European Biofuels Technology Platform – Support for Advanced Biofuels Stakeholders

Overview on detailed information for each of the 9 topics

Deliverable Number: D.2.5
Due date: 31/08/2016
Actual submission date: 31/08/2016

Work package: 2. Biofuels sector monitoring
Task(s): 2.3. Production of detailed information
Lead beneficiary for this deliverable: BE2020
Editor:
Authors: Dina Bacovsky, Stephanie Holzleitner, Monika Enigl

Dissemination level

Grant Agreement no.: FP7-609607
Call identifier: FP7-ENERGY-2013-IRP

Information submitted on behalf of EBTP-SABS

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This project has received funding from the European Union's Seventh Programme for research technological development and demonstration under grant agreement No 609607

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FINAL

PROJECT PARTNERS

FNR – Fachagentur Nachwachsende Rohstoffe e.V., Germany

CPL – CPL Scientific Publishing Services Ltd, UK

BE2020 – BIOENERGY 2020+ GmbH, Austria

INCE – CEI – Iniziativa Centro Europea, Italy

EXECUTIVE SUMMARY

This deliverable displays the detailed information available on biofuels at the EBTP website as per 25 July 2016. The topics addressed are biomass resources, fuel production, fuels, fuel end-use, markets/policies/regulations, and sustainability.

Biomass feedstocks used for the production of biofuels include dedicated feedstocks such as sugar and starch crops, oil crops, lignocellulosic crops, algae and aquatic biomass, residues, such as forestry residues, agricultural residues, waste oils and fats, MSW, other organic residues and waste gases. Plant breeding and biotechnology are also covered in this section.

Technologies for the conversion of biomass into fuels include biochemical, thermochemical and oleochemical technologies as well as a couple of other innovative technologies. A large number of different fuels can be produced from biomass, and each of them is described in detail.

Although the main focus of biofuels is their application in road transport, they are also being discussed as alternatives in other transport modes such as off-road, air, water, rail and for heat and power production.

The deployment of advanced biofuels is driven by current policies and currently stalled by sustainability concerns, unsecure biofuels markets and low oil prices. The regulatory framework includes requirements for certification of sustainability as well as requirements to install infrastructure for the deployment of alternative fuels. Standards and certification systems serve to safeguard this deployment. Sustainability assessments have moved into focus of public discussion of biofuels, thus several aspects such as environmental impacts, land availability, the food versus fuel discussion, indirect effects and bio-CCS are discussed in detail.

The detailed information given facilitates an informed discussion on biofuels.

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Project Title	European Biofuels Technology Platform – Support for Advanced Biofuels Stakeholder EBTP-SABS
Deliverable nature	Pdf
Dissemination Level	World wide web
Start Date of the Project	01/09/2013
Duration	36
Contractual Delivery Date	31/08/2016
Actual Delivery Date	31/08/2016
Status	Completed
Contractual	Completed
Version	1
Total Number of Pages	228
Work Package Number	2
Work Package Leader	Bioenergy 2020+ GmbH
Lead Beneficiary of Deliverable	EBTP

Revision Table

Issue	Date of issue	Modifications	Author
		-	
		-	
		-	

Registration of Internal Approvals

Internal Ref.	Classification	Distributed to:	Date of Approval

Internal Ref.	Classification	Distributed to:	Date of Approval

LIST OF ABBREVIATIONS

e. g.	for example
i.e.	id est

Introduction

This deliverable displays the detailed information available on biofuels at the EBTP website as per 25 July 2016. The topics addressed are biomass resources, fuel production, fuels, fuel end-use, markets/policies/regulations, and sustainability.

BIOMASS / FEEDSTOCKS

Dedicated feedstocks

Sugar crops for production of advanced biofuels

Sugar crops, such as sugar cane, sugar beet and sweet sorghum, can be used as feedstocks for both conventional biofuels (ethanol via fermentation of sugar) and/or advanced biofuels. Residual beet pulp and bagasse (the fibrous material left after sugar extraction from cane or sorghum) can be used to produce cellulosic ethanol. Fermentable sugars can also be converted to 'drop-in' biofuels via biotechnology (e.g. Amyris/Total) or chemical catalysis (e.g. Virent). Examples of other companies developing technology for producing advanced biofuels from sugars include: Renewable Energy Group Inc - sugarcane biodiesel; Gevo - isobutanol; Butamax™ Advanced Biofuels - isobutanol; Avantium Furanics - furan derivatives.

C5 and C6 sugars can also be produced from lignocellulosic crops or wastes and residues via various pretreatments.

From the sugar platform to biofuels and biochemicals

A detailed review of the technologies used to convert sugar is provided in the report From the Sugar Platform to biofuels and biochemicals (April 2015), produced by E4Tech, RE-CORD and WUR for the European Commission Directorate-General Energy (ENER/C2/423 - 2012/SI2.673791).

Sugar beet

Sugar beet is a demanding crop in terms of soil conditions, fertilizer and irrigation. In Europe 188.4 million tons of sugar beet were produced in 2012 (FAO, 2014) and it was ranked # 11 in agricultural commodity production. In Europe, sugar beet is used to produce fuel ethanol, but is subject to the proposed 7% ceiling on biofuel production from food crops (see proposed changes to the Renewable Energy Directive and Fuel Quality Directive).

Mendota Bioenergy LLC operates a demonstration plant in Fresno County, California, which uses year-round, 'carbon-optimized' low-water-use energy beets. The whole beet is used as a feedstock for ethanol production.

Britian's first bioethanol plant at Wissington sugar factory. The bioethanol refinery uses local sugar beet to make 75 million litres of bioethanol a year – equivalent to about 2% of the petrol used by all cars in the UK. The green fuel delivers 71% savings in CO_2 emissions when compared to petrol. View at larger size >>

Sugar Cane

Sugar cane harvesting.

Although sugar cane is a 'first generation' feedstock, it is generally considered to be relatively sustainable as it offers a high energy balance and high GHG reduction. It has not been shown to have significant impact on food supply or prices in Brazil, where there are 9 million vehicles that use ethanol or ethanol blends from sugar cane. Sugar cane is also being developed as a potential energy crop (i.e. using crushed bagasse as a feedstock) in Europe and Brazil.

Energy Cane

In January 2015, Alkol Biotech announced the first shipments of its EUnergyCane sugarcane hybrid grown near Motril in southern Spain. The energycane (energy cane) is being supplied to a 2G ethanol producer in Denmark. In April 2014, Alkol Bioenergy and the Universidad Politécnica de Madrid signed an agreement to develop a hybrid of Brazilian sugarcane varieties for Spain, where the plant has been cultivated for over two centuries, but where farmers currently use older varieties with lower yields and lower resistance to disease. The aim is to use the bagasse from the new sugar cane hybrid for cellulosic ethanol production. The project is being developed by the UPM School of Forestry, ETSI.

An energycane variety "Cana Vertix" is also being developed by Granbio for use in cellulosic ethanol production. It is 3 times more productive than conventional sugar cane and can be planted on degraded land. Energy cane varieties have also been trialled in North America with positive results (for example, by Louisiana State University AgCenter).

Arcadia Biosciences Inc has developed a Nitrogen Use Efficiency (NUE) trait for sugarcane, which improves yields while reducing fertiliser inputs [Source: Arcadia Biosciences, April 2015].

Sweet Sorghum

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Sweet sorghum, as a source of either fermentable free sugars or lignocellulosics, has many potential advantages, including: high water, nitrogen and radiation use efficiency; broad agro-ecological adaptation; rich genetic diversity for useful traits; and the potential to produce fuel feedstock, food and feed in various combinations. Further research on Sweet Sorghum has been carried out by **SWEETFUEL - Sweet sorghum: an alternative energy crop (FP7 - 227422)**

Sweet Sorghum is also being developed as a biofuel feedstock in the US (e.g. Regional Strategy for Biobased Products in the Mississippi Delta). In April 2013, construction started on a 20 MMgy sweet sorghum-to-ethanol plant in Florida [Ref: Southeast Renewable Fuels LLC]. Also in the US, NexSteppe has developed low-input, high-yield Sweet Sorghum and 'High Biomass Sorghum' strains for use as bioenergy feedstocks. In October 2014, NexSteppe announced $22m to further develop its Palo Alto biomass sorghum and Malibu sweet sorghum product lines. New investors include Total Energy Ventures and ELFH Holding GmbH, Germany. In the growing season (2014/2015) NexSteppe sold 10,000 hectares of its hybrid Sorghum varieties.

Ceres has also developed varieties of Sweet Sorghum that are being commercially planted in Brazil. In March 2013, Chromatin signed an agreement to supply POET with Sorghum for its bioethanol plant in South Dakota. In November 2013, Arcadia Biosciences and DuPont Pioneer are collaborating on a project to use biotech and breeding techniques to improve the productivity of Sorghum.

Starch crops for production of biofuels

Overview

Starch-based feedstocks include grains, such as corn or wheat, and tubers such as (sweet) potatoes and cassava. These feedstocks contain long complex chains of sugar molecules. The starch can easily be converted to fermentable sugars. The sugar can then be converted to ethanol or drop-in fuels. The fibrous part of the plants (e.g. wheat straw or corn stover) can be converted to advanced biofuels (see cellulosic ethanol).

In Europe, wheat is currently the main starch crop for bioethanol production. 0.7% of EU agricultural land and 2% of Europe's grain supply is used for production of renewable ethanol [Source: ePure]. The EC has proposed to limit biofuel produced from "food crops" at 7% of energy use in transport, due to concerns about food price and land use impacts. However, recent reports (and the latest statistics) suggest that the impacts of biofuels production from starch crops may have been greatly exaggerated and the many benefits of biofuels (European fuel security, job and wealth creation, production of valuable byproducts, GHG reduction) have not been fully taken into account.

Research on conversion of starch to sugars

A research team from York University, UK, CNRS Marseille, France, University of Copenhagen and Novozymes, Denmark, and the University of Cambridge, UK published a study on lytic polysaccharide monooxygenases (LPMOs), which can convert starch to sugars. The work is part of the project Critical Enzymes for Sustainable Biofuels from Cellulose, funded by the European Research Area Industrial Biotechnology network.

Starch crop species

Wheat (Triticum species)

After corn and rice, wheat is the most produced crop worldwide (FAO 2014) with a starch content of about 70 %. It is a major food crop but can also be converted to bioethanol. 2.8 million metric tons of wheat were processed to ethanol in 2014 (see EU Biofuels Annual 2016)In the UK, Vivergo opened a 420 Mio litre wheat-to-ethanol plant in 2013 that also produces high protein animal feed as a by product.

