbicon.com, web: www.inbicon.com

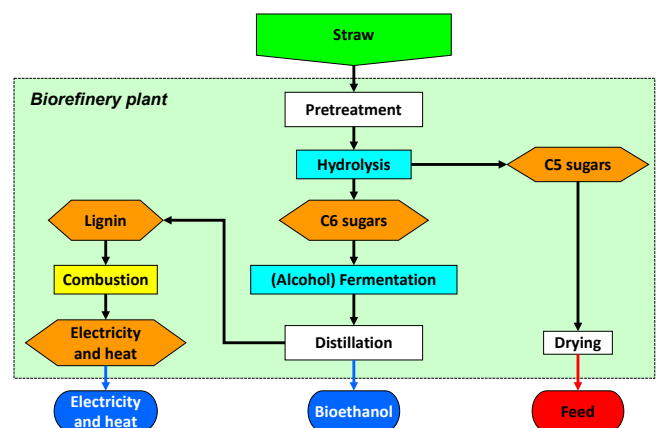


Figure 22. Inbicon demonstration plant Kalundborg, Denmark [Inbicon A/S]

BIOLIQ (Germany)

State-of-the-art: Pilot Plant

Type of biorefinery: A 3-platform (pyrolysis oil, syngas, electricity&heat) biorefinery producing customised BtL-fuels from residual biomass (straw)

Location: Karlsruhe, Baden-Württemberg

Owner: Karlsruhe Institute of Technology (KIT)

Feedstocks: Residual biomass

Outputs: BioliqSynCrude®, BtL-fuels

Description: The Bioliq® pilot-plant covers 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.

Contact: Bioliq® Marketing & PR, Dipl.-Ing. Christina Ceccarelli, Hermann-von-Helmholtz-Platz 1, D-76344 Eggenstein-Leopoldshafen, phone: +49-721-608-22614, e-mail: christina.ceccarelli@kit.edu, web: <http://www.bioliq.de/english/24.php>

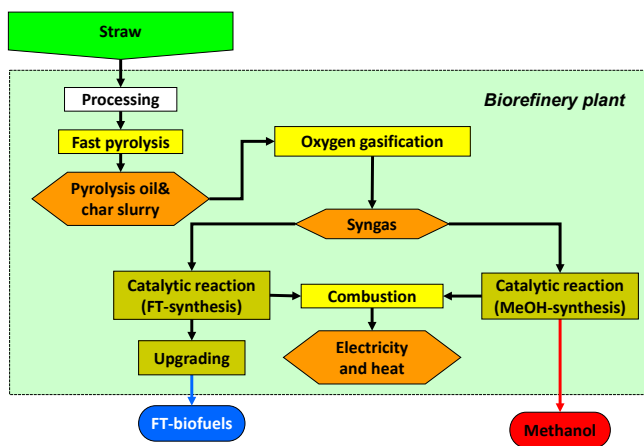


Figure 23. Bioliq pilot-plant [KIT]

BIOWERT (Germany)

State-of-the-art: Commercial Scale

Type of biorefinery: A 4-platform (biogas, green juice, fibres, electricity&heat) biorefinery producing bioplastics, insulation materials, fertilizer and electricity from grass silage and food residues

Location: Brensbach

Owner: BIOWERT GmbH

Feedstocks: Grass

Outputs: High-quality cellulosic fibres for insulation material, composite granulate and/or profiles; nutrients and biogas

Description: The BIOWERT plant is directly connected to a biogas plant; the latter produces heat and electricity, which are partly used together with the process water of the biogas plant within the BIOWERT plant. Grass is used as regionally available feedstock. The grass is mixed with process water from the biogas plant and heated. The heated suspension is mechanically treated in a multi-stage process, subsequently gently dried in order to produce fibres.

The specially developed two-step drying process is paramount for the production of high quality cellulosic fibres. The purified fibres are further processed to insulation material, composite granulate and/or profiles, depending on customers demand.

In addition nutrients from the digestate of the biogas plant are recovered and redistributed to farmers that have grown the grass. In that way a closed-loop process chain is realized that follows the leading principles of industrial ecology.

Contact: Biowert Industrie GmbH, Gewerbegebiet Ochsenwiesen, Ochsenwiesenweg 4, 64395 Brensbach/Odw., phone: +49-6161-806630, e-mail: kontakt@biowert.de, web: www.biowert.de, Please use the contact form provided at the website, <http://www.biowert.de/biowert/index.php/Startseite>

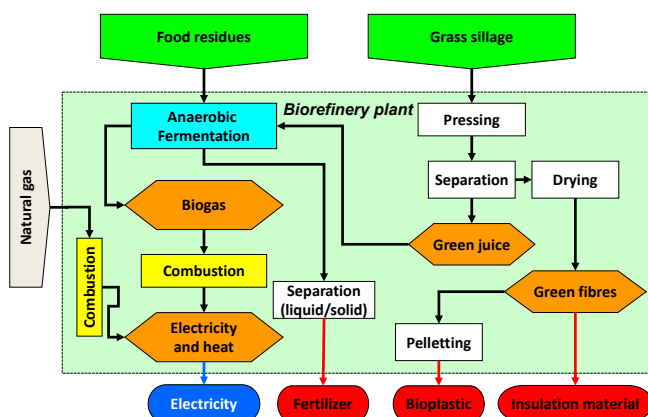


Figure 24. BIOWERT grass refinery plant [BIOWERT GmbH]

LEUNA (Germany)

State-of-the-art: Pilot Plant

Type of biorefinery: A 2-platform (C5&C6 sugars, lignin) biorefinery for the production of bio-based synthesized building blocks and polymers from ligno-cellulosic residues (wood, straw)

Location: Leuna, Germany

Owner: Fraunhofer Center for Chemical-Biotechnological Processes CBP

Feedstocks: Ligno-cellulosic residues (wood, straw)

Outputs: Bio-based synthesized building blocks and polymers

Description: The Chemical-Biotechnological Processes (CBP) in Leuna close the gap between the pilot plant and industrial implementation. By making infrastructure and plants/miniplants available, the CBP makes it possible for cooperation of partners from research and industry to develop and scale-up processes for utilizing renewable raw materials up to an industrial scale. Thus the CBP represents a hitherto unique platform for the development of new processes up to and including product relevant dimensions, with a direct link to the chemical industry on the one hand and to Fraunhofer research on the other.

In the "Lignocellulose biorefinery" project, which is funded by the Federal Ministry of Food, Agriculture and Consumer Protection (BMELV), 14 research and business partners want to make use of the substances from wood and straw. The aim is to establish an economic and sustainable integrated process for the complete usage of all the components of lignocellulose on a large industrial-scale, and to produce bio-based synthesized building blocks and polymers.

The following sub-processes are being developed and tested in the current project by the affiliated partners:

- fractionation of beech and poplar wood on pilot-scale using water/alcohol mixtures,
- enzymatic cleavage of the cellulose and hemicellulose obtained into sugars usable for chemical synthesis and biotransformation on pilot-scale,
- chemical and biotechnological conversion of the C5 and C6 sugars obtained,
- chemical and biotechnological conversion of the lignin fraction obtained,
- thermoplastic and duro-plastic processing of the lignin fraction obtained

Contact: Dr Moritz Lechinsky, Am Haupttor (Building 4310), 06237 Leuna, phone: +49-3461-433502, e-mail: please use contact form provided at the website, http://www.cbp.fraunhofer.de/en/Projects/Project_1.html, web: www.cbp.fraunhofer.de

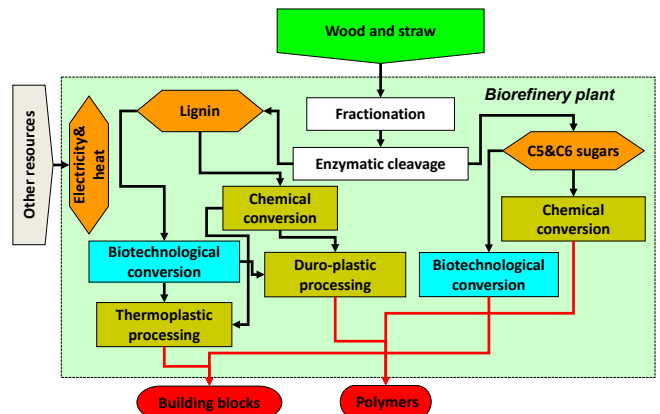


Figure 25. a) Module-1 (scale-up experiments) b) Module-2 (digestion and fractionation) [Fraunhofer]

CELLULAC (Ireland)

State-of-the-art: Commercial Scale – 100,000 Metric Tonnes

Type of biorefinery: A 3-platform (C5, C6 sugars and lignin) for the production of chemicals and fuels from lactose whey permeate and lignocellulosic biomass

Location: Great Northern Brewery, Dundalk, Co. Louth, Ireland

Owner: Cellulac Ltd. Galway, Ireland

Feedstocks: Lactose whey permeate and lignocellulosic biomass

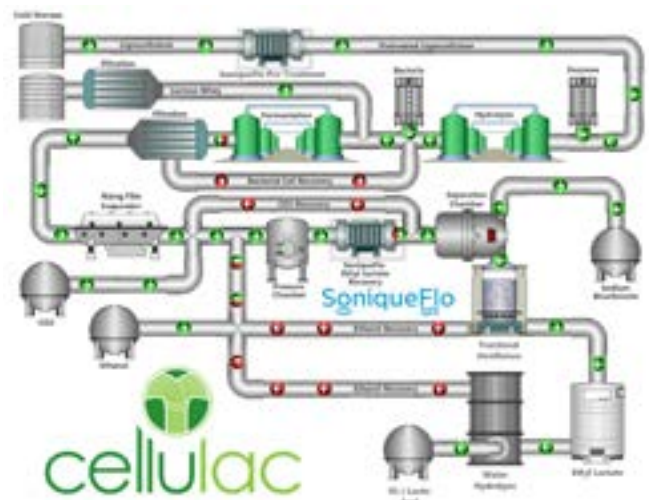
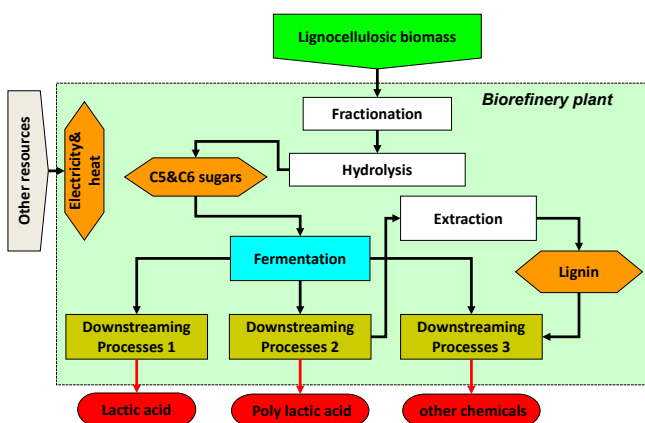
Outputs: Chemicals (LA, Ethyl Lactate and PLA)

Description: Cellulac intends to commence production of up to 100,000 metric tonnes of high value, specialty chemicals from a wide variety of second generation (2G) feedstocks, on completion of a retrofit of the fermentation and processing facilities in the Great Northern Brewery, Dundalk, Ireland which was the second largest brewery in Ireland, to generate, at a production cost 40% below current producers, Lactic Acid and related products. Production is scheduled to commence in the first quarter 2015. Cellulac has developed an end-to-end proprietary biochemical and process engineering platform to produce Lactic Acid, PolyLactic Acid and Ethyl Lactate, a \$2.5 billion+ market currently growing at 20% pa. These products have significant established markets in (a) for use as a bio-degradable plastic ingredient; (b) the food

packaging industry; (c) for medical implants; and (d) as organic solvents.

The company expects to extract net cost savings in excess of 40% versus alternative methods of production of these specialty chemicals. Central to this is (i) the flexibility to use a variety of environmentally-benign second-generation feedstocks in a bio-cascading process; (ii) the ability of the Group's complementary chemical and process technologies to extract extremely high yields of fermentable sugars from the feedstocks; and (iii) the significant energy savings achieved by the Group's technologies in the production process. These technologies, which are complementary include enzyme cocktails, fermentation protocols, non-genetically modified bacteria (non-GMO) and Hydro Dynamic Cavitation (HDC) SoniqueFlo, all of which are protected by an extensive portfolio of 140 patents (granted and pending) along with proprietary know-how.

Contact: Camillus Glover, Cellulac Ltd, Second Floor, Unit 14, Galway Technology Park, Parkmore, Galway, Ireland, e-mail: cglover@cellulac.com



Matrica SPA (Italy)

State-of-the-art: Commercial Scale, under construction. The complex is expected to employ directly 680 people with a total investment of 500 million Euro.

Type of biorefinery: A 1-platform (bio-oil) biorefinery for the production of chemicals (bio-lubricants), bio-polymers, bio-fillers from oil-seed

Location: Porto Torres (Sardinia), Italy

Owner: Matrica SPA (50/50 JV between Novamont and Eni Versalis)

Feedstocks: Oil-seed from non-food Autochthonous crops grown in marginal not irrigated and pasture land, in cooperation with local shepherds and farmers

Outputs: Chemicals (bio-lubricants), bio-polymers, bio-fillers

Description: Novamont is working on a third generation biorefinery for bio-plastics, bio-lubricants and bio-fillers/additives for low-rolling-resistance rubber, within Matrica, a 50/50 JV of Novamont-Polimeri Europa and ENI. With a total investment of 500 million Euro (\$700 million), the project consists of seven new plants – an integrated production chain from vegetable oil to bio-plastics – to be completed within the next six years; and a research centre devoted to bio-chemistry that already is running since January 2012. With high-level integration in the local territory, the initiative foresees the upstream cultivation and production of vegetable oil, which is the raw material for the bio-monomers plant in Sardinia. The location of the new initiative represents an advantage in terms of

the agricultural vocation of Sardinian land, and the large amount of land available. The third generation biorefinery developed by Matrica is based on the following key principles: integration of chemical and bio-technological process to produce chemicals; use of multiple feedstocks from local areas, non-irrigated land, and marginal areas (i.e. dedicated non-food crops, waste and residues like lignocellulosic materials) preserving and enhancing local biodiversity and soil fertility; integration of a wide and growing range of technologies and plants; energy needed for the processing phase produced from residues with efficient and low impact technologies; research, pilot-plants and large-scale plants simultaneously interconnect; enabling conversion of dismissed old chemical plants.

In perspective, this new model of Biorefinery represents not only a sound opportunity in terms of securing a European competitive niche in the field of bio-materials, but also a case study capable of creating knowledge spill over and replication for converting local de-industrialised chemical sites in innovative and sustainable plants.

Contact: Matrice SPA, Zona Industriale La Marinella, 07046 Porto Torres (SS), Italy, phone: +39-079-509000, e-mail: info@matrica.it/giulia.gregori@novamont.com, web: www.matrica.it



Figure 26. Sky view of the future complex under development in Porto Torres [Matrica]

Beta Renewables – Crescentino (Italy)

State-of-the-art: Demo Plant, in operation since the end of 2012

Type of biorefinery: A 3-platform (C5/C6-sugars, lignin, power/heat) biorefinery for the production of bioethanol and feed from Arundo Donax, miscanthus, switch grass and straw

Location: Crescentino (Vercelli Province), Italy

Owner: Beta Renewables (Mossi & Ghisolfi Group)

Feedstocks: Giant reed (Arundo Donax), miscanthus, switch grass, agricultural waste (straws)

Outputs: Bioethanol and animal feed

Description: The plant is based on the PROESA™ technology. It is a second-generation cellulosic biomass technology which uses inedible biomass, like: energy crops (such as **Arundo Donax**) or agricultural wastes, and converts them into high-quality, low-cost, fermentable C5 and C6 sugars. These sugars can then be used to cost-competitively produce bio-products with a smaller environmental footprint than fuels and chemicals made from oil or natural gas. The plant started its production by the end of 2012. It has a design capacity of 60,000 metric tons per year (20 million gallons), ramping up from an initial 40,000 tons. PROESA™ is the result of over €140 million invested in R&D since 2006. The process starts with a chemical-free pre-treatment

phase “smart cooking” of the biomass, which minimizes the formation of inhibitors and increases the overall efficiency. The parameters of the PROESA viscosity reduction technology and enzymatic hydrolysis can be tailored to optimize use of different feedstocks, transforming glucans and xylans into monomeric sugars best-suited for a target bio-product; while using low enzyme dosages and power consumption. The PROESA™ technology includes a strain engineered to convert both C5 and C6 sugars to ethanol. Beta Renewables claims that the process runs significantly faster than other enzymatic hydrolysis approaches, and provides better overall performance and economics than competing lignocellulosic conversion techniques. Concerning the research on feedstocks, Beta Renewables has assessed 89 phenotypes of **Arundo Donax** from Southern Europe, North Africa, and Southern China to select the variety most suitable to the plant geography, climate and soil type, resulting in yields up to 50 tons per hectare.

Contact: Michele Rubino of Chemtex,
phone: +39-339-2581789, e-mail: michele.rubino@chemtex.com,
web: www.betarenewables.com

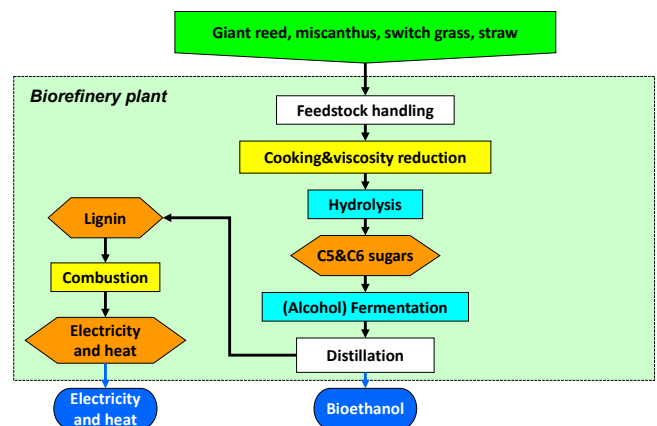
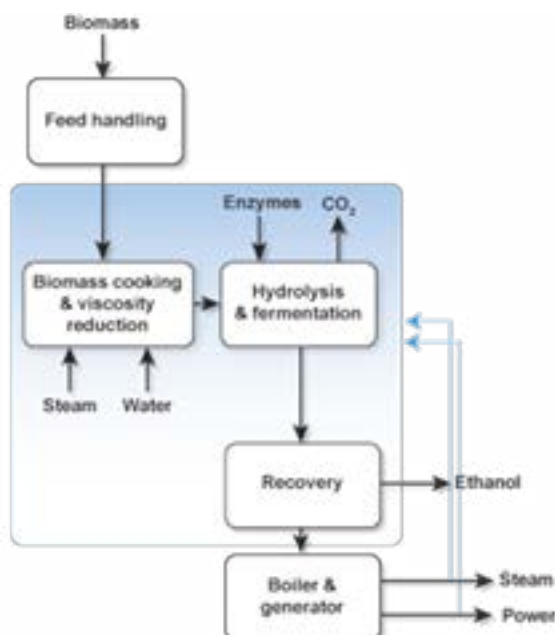


Figure 27. Demo Plant Crescentino, Italy [Beta Renewables]

Avantium YXY Fuels & Chemicals (The Netherlands)

State-of-the-art: Pilot Plant

Type of biorefinery: 3-platform (C₅, C₆ sugars and lignin) biorefinery for the production of furan-based biofuels, monomers for polymers, fine and specialty chemicals, and solid fuels from lignocellulosic biomass

Location: Furanics, Amsterdam/Geleen, the Netherlands

Owner: Avantium Chemicals B.V.

Feedstocks: Cellulose, hemi-cellulose, starch, sucrose

Outputs: Furan-based biofuels, monomers for polymers (furan dicarboxylic acid, furan diamine), fine and specialty chemicals (organic acids, solvents, flavors & fragrances), solid fuels (humins and lignin residues)

Description: The Furanics process integrates production of chemical building blocks, biopolymers and fine & specialty chemicals with production of biofuels, power, heat and hydrogen in a power or gasification plant. Furan derivatives, obtained by catalytic dehydration/etherification of carbohydrates, can serve as substitutes for petroleum-based building blocks used in production of fuels, plastics and fine chemicals. Integration with a Combined Heat & Power (CHP) or gasification plant will ensure efficient use of solid residues (lignin & humins) by co-firing with coal or biomass, thus enabling cost-effective use of excess steam and heat from the power plant. The technology which has been demonstrated at pilot plant level, can also be used to refine biomass streams, such as food processing waste, corn stover, grass, bagasse, household waste. A pilot plant on a 24/7 basis has been operational since the end of 2011.

Avantium explores novel furan (YXY) chemistry, focused on efficient and, compared to enzymatic biorefinery processes, low cost conversion of C₆ sugars (i.e. glucose, mannose, galactose and fructose) and C₅ sugars (xylose and arabinose) into derivatives of the promising chemical key intermediate hydroxymethyl furfural (HMF). YXY's main building block, 2,5-furandicarboxylic acid (FDCA), can be used as a replacement for terephthalic acid (TA),

a petroleum-based monomer that is primarily used to produce PET. Because of the enormous potential of furanics-based materials the chemical conversion of plant-based carbohydrates into FDCA has been a hot topic of intensive R&D efforts for decades. Applying Avantium's expertise in advanced catalyst development, catalytic process technology and high-throughput evaluation, Avantium is the first company to find an economically viable route to unlocking the furanics' full potential.

The FDCA monomer offers exciting opportunities to create a wide range of polymers – polyesters, polyamides and polyurethanes – as well as coating resins, plasticizers and other chemical products.