Corn (Zea mays)

Corn contains about 70 % starch. In 2014 5.2 million metric tons of corn served the bioethanol business in Europe (see EU Biofuels Annual 2016). Corn is the feedstock for more than 90% of ethanol production in the United States due to its abundance and low price; most ethanol is produced in the corn-growing states of the Midwest. The economic output of the 'renewable fuels industry' is $184 billion. It supports over 852,000 jobs and $56 billion in wages and generates about $14.5 billion in local and state tax revenue every year [Source: National Corn Growers Association, April 2014].

Barley (Hordeum vulgare)

Barley is a winter crop that's planted in rotation with crops such as corn and soybean. It therefore helps to anchor the soil during a time when fields would otherwise lie fallow. It requires much less nitrogen fertilizer than, for example, corn. It shows potential as a biofuel feedstock, particularly in regions where the market for barley is not so big. 541,000 metric tons of barley were used as feedstock for ethanol in Europe in 2014 (seeEU Biofuels Annual 2016)). The starch content of barley varies between 50 and 75 %.

Rye (Secale sereale)

Rye is a rather robust grain that also grows on poorer soils. Its starch content is about 60 %. In 2014 846,000 metric tons served as biofuel feedstock in Europe (see EU Biofuels Annual 2016).

Millet/Sorghum (Species of e.g. *Sorghum, Penisetum, Panicum)*

Millet/Sorghum species can grow on marginal soils, need low inputs and improve soil productivity, and can be used in crop rotation systems as an ameliorant. Their starch content is about 75 %. In 2012, a study by the University of Nebraska–Lincoln compared ethanol production from millet cultivars and advanced breeding lines with that from normal corn and "highly fermentable" corn. Fermentation efficiencies in the tested millet varieties ranged from 84 percent to 91 per cent compared to 97 per cent from the highly fermentable corn hybrid.

Potatoes (Solanum tuberosum)

Potatoes contain up to 19 % starch. In recent years, the food versus fuel debate, has focused attention on the use of waste from potato processing industries as a biofuels feedstock. For example, see Bioethanol production from Potato Peel Waste (PPW).

Cassava (Manihot esculenta)

Cassava is an important food and feed crop in many tropical countries. It can also be cultivated on drier or poorer soils. Under good gowing conditions, yields can be as high as 150 tonnes/ha. Cassava contains circa 40 % of starch. China is a big promoter of cassava as biofuel feedstock. In Thailand, the amount of ethanol produced from cassava is expected to double to 3 million tonnes in 2014 [Source: Biofuels Digest]. In October 2013, China New Energy Ltd announced a partnership with Sunbird Bioenergy Africa Ltd to build a cassva-to-bioenergy refinery in Nigeria (with a potential 9 more to follow). Mozambique also has a cassava-to-ethanol facility in operation.

Sweet potatoes (*Ipomoea batatas*)

Sweet potatoes can be cultivated in tropical or warm regions and offer relatively high ethanol yields since their starch content is about 70 %. The potential of sweet potatoes as a feedstock has been investigated for many decades [*See* Dehydrated Sweet Potatoes for Ethanol Production, Jump *et al*, 1944]. A USDA study in 2008 suggested sweet potatoes may offer three times the yield of corn (in terms of ethanol per hectare). However, researchers at North Carolina State University have suggested that production costs of ethanol from sweet potato are "ten times those for corn". Worldwide, China is the biggest producer of sweet potatoes, and is active in their conversion to fuel ethanol [*See* High Performance Technologies for Ethanol Production from Sweet Potato, Zhao hai, Chengdu Institute of Biology].

References and Links

FAOSTAT (FAO, 2014)

EU Biofuels Annual 2016 (USDA, 2016)

Oil crops for production of advanced biofuels

Overview

Oil crops are the base for biodiesel production. In Europe, rapeseed is the most common feedstock for biodiesel production. In the US, Argentina and Brazil, soybean oil is the most dominant biodiesel fuel feedstock. In Indonesia and Malaysia, palm oil is the main feedstock cultivated. In 2008, 66 % of biodiesel in Europe came from rapeseed, 13 % from soybean and 12 % from palm oil (Junginger et al., 2014). Besides the most prominent oil crops (palm, soybean, rapeseed and sunflower), many other crops such as, canola, mustard, flax, jatropha, coconut, hemp, and pennycress are good resources of oil.

The use of corn oil is also gaining momentum in the United States, where large volumes of maize are used in ethanol production. Companies such as Corn Oil One are developing improvements to crude corn oil to facilitate conversion into biodiesel. Innovative technologies for separation of corn oil are included on the process innovation page.

In the EU, concerns over iLUC and the Food vs. Fuel debate have led to proposals to limit biofuel production from food crops to 7 % (see proposed changes to the Renewable Energy Directive and Fuel Quality Directive). This has accelerated interest in drought-resistant oil crops that can be cultivated on marginal lands and don't compete with food crops.

However, there are doubts cast on the validity of the assumptions made and models used to underpin the iLUC debate. For example, in Germany in early 2015, UFOP published a brochure Opportunity or risk for the future!? presenting a more positive outlook on the benefits offered by Rapeseed and other oil crops.

Improving sustainability of existing oil crops has been a key focus of producers in the last decade. For example, the RSPO Roundtable on Sustainable Palm Oil was inaugurated in August 2003. Sustainable winter oilseed rape - a 24 page brochure was jointly published in 2007 by Unilever N.V., and UFOP (UNION ZUR FÖRDERUNG VON OEL- UND PROTEINPFLANZEN E. V.).

Worldwide Production of selected Oil Crops 2014

Oil Crops	Production (tonnes per year)
Oil palm	52,821,076
Soybean	308,436,057
Rapeseed	70,954,407
Palm kernels	15,913,911
Cottonseed	46,657,005
Groundnut with shell	42,316,355
Olive	15,516,980
Coconut	61,440,691
Maize	1,021,616,584
Sesame seed	5,469,023
Linseed	2,564,535
Safflower seed	867,659

A = Aggregate, may include official, semi-official or estimated data

Source: FAOSTAT | © FAO Statistics Division 2016| 02 August 2016

Oil crops

Oil seed rape (Brassica napus, B. rapa, B. juncea)

Globally, commercial supply is dominated by two species, *Brassica napus L.* and *B. rapa L*. Both species contain spring and winter forms that are distinguished by vernalization requirement. Seeds of these species contain 40 % or more oil and produce meals with 35 to 40 % protein. Compared to soybeans, rapeseed can have more than twice the oil content but a lower protein level. In 2013/2014 rape seed holds ca. 14 % of the world production of major oil crops (FAO, 2014). According to FAO statistics (2014), rapeseed ranked number 14 in agricultural commodity production in Europe in 2012.

Soybean (Glycine max)

Soy is a bushy, leguminous plant, native of South-East Asia that is grown for the beans, which are used in the food industry, for protein in cattle feed and for oil production. The beans typically contain about 18 - 20% oil, 40% protein, 17% cellulose, minor contents are sugar, ash, fibre and other components. Soybeans are the world’s largest oilseed crop, with a production of about 56 % of the world’s total oilseeds. The United States is the largest single producer of soybeans (FAO, 2014).

Sunflower (Helianthus annuus)

Sunflower grows in a variety of soil conditions but performs best in well-drained soils with high water-holding capacity. In drier regions it often needs at least supplemental irrigation for best yields. However, sunflower is considered a drought tolerant crop and has a deeper root system than most crops. Sunflower seeds contain 45 – 55 % oil that is used for food, cosmetics or biofuel production. About 8 % of the world oil crop production were sunflower seeds according to the FAO (2014).

Jatropha (Various Jatropha species)

Images of *Jatropha curcas* © copyright JatroSolutions GmbH, which offers expertise in tropical plant production, including cultivation of Jatropha for biofuel production. The top picture shows pollination of Jatropha by bees. The picture immediately above shows male flower (right) and female flower (left).

Jatropha curcas is a tropical plant that grows well on marginal land, is drought tolerant and has seeds with high oil content (~40%). In Singapore, Temasek Life Sciences Laboratory and JOil Pte Ltd. have developed Jatropha strains with 75% oleic acid content, compared to the typical 45% percent (May 2012).

In common with other members of the family Euphorbiaceae, Jatropha contains toxic substances and therefore is unsuitable as a food/feed crop. Jatropha seemed a very promising candidate as a biofuel feedstock and an investment boom followed in the mid-2000s. However, initial claims of high yields could not be verified on marginal lands; the early cultivars tested required lots of water, good soils and high fertiliser inputs to achieve high yields.

However research and investment in Jatropha continues. In 2014, Lufthansa signed a Memorandum of Understanding with JatroSolutions GmbH (a subsidiary of EnBW, the third-largest German energy company) to make jatropha production commercially viable. In future, Lufthansa will help the start-up company to set up a raw materials supply chain to ensure the provision of biosynthetic fuel derived from the jatropha plant. [Source: Lufthansa Press Release, September 2014].

In 2014, Jatropower AG, Switzerland, acquired the assets of Qunivita BV. Jatropower offers a wide range of hybrid seeds and Jatropha cultivars. Jatropower has a focus on high-yielding, non-toxic edible jatropha, which enables safer handling of the plant and allows for the use of the kernel meal (after oil extraction) as animal feed. Its main research farms are situated in India, and it operates variety testing sites in Paraguay and Kenya. [Source: Jatropower].

Previously, in 2009, Archer Daniels Midland (ADM), Bayer CropScience AG and Daimler AG announced that they would collaborate on use of Jatropha. NesteOil has also researched the use of Jatropha for biodiesel production. Galp Energia, Portugal is leading a research project on Jatropha for biofuels production in Mozambique.

Live-fence hedges of Jatropha with a double benefit may be a profitable option for small scale farmers in Africa. This needs to be further investigated (see Bioenergy In Africa).

Camelina (Camelina Sativa)

Picture credit: Wikipedia.

Camelina sativa is an oil plant that grows well on marginal land, is cold-tolerant and has an oil-yield of 35-38%. Sustainable Oils (a partnership between Targeted Growth, Inc. and Green Earth Fuels, LLC) currently has 30 Camelina breeding trials in the US and Canada. The company first provided Camelina-based biodiesel for a Japan Airlines test flight in January 2009. Biojet fuel derived from Camelina has been successfully used on many demonstration flights in the last five years. The Eureka BIOFUEL-CAMELINA Project, coordinated by ISCO, Poland, studied the cultivation of Camelina sativa and cameline oil production, biofuel production and evaluation. The Camelina Association of Ukraine was established in 2014 for cultivation and commercial exploitation of *Camelina sativa* products in Ukraine.