Avantium's lead application PEF, used to create bottles, films and fibres, is a next-generation polyester that offers superior barrier and thermal properties, making it ideal material for the packaging of soft drinks, water, alcoholic beverages, fruit juices, food and non-food products. Therefore PEF is the 100% biobased alternative to PET. PEF is made from plant-based sugars, which means it is renewable: The polymerization process to make PEF has already been successfully initiated at pilot plant scale. In combination with a significantly reduced carbon footprint, the added functionality, gives PEF all the attributes to become the next generation polyester. Currently, Avantium is working in collaboration with the Coca Cola Company, Danone and ALPLA to bring 100% bio-based PEF bottles to the market.

Contact: Avantium BV, Zekeringstraat 29, 1014 BV Amsterdam, The Netherlands, phone: +31-20-586 8080, e-mail: info@Avantium.com, web: www.avantium.com



Figure 28. Pilot-plant in Geleen, the Netherlands [Avantium]



Figure 29. 100% PEF-bottles [Avantium]

AlgaePARC (The Netherlands)

State-of-the-art: Pilot Plant

Type of biorefinery: A multi-platform biorefinery for the production of proteins, lipids, carbohydrates and pigments from microalgae

Location: Wageningen, the Netherlands

Owner: AlgaePARC, Wageningen UR; other stakeholders involved: TOTAL, BASF, DSM, EWOS, GEA-Westfalia, BODEC, Evodos, Dyadic, POS Bioscience

Feedstocks: Micro-algae

Outputs: Proteins, triacylglycerides, omega-3 fatty acids (EPS/DHA), carbohydrates and pigments

Description: The successful implementation of microalgae as a feedstock for bulk products entails the development of a biorefinery plant to fractionate the different products. Dependent on the market potential a strain and/or process conditions could be selected for delivering in larger quantities the main product(s) of interest. A very important issue to address is the flexibility of the biorefinery plant. In contrast to the inflexibility of existing oil refineries, new biorefineries need to be flexible and be able to cope with different products and the expected changes/developments in the market; starting with feed and food, going through the chemical and at last reaching biofuels, with a concomitant increase in scale of production, and decrease in production costs. It is therefore of importance for both the successful

implementation of algae as a feedstock for biofuel production and for a biobased economy to develop a sustainable biorefinery concept for microalgae. A novel integrated biorefinery concept with new cell disruption/extraction technologies for the mild recovery and fractionation of high valuable components (proteins, lipids, carbohydrates) from cytoplasm and different organelles (e.g. mitochondria, chloroplasts) of microalgae is needed. To make production of these high valuable components economically feasible it is essential to make use of all biomass components. The highest benefit will be obtained if we are able to efficiently harvest and fractionate biomass from microalgae into different components while keeping their full functionality and minimizing the energy requirement.

In parallel to this novel approach with a focus on long-term implementation (>10 years), the application of existing scalable technologies to microalgae will be considered for a short to medium term implementation (3 to 10 years). This is of importance to help to define the markets, increase production, and demonstrate the commercial potential of microalgae.

AlgaePARC Biorefinery aims to develop a sustainable microalgae biorefinery concept, and implement it at pilot-scale. To reach this goal, there are three interrelated main topics:

- Technology development: research at laboratory and pilot-scale to develop new continuous and scalable technology and processes to fractionate microalgae biomass into the different components (lipids, proteins and carbohydrates), while keeping its functionality and minimizing the energy requirements.
- Systems analysis, sustainability assessment and flexibility.
- Enabling tools: basic knowledge on cell wall composition, knowledge for "design" and induced self-disruption; product mapping and functionality.

Contact: Wageningen University and Research Centre, P.O. Box 17, 6700 AA Wageningen, The Netherlands, Dr. Maria Barbosa, phone: +31-317-480077, e-mail: maria.barbosa@wur.nl, www.AlgaePARC.com



Figure 31. AlgaePARC Pilot Facility [Wageningen UR]

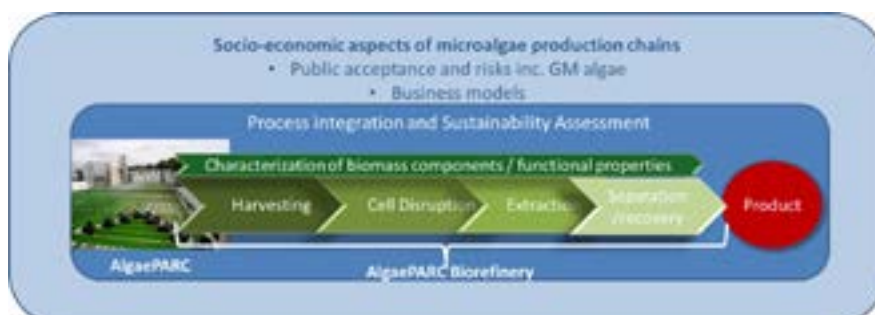


Figure 30. Development AlgaePARC Biorefinery [Wageningen UR]

BTG Bioliquids Refinery (The Netherlands)

State-of-the-art: Construction Phase, start-up 2015

Type of biorefinery: 1-platform (pyrolysis-oil) biorefinery for the production of chemicals, fuels, power and heat from lignocellulosic biomass

Location: Hengelo, the Netherlands

Owner: Empyro BV

Feedstocks: Wood

Outputs: Pyrolysis-oil, power, heat

Description: Biorefining based on pyrolysis – heating without oxygen – of biomass is an important step in the transition towards a sustainable BioEconomy. The Bioliquids Refinery makes maximum use of the Dutch existing agricultural and (petro)chemical infrastructure, facilitating a smooth and cost-effective greening of the Dutch Economy. The basis of the Bioliquids Refinery is the production and fractionation of pyrolysis-oil. Fractionation results in a sugar syrup, a lignin fraction and an aqueous stream that can be further processed to chemicals, fuels, power and heat. Advantages of the Bioliquids Refinery concept are that the pyrolysis-oil can be produced at regional level where the biomass is available, closing the mineral loop, after which the high-energy oil can be cost-effectively transported to existing centralized refinery facilities for further processing.

Empyro BV is currently implementing the first step of the roadmap to a full-scale biorefinery beyond 2020, viz. the implementation of the pyrolysis oil production facility.

The pyrolysis facility of Empyro that is currently under construction at the AkzoNobel site in Hengelo, the Netherlands, will be in operation from 2015 onward, gradually increasing its production capacity to 20 million litres pyrolysis oil per year. In the pyrolysis process 120 tonne/day biomass (e.g. wood chips) is mixed with hot sand and converted within a few seconds into 22.5 ktonne/year pyrolysis-oil, char and gas (power: 6000 MWh/year, 80 ktonne/year steam). This process was invented at the University of Twente and has been further developed in the past 20 years by BTG in Enschede, the Netherlands. Empyro BV has been founded by BTG Bioliquids BV (supplier of the technology) and Tree Power (long-term investor in renewables) to demonstrate the technology on a commercial-scale. In the plant every hour 5 tonne of biomass is converted into 3.5 tonne of pyrolysis oil. The plant will also produce enough electricity for its own use and steam is supplied to the salt production of AkzoNobel located next to Empyro. Long-term purchase contract has been concluded with the company FrieslandCampina, which will use the oil in its production location in Borculo to replace 10 million cubic meters of natural gas annually.

Contact: Pyrolysis-oil production: BTG-Bioliquids BV & Empyro BV, Gerhard Muggen, e-mail:

gerhard.muggen@btg-btl.com, web: www.btg-btl.com

Bioliquids Refinery: BTG Biomass Technology Group BV, Bert van de Beld, e-mail: vandebeld@btgworld.com, web: www.btgworld.com

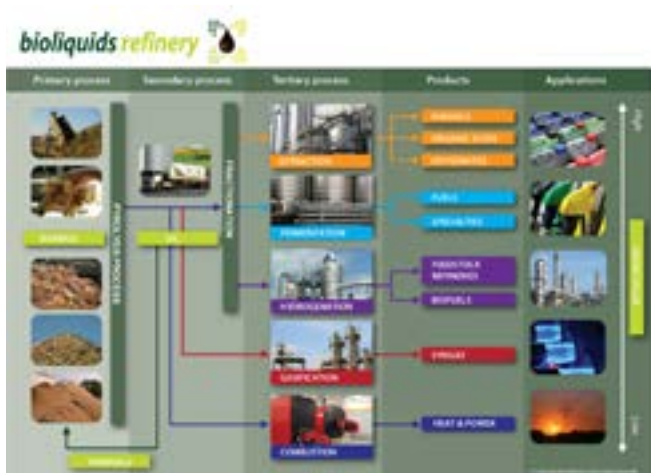


Figure 32. Bioliquids Refinery [BTG]

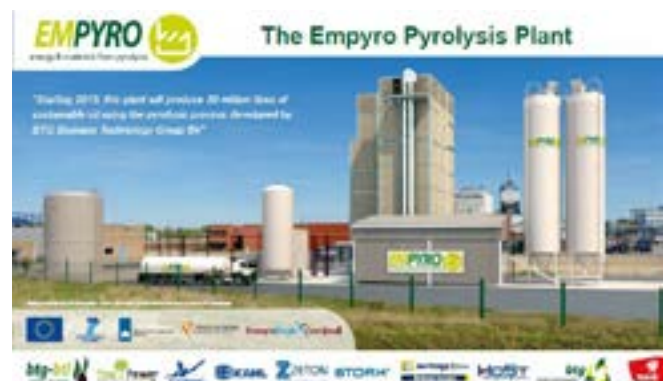


Figure 34. Empyro pyrolysis facility [Empyro]

Bioprocess Pilot Facility – BPF (The Netherlands)

State-of-the-art: Pilot Plant, open access, in operation

Type of biorefinery: A sugars and lignin platform biorefinery for the production of bio-based products and bioenergy from lignocellulosic biomass

Location: Located at the Biotech Campus Delft in the Netherlands, the facility is a centre of bioprocessing expertise and technology. Both its scale and its open nature make the facility unique, in an area that stands at the frontline of the development of the biobased economy.

Owner: Consortium of industrial partners and knowledge institutions led by Delft University of Technology

Feedstocks: Various, ligno-cellulosic-based

Outputs: Bio-based products (food ingredients, chemicals) and bioenergy (fuels)

Description: The Bioprocess Pilot Facility (BPF) in Delft, The Netherlands, is established as an open-access multi-purpose facility where companies and knowledge institutes can develop new sustainable production processes on a pilot-scale. Here, issues that do not occur at laboratory scale can be detected and studied. Scale-up of novel production processes from laboratory to pilot to industrial-scale currently encounters major bottlenecks. The need for complex equipment to investigate scale-up issues slows down scientific as well as commercial progress.

BPF allows users to construct complex operations by linking separate process modules. BPF is a state-of-the-art 5000 m² facility consisting of piloting equipment and supporting labs. Both its scale and its open nature make it unique, and make

the Netherlands a pioneer in the development of the biobased economy. The pilot-scale units prove the whole integrated process, support the development of scale-up rules and generate basic data for scale-up. BPF offers the following modules/technologies: pre-treatment and hydrolysis, fermentation, downstream processing and food grade. For the execution of a specific project, it might be required that clients want to test their own equipment or that equipment needs to be externally rented. In addition, it may occur that the available equipment needs some modification. According to the wishes of the client, the above activities can be performed.