Macaw palm - Acrocomia aculeata

The above images (and that of fruits, below) are © Copyright Acrocomia Solutions, and kindly provided by University of Hohenheim, Germany

The neo-tropical palm species *Acrocomia aculeata* naturally occurs in a wide range of tropical and subtropical environments. In contrast to the African oil palm, it tolerates low temperatures (> -5°C) without negative impacts on yields. It grows between 30° north and south of the equator and is even found in areas with longer dry seasons up to six months such as the Chaco region of Paraguay and cerrado region of Brazil. After five to six years it yields a harvest of 20 t/ha/a. Since this fruit is nontoxic, all parts of it can be used. All have their own market; however its potential in terms of food, feed and fuel is still underexploited. Considering the yield of perennial plants, the Acrocomia palm (2 t/ha/a of Pulp oil and 1 t/ha/a of Kernel oil) can ranked in-between the African oil palm (*Elaeis guineensis*, 3 – 6 t/ha/a of Pulp oil and 1 t/ha/a of Kernel oil) and Jatropha (*Jatropha curcas*, 1 t/ha/a).

For the past decade, the University of Hohenheim in Germany and the Catholic University of Paraguay have worked together on the domestication of *Acrocomia aculeata*, which is endemic to the Americas. There is substantial knowledge available on growth and yield performance to establish sustainable and rentable plantations. This palm is ideal for 'peasant farmer' cultivation, but is also well suied to sole cropping and agroforestry systems including silvo-pastoral systems. Due to its perennial growth pattern and long-term ability to provide economic yields it offers a huge potential for carbon sequestration as well.

The fruits of Macaw palm, can be used to produce food, feed, energy/fuel and raw materials for the cosmetic and chemical industry. In Paraguay, currently ten oil mills are in operation using *Acrocomia* fruits for oil extraction, although almost all fruits are collected from wild growing palms with minor control of quality aspects.

Currently, further reseach to commecialise *Acrocomia* is taking place offering future potential, especially in Paraguay, Brazil, and Costa Rica where Acrocomia palm is planted and growing in various environments [Source: University of Hohenheim, 2015].

Dwarf saltwort / Dwarf glasswort (*Salicornia bigelovii*)

A salt mash halophyte that is found on both the east and west coast of the US and Mexico. The plant is of interest as a biofuel feedstock as it grows in desert environments, can be irrigated with seawater, and the seed contains around 30% oil content. It is being grown extensivley across the globe, for example in India. In The United Arab Emirates, the Sustainable Bioenergy Research Consortium is developing an Integrated Seawater Energy and Agriculture System (ISEAS) to cultivate the halophyte *Salicornia* as a sustainable feedstock for biofuel production

Cardoon (Cynara cardunculus)

The oil content of cardoon seeds (artichoke oil) is between 20–32 % (Pasqualino, 2006). The suitability as a feedstock for biodiesel production has been investigated in several studies (e.g. Pasqualino 2006, Torres et al. 2013).

Cynara cardunculus (Cardoon) has also been investigated as an energy crop for co-firing with lignite at the PPC Kardia Power Plant, Greece, as part of the FP6 DEBCO project.

Pennycress (Thlaspi arvense)

Has been investigated in the U.S. by USDA-ARS as a potential feedstock for biodiesel. Pennycress can be grown as a winter ground cover crop and harvested in the spring, providing soy farmers with additional income. *Thlaspi arvense* varieties are being commercially developed by companies such as Arvegenix.

Ethiopian mustard (*Brassica carinata*)

Brassica carinata oilseed has been developed as a biofuel feedstock (Resonance™) by Agrisoma Biosciences (Canada). It is suited to semi-arid areas and produces seed with 44% oil content. In April 2012, Agrisoma announced that Resonance™ will be evaluated as a feedstock for Honeywell Green Jet Fuel™, and reported that the world's first civilian flight powered solely by biofuel was flown from Ottawa, Canada.

Indian Beech (Millettia pinnata, Pongamia pinnata)

Millettia pinnata (Pongamia pinnata) is a leguminous tree species (15-25m) that grows widely Asia, including arid regions. It is pest resistant and produces seeds with 25–40% lipid content (nearly half oleic acid). It also produces extensive root networks and can be used to prevent soil erosion (but also may cause problems as an invasive weed, if not properly managed). It has been widely investigated in India as a biodiesel feedstock - see Pongamia as a source of biodiesel in India (Gaurav Dwivedi et al, 2011). The University of Queensland is also carrying out R&D on *Pongamia pinnata* as a biofuel feedstock.

Castor bean (Rizinus communis)

Castor oil is also being developed as a potential industrial-scale biofuel feedstock. "Castor bean is a non-edible, high oil-yielding crop (40%-50% seed oil content) with high tolerance for growth under harsh environmental conditions, such as low rainfall and heat" [Source: Evogene].

Links and References

Pongamia as a source of Biodiesel in India *Dwiwedi et al. (2011)*

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Lignocellulosic crops for production of advanced biofuels

Overview

The term lignocellulosic covers a range of plant molecules/biomass containing cellulose, with varying amounts of lignin, chain length, and degrees of polymerization. This includes wood from forestry, short rotation coppice (SRC), and lignocellulosic energy crops, such as energy grasses and reeds. Specific felling of forestry wood for biofuels is generally not considered sustainable and is therefore not further discussed here. Wood wastes and forestry residues are, however, promising feedstocks for advanced biofuels.

Lignocellulosic materials have potential for use as a feedstock for advanced diesel and drop-in biofuels (via thermochemical conversion) and for production of cellulosic ethanol (via biochemical conversion). Lignocellulosic crops generally have a higher GHG efficiency then rotational arable crops since they have lower input requirements and the energy yield per hectare is much higher.

The degree of yield per hectare, lignification, and ability to tolerate environmental stresses (limited water, low nutrient levels, etc) varies from crop to crop. So different species are more suited to different types of marginal land, and to different types of conversion process (e.g. acid and enzymatic hydrolysis, pyrolysis, torefaction and gasification). Plant breeding and biotechnology is being used to optimise the traits of potential energy crops.

Examples of lignocellulosic energy crops

Miscanthus (Miscanthus giganteus and other Miscanthus spp.)

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Miscanthus (above) has been trialled extensively in Europe and the US as an energy crop for biofuel production.

In Europe, there are presently an estimated 30,000 ha of miscanthus planted (see OPTIMISC, FP7 Project). *Miscanthus x giganteus* is best adapted to temperate climates but the traits of other Miscanthus species should also be considered. For example, *Miscanthus sinensis* genotypes are better adapted to more extreme climates.

Miscanthus is a promising lignocellulosic feedstock with various applications due to its rapid biomass accumulation in temperate climates. Trials indicate that Miscanthus provides relatively high yields (double that of corn), requires limited fertiliser, few other inputs and adds significant amounts of organic matter to the soil.

For example, a ten year trial of Miscanthus (2003-2013) by University of Illinois showed an average annual yield of 10.5 tons per acre (double that of a corresponding area planted with Switchgrass). The trial confirmed that Miscanthus grows well with little or no fertiliser input. After five years, the roots and rhizomes contribute 12 tons of biomass per acre to the soil (dry mass). The extensive root system of Miscanthus makes it suitable for stabilizing slopes or soils.

In March 2012, it was announced Mendel Biotechnology (Mendel Bioenergy Seeds) will carry out a 4-year field trial of PowerCane™ Miscanthus with BP Biofuels, as a potential feedstock for the cellulosic ethanol demonstration plant in Jennings.

Giant reedgrass (*Arundo donax*)

Giant reedgrass is adapted to a wide variety of ecological conditions, but is generally associated with riparian and wetland systems. Several field studies have highlighted the beneficial effect of the crop on the environment due to its minimal requirements on soil tillage, fertilizer and pesticide (e.g. Riffaldi et al, 2010). Moreover it offers protection against soil erosion, is well adapted to saline soils and saline water, and resistant to biotic and abiotic stresses. The fact that it can be cultivated fo between 20 to 25 years without replanting also makes it an interesting energy crop. Giant reedgrass (Spanish cane) is considered to be one of the most promising species for biomass production in Europe. It is being cultivated as a feedstock for the Beta Renewables commercial scale cellulosic ethanol plant in Crescentino.

Reed canary grass (Phalaris arundinaces)

Reed canary grass*,* *Phalaris arundinacea*, provides good yields on poor soils and contaminated land and is thus an interesting candidate for bioremediation of brownfield sites as well as a source of biomass for bioenergy (typically as briquettes) or pulp. Is also considered a suitable feedstock for cellulosic ethanol production [Source: Pahkala et al, VTI Finland, 2007].

Giant King Grass, Napier Grass, Elephant Grass (*Pennisetum purpureum*)

Pennisetum purpureum is a member of the Poaceae family and a perennial tropical grass native in Africa, where it is used as a fodder plant. It is an attractive energy crop because it reaches yields up to 40 tons/ha/yr and can be harvested 4–6 times a year. Furthermore water and nutrient requirements are low. In California, Viaspace Inc. is developing projects using Giant King Grass as a feedstock for advanced biofuels, and biomethane for energy production.

Switchgrass (Panicum virgatum)

Switchgrass has qualities that make it attractive as a biofuel source, including a seed that is easy to work with, adaptation across a wide geographic range, and a seed market already established for forage. Extensive research is being carried out into cultivation of Switchgrass as a biofuels feedstock in the US. The plant is a tall-growing, perennial grass that is native to North America.

Samuel Roberts Noble Foundation has developed novel strains of switchgrass that contain lower amounts of lignin and hence boost biofuel yields by over a third [Source: Proceedings of the National Academy of Sciences]. Following a $5m grant from the DOE in 2009, University of Tennessee and Genera Energy have developed a new feedstock logistics systems using chopped switchgrass, which aims to bridge the gap between growers and biofuel producers.

Short Rotation Coppice of Willow and Poplar (*Salix spp. and Populus spp.*)

Short Rotation Coppice SRC - where species such as willow and poplar are grown on marginal land typically over 3-5 year cycles - has potential for providing feedstocks for advanced biodiesel and drop-in biofuels (via thermochemical conversion) and for production of cellulosic ethanol (via biochemical conversion).

"Willow is planted as rods or cuttings in spring using specialist equipment at a density of 15,000 per hectare. The willow stools readily develop multiple shoots when coppiced and several varieties have been specifically bred with characteristics well suited for use as energy crops. During the first year it can grow up to 4m in height, and is then cut back to ground level in its first winter to encourage it to grow multiple stems. The first harvest is in winter, typically three years after cut back, again using specialist equipment, however a cycle of 2 or 4 to 5 years is also common. In fertile sites growth can be very strong during the first two years after coppicing, giving rapid site capture, reducing thereafter and so a 2 year cutting cycle may be more appropriate.