BPF is also a centre of expertise where students, researchers and technologists can be trained.

In order to ensure that the food products are intrinsically safe for consumption by a test panel, the BPF has a dedicated Food-area. The equipment and infrastructure is designed and built according to Food Regulations and Standards (HACCP). The Food section is fully separated from the other activities in the BPF, having a controlled access for personnel and raw materials.

Contact: Bioprocess Pilot Facility B.V., P.O. Box 198, 2600 AD Delft, the Netherlands, phone: +31-15-5150200, e-mail: info@bpf.eu, web: www.bpf.eu



Figure 35. Open access Pilot Plant [BPF]

Application Centre for Renewable RESources – ACRRES (The Netherlands)

State-of-the-art: Pilot Plant, in operation

Type of biorefinery: Multi-purpose pilot-scale biorefinery facility

Location: Lelystad, The Netherlands

Owner: Wageningen UR, with participation of private companies

Feedstocks: Digestible and fermentable feedstocks (residues and crops), waste waters

Outputs: Biogas, proteins, microalgae, bioethanol, ...

Description: This public-private co-operation aims at realising added-value that can be achieved through biorefining processes, fermentation and reuse of tributaries, such as heat, CO₂, nutrients and process streams, based on (new or modified) sustainable resources. The valorisation of residues and connecting processes play a key role in enhancing the economic efficiency and sustainability of production of green gas, electricity, and basic components for feed, food or fuels based on (co)fermentation.

In order to research and test new production methods, nutrient recycling and soil quality issues, the pilot-plant currently comprises:

- A pilot digester, CHP-unit and associated clamp silos and digestate storage
- A bio-ethanol pilot-plant with a capacity of 150000 l per year
- An installation for hydrolysis of recalcitrant biomass for fermentation processes, and other follow-up processes
- Open production systems for algae situated in a greenhouse or in the open field
- An installation to upgrade biogas to green gas
- Arable land and grassland available to produce biomass

In addition, the possibility of decentralised processing of (aqueous) residues that occur locally within farms, landscape and water management organisations and processing industries is being explored.

Contact: Acrres, Edelhertweg 1, 8219 PH Lelystad, The Netherlands, contact: Rommie van der Weide, phone: +31-320-291631, e-mail: rommie.vanderweide@wur.nl, web: www.acrres.nl

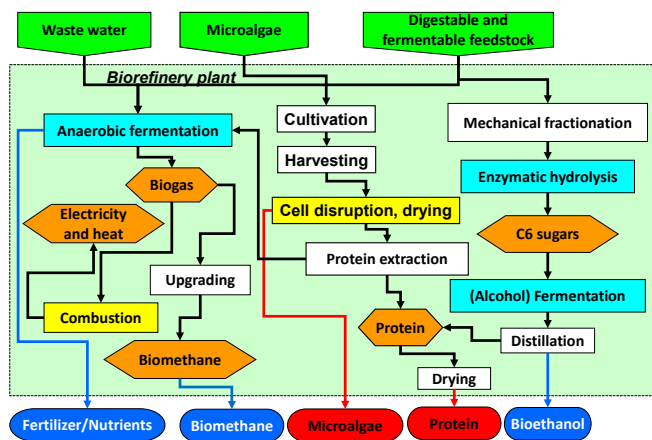


Figure. 36 Scheme and picture ACRRES pilot-facility [Wageningen UR]

Kinleith Pulp Mill (New Zealand)

State-of-the-art: Commercial Scale

Type of biorefinery: A 3-platform (pulp, black liquor, electricity&heat) biorefinery producing pulp/paperboard products, chemicals, electricity and heat from wood

Location: Kinleith, central North Island

Owner: Carter Holt Harvey

Feedstocks: Pinus radiata wood

Outputs: Pulp/paperboard products, chemicals, electricity & heat

Description: Kinleith mill is New Zealand's largest pulp and paper mill located in the central North Island. The mill produces bleached softwood kraft pulp, and a range of linerboards and medium used in packaging from plantation-grown Pinus radiata

wood. Lignin from the pulping process and waste wood are burnt to generate electricity and heat, supplying 80% of the plant's primary energy demand. The recovery plant also produces chemical by-products, including: crude tall oil, crude sulphate turpentine and red-oil (terpene extracts). These products are refined by customers into a range of biomaterials (e.g. resins, coatings, emulsifiers), solvents and fine chemicals.

Contact: Carter Holt Harvey Pulp & Paper, Kinleith Mill, Private Bag 6, Tokoroa 3444, New Zealand, phone: +64-7-885-5999, e-mail: chemicals@chh.co.nz web: <http://www.pedersen-group.co.nz/operations/kinleith/>

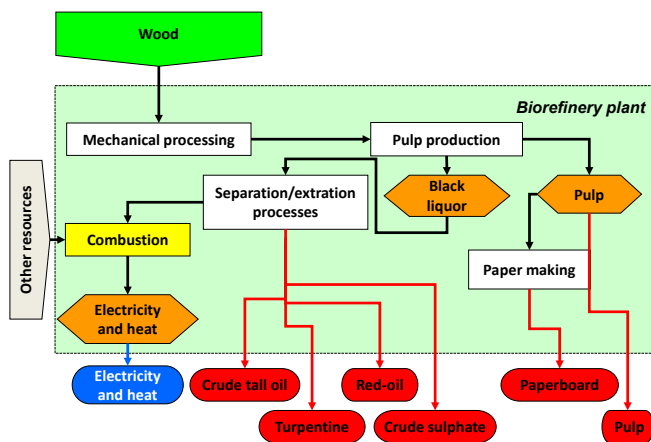


Figure 37. Kinleith Pulp Mill, New Zealand

Edgcumbe Milk Processing Plant (New Zealand)

State-of-the-art: Commercial Scale

Type of biorefinery: 2-platform (whey/protein) biorefinery for production of food products and bioethanol from milk

Location: Edgcumbe, central North Island

Owner: Fonterra Cooperative Group Limited

Feedstocks: Milk

Outputs: Food products and bioethanol

Description: Fonterra's Edgcumbe milk processing plant, located in the central North Island of New Zealand, processes 3.2 million litres of milk per day in its protein, cream and whey product plants. The protein plant manufactures, on average, 100 tonnes of protein-based food products every day. Anchor Ethanol Limited (a subsidiary of Fonterra) has an ethanol plant at this site for

the production of anhydrous ethanol for industrial and fuel-grade markets. The ethanol is produced from whey/permeate, a by-product of manufacturing cheese and protein products from milk. Anchor Ethanol Ltd has been producing ethanol from whey/permeate for 30 years. The Edgcumbe plant, together with two other plants (Tirau, Reporoa) can produce 15 million litres of ethanol per year. The recent growth in global demand for alternative fuels has opened up new opportunities for Anchor Ethanol Ltd to market its anhydrous grade ethanol for biofuels.

Contact: Anchor Ethanol Limited, Dave McCrorie, General Manager, phone: +64-9-374-9172, e-mail: dave.mccrorie@fonterra.com, web: www.fonterra.com

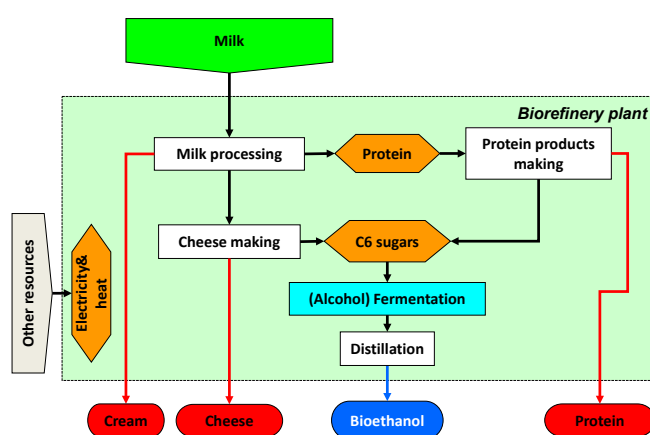


Figure 38. Ethanol fermentation tanks and distillery [Fonterra]

LanzaTech Pilot Plant (New Zealand)

State-of-the-art: Pilot Plant

Type of biorefinery: A 2-platform (syngas, chemical building blocks) biorefinery producing bioethanol and chemical building blocks from wood waste and MSW by syngas fermentation

Location: BlueScope Steel mill, Glenbrook, New Zealand

Owner: LanzaTech NZ Ltd

Feedstocks: Wood waste and MSW

Outputs: Fuel ethanol

Description: LanzaTech was founded in New Zealand in 2005 to develop, and commercialize proprietary gas fermentation technologies for the production of fuel ethanol from the carbon monoxide in low-hydrogen waste gases produced by the steel industry. With additional funding LanzaTech expanded the focus of its process development program to include syngas derived from waste woody biomass and municipal waste.

LanzaTech operates a pilot-plant at the BlueScope Steel mill, Glenbrook, New Zealand and has used this plant to successfully demonstrate the LanzaTech process using real waste gases.

LanzaTech is using synthetic biology to develop new organisms capable of producing a range of chemical building blocks from CO, CO₂ and H₂.

Other LanzaTech projects include two 100,000 gallon demonstration facilities, with Baosteel and Capital Steel in China, and development of an integrated biorefinery in the Soperton, Georgia, USA using forestry waste (Freedom Pines Biorefinery).