Poplar displays more apical dominance than willow and is therefore less ready to develop multiple stems following coppicing. Shoots can reach up to 8m by the end of the first rotation. It therefore tends to develop fewer, thicker stems than willow, and consequently has a lower bark to wood ratio. Individual shoots can reach up to 8m by the end of the first 3 year rotation. Poplar is planted in spring, from cuttings. These cuttings must have an apical bud within 1 cm of the top of the cutting. Because of this it is difficult to use poplar in equipment developed for planting willow short rotation coppice" [Source: Bioenergy Centre, UK © DEFRA].

Planting density for poplar is lower than that for willow, typically 10-12,000 per ha. Cut back takes place late in the following winter.

Improving performance and availablity of Short Rotation Plantations is one of the aims of the FP7 project, ROKWOOD, which supports cooperation between six European research-driven clusters in order to improve RTD, market uptake and to increase investments in wooden biomass production and utilisation schemes at regional level.

The EC project ENERGYPOPLAR (2008-2012) aimed to develop energy poplar trees with both desirable cell-wall traits and high biomass yield under sustainable low-input conditions to be used as a source of cellulosic feedstock for bioethanol production.

Willow and poplar may be grown and harvested in 2-5 year cycles as an energy crop (Short Rotation Coppice).

Energy cane

See the sugar crops page for development of energy cane varieties.

Rusby or Virginia mallow (*Sida hermaphrodita*)

Sida belongs to the mallow family and is native to North America. It can grow 1 – 3 m tall, has hairy stems and leaves with toothed lobes. Plantations can be used up to 25 years whereby the dry woody parts are harvested from late autumn to spring with high and stable yields. It is an easy to handle crop that can be cultivated with conventional farming methods and machinery.

Halophytes (Various species)

Halophytes as feedstock for bioethanol production were explored by Abideen *et al* (2011). Their study shows that species such as *Halopyrum mucronatum, Desmostachya bipinnata, Phragmites karka, Typha domingensis* and *Panicum turgidum*, have potential as bio-ethanol crops. These perennial grasses are salt tolerant with high growth rates and produce lignocellulosic biomass of "good" quality as a feedstock.

Recent Research on Lignocellulosic Crops

Research funded by the BBSRC, UK has identified natural variants of 'straw plants' that are easier to break down but are not otherwise weaker or smaller. Researchers in the Centre for Novel Agricultural Products at the University of York, working with colleagues in France, screened a large collection of variants of the model grass species Brachypodium for digestibility. Reseachers also found that the genes responsible for the digestibility of the cell wall can be identified [Source: BBSRC 2014].

See also the page on Plant Biotechnology.

References and Links

Cascading of woody biomass: definitions, policies and effects on international trade IEA Bioenergy Task 40 Working Paper. Ollson et al. (2016)

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Production of bio-ethanol from barley, straw and reed canary grass: A raw material study *Pahkala et al (2007)*

Comparison of Soil Organic-Matter Characteristics under the Energy Crop Giant Reed, Cropping Sequence and Natural Grass. Communications in Soil Science and Plant Analysis, 41:173–180 *Riffaldi, R et al* (2010)

Algae, cyanobacteria and aquatic plants for production of biofuels

Contents

Overview

"Algae and aquatic biomass has the potential to provide a new range of "third generation" biofuels, including jet fuels. Their high oil and biomass yields, widespread availability, absent (or very reduced) competition with agricultural land, high quality and versatility of the by-products, their efficient use as a mean to capture CO_2 and their suitability for wastewater treatments and other industrial plants make algae and aquatic biomass one of the most promising and attractive renewable sources for a fully sustainable and low-carbon economy portfolio." (Source: European Algae Biomass Association - EABA).

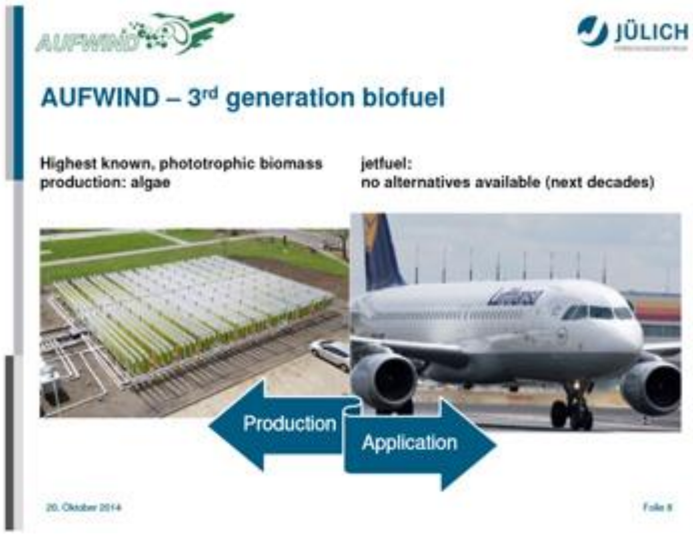
Photomicrograph of *Botryococcus* species, with oil droplets being released.

At the moment some companies refocus their initial strategy from the production of algal biofuels to the production of algal nutriceuticals, food and feed. This is also indicated by the change of company names (Solix Biofuels – Solixalgredients, Petroalgae – Parabel, HR Biopetroleum – Cellana, Solazyme – TerraVia, …). This trend is the answer to the current extremely low oil prices, changing sentiment around the benefits of biofuels, and uncertain government policies. A promising alternative are biorefinery concepts which focuses on processing biomass into a spectrum of marketable products and energy.

Use of algae for production of advanced biofuels

The use of algae for the production of advanced biofuels presented by Dominik Behrendt, FZ Jülich, Germany, at EBTP SPM6, October 2014, focuses on the Aufwind Project on biojet fuels from algae.

The AUFWIND project, Germany, was launched in 2013 and involves twelve partners from research and industry, who are developing microalgae as a basis for the production of biokerosene. Key questions addressed are the economic and ecological feasibility of the process. The Federal Ministry of Food, Agriculture and Consumer Protection (BMELV) is funding the project with € 5.75 million via its project management organization FNR (Fachagentur Nachwachsende Rohstoffe). Total funding for the project amounts to some € 7.4 million.



Cultivation of algae as advanced biofuel feedstocks

Algae have the potential to produce considerably greater amounts of biomass and lipids per hectare than terrestial biomass, and can be cultivated on marginal lands, so do not compete with food or other crops. Algae can be cultivated photosynthetically using sunlight for energy and CO_2 as a carbon source. They may be grown in Shallow lagoons or raceway ponds on marginal land (e.g. Sapphire Energy, Aurora BioFuels, Live fuels) or closed ponds (e.g. Green Star). Green Star also produces a micronutrient formula to greatly increase the rate of algal growth.

A number of closed photobioreactors are being investigated, including: Horizontal tubes (e.g. AlgaeLink NV), Vertical (e.g. BioFuel Systems SL), Thin film, Open/Closed systems (e.g.Parabel, Cellana). See also Subitec, Germany.

Productivity is higher in the controlled, contained environment of a photobioreactor, but capex and opex are also both substantially higher than for open systems. Significant investment in research is required before high levels of productivity can be guaranteed on a commercial scale.

Algae to biofuels plants may be developed on land adjacent to power stations, for converting the carbon dioxide from exhausts into fuel.

Conversion of algae to biofuels

Algae may be used to produce biofuels in several ways:

- Conversion to bioethanol (e.g. Algenol)
- Extraction of oils (e.g. SGI, Solixalgredients, Sapphire Energy, Algasol).
- Production of oils from feedstock via dark fermentation (e.g. Solazyme)
- Conversion of whole algae to biocrude via pyrolysis (e.g. BioFuel Systems SL)
- "Green crude" (e.g. Sapphire Energy, Muradel)
- Algal biorefinery - biofuels and other products (Parabel, Cellana)

Following extraction, algal oils may be further refined (e.g. by hydrocracking and hydrogenation) to produce gasoline or jet fuels.

Algal Biorefineries

In addition to producing oils, algae are rich sources of vitamins, protein and carbohydrates. The following steps have been identified for development of microalgae biorefineries.

- Development of mild and efficient cell disruption, extraction and fractionation technologies
- Effective technologies for separation of carbohydrates, proteins and lipids
- Lipid /oil refining technologies
- Improvement of energy consumption and environmental performance, decrease of capital costs
- Integrate knowledge & facilities for oil, food and fine chemical industry
- Biomass provision (quantity and quality)

Source: Wageningen University, Netherlands

Associations

EABA - European Algae Biomass Association aims to act as a catalyst for fostering synergies among scientists, industrialists and decision makers in order to promote the development of research, technology and industrial capacities in the field of algae.

Algal Biomass Association (US) - promotes the development of viable commercial markets for renewable and sustainable commodities derived from algae.

European Projects on Algae Production and Algal Biofuels

FUEL4ME, FUture European League 4 Microalgal Energy

FUEL4ME is a 4-year project funded by the EU, which is aiming to develop a sustainable, scalable process for biofuels from microalgae and to valorize the by-products by 2017. The specific aims are:

1. To develop a continuous one-step process in which the lipid productivity in microalgae cultures is maximized and the lipid profile is optimized for the biofuel production.

2. To translate the developed one-step process to outdoor, thereby achieving a robust and reliable production process with short downtime, continuous year round lipid production under different climates and an oil production of constant quality.

3. To develop and integrate an innovative and continuous downstream process for conversion of microalgae into biofuels with consistent volume and quality, resulting into a technically feasible and sustainable process chain.

4. To demonstrate the capability of the optimised process at a pilot scale under representative industrial conditions in a pilot facility in Spain.

5. To assess the environmental, social and economic sustainability of the continuous production and conversion process developed by Fuel4me consortium.

DEMA - Direct Ethanol from MicroAlgae

The DEMA project runs from 01.12.2012 to 31.05.2017. The Consortium, coodinated by University of Limerick, Ireland, will develop, demonstrate and licence a complete economically competitive technology for the direct production of bioethanol from microalgae with low-cost scalable photobioreactors by 2016. Initial proof-of-concept results show via Life Cycle Assessments (LCA) and economic balance that it is feasible to use microalgae to produce bioethanol for less than 0.40 per litre. The catalytic conversion of solar energy, H2O and CO2 into ethanol will be carried out by a metabolically engineered strain of the cyanobacterium, Synechocystis sp. PCC 6803.

FP7 Algae Cluster - BIOFAT, ALL Gas, and InteSusAl

Following the 2010 FP7 call on demonstration at industrial scale of algae and its subsequent use in biofuel production, a total EC contribution of €20.5 M was announced in support of three projects - BIOFAT, ALL Gas, and InteSusAl - which form the FP7 Algae Cluster.

The **BIOFAT** demonstration project aims to integrate the entire value chain in the production of ethanol and biodiesel. The process begins with strain selection and proceeds to biological optimization of the culture media, monitored algae cultivation, low-energy harvesting and technology integration. The project will be implemented in two phases: 1) Process optimization in two pilot scale facilities, each of 0.5 ha size, located in Italy and Portugal; and 2) Economical modeling and scale-up to a 10-hectare demo facility.