Contact: LanzaTech NZ Ltd, Sean Simpson, CSO,
 phone: +64-9373-4929, e-mail: Barbara@lanzatech.co.nz,
 web: www.lanzatech.co.nz

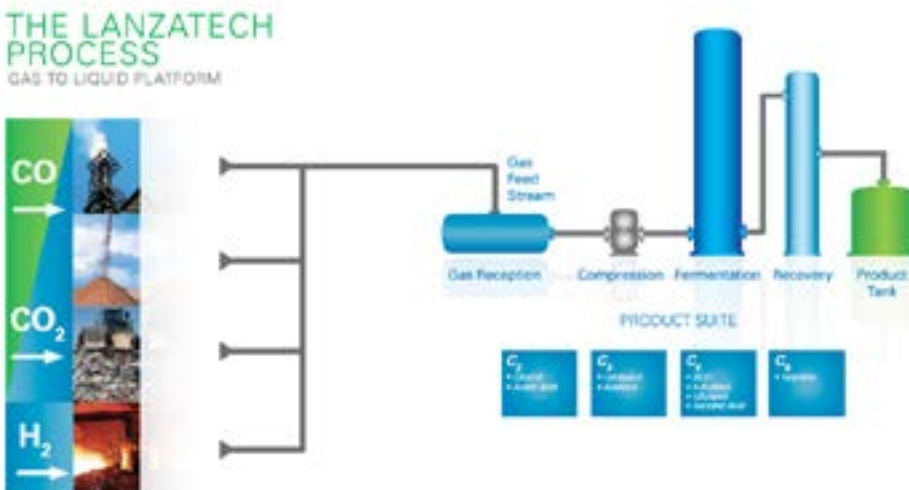
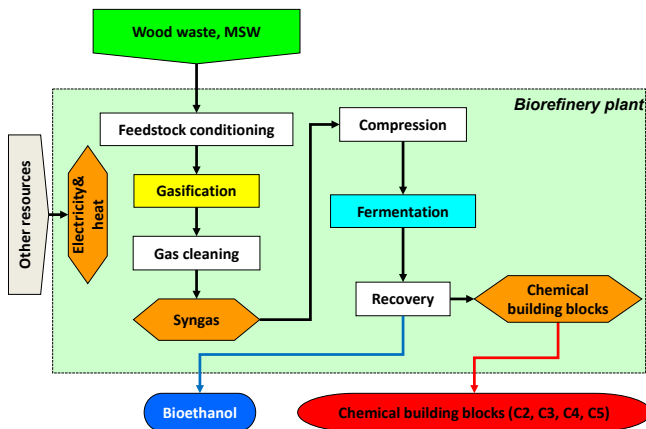


Figure 39. Pilot Plant Set-up [Lanzatech]

INEOS (United States of America)

State-of-the-art: Commercial Scale

Type of biorefinery: A 2-platform (syngas, power&heat) biorefinery producing bioethanol and power from vegetative, yard, and MSW by syngas fermentation

Location: Indian River County BioEnergy Center, Florida

Owner: INEOS New Planet BioEnergy

Feedstocks: Vegetative, yard, and MSW

Outputs: Bioethanol, power

Description: INEOS Bio and its joint venture partner, New Planet Energy, have invested millions of dollars to build an advanced bioethanol facility, bringing clean energy jobs to Florida. The Indian River County BioEnergy Center (Center), near Vero Beach, Florida, will produce eight million gallons of third-generation bioethanol per year from renewable biomass, including: vegetative, yard, and municipal solid waste (MSW).

The Center will also generate 6 megawatts (gross) of clean renewable power to run the facility with the excess exported to the local community.

The Center is the first commercial-scale facility employing the INEOS Bio Bioenergy technology. The project broke ground in February 2011 and construction was completed in the second quarter of 2012, with commissioning and start-up in the third and fourth quarters. Utilizing a unique combination of gasification and fermentation processes, the facility is demonstrating key equipment at full commercial-scale, using vegetative, yard, and MSW as feedstock.

Contact: Dan Cummings, phone: +630-857-7165, e-mail: bioinfo@ineos.com, web: www.ineosbio.com

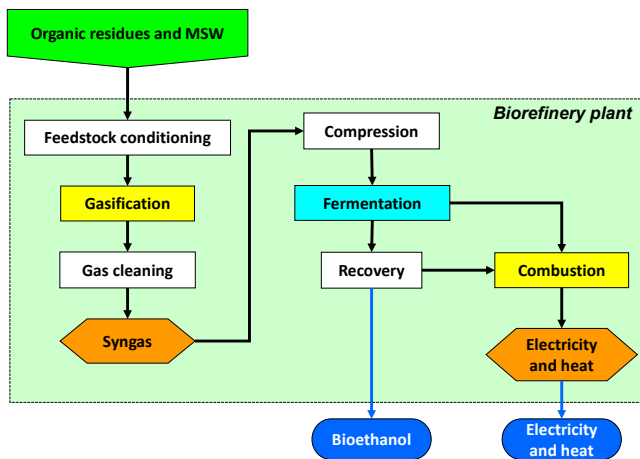


Figure 40. Commercial syngas-based bioethanol plant [INEOS]

ICM (United States of America)

State-of-the-art: Pilot Plant

Type of biorefinery: A 4-platform (C5&C6 sugars, C6 sugars, lignin, power&heat) biorefinery for the production of fuel-grade bioethanol and co-products (feed) from corn fiber, switch grass and energy sorghum by integration with a conventional starch biorefinery

Location: LifeLine Foods, LLC in St. Joseph, Missouri

Owner: ICM, Inc.

Feedstocks: Corn fiber, switch-grass, energy sorghum

Outputs: Fuel-grade ethanol and co-products (feed)

Description: ICM, Inc. has modified its existing pilot-plant and begun operations to use its biochemical conversion technology to produce fuel-grade ethanol from corn fiber, switch-grass, and energy sorghum. ICM, Inc. is leveraging its existing dry fractionation grain-to-ethanol pilot plant, located at LifeLine Foods, LLC in St. Joseph, Missouri. Co-locating the cellulosic biorefinery with the existing grain-to-ethanol pilot-facility is accelerating pilot operations, and improving the economics

of the process. Each day, the integrated biorefinery processes 10 bone-dry tons of feedstock into ethanol. ICM, Inc. is operating the pilot cellulosic integrated biorefinery using a biochemical platform pre-treatment and enzymatic hydrolysis technology coupled with a robust C5/C6 co-fermenting organism to refine cellulosic biomass into fuel ethanol and co-products. ICM's process addresses pre-treatment, hydrolysis, fermentation, and feed production, which represent key technology advances needed for the cost-effective production of ethanol from cellulosic biomass. ICM, Inc. plans to use energy sorghum and switch-grass to evaluate the advantages of a co-located cellulosic/starch biorefinery against a standalone cellulosic biorefinery.

Contact: Douglas B. Rivers, Ph.D., Director of Research and Development, phone: +316-977-8502, web: www.icminc.com; company media: Monique Pope, Governmental Affairs, phone: +316-997-6508

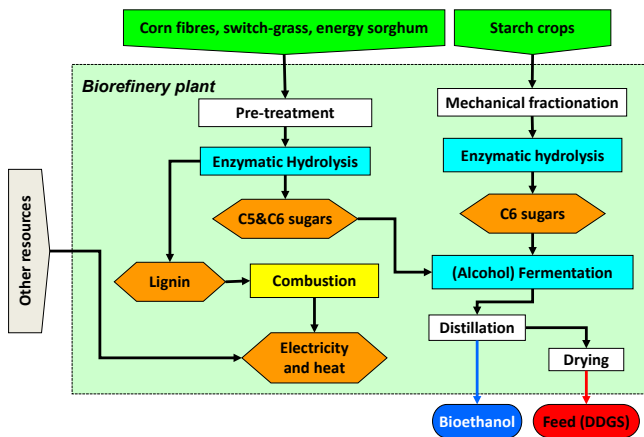


Figure 41. a) 35,000 Gal. Hydrolysis Reactors and b) 10T/D Pre-treatment Skid [ICM]

ZeaChem (United States of America)

State-of-the-art: Commercial Scale

Type of biorefinery: A 5-platform (C5&C6 sugars, lignin, acetic acid, acetate ester, electricity&heat) biorefinery producing bioethanol and acetate ester from LC biomass by acetate ester hydrogenolysis

Location: Boardman, Oregon

Owner: ZeaChem, Inc.

Feedstocks: Cellulosic feedstock (poplar trees, corn stover, wheat straw)

Outputs: Bioethanol, ethyl acetate ester,

Description: ZeaChem is constructing a 250,000-gallon-per-year cellulosic biorefinery in Boardman, Oregon. The biorefinery will convert 10 bone-dry tons per day of cellulosic feedstock into ethanol. ZeaChem anticipates a 95% reduction in life-cycle greenhouse gas emissions for fuel production in its commercial biorefineries compared to conventional gasoline. The technology uses chemical fractionation to separate the feedstock into a sugar-rich stream and a lignin-rich stream. The sugar stream is converted into acetic acid using naturally occurring bacteria, or acetogens, which produce no carbon

dioxide during the fermentation process, and enable 100% carbon conversion. The acetic acid is processed into an acetate ester, an intermediate bio-based chemical that can be marketed and sold. The ester is then converted into ethanol via hydrogenolysis. Funds from this cooperative agreement will be used by ZeaChem to construct and operate an addition to ZeaChem's existing ethyl acetate production facility, resulting in a fully integrated cellulosic ethanol facility. The operations plan includes a step-wise start-up of the facility beginning by the end of 2011, followed by fully integrated operations. ZeaChem will begin running the integrated pilot-plant on hybrid poplar trees supplied by Green Wood Resources, as the feedstock is readily available in the vicinity of the plant. After completing the trials on poplar trees, ZeaChem will also run trials on alternative cellulosic feedstocks, including corn stover and wheat straw to ensure that its technology can be duplicated at other locations in the United States.

Contact: Tim Eggeman, Ph.D., P.E., Chief Technology Officer, Founder, e-mail: time@zeachem.com, web: www.zeachem.com

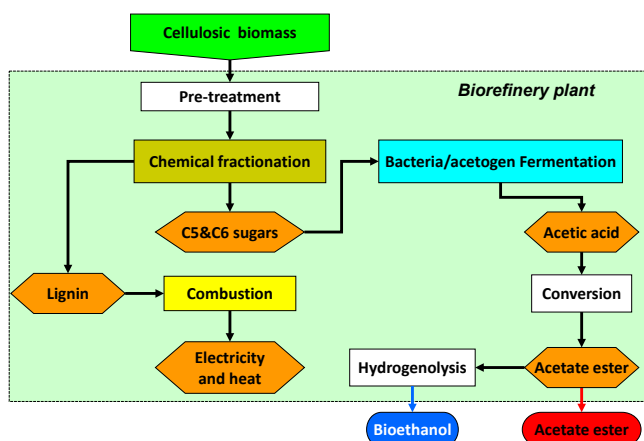


Figure 42. 250,000 gpy integrated biorefinery under construction in 2012 [ZeaChem]

ANNEX Overview commercial, demo, pilot-scale biorefining facilities and concepts in participating countries

ANNEX Overview commercial, demo, pilot-scale biorefining facilities and concepts in participating countries