The raw material wil be industrial CO_2 derived from fermentation. Production will be based on low-energy consuming photobioreactors. Algal oils will be transformed into FAME biodiesel and ethanol through fermentation. The project will also demonstrate the algorefinery concept with production of added value products in addition to biofuel.

BIOFAT is coordinated by A4F-AlgaFuel (Portugal). Partners include: Abengoa Bioenergia Nuevas Tecnologias (ABNT), University of Florence, Ben-Gurion University (Israel), Fotosintetica & Microbiologica (Italy), Evodos (Neherlands), AlgoSource Technologies (France), IN SRL (Italy) and Hart Energy (Belgium).

The **ALL Gas** project (Industrial scale Demonstration of Sustainable Algae Culture for Biofuels Production) will use wastewater, and will introduce a patented ' Light Enhancement Factor (LEF)', to increase the biomass yield of raceway ponds. The residual algae will be digested with wastewater solids to produce biogas, which will be purified and used as fuel for at least 200 vehicles. Additional CO_2 will be generated via thermal conversion of agricultural residues and digestate from algal residues.

InteSusAl (Demonstration of Integrated & Sustainable enclosed raceway and photobioreactor microalgae cultivation with biodiesel production and validation) aims to cultivate 1,500 dry tonnes from 10 ha over 18 months, which will be used to produce 580 tonnes of FAME biodiesel. Glycerine, will be used to enhance alagal growth rates. The production site will be developed near the site of the existing E-BIO biodiesel production plant.

INTERREG IVB EnAlgae Project

EnAlgae brings together 19 partners and 14 observers across seven EU Member States. The project is developing sustainable technologies for algal biomass production, bioenergy and greenhouse gas (GHG) mitigation, taking them from pilot facilities through to market-place products and services. By developing and sharing nine pilot-scale facilities across Europe, cost and access barriers can be overcome. The facilities will also give plant operators the ability to experience the full range of physical parameters (ranging from rural countryside to industrialised areas) that are present within the region.

See EnAlgae interactive Map of Algae Initiatives in North West Europe.

MED-ALGAE Production of biodiesel from Algae in selected Mediterranean Countries

The ~2.0 million Euro MED-ALGAE project "Production of biodiesel from Algae in selected Mediterranean Countries", started in 2014 and runs for 36 months. The methodology includes all stages in the production of biodiesel from microalgae: sampling of seawater or freshwater, the selection of microalgae, species identification, cultivation of microalgae, harvesting and extraction of biodiesel and determination of properties of biodiesel produced in accordance with Standard EN14214 and its testing. Five pilots will be established in each participating country: Cyprus, Italy, Malta, Lebanon and Egypt. The project is implemented under the ENPI CBC Mediterranean Sea Basin Programme, and financed (~90%) by the European Union through the European Neighbourhood and Partnership Instrument.

ALGAEBIOGAS (algal treatment of biogas digestate with significant economic and environmental benefits for biogas plants operators) is focused to market introduction of algal-bacterial treatment of biogas digestate and feedstock production, an innovative technology which has significant economic and environmental benefits to biogas operators. The project is co-founded by the Eco-innovation Initiative of the European Union.

The project **PHOTOFUEL** (Biocatalytic Solar Fuels for sustainable mobility in Europe) will develop a next generation technology for the sustainable production of alternative, liquid transportation fuels. The challenge is to advance the base technology of microalgae cultivation in closed bioreactors by enabling phototrophic algae or cyanobacterial microorganisms to produce alkanes and alcohols, which are excreted to the culture broth for direct separation without cell harvesting. This thereby turns the microbial cells into self-reproducing biocatalysts allowing the process to directly convert solar energy, water and CO2 into engine-ready fuel instead of being used to form biomassOther FP7 projects on biofuels production from algae (and associated techniques for producing value-added bioproducts)

BioAlgaeSorb - focuses on enabling European SMEs to remediate wastes, reduce Green House Gas emissions and produce biofuels via microalgae cultivation.

The FP7 project **BioWALK4Biofuels** aims to develop an innovative system for the treatment of biowaste and use of GHG emissions to produce biofuels, where macroalgae is used as a catalyser.

D-Factory: In February 2014, the University of Greenwich, UK, announced it is leading a 4-year €10 million project supported by EC FP7 to develop the microalga *Dunaliella* as a sustainable raw material that captures carbon dioxide and can grow in some of the world’s harshest environments. The project will build a biorefinery called the 'D-Factory'. The 13 D-Factory partners include:

Universities and research institutes: University of Greenwich, UK; National Technical University of Athens, Greece; Institute for Energy and Environmental Research Heidelberg, Germany; Marine Biological Association, UK.

Small and medium enterprises (SMEs): A4F AlgaFuel S.A., Portugal; Nature Beta Technologies, Israel; SPTechnical Research Institute of Sweden; Dynamic Extractions, UK; NateCO2, Germany; Instituto de Biologia Experimental e Tecnologica, Portugal; Evodos, Netherlands; Hafren Investments, UK; IN, Italy.

GIAVAP (Genetic Improvement of Algae for Value Added Product) is a large scale integrating project involving twelve partners from five European and one associated country. The consortium will adapt genetic engineering techniques to various algal strains of economic interest focusing on carotenoid and PUFA production and the overexpression of peptides of commercial value. In parallel the project will develop cultivation technologies, harvesting and extraction methods using model algae strains and suitable improved strains. Techniques developed could potentially also have applications in the energy field.

PHOTO.COMM - includes close collaboration with three European companies, **AlgaFuel**, **Novagreen** and **Algae Biotech**, who will test strains under full production conditions in state-of-the-art photobioreactors. The aim is the development of novel, carbon-neutral production platforms and the ultimate establishment of state of the art photobioreactor technology in Denmark. The project will fund a consortium of 9 groups and provide trans-European training for a network of PhD students.

The **AQUAFUELs** project, supported under FP7, started in January 2010. AquaFUELS investigated the state of the art on research, technological development and demonstration activities regarding the exploitation of various algal and other suitable non-food aquatic biomasses for 2nd generation biofuels production.

BISIGODOS (High value-added chemicals and bioresins from algae biorefineries produced from CO2 provided by industrial emissions) aims to address the production of valuable algae derived chemicals, amino acids and high added-value bio-resins starting from algae biomass fed directly with CO2 from industrial emissions (cement, steel factory, thermal power plants, etc.) as a raw material that is cost-effective and renewable. The process is assisted by solar radiation, nutrients and sea water microalgae. This approach is based on the technology developed by the Partner Biofuel Systems (BFS) to produce bio-oil.

Other European projects include SUNBIOPATH towards a better sunlight to biomass conversion efficiency in microalgae (FP7 245070), CO2ALGAEFIX (CO2 capture and bio-fixation through microalgal culture), MIRACLES (Multi-product Integrated bioRefinery of Algae: from Carbon dioxide and Light Energy to high-value Specialties), PUFA-Chain (The Value Chain from Microalgae to PUFA) and SPLASH (Sustainable PoLymers from Algae Sugars and Hydrocarbons).

Commercial-scale demonstrations of algae for biofuels production

Sapphire Energy Green "Crude Farm"

Sapphire Energy is operating the most advanced, algae crude oil production facility in the world. The company's Green Crude Farm is the world's first commercial demonstration scale algae-to-energy site, integrating the entire value chain of algae-based crude oil production, from cultivation, to harvest, to extraction of ready-to-refine Green Crude. Sapphire Energy's Green Crude Farm features 100 acres of cultivation ponds and all the necessary mechanical and processing equipment needed to harvest and extract algae and recycle water. At full capacity the facility will be 300 acres. It is in continuous operation of all unit processes since 2012 and producing 5,000 – 10,000 barrels of green crude per day.

© Copyright Sapphire Energy

Above is the world's first plug-in hybrid vehicle to cross the US on fuel containing a blend of algae-based renewable gasoline. Sapphire Energy has constructed a 300-acre integrated algae-to-biofuel demonstration facility, (Green Crude Farm) in Luna County. The First Phase became operational in August 2012, and the facility is now on schedule to reach commercial-scale production by 2018.

Muradel "algae-crude" demonstration, Australia

In November 2014, Muradel launched a $10.7m 30000 litre/annum plant to demonstrate its Green2Black™ (algae to crude oil) technology at industrial scale. This is the first step towards an 80 million liter commercial plant. Muradel uses an energy-efficient subcritical water reactor to rapidly convert algae to crude oil that is "functionally equivalent" to fossil crude.

Solazyme demonstration of commercial production of biofuels and biochemicals using heterotrophic algae

Solazyme has used molecular biology and chemical engineering to develop proprietary microalgae to convert sugars into fuels and other products. The algae are heterotrophic, meaning they grow in the dark (in fermenters) using the sugar as a food source. Using standard industrial fermentation equipment, Solazyme is able to efficiently scale and accelerate microalgae's natural oil production time to just a few days and at commercial levels. The company is currently focused on production of high margin ingredients, rather than high volume fuels [Source: Solazyme, November 2014].

In May 2014, production started at the Solazyme Bunge Renewable Oils plant. Solazyme is now manufacturing products at three large scale facilities, including our 2,000 MT/year integrated facility in Peoria, the 20,000 MT/year Iowa facilities in Clinton/Galva and the 100,000 MT/year facility in Brazil.

In April 2012, Solazyme announced a joint venture with Bunge (Solazyme Bunge Produtos Renovaveis Ltda.) to develop a commercial-scale (100,000 t.p.a.) oil production facility in Brazil, using Solazymes technology to convert sugar (from cane) to 'tailored oils'. In January 2013, Solazyme Bunge Renewable Oils received approval for a loan of $120 million from the Brazilian Development Bank.

Solazyme Bunge Renewable Oils broke ground in June 2012 and was scheduled to be operational in the fourth quarter of 2013. It will service the renewable chemical and fuel industries within the Brazilian marketplace and will initially target 100,000 metric tons per year of renewable oil production. In November 2012, Solazyme and Bunge announced in a framework agreement that they intend to expand production capacity from 100,000 metric tons to 300,000 metric tons globally by 2016, and that the portfolio of oils will broaden to include a range of healthy and nutritious edible food oils for sale in Brazil [Source: Solazyme website].

Solazyme has partnerships with Chevron, and has a contract to provide 450000 gallons of algal biofuels for the US Navy trials. Solazyme microalgae produce linear fatty acids and esters that can be readily be converted into fuels and other added value bioproducts. Solazyme technology has been deployed successfully at commercial manufacturing scale. The company has received a $21.8m grant from the DoE for a demonstration plant. Soladiesel™ has exceeded the requirements of ASTM D6751 for jet fuel, EN 14214, D-975 and Military Specifications. In 2012 Solazyme tested its fuel with VW TDI Clean Diesel technology.