Name	Feedstock	Products	Description (technology, capacity, status)	Classification	Info
Austria					
Bioethanol plant Pischelsdorf	Maize, wheat, sugar juice, barley	Bioethanol, DDGS, biogenic CO ₂	Commercial plant, 240,000 m ² Ethanol, 190,000 t/a DDGS, 100,000 t/a CO ₂	1-platform (C6 sugars) biorefinery producing bioethanol, feed and biogenic carbon dioxide from sugar & starch crops.	www.agrana.com
Starch plant Pischelsdorf	Wheat	Gluten, starch slurry A&B&C, bran, biogas, bioethanol, DDGS	Commercial plant, under construction, opening 2014, integrated to the existing bioethanol plant	2-platform (starch, C6 sugars) biorefinery producing starch products, bran, gluten bioethanol and animal feed from wheat.	www.agrana.com
Green Biorefinery Utzenaich	Grass silage	Biogas, electricity, heat, lactic acid, amino acid, biomaterials, fertilizer	Demonstration plant	5-platform (biogas, biomethane, green pressate, fibres, electricity&heat) biorefinery producing biomethane, lactic acid, biomaterials and fertilizer from grass and manure.	www.energieinstitut-linz.at
Biodiesel plant Vienna	Rape seed oil, soya feed oil, sun flower oil, waste cooking oil	Biodiesel, glycerine	Commercial plant, 140,000 t/a biodiesel, 15.000 t/a glycerine	1-platform (bio-oil) biorefinery producing biodiesel and glycerine from oil-based residues&oiledseed crops.	http://www.muenzer.at/en/our-services/biodiesel/
Biodiesel plant Arnoldstein	Waste cooking oil, animal fat	Biodiesel, glycerine, biogas	Commercial plant, 50,000 t/a biodiesel, 5,000 t/a glycerine	1-platform (bio-oil) biorefinery producing biodiesel, glycerine and biogas from oil-based residues.	http://www.biodiesel-kaernten.at/
Biorefinery Lenzing	Wood	Furfural, cellulosic fibres, food grade acetic acid, xylose-based artificial sweetener	Commercial plant	2-platform (C5 sugars, lignin) biorefinery producing biomaterials, chemicals, food, electricity and heat from wood.	http://www.lenzing.com/
BioCrack Schwechat	Wood, straw	Biogenic diesel, gas, bio-char, pyrolysis-oil	Demonstration plant, liquid phase pyrolysis of solid biomass integrated in an oil refinery	1-platform (oil) biorefinery producing raw diesel, pyrolysis-oil and bio-char from wood and straw.	http://www.bdi-bioenergy.com/
BioSNG Güssing	Wood	Biomethane from synthetic natural gas (SNG), biogenic CO ₂ , H ₂	Demonstration plant, 1 MW SNG output, steam gasification	4-platform (electricity&heat, hydrogen, biomethane, syngas) biorefinery producing biomethane (SNG), hydrogen and carbon dioxide from wood chips.	http://www.bio-sng.com/Index.htm
FT-Biofuel Güssing	Wood, other solid biomass	FT-diesel, FT-gasoline, methanol, waxes	Pilot-plant, about 1 barrel a day FT-raw product, steam gasification	2-platform (syngas, electricity&heat) biorefinery producing for FT-biofuels, waxes and methanol from wood chips.	http://www.bioenergy2020.eu/content/kompetenzbereiche/biotreibstoffe/bio_ft

ANNEX Overview commercial, demo, pilot-scale biorefining facilities and concepts in participating countries

Name	Feedstock	Products	Description (technology, capacity, status)	Classification	Info
Algae Biorefinery Bruck/Leitha	Algae	Biogas, biomethane, electricity, heat, algae oils, fertilizer	Demonstration plant, photo-bioreactors using CO ₂ from a biogas upgrading plant	4-platform (biogas, biomethane, bio-oil, electricity&heat) biorefinery producing biogas/biomethane, electricity, heat and omega 3 and fertilizer from algae.	http://www.ecoduna.com
Canada					
Lignol Innovations Ltd – pilot-scale biorefinery (Burnaby, BC)	Wood, straw, energy crops	Cellulosic ethanol, lignin, specialty cellulose, acetic acid, lignin, furfural, sugars	Organosolv-based fractionation, hydrolysis, enzymatic saccharification, fermentation, lignin recovery and drying. 1 t/d feedstock pilot-plant since 2009. Working on scale-up to 400 t/d.	2-platform (C6&C5 sugars, lignin) biorefinery for bioethanol, chemicals and biomaterials from lignocellulosic crops or residues.	www.lignol.ca info@lignol.ca
Bio-economy Technology Centre – pilot-plant located at Resolute Forest Products pulp and paper mill (Thunder Bay, ON)	Wood chips from a sustainably managed forest certified under Forest Stewardship Council	574,000 t/a of market pulp, newsprint, commercial printing papers; 43MW cogeneration plant; 10 kg/hr lignin sold for product development (e.g. industrial resins, carbon fibre)	Traditional Kraft mill production with new 10 kg/hr lignin pilot-scale production facility. The lignin is separated from the black liquor using an acidification process.	3-platform (pulp&paper, lignin, electricity&heat) biorefinery producing pulp & paper, lignin and bioenergy from wood chips.	www.resolutefp.com
Enerkem – pilot-facility (Sherbrooke, QC)	Over 25 different types of feedstocks	Small quantities of syngas, methanol, acetates and second-generation ethanol	Biomass gasification and catalytic conversion of syngas.	1-platform (syngas) biorefinery producing bio-chemicals and biofuels from a variety of biomass feedstocks.	www.enerkem.com
GreenField Ethanol Inc. cellulosic ethanol pilot-facility (Chatham, ON)	Low to high lignin cellulosic feedstocks (residues and purpose grown crops)	Cellulose and hemicellulose sugar monomers, cellulosic ethanol, acetic acid, distillers grain, CO ₂ , lignin used for process energy	Percolation/hot water/steam explosion pre-treatment equipped with proprietary Modified Extruder Technology followed by hydrolysis, fermentation of C5 and C6 sugar monomers, and the production of acetic acid. ¹	4-platform (C6&C5 sugar, distillers grains, acetic acid, heat) biorefinery producing bioethanol, chemicals, value added products and bioenergy from agricultural and forest residues.	www.greenfieldethanol.com
Enerkem - demo facility (Westbury, QC)	wood waste from used utility poles	Cellulosic ethanol, methanol	Biomass gasification, catalytic conversion of syngas. Production capacity: 5 million litres per year.	1-platform (syngas) biorefinery producing biofuels and bio-chemicals from wood waste and other residues.	www.enerkem.com

ANNEX Overview commercial, demo, pilot-scale biorefining facilities and concepts in participating countries

Name	Feedstock	Products	Description (technology, capacity, status)	Classification	Info
Domtar commercial Kraft pulp and paper mill with new demo facility - CelluForce joint venture between Domtar and FPInnovations (Windsor, QC)	Wood chips from sustainably managed forest certified under Forest Stewardship Council and Sustainable Forestry Initiative	Uncoated freesheet papers, bleached hardwood market pulp, bioenergy, nanocrystalline cellulose (NCC) for product development	Traditional Kraft pulp and paper production with new patented acid hydrolysis demo plant producing 1 t/d nanocrystalline cellulose (NCC). A portion of the mill's Kraft pulp is converted into NCC. The NCC plant includes acid recovery and anaerobic treatment of effluent that produces biogas.	3 platform (pulp & paper, nanocrystalline cellulose, electricity&heat) biorefinery producing pulp & paper, nanocrystalline cellulose and bioenergy from wood chips	www.domtar.com www.celluforce.com
Highmark Renewables (Vegreville, AB)	Wheat grain, cattle manure, slaughtering waste	Ethanol, DDGS used as animal feed, fertilizer, electricity and heat (used internally)	Conventional biochemical conversion process to produce ethanol integrated with an anaerobic digester next to a cattle feedlot.	2-platform (biogas and C6 sugars) biorefinery for bioethanol, animal feed, fertilizer, electricity and heat from organic residues and starch crops	www.highmark.ca
Ensyn -commercial facility (Renfrew, ON)	Wood residues from flooring plant and sawmill	Food flavouring, polymer resins and bioenergy used internally	Fast pyrolysis using Rapid Thermal Processing (RTP) technology; pyrolysis oil fractionation.	1-platform (pyrolytic liquid) biorefinery for resins, food flavouring, and heat from wood residues	www.ensyn.com
Permolex International -commercial facility (Red Deer, AB)	Wheat (grain)	Ethanol, flour and gluten food ingredients, DDGS sold for animal feed, CO ₂	Integrated flour mill, gluten plant and ethanol production facility; grain fractionation; conventional grain ethanol plant.	1-platform (C6 sugar) biorefinery for bioethanol, animal feed, and food ingredients from starch crops	www.permolex.com
GreenField Ethanol Inc.- commercial facility (Chatham, ON)	Corn (grain)	Ethanol, corn oil, DDGS sold for animal feed, CO ₂ sold for industrial uses; 2013: use of CO ₂ and heat by adjacent greenhouse	Conventional biochemical conversion process to produce ethanol (197 million litres per year) and DDGS (132,000 tonnes per year); High speed centrifuge extraction produces 3,500 tonnes per year of corn oil.	1-platform (C6 sugar) biorefinery for bioethanol and 2 animal feed products from starch crops	www.greenfielddethanol.com

ANNEX Overview commercial, demo, pilot-scale biorefining facilities and concepts in participating countries

Name	Feedstock	Products	Description (technology, capacity, status)	Classification	Info
Alberta Pacific Forest Industries - commercial pulp mill with new methanol purification system (Boyle, AB)	Wood (aspen, poplar) from sustainably managed forest certified under Forest Stewardship Council	650,000 tons of bleached Kraft pulp per year; 50 MW cogeneration plant selling power to the grid; 4,000 tons per year of biomethanol used internally or sold as solvent, antifreeze, fuel, or for formaldehyde production.	Traditional Kraft pulp production with new 4,000 t/yr bio-methanol extraction & purification commercial demo unit. The unit, a 2 stage distillation proprietary technology, was developed by A.H. Lundberg Systems Ltd. It converts steam stripper off gas, a by-product stream from the chemical recovery area of the Kraft pulping process, into high purity methanol.	3 platform (pulp, stripper off gas, electricity&heat) biorefinery producing Kraft pulp, electricity and biomethanol from wood chips	www.alpac.ca http://www.alpac.ca/content/files/BioMethanolNewsRelease.pdf
Enerkem Alberta Biofuels waste-to-biofuels facility - Commercial under construction (Alberta, QC)	Sorted municipal solid waste	Cellulosic ethanol, biomethanol	Biomass gasification, catalytic conversion of syngas. Capacity: 38 million litres per year. Subsidiary of Enerkem Inc.	1-platform (syngas) biorefinery producing biofuels and biochemicals from municipal solid waste	www.enerkem.com
Vanerco waste-to-biofuels facility - Commercial under development (Varennes, QC)	Sorted industrial, commercial and institutional waste	Cellulosic ethanol, biomethanol	Biomass gasification, catalytic conversion of syngas. Capacity: 38 million litres per year 50/50 joint venture between Enerkem and GreenField	1-platform (syngas) biorefinery producing biofuels and biochemicals from industrial, commercial and institutional waste	www.enerkem.com
Denmark					
Biogasol	Lignocellulosic biomass	Biomethane, bioethanol, solid fuel, fertiliser	Fully integrated continuous demonstration plant based on BioGasol pre-treatment and C5 fermentation technology. Under construction.	3-platform (C5&C6 sugar, lignin, biogas) biorefinery producing biomethane, bioethanol, solid fuel and fertilizer from straw or agricultural residues.	www.biogasol.dk
Inbicon	Lignocellulosic biomass	Bioethanol, solid fuel, feed	Demonstration plant using hydrothermal pre-treatment followed by enzymatic hydrolysis and fermentation. Capacity: 4 tons biomass/h producing annually 5.4 10 ⁶ litres of cellulosic ethanol, 11,400 metric tons of lignin pellets, and 13,900 metric tons of C5 molasses.	4-platform (C6 sugars, C5 sugars, lignin, electricity&heat) biorefinery producing bioethanol, electricity, heat and feed from straw.	www.inbicon.com