Cellana and Neste Oil agreement for commercial-scale algae production

In June 2013, Cellana, a leading developer of algae-based feedstocks for biofuels, animal feed, and Omega-3 nutritional oils, announced has entered into a multi-year off-take agreement with Neste Oil for commercial-scale quantities of Cellana's ReNew™ Fuel algae oil feedstocks for biofuel applications. Since 2009, Cellana has operated its Kona Demonstration Facility, a 6-acre, state-of-the-art production and research facility in Hawaii. To date, more than 20 metric tons of whole algae (dry weight) have been produced using Cellana's process with highly diverse strains, making one of the most flexible, thoroughly tested, and validated outdoor algae production technologies in the world

Algae.Tec Ltd production facility in Australia

Algae.Tec Ltd, Australia, has signed agreements with in Australia (Macquarie Generation) and India (Reliance) to provide facilities to convert carbon dioxide from energy plants to biofuels. In May 2015, Algae.Tec shipped the first photobioreacor to Reliance.

In August 2012, Algae.Tec opened its Shoalhaven production facility in Bomaderry, NSW - consisting of a series of photobioreactors, which will be fed with carbon dioxide from a neighbouring ethanol plant operated by the Manildra Group.

In September 2012 Algae.Tec Ltd. signed a collaboration agreement with Lufthansa for an industrial-scale algae to aviation biofuels production facility in Europe.

BioProcess Algae commercial scale algae platform in US

BioProcess Algae LLC has constructed four commercial scale Grower Harvester™ platforms in Iowa. The facility will use the carbon dioxide from Green Plains' ethanol plant to produce high quality algal feedstocks. In April 2013, BioProcess Algae received $6.4m funding from US DOE to further develop its platform to produce military biofuels, with a focus on faster lipid production and conversion of lipids to various hydrocarbons.

Algenol Direct to Ethanol® process

Algenol recently won the 2014 Global Leadership in Biofuels award from PLATTS. Algenol's first commercial facility will include phased deployments of photobioreactors on an initial site of up to 2,000 acres of photobioreactors, with additional acreage available for future scale-up, along with upstream and downstream processing equipment and related infrastructure. It will be located on marginal land with access to salt water, an industrial source of CO_2 and distribution infrastructure. Algenol uses fully closed and sealed photobioreactors for ethanol production directly from enhanced algae. Waste algae are converted into diesel, jet fuel and gasoline using hydrothermal liquefaction and other conversion technologies.

Joule Demonstration Plant

Joule has pioneered a CO_2-to-fuel production platform, effectively reversing combustion through the use of solar energy. The company's platform applies engineered catalysts to continuously convert waste CO_2 directly into renewable fuels such as ethanol or hydrocarbons for diesel, jet fuel and gasoline. At full-scale commercialization Joule is targeting productivity of up to 25,000 gallons of ethanol/acre/year and 15,000 gallons diesel/acre/year.

Algal Biofuels R&D and demonstration in Europe and Globally

The EnAlgae project has produced an interactive Map of Algae Initiatives in North West Europe. Currently, the map includes links to over 260 commercial and scientific activities.

Algae-based biofuels form one of the value chains proposed in the European Bioenergy Industrial Initiative (EIBI)

Companies and universities involved in algal biofuels R&D&D are listed on the EABA website.

Solazyme abandons algal biofuels, refocuses on food: Solazyme, a Californian algae-based bio-product producer, has abandoned its biofuels business and will be focusing its algae oil production on food and personal care industries. Renamed TerraVia, the company lists the current extremely low oil prices, changing sentiment around the benefits of biofuels, and uncertain US government policies as reasons behind the business restructuring.

In 2014, Schott financed a Helix™ photobioreactor built by Heliae and installed at Arizona State University DOE-funded algae testbed facility. In April 2015, Schott announced that its new oval glass tubes for photobioreactors (PBRs) increased maximum dry biomass output per day by more than 22 per cent.

Algenol Biofuels has developed a platform for converting CO_2 to ethanol at lower cost and higher efficiency (one tonne of CO_2 to 144 gallons of fuel / 8,000 gallons per acre per year). The technology, using patented photobioreactors and downstream technology, can be used to produce ethanol, gasoline, diesel or jet fuel. Algenol Technology is being demonstrated in India where Reliance Industries has commenced operations near the Jamnagar Refinery in India. In April 2015, Algenol was part of a US trade mission to China.

Algae Systems LLC and IHI Corp, Japan have demonstrated an integrated process to treat wastewater and produce algae, which is dewatered, converted to bio-oil, and used to produce drop-in biofuel (biojet, biodiesel and biogasoline). Further development of the novel hydrothermal liquefaction process is being funded by a £3.2m grant from the US DoE to a consortium coordinated by Algae Systems (led by SRI International). The algae production technology uses off-shore floating membrane photobioreactors.

Genifuel Corp in Utah is also developing a process for rapidly converting algal slurry into bio-crude, and announced plans for a pilot plant in December 2013.

The University of Greenwich is part of a UK initiative led by Durham University on biofuels production from macroalgae via conversion of wet seaweed to gas. The MacroBioCrude project, supported by a £1.6m grant from the Engineering and Physical Sciences Research Council, will establish an integrated supply and processing pipeline for the sustainable manufacture of liquid hydrocarbon fuels from seaweed. The consortium includes 6 UK universities: Greenwich, Durham, Aberystwyth, Swansea, Harper Adams, and Highlands and Islands, and 6 industrial partners: Johnson Matthey Catalysts, Johnson Matthey Davy Technologies, Silage Solutions Ltd, Shell, and the Centre for Process Innovation (CPI).

In August 2013, Aurora Algae announced it had constructed a demonstration algae cultivation site in Western Australia.

In May 2013, a new $19m demonstration algae biorefinery on Alberta Canada was announced. The Algal Carbon Conversion Pilot Project will use carbon dioxide from oil sands facilities and is a partnership between the National Research Council, Canadian Natural Resources Limited and Pond Biofuels

In the US, ATP3 - a sustainable network of regional test beds - is funded through a $15 million grant from the US Department of Energy. Funding helps support a range of outdoor algae cultivation systems in Arizona, Hawaii, California, Ohio and Georgia, including those for production of advanced biofuels. Partners work both independently and in cooperation with the wider ATP3 network. The PPP is coordinated by Arizona State University - see AzCATI Arizona Centre for Algae Technology and Innovation.

In July 2012, Subitec, Germany, announced an investment of €4.5m for manufacturer of algae photobioreactors.

See Algae Technology (SAT), Austria is to construct a $9.8m biofuels plant using seaweed (macroalgae) for the Brazilian state of Pernambuco (pending approval). The plant will produce up to 1.2m litres of biofuels a year, using carbon dioxide from an adjacent sugar cane to ethanol plant.

In 2011, Abengoa started construction work at the ECOALGA project plant in Cartagena. The 5000m^2 experimental plant will be supplied with CO_2 generated by the neighbouring bioethanol facility. The project will evaluate strains of microalgae and cyanobacteria, harvesting technique, optimum CO_2 concentrations etc, for the production of biofuels and animal feed.

The ECOALGA Project has received funding from the Ministry of Science and Innovation, under the National Plan for Scientific Research, Development and Technological Innovation 2008-2011, managed by the Spanish Institute of Oceanography, within the scope of the Special State Fund For Stimulating the Economy and Employment, Plan E. For the project's execution, ABNT receives technical support from the National Centre for Renewable Energies (CENER), the University of Murcia, the Polytechnic University of Cartagena and Ecocarburantes Españoles. [Source; Abengoa].

In Senftenberg, Germany, Vattenfall Group operates a closed algae-breeding facility (photobioreactor) supplied by ecoduna, Austria. The facility uses carbon dioxide from a neighbouring power plant.

Enalg S.p.A. holds the exclusive rights in Italy for the production of bio-fuel from algae granted by Spanish BFS Biofuel System SL (since 2010 Enalg has been a shareholder of BFS SL). A first industrial pilot plant has been operating in Alicante (Spain) since 2010 for the continuous-cycle production of Blue Petroleum. Construction work has started on the Island of Madeira for the first industrial plant to be implemented in collaboration with the local Government and the Electric Power Supply Agency. CO_2 captured from the Cemex cement works will be used to produce biopetrol via microalgae, which are multiplied and transformed through daily treatment cycles. During the first phase of processing high-value nutrients like EPA and omega fatty acids can also be extracted from the biomass.

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"Blue petroleum" algae biofuels industrial pilot plant in Alicante.

View at larger size

AlgaeLink N.V. and KLM Royal Dutch Airlines are currently cooperating on a pilot project for the development of alternative aviation fuels from algae.

In October 2012, Genesis Biofuel Inc. signed a M.o.U. with Abundant Energy Solutions for a joint venture to develop Algal Biofuel Refineries.

Within the Dutch AlgiCoat initiative (supported via SenterNovem EOS programme) an integral marine biorefinery is being developed for potential production of biodiesel, CHP and chemicals. A small pilot plant has been constructed by AkzoNobel and Essent to demonstrate co-production in principle. Research by WUR-AFSG and Ingrepro is now being carried out to facilitate potential full-scale operation.

In June 2010, the first flight by an airplane using 100% algal biofuels was demonstrated by EADS at the Berlin Air Show. The microalgae oil was produced by Biocombustibles del Chubut S.A. at its plant in Puerto Madryn, Argentina, and then refined and converted into biofuel by VTS Verfahrenstechnik Schwedt in Germany.

EADS has also partnered with IGV GmbH on the use of algae-based biofuels in aviation. An IGV photobioreactor, which multiplies microalgae, was also exhibited at the Berlin Air Show. In 2012, IGV GmbH signed a contract with Bioalgostral SAS (BAO) for the delivery and establishment of an industrial plant for the production of biofuels from microalgae with a total volume of 82000 L [Source: IGV].

FeyeCon D&I BV, Netherlands specialises in the commercialisation of innovative CO_2 technology. The company has created two business ventures within the algae sector. Algae Biotech SA creates innovative products and processes in the field of micro-algae, and aims to improve all aspects relating to growing, harvesting, extraction and other downstream processes. It works closely with a sister company Clean Algae SA which specializes in the growing of microalgae at competitive cost, and maintains growing facilities on Grand Canaria.

Reseachers at Western Washington University and Woods Hole Oceanographic Institution have investigated alkenones produced by *Isochrysis* as an additional source of algal biofuels. Olefin metathesis is used to reduce the chain length of the alkenones, to produce shorter chains suitable for biojet fuel production. *Isochrysis* also produces fatty acids, which can be converted into biodiesel. The first step in the process is to separate these from the alkenones [Source: WWU Press Release, January 2015].