ANNEX Overview commercial, demo, pilot-scale biorefining facilities and concepts in participating countries

Name	Feedstock	Products	Description (technology, capacity, status)	Classification	Info
Inbicon	Lignocellulosic biomass	Bioethanol, solid fuel, feed	Pilot plant using hydrothermal pre-treatment followed by enzymatic hydrolysis and fermentation. Capacity: 1 ton biomass/h.	4-platform (C6 sugars, C5 sugars, lignin, electricity&heat) biorefinery producing bioethanol, electricity, heat and feed from straw.	www.inbicon.com
REnscience	MSW	Biogas and solid fuel	1000 kg/h pilot plant. The REnscience technology provides – by means of mild hydrothermal pre-treatment and enzymes – a separation of unsorted MSW into valuable fractions.	2-platform (bio-slurry and biogas) biorefinery producing biogas, fertilizer, electricity and heat from unsorted MSW.	www.dongenergy.com/renscience
Steeper Energy	Lignocellulosic biomass or sludge	Bio-oil, mineral product (fertiliser), liquid CO ₂	Bench/pilot scale plant operated with a capacity of 15-20 kg biomass/h producing 3 l/h bio-oil.	1-platform (bio-oil) biorefinery producing bio-oil, fertiliser, and liquid CO ₂ from straw, agricultural residues or sludge.	http://steeperenergy.com
Germany					
Zeit	Sugar beet, grain	Energy and material products	Commercial	A 2-platform (sugars or starch) biorefinery for the production of energy and material products (such as 1st generation bioethanol and multiple other products) from sugar beet or grain.	www.cropenergies.com/en/Unternehmen/Standorte/Zeit/
Krefeld	Maize	Various material and chemical products	Commercial	A 1-platform (starch) biorefinery for various material and chemical products (such as food starch, paper starch, protein, keto-gulonic acid, sorbitol, etc.) from maize.	www.cargill.de/en/products/starches/index.jsp
Schwedt	Sugar beet, grain	Energy and material products	Commercial	A 2-platform (sugars or starch) biorefinery for the production of energy and material products (such as 1st generation bioethanol, biogas and organic fertiliser, etc.) from sugar beet or grain.	www.verbio.de

ANNEX Overview commercial, demo, pilot-scale biorefining facilities and concepts in participating countries

Name	Feedstock	Products	Description (technology, capacity, status)	Classification	Info
Brensbach	Grass and silage	Energy, material and chemical products	Commercial and Demo	A 2-platform (green liquid, fibres) biorefinery that uses grasses and silage as feedstock for the production of energy, material and chemical products (such as biogas, reinforced composites, insulation material and organic fertiliser, etc.) from grass silage.	www.biowert.de
Leuna	Lignocellulosic biomass (hard wood, SRC wood)	Material and chemical products (such as glucose, xylose and lignin)	Pilot	A 2-platform (C5/C6-sugars and lignin) biorefinery for the production of material and chemical products (such as glucose, xylose and lignin) from lignocellulosic biomass (hard wood, SRC wood).	www.cbp.fraunhofer.de
Sunliquid® Straubing	Straw	2 nd generation bioethanol, biogas and lignin	Pilot	A 2-platform (C5/C6-sugars and lignin) biorefinery for the production of energy products (such as 2 nd generation bioethanol, biogas and lignin) from lignocellulosic biomass (straw).	www.sunliquid.com
Selbelang	Grasses	Material and chemical products, such as lactic acid, amino acids and animal feed, etc	Pilot concept	A 2-platform (green liquid, fibres) biorefinery for the production of material and chemical products (such as lactic acid, amino acids and animal feed, etc.) from grasses.	www.biopos.de
Ireland					
Cellulac Ltd	Lignocellulosic materials	High enantiopurity L and D Lactic Acid and Ethyl Lactate	>1000 t/yr Building design phase, Construction/implementation 2013. Ethyl lactate first quarter 2014	A 3-platform (C5, C6 sugars and lignin) for the production of chemicals and fuels from lactose whey permeate and lignocellulosic biomass	http://www.cellulac.com/
Italy					
Mossi and Ghisolfi	Lignocellulosic crops/wastes	Bioethanol	Production of 40 kt/y ethanol to be used as fuel additive and raw material for PET.		terry.tyzack@betarenewables.com
ENI	CO ₂ and discharge waters from the oil refining plant in Gela	Microalgae	1 ha pilot production of microalgal biomass that can be converted into biofuel and/or other energy vectors.		www.eni.com

ANNEX Overview commercial, demo, pilot-scale biorefining facilities and concepts in participating countries

Name	Feedstock	Products	Description (technology, capacity, status)	Classification	Info
Royal DSM N.V.	Starch (in the future cellulose)	Succinic acid	1.0 kt/y yeast based fermentation.		PHILIPPE.BOSQUILLON-DE-JENLIS@roquette.com
Mater-biotech	Sugar and lignocellulosic biomass	1,4 bio-butandiol	Located in B0ttrighe (Veneto). About 20 kton/y fermentation process in collaboration with Genomatica,		giulia.gregori@novamont.com
NOVAMONT	Maize	Compostable bioplastics	Destruction of the starch proteins, and complexation with polyester. The plant is located in Terni. Capacity: about 80 kton/y.		giulia.gregori@novamont.com
Matrica	Oil seed	Chemicals and polymers (biolubricants, biopolymers), biofillers	The complex will include 7 plants and will be located in Porto Torres (Sardinia). It is expected to employ directly 680 people		giulia.gregori@novamont.com
Netherlands					
BIC-ON (2014)	LC-biomass, fresh biomass, manure/ sludge, microalgae	Food and feed ingredients, biobased products and bioenergy	Regional North-East NL public-private-partnership on BioEconomy. BIC-ON: BioEconomy Innovation Cluster North East NL.		http://www.kiemt.nl/kiemt-projecten/bic-on.aspx
BioMCN (2010) – Delfzijl – Commercial Scale	Glycerin	Bio-merthanol	Upgrading of the biodiesel byproduct glycerin to bio-methanol for transportfuel. Bio-methanol can also be used as a chemical building block for a range of future-oriented products, including bio-MTBE, bio-DME, bio-hydrogen and synthetic biofuels (synthetic hydrocarbons). The plant in Delfzijl was opened officially on the 25 th of June 2010. Production capacity of 200,000 tonnes.		www.biomcn.eu
Cargill/Royal Nedalco (2007) – Sas van Gent – Commercial Scale	Wheat and corn at Cargill; wheat by-products of Cargill plant to Nedalco	Starches, starch derivatives, wheat proteins and glucose; bioethanol	Integrated biorefinery of Cargill starch industry together with Royal Nedalco bioethanol plant. Cargill's wheat processing plant supplies Nedalco with raw materials for its alcohol production process. 1 st generation plant (2005): 2.2 Ml/a; 2 nd generation plant (2007) 2.0 Ml/a.		www.cargill.com/company/businesses/nedalco/index.jsp
VION Ecoson (2013) – Son – Commercial Scale	Waste meat industry	Biogas, CHP, biodiesel	Integrated production of biogas, CHP and biodiesel from animal waste. Preparations to build the biogas installation were started in 2011 and actual production was started in 2013. Furthermore Ecoson has a refining capacity for 2 nd generation biodiesel. Production capacity per year: 9,000 MWh from biogas, 50,000 ton refined fat and 5,000 ton biodiesel.		www.ecoson.nl

ANNEX Overview commercial, demo, pilot-scale biorefining facilities and concepts in participating countries

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Greenmills (Orgaworld et al) (2014) – Amsterdam – Commercial Scale	Waste frying fat/oil and food waste	Biodiesel, bioethanol, and biogas	The waste cooking oils – previously used for preparing French fries (chips) and similar fried snacks – will be collected, cleaned and processed further by Rotie BV to turn them into suitable raw materials for the biodiesel plant. Biodiesel 100 Mton = 113 Ml/a, Bioethanol 5 Ml/a and biogas 25 m ³ /a.		www.orgaworld.nl/en/greenmills.html
UCO Kampen B.V. (2007) – Kampen – Commercial Scale	Waste oils / animal fats	Biodiesel	Waste plant oils and animal fats from the food industry are upgraded to biodiesel. The plant is in production since January 2007. In 2009 the production capacity was expanded to 100,000 tons of biodiesel.		www.uco-kampen.com and www.biodieselskampen.com
Empyro (BTG Bioliquids BV) (2014) – Hengelo – Demonstration Plant	E.g. wood chips	Pyrolysis oil	Commercial pyrolysis plant. On 8 February 2014 the construction of the pyrolysis plant (biomass-to-liquid) has started. 20 million litres of pyrolysis oil per year.		www.empyroproject.eu
AlgaePARC – Wageningen – Pilot Plant	Waste water, CO ₂ , sunlight	Algae	The goal of AlgaePARC (Algae Production And Research Centre) is to fill the gap between fundamental research on algae and full-scale algae production facilities. This will be done by setting up flexible pilot scale facilities to perform applied research and obtain direct practical experience.		www.wageningenur.nl/en/Expertise-Services/Facilities/AlgaePARC.htm
Algae Pro-concept (AlgaePro, TNO) – Pilot Plant	Industrial waste water	Microalgae to biobased products and bioenergy	Industrial waste streams to algae biomass. Pilot-project: development of algae refinery concept.		http://algaepr.o.org/
Aquafarming (Maris, Leuven, FeyeCon) – Demonstration Plant	Organic waste water	Microalgae to Omega-3 and energy	Algae production and refining for healthy food, feed and fuels.		www.maris-projects.nl
BioChemBouw (Hygear, WUR, Abengoa) – Pilot Plant	Non-food biomass	Isopropanol, butanol, ethanol, hydrogen	Chemical building blocks from biomass: High efficient de-central continuous refining of biomass into added-value Biobased Products		www.hygear.nl
Bioliquids Biorefinery (BTG, Albemarle, RUG) – Pilot Plant	Non-food biomass	Bulk chemicals and fuels	De-central bio-oil production via fast pyrolysis coupled to central biorefineries for further processing and/or classical oil refineries for co-production of bulk chemicals (and fuels). The refinery route includes: the separation of chemicals from the hemicellulose and lignin fraction, hydrogenation of the lignin fraction, and fermentation of the cellulose fraction.		www.btgworld.com
BUMAGA (Bumaga et al) – Pilot Plant	Waste water paper industry	Fatty acids	Separation of added-value organic fatty acids from waste water paper industry. Conversion to PHA's (polyhydroxyalkanoates) building blocks for bioplastics.		www.kcplk.nl
COSUN – The unbeatable beet – Pilot Plant	Beet	Food, feed, chemicals, materials, energy	Cosun processes about 75,000 ha (22-25 tonnes d.m. per ha/year) into sugars and animal feed. Within this pilot project they will valorise the whole beet plant, i.e. : the beet, the leaves and the carrots into food, feed, chemicals, materials and energy.		www.cosun.com

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CRODA – Pilot Plant	Residual plant oils	Biobased polymers, coatings, chemicals and personal care products	Green chemical intermediates for polymers by oleochemical biorefining.		www.crodaoleochemicals.com
GRASSA! – Pilot Plant	Grasses and protein-rich agroresidues	Proteins (feed), fibres (paper/cardboard), phosphate	High-value sustainable protein and fibre based products from grasses and protein-rich agroresidues (beet leaves). A mobile, small-scale modular process installation has been built with a capacity of 1-5 tonnes fresh materials per hour.		www.grassanederland.nl
Greenmills – Demonstration Plant	Organic residues	NPK (fertiliser)	High energy-efficient NPK recovery from organic residues. Demo-plant: 8-10 kt product per year (90% d.b.). Will be part of the Greenmills Biorefinery in the Amsterdam harbour area.		www.orgaworld.nl/en/greenmills.html
Harvestagg	Cultivated grass	Energy and turf	Small-scale Green Biorefinery		www.harvestagg.nl/en/
Indugras (CEFM/TNO)	Grass from nature management	Feed	Small scale Green biorefinery. Super-Heated Steam technology (SHT) tested for production of animal feed and chemicals		.http://www.h2obuffalo.nl/cleanenergyfor/me/projecten_indugras.html
Millivision/Greencell-ID – Pilot Plant	Nature and verge grass	Fibres for paper and cardboard	Refinery of protein-poor nature and verge grass into cellulosic fibres and value-added Biobased Products by mild fractionation. Production of grass box Greencell-ID.		www.greencell-id.eu
Modular multi-purpose Bioprocess Pilot Facility (BPF) Delft – Pilot Plant	Non-food biomass crops and residues	Biobased products and biofuels	This includes biomass pretreatment, fermentation, recycling and purification to third-generation bioprocesses.		www.be-basic.org
NewFoss – Pilot Plant	Verge grass and grass from nature management	Energy, fibres, feed	Small scale green refinery.		www.newfoss.com
Purac (Corbion et al) – Pilot Plant	Residues paper industry	Lactic acid and its derivatives	Lactic acid production from residues paper industry. Residues (a.o. cellulose) produced by a paper factory are separated and fermented to lactic acid and its derivatives. The process has been tested on pilot scale.		www.purac.com
YXY (Avantium) – Pilot Plant	Non-food biomass crops and residues	Furanics-based biopolymers and biofuels	Pilot-scale catalytic conversion hydrocarbons to furanics, raw material for biopolymers and biofuels. Production of some 1,000 kg furanics for downstream application testing.		www.avantium.com
ACRRES – Pilot Plant	Multi-purpose biorefining pilot-facilities WUUR	Digestible and fermentable feedstocks (residues and crops), waste waters	Multi-purpose biorefining pilot-facilities WUUR, including: digestion, fermentation, protein separation, microalgae cultivation, ...		www.acrres.nl

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New Zealand					
CHH Kinleith and Tasman pulp mills	Wood	Pulp and paper products, biochemicals, power	Commercial kraft mills producing ~900,000 t/yr pulp/paper products. Co-production of electricity and heat from black liquor, and tall oil/turpentine chemicals.	2-platform (pulp, black liquor) biorefinery producing pulp, paper/board, chemicals, electricity and heat from wood.	http://www.chhpulpandpaper.com/Pages/home.aspx
Fonterra milk processing plants - Edgecumbe, Tirau, Reporoa	Cow's milk	Food products and bioethanol	Commercial milk processing plants. Co-production of bioethanol from fermentation of lactose in whey. Annual production of 15 million litres of ethanol.	2-platform (protein, whey) biorefinery producing food products and bioethanol from cow's milk	http://www.fonterra.com/nz/en
Carbonscape	Wood	Biochar, activated charcoal, power	Pilot-plant for wood pyrolysis to carbon-products (5000 t/yr) using microwave technology. Bio-oil and syngas by-products could be used for electricity/heat.	2-platform (pyrolysis char/oil, syngas) biorefinery producing biochar, biomaterials and electricity from wood	http://carbonscape.com/
Scion-Rotorua District Council TERAXã plant	Sewage bio-solids	Chemicals, fertiliser, electricity	Pilot-plant for processing of municipal sewage bio-solids. Two-stage process that includes anaerobic fermentation followed by hydrothermal oxidation.	A biorefinery for chemicals, fertiliser, electricity from organic residues	http://www.terax.co.nz
LignoTech Developments Ltd	Distillers grain, lignocellulosic residues	Biomaterials, bio-composite plastics	Pilot-plant steam hydrolysis of biomass to bio-composite materials.	A biorefinery for biomaterials from lignocellulosic residues	http://lignotech.co.nz/
LanzaTech	Waste flue gases	Bioethanol, chemicals	Pilot plant gas to bioethanol (capacity of >50,000 litres/yr). Technologies for biomass-derived syngas to butanol/chemicals are under development. Expansion into demo and commercial scale plants in China and USA.	A syngas biorefinery for bioethanol and chemicals from waste flue gas and lignocellulosic residues.	www.lanzatech.co.nz
Aquaflow	Algae, wood residues	Fuel oils, biofuels, chemicals, fertiliser	Pilot scale algae harvesting and bio-crude oil production facilities. Collaborating with CRI catalyst company (USA) on jet/diesel fuels by hydrolysis of mixed biomass feedstocks.	An oil biorefinery for biofuels, chemicals, fertiliser from algae and lignocellulosic residues	http://www.aquaflowgroup.com/

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Solvent Rescue Ltd (previously Solray Energy Ltd)	Algae	Crude bio-oil, fertiliser	Pilot plant for supercritical water processing of algae to bio-crude oil. Development work on woody feedstocks.	An oil biorefinery for biofuels and fertiliser from algae	http://www.solventrescue.co.nz/
United States					
Amyris	Sweet sorghum (syrup and bagasse)	Renewable hydrocarbons	The pilot plant will integrate technology to produce a diesel substitute through the fermentation of sweet sorghum; co-products include lubricants, polymers, and other petrochemical substitutes; EPA approved blending up to 35%; FedEx conducting road vehicle testing; demonstrating process in Brazil on sugar cane. Amyris has developed genetic engineering and screening technologies that enable us to modify the way microorganisms, or microbes, process sugar.	Fermentation processes to convert plant-sourced sugars into target molecules.	www.amyris.com
American Process Inc. (API)	Hardwood derived hydrolyzate from existing mill board wastewater stream	Cellulosic ethanol	This pilot scale project will produce fuel and potassium acetate via hydrolysis and fermentation using the wood hydrolyzate from Decorative Panels International, an existing hardboard manufacturing facility in Alpena. The pilot plant will have the capacity to produce up to 890,000 gallons of ethanol and 690,000 gallons of potassium acetate per year starting in 2011. The hemicelluloses are then hydrolyzed to sugars. The rest of the biomass is sent to its original use, i.e. to make electricity, pellets or pulp.	Fermentation to produce fuel and chemicals.	www.americanprocess.com www.alpenabiorefinery.com

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Rentech ClearFuels	Woody waste and bagasse	Renewable diesel and jet fuel	The pilot plant will convert wood waste and bagasse to renewable diesel and jet fuel (direct petroleum substitutes) via gasification with Fischer-Tropsch synthesis, thus providing the design basis for two planned commercial scale facilities (in Hawaii).	Biomass gasification	http://www.rentechinc.com/clearFuels.php
ICM Inc.	Corn Fibre, Switchgrass, Energy sorghum	Cellulosic ethanol	This pilot plant project will add cellulose-specific unit operations to an existing corn-ethanol facility, integrating waste and recycle streams and utilizing the existing feedstock infrastructure. ICM's pilot plant will convert switchgrass, energy sorghum, and captive fibre to biofuels using enzymatic hydrolysis and fermentation using a novel yeast.	A 4-platform (C5 and C6 sugars, C6 sugars, lignin, power&heat) biorefinery for the production of fuel-grade bioethanol and co-products (feed) from corn fiber, switch grass and energy sorghum by integration with a conventional starch biorefinery	www.icminc.com
INEOS	Municipal Solid Waste (MSW)	Cellulosic ethanol	This demonstration scale project will produce 3 million gallons per year of ethanol and electricity from wood and vegetative wastes and construction and demolition wastes via combined biomass gasification and synthesis gas fermentation. The planned facility will have the capacity to produce 8 million gallons of ethanol and 2 megawatts of electricity per year by the end of 2012.	A 2-platform (syngas, power&heat) biorefinery producing bioethanol and power from vegetative, yard, and MSW by syngas fermentation	www.ineosbio.com

IEA Bioenergy

IEA Bioenergy is an international collaboration set-up in 1978 by the International Energy Agency (IEA) to improve international co-operation and information exchange between national bioenergy RD&D programmes. IEA Bioenergy's vision is to achieve a substantial bioenergy contribution to future global energy demands by accelerating the production and use of environmentally sound, socially accepted, and cost-competitive bioenergy on a sustainable basis, thus providing the increased security of supply whilst reducing greenhouse gas emissions from energy use. Currently (June 2014), IEA Bioenergy has 24 Members and is operating on the basis of 11 Tasks covering all aspects of the bioenergy chain, from resource to the supply of energy services to the consumer.

IEA Bioenergy | Task 42 Biorefining

IEA Bioenergy Task42 Biorefining deals with knowledge building and exchange within the area of biorefining, i.e. the sustainable processing of biomass into a spectrum of marketable Food and Feed Ingredients, Bio-based Products (Chemicals, Materials) and Bioenergy (Fuels, Power, Heat). The Task was started in 2007, and is now very successfully in operation involving Australia, Austria, Canada, Denmark, Germany, Ireland, Italy, Japan, the Netherlands, New Zealand, and the United States of America. Within the first triennium (2007-2009) the main focus of activities was on setting a common international framework on biorefining (i.e. definition, classification system, state-of-the-art in participating countries). In the second triennium (2010-2012) the focus of the activities was on the integral technical, economic and ecological assessments of full biofuel-driven biorefineries; the analysis of the types of Bio-based Chemicals that potentially could be co-produced with secondary energy carriers to maximise full biomass valorisation chain economics, and to minimise the overall environmental impact, to study overall sustainability aspects of integrated biorefineries, and to organise a Biorefining Summer School to get both industrial stakeholders, policy makers and students acquainted with the principles, current state-of-the-art, and future possibilities of applying the biorefining approach as base for a Bio-based Economy. This triennium (2013-2015) Task42 focuses on tackling market deployment aspects for integrated biorefineries, supporting stakeholders in the energy sector finding their position within a future Bio(-based) Economy, assessing optimal sustainable use of biomass for Food and Non-food applications, and dissemination & training activities.

Further Information

IEA Bioenergy Website
www.ieabioenergy.com

IEA Bioenergy Task42 Website
www.iea-bioenergy.task42-biorefineries.com

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