In 2015, OriginClear Inc. and Idaho National Laboratory of the U.S. Department of Energy announced collaboration on a project to develop OriginClear's Electro Water Separation process to improve the efficiency of algal biofuel production.

Spanish biotech company, BioSerentia, is developing modified microalgae strains able to produce larger volumes of biomass for biofuels production.

Politecnico di Torino (Department of Environment, Land and Infrastructures Engineering), Italy, led the project BioAlma, biofuel from algae for sustainable mobility in urban areas**,** which ran from 2012-2014. The project focused on optimising the yield of ethanol from conversion of algae.

As part of its System Research programs, ENEL is examining the possibility of producing algae using carbon dioxide emitted by its coal-fired plants.

ENI has operated a small scale algae pilot plant at the Gela Refinery.

Other companies developing photo bioreactors include Fotosintetica & Microbiologica S.r.l., IGV GmbH, BISANTECH NUOVA GmbH & Co KG, and B. Braun Biotech International GmbH (BBI).

Based on research carried out at the University of Alicante, Bio Fuel Systems in Spain has developed a pilot plant for bio-petroleum production.

In June 2010, US D.o.E. announced up to $24M to three projects that aim to commercialize produciton of biofuels from algae:

The Sustainable Algal Biofuels Consortium, Mesa, Arizona will investigate biochemical conversion of algae

The University of California, San Diego (Cal-CAB) leads the Consortium for Algal Biofuels Commercialization - focusing on algal feedstocks

Cellana develops large-scale production of fuels and products from microalgae grown in seawater

Previous reseach on algae biofuels

In January 2010, US D.o.E. announced a $44 million investment in algal biofuels development and demonstration to be carried out by the National Alliance for Advanced Biofuels and Bioproducts (NAABB). Led by the Donald Danforth Plant Science Center (St. Louis, MO), NAABB will develop a systems approach for sustainable commercialization of algal biofuel (such as renewable gasoline, diesel, and jet fuel) and bioproducts. NAABB will integrate resources from companies, universities, and national laboratories to overcome the critical barriers of cost, resource use and efficiency, greenhouse gas emissions, and commercial viability. It will develop and demonstrate the science and technology necessary to significantly increase production of algal biomass and lipids, efficiently harvest and extract algae and algal products, and establish valuable certified co-products that scale with renewable fuel production. Co-products include animal feed, industrial feedstocks, and additional energy generation. Multiple test sites will cover diverse environmental regions to facilitate broad deployment.

In October 2009, the report Cultivating Clean Energy: The Promise of Algae Biofuels (2.8 Mb pdf) was produced by Terrapin Bright Green LLC and the Natural Resources Defence Council.

In July 2009, Exxon Mobil Corporation announced an alliance with leading biotech company, Synthetic Genomics Inc. (SGI), to research and develop next generation biofuels from photosynthetic algae. Under the program, if research and development milestones are successfully met, Exxon Mobil expects to spend more than $600 million, which includes $300 million in internal costs and potentially more than $300 million to SGI.

In December 2007, Royal Dutch Shell plc and HR Biopetroleum (now Cellana) formed a joint venture Cellana for the construction of a pilot facility in Hawaii to grow marine algae and produce vegetable oil for conversion into biofuel.

In October 2007, it was announced that Chevron and NREL scientists would collaborate to identify and develop algae strains that can be economically harvested and processed into finished transportation fuels such as jet fuel. Chevron Technology Ventures, a division of Chevron U.S.A. Inc., was funding the initiative.

In July 2009, a paper on Life-Cycle Assessment of Biodiesel Production from Microalgae by Laurent Lardon et al, INRA, UR50 Laboratoire de Biotechnologie de l'Environnement, France was published in Environmental Science and Technology.

A Review of the Potential of Marine Algae as a Source of Biofuel in Ireland (2.5 Mb PDF) was commissioned by Sustainable Energy Ireland in order to provide an overview of marine algae as an energy resource, from either macroalgae or microalgae. Tentative roadmaps based on high, medium and low scenarios are included for development of these resources by 2020.

The Sustainable Fuels from Marine Biomass project, Biomara, was a UK and Irish joint project that aims to demonstrate the feasibility and viability of producing third generation biofuels from marine biomass. It will investigate the potential use of both macroalgae and microalgae as alternatives to terrestrial agri-fuel production.

Other microorganisms and aquatic plants being investigated as biofuels feedstocks

Modified Cyanobacteria

Proterro has developed a patented method using modified cyanobateria in bioreactors to produce sugars, which could be used as feedstock for advanced biofuels. Proterro says that the system potentially offers higher productivity (per acre of land used) and costs less than producing sugar from corn, cellulose or sugar cane.

Researchers at the Biodesign Institute, Arizona State University have modified cyanobacteria (photosynthetic bacteria) to excrete oil, which can be collected without killing the cells. The technique could be used to optimise microbial oil production for conversion into biofuels. The Biodesign Institute is also carrying out research to optimise Photobiorectors (e.g. phosphorous, CO_2 light irradience) for cyanobacetria.

Researchers at J. Craig Venter Institute in Rockville, Md. and Waseda University in Tokyo have modified the circadian clock of cyanobacteria to remain in its daytime state and hence increase productivity. Researchers on the project include Professor Carl H. Johnson, Vanderbilt University.

Aquatic plants with potential as biomass feedstocks

Aquatic plants, such as *Spirodela polyrhiza,* commonly called Greater Duckweed, have low levels of cellulose and lignin and have the potential to be converted to biofuel at a cost competitive with fossil fuels. In 2014 the genome was being investigated by researchers at the Waksman Institute of Microbiology, with a view to optimising the pond plant as a future feedstock. Thermochemical Conversion of Duckweed to gasoline, diesel, and jet fuel - the 'duckweed biorefinery' concept - is also being studied by Department of Chemical and Biological Engineering, Princeton University, and the Institute of Process Engineering, Chinese Academy of Sciences et al.

Wastes & residues

Forestry residues and wood waste for biofuel production

Overview

A study on the Future of the European Forest-Based Sector: Structural Changes Towards Bioeconomy was published in late 2014 by the European Forest Institute. Further links to EC and national activites on forest biomass production and use are included below.

Two main types of forestry resources are used for demonstrations of advanced biofuel production:

a) Residues from harvest operations that are left in the forest after stem wood removal, such as branches, foliage, roots, etc.

b) Complementary fellings which describe the difference between the maximum sustainable harvest level and the actual harvest needed to satisfy round wood demand.

Not all forest residues can be removed, some must be left in situ to provide ecological benefits (e.g. to provide habitat, and improve soils).

In addition, wood wastes from a range of sources (e.g. construction or demolition wastes, waste from manufacturing of wood-based products) can potentially be used for bioenergy and biofuels production. Wood wastes are widely used as local fuel sources across the world, by combustion in wood burners or larger biomass boilers.

At industrial scale, forest residues and waste wood can be converted to advanced biofuels or intermediates, such as BioSNG, Biocrude, BtL, Methanol or BioDME, through various thermochemical pathways.

Environmental and commercial benefits of harvesting biomass to both maintain forest health and provide feedstock

In 2014, 200,000 tons of biomass were removed from federal lands through the Biomass Crop Assistance Program in the US. This provided dual commercial/environmental benefits of removing diseased and hazardous trees, and optimising forest health, while providing valuable feedstock for bioenergy production.

Examples of demonstrations using wood waste for advanced bioenergy and biofuels production

The **GoBiGas facility** is the first plant in the world to produce bio-methane from biomass continuously through gasification, hereby using forest residues as feedstock, generating fuel and heat at the same time, and injection bio-methane into the transmission grid for use as vehicle fuel, fuel for CHP or heat production, or as feedstock to the processing industry.

The technology was planned to be commercialized in two phases:

- Phase 1 - 20 MW demo plant, partly financed by Swedish Energy Agency
- Phase 2 - 80 – 100 MW commercial plant, when the technology is proven in phase 1 and the market conditions are sufficient

Phase 2, was selected project by the EU Commission to receive NER300 funding, but is currently not being developed. (See GoBiGas presentation at SPM7)

In December 2013, it was announced that work will begin on a 10.3 MW biomass gasification plant in Tyseley, UK. The plant will be developed by Carbonarius, a joint venture of O-Gen UK and UNA Group, with a £47.8m investment by the UK Green Investment Bank and Foresight Group. The plant will be built and operated by MWH, based in Broomfield, US, and will use the biomass gasification process of the Canadian firm Nexterra Systems to convert 67,000 metric tons of locally-sourced woodwaste into power. The feedstock will be supplied by JM Envirofuels Ltd.

In 2013, , Fortum started up its fast pyrolysis facility in Joensuu, Finland. The facility is integrated into the local CHP plant, which uses the bio-oil from the pyrolysis facility for heat and power production. The bio-oil raw materials include forest residues and other wood based biomass.

In 2015, BTG BioLiquids opened its fast pyrolysis facility which was supported under FP7 under the Empyro project. The plant will produce bio-oil, electricity - to cover its own use - and steam. The steam will be supplied to the neighbouring salt factory. The pyrolysis oil will be supplied almost exclusively to the dairy company FrieslandCampina. They will use the oil to produce steam in their boilers. This replaces an amount of natural gas that is equivalent to the annual use of 8,000 households

2 pyrolysis projects using wood waste were selected for counterpart funding under the second phase of NER300. These included a fast pyrolysis plant in Estonia to convert 130,000 tonnes of wood chips to pyrolysis oil (heavy fuel oil), and a CHP pyrolysis facility in Latvia using 100,000 tonnes of wood chips. Both plants plan to export pyrolysis oil to replace heavy fuel oil in Sweden and Finland.

In December 2011, CHO Power SAS (a subsidiary of Europlasma) and Sunrise Renewables announced plans to build 4 high temperature plasma gasification facilities at UK docks to convert waste wood into clean syngas. The Syngas will be cleaned further and the tar removed, prior to power production via gas engine generators.

CHO Power is also developing a demonstration facility in Morcenx, France that will gasify 37,000 tonnes of ordinary industrial waste and 15,000 tonnes wood chips per annum, generating power for EDF.

In northern Europe (e.g. Sweden, Finland) it has been demonstrated in long-term experiments that the potential sustainable harvest level can be drastically increased by means of fertilisation, which will increase the amount of biomass available for bioenergy and round wood for the industry.

EC and national activites on production and mobilisation of forestry residues

A report by IEA Bioenergy "Balancing Different Environmental Effects of Forest Residue Recovery in Sweden: A Stepwise Handling Procedure" was published in 2016.

"Forest biomass for energy in the EU: current trends, carbon balance and sustainable potential" was finished in 2014 by IINAS, EFI and JR.

On 20 September 2013 the Commission adopted a new EU Forest Strategy which responds to the new challenges facing forests and the forest sector. The new Strategy gives a new framework in response to the increasing demands put on forests and to significant societal and political changes that have affected forests over the last 15 years. It was developed by the Commission in close cooperation with Member States and stakeholders over the past two years and has been submitted to the European Parliament and the Council.

See also Sustainable Foresty and the European Union and Sustainable Forestry Initiative (US).

ROKWOOD is an FP7 project to support the cooperation between six European research-driven clusters in order to improve research and technological development (RTD), market uptake and to increase investments in wooden biomass production and utilisation schemes at regional level. The six participating regional clusters will be co-ordinated in order to develop a Joint Action Plan (JAP) at

European level to drive economic development through research and technological development activities in the selected topics of sustainable production and efficient use of wooden biomass.

Futureforest project is a partnership of regions sharing ideas on how the forests of Europe could adapt to climate change using innovative natural solutions, contribute towards carbon sequestration and reduce risks caused by climate change such as flooding, drought, fire and soil erosion.

EuWood - Real Potential for Changes in Growth and Use of EU Forests addressed biomass demand, supply, potential and constraints and review of policies. Download all presentations (8Mb Zip file) from the EUWood Stakeholders meeting on 4 2010 June.

In June 2010, the EUwood project published a report that examines the potential availability of wood in Europe: Real potential for changes in growth and use of EU forests.

Agricultural residues as feedstocks for biofuels production

Overview

Field residues such as straw of grain crops and processing residues such as husks, chaff, cobs or bagasse can be used for biofuel production. 139 million tonnes of crop residues (See **Wasted - Europe's Untapped Resource: An assessment of advanced biofuels from wastes and residues**). Such biofuels are generally considered sustainable as they use waste materials from food crop production, and do not compete with food crops for land.

Mobilisation of agricultural residues

Optimising removal of above-ground biomass residues is compulsory to maintain yields and soil fertility, in practice that means that 20 to 25 % of the residues can be taken off the fields. In September 2013, research commissioned by Poet-DSM Advanced Biofuels and carried out over 5 years by Iowa State University and USDA, showed that the use of cobs, leaves, husk and some stalk to produce cellulosic ethanol does not have a detrimental effect on soil health. For the Poet-DSM Project Liberty facility it was determined 1 ton per acre, 20-25%, of residual biomass could be removed.

The research suggests that, in general, fields with yields above 175 bushels per acre could remove up to 2 tons of biomass per acre, without any need for additional nitrogen or phosphorous applications. However a small additional amount of potassium may be of benefit in some conditions.

In February 2016 the IEA-webinar “Mobilising Sustainable Energy Supply Chains” was held.

In May 2016 the IEA-workshop “Mobilising sustainable bioenergy supply chains: opportunities for agriculture” was held in Rome collaboration with GSE, FAO and IRENA. Subjects were:

- Biomass perspectives and mobilisation
- Discussion / debate on assumptions behind biomass perspectives
- Case studies and strategies showing synergies in food and energy production
- Biogas and applications
- Interactive discussion with the audience on strategies and good practices of biomass mobilisation in agriculture

Presentations

See also Mobilising Cereal Straw in the EU to Feed Advanced Biofuel Production

Conversion of agricultural residues to advanced biofuels

A number of conversion technologies can be used with agricultural residues. For example, conversion of:

Wheat straw or corn stover to cellulosic ethanol via pretreatment, hydrolysis and fermentation

Wheat straw and other agricultural wastes to BtL via various thermochemical pathways.

Mixed agricultural wastes may also be converted to bio-crude via Pyrolysis / Thermochemcial Conversion

Innovative conversion pathways based on catalysis and biotechnology can also be used to convert agricultural and other cellulosic wastes to drop-in biofuels.

Waste oils and fats as feedstocks for biofuels production

Overview

Used Cooking Oil, tallow, lard, yellow grease, chicken fat, and the by-products of the production of Omega-3 fatty acids from fish oil are increasingly used as biodiesel fuel feedstocks. For example, the feedstock used by Neste Oil NEXBTL (HEFA) production facility in Rotterdam is now over 65% waste oils and fats. See presentation from EBTP SPM6, **Large-scale chemical conversion of oils and residues in Rotterdam** made by Petri Lehmus NesteOil.

Neste Oil has developed the NexBTL process for production of "Renewable Diesel Fuel". The company has 4 facilities (Finland, Singapore and Rotterdam) that are able to produce HEFA. Initially, the main feedstock was palm oil (now 100% certified and traced back to the plantation where it originally comes from). A major challenge is sourcing and certifying of alternative feedstocks. In April 2014, Neste Oil introduced its own sustainability verification system (approved by the EC) to accelerate the utilisation of waste oils and fats, which is now steadily increasing.

Recent developments

Double counting of UCO and animal fats as 'sustainable' biofuel feedstocks

UCO and animal fats are "double-counted" as a feedstock under the latest Energy Council proposal to revise the Renewable Energy Directive and Fuel Quality Directive to address concerns over iLUC and the impacts of biofuels produced from "food crops" (including palm, rape, soy, etc). However, biofuels produced from UCO or animal fats are not counted towards the proposed target for advanced biofuels. See the biofuels legislation page for further details.

Increasing use of UCO as a feedstock for road biodiesel and biojet fuels

In the UK, UCO-derived biodiesel now accounts for a third of biodiesel supplied to the market [Source: Convert2Green/UKSBA]. See also Written evidence submitted by UK Sustainable Bio-Diesel Alliance

(UKSBA) (to Environmental Audit Committee of the UK Parliament) on effectiveness of double-counting and other support measures. There has been some debate about the large volumes of UCO imported to UK from the Netherlands. *See* Ecofys report Trends in the UCO Market (2013).

In Greece, CEPRI has developed the BIOFUELS-2G project to collect UCO and convert to biofuels.

UCO has also attracted significant interest from airlines and fuel producers as a sustainable feedstock for biojet fuels. For example, in April 2012, Qantas used a blend of 'UCO-biojet' and conventional jet fuel in a trial flight from Sydney to Adelaide. The fuel produced by SkyNRG, Netherlands, has been used by various other airlines (See SkyNRG assessed feedstocks).

Novozyme enzyme technology to convert waste oil into biodiesel

In Decembr 2014, Novozymes announced the launch of Novozymes Eversa®, the first commercially available enzymatic solution to make biodiesel from waste oils. The enzymatic process converts used cooking oil or other lower grade oils into biodiesel. Biodiesel producers can thereby reduce their raw material costs. The resulting biodiesel is sold to the same trade specification as biodiesel created through traditional chemical processing.

View video on enzymatic biodiesel

Quality benefits of Animal Fat-based biodiesel

Waste animal fat is also increasingly used as a feedstock. Besides the environmental benefits, recent studies claim that biodiesel produced from 100 per cent animal fat - also called Animal Fat Methyl Ester AFME - contributes to better overall engine performance. Compared with conventional fossil diesel, this type of biodiesel improves engine efficiency, reduces exhaust emissions and lowers engine noise levels (See Alfa Laval - Cash from Trash).

Expansion of biofuels production from animal and fish processing wastes

Today, multi-feedstock production facilities for biodiesel fuel produce animal-fat based biodiesel of high quality. In Europe, BDI has built >30 biodiesel plants within the last 15 years with capacities of up to 100,000 tons per year. BDI offers multi feedstock technology to produce biodiesel at an industrial level. At present, a $5m plant is being built in the USA, with the intention of making 3 million gallons of biodiesel fuel from some of the estimated 1 billion kg of chicken fat produced annually at the local Tyson poultry plant.

Likewise, some small-scale biodiesel factories are using waste fish oil as biodiesel fuel feedstocks. A Vietnamese plant aims to produce 13 tons/day of biodiesel from catfish from 81 tons of fish waste (See Berkley Biodiesel Feedstocks Review).

European Projects on conversion of Waste Oils to biofuels

At a local level, several EC-funded projects have addressed UCO collection, to avoid dumping down drains and to increase the availability of UCO as a sustainable feedstock for local fuel producers, e.g. the IEE project Recoil.

Further information on production of biofuels from Waste Oils

European Waste to Advanced Biofuels Association - EWABA brings together EU Used Cooking Oil (UCO) Collectors and other actors from the waste-based biofuels industry.

MSW as a feedstock for biofuels production

Overview

It is estimated that a potential 44 million tonnes of Municipal Solid Waste MSW could be available in the EU in 2030 (See **Wasted - Europe's Untapped Resource: An assessment of advanced biofuesl from wastes and residues**). Municipal Solid Waste.

The latest EurObserv'ER Renewable Municipal Waste Barometer estimated that the production of primary renewable energy recovered by household refuse incineration plants in the EU increased by just 0.7% in 2013 to achieve 8.7 million toe. However, heat sales to networks surged, reflecting better use of the primary energy.

MSW can also be converted into liquid and gaseous biofuels for production of heat and power or be used as a transport fuel. Typically, management of domestic wastes involves separation at source into:

- Recylable materials (metals, paper and plastics) - used for manufacture of recycled products
- Organic fraction (putrescible food waste) - may be converted to biogas via anaerobic digestion
- Solid Recovered Fuel SRF (the fraction of MSW that cannot be recycled e.g. shredded textiles, wood, paper, card and plastics) - SRF can be combusted or converted to syngas, and then be use for bioenergy or be processed into advanced biofuels.

An advantage of using MSW is that the feedstock is often supplied for free by Waste Managament companies (as an alternative to landfill, with the economics in many cases driven by landfill taxation). This balances the relatively high capital expenditure required for an integrated gasification system and fuels synthesis facility (for example, based on Fischer Trospch or catalytic conversion) to convert syngas to diesel, jet fuel, or methanol/ethanol.

Examples of MSW for production of bioenergy and biofuels via gasification

For example, a 160 MW thermal waste gasifier in Lahti, Finland, uses SRF that would otherwise be destined for landfill. The gas is cooled and cleaned before being passed to the boiler.

On 6 January 2016, British Airways announced that it has been forced to shelve its GreenSky project to create 16m gallons of jet fuel from waste every year, partly due to a lack of government support [Source: The Guardian, UK]. British Airways planned to use 600,000 tonnes of MSW (collected in

London) to produce over 50000 tonnes of biojet fuel and 50000 tonnes of biodiesel annually. The GreenSky project was to have used Solena's Plasma Gasification (SPG) technology, which can process 20-50% more waste than conventional gasification technologies, and Velocys technology for production of the jet fuel.

In June 2013, Abengoa Bioenergy inaugurated its W2B Demonstration Plant for conversion of MSW to cellulosic ethanol. The plant has a capacity to treat 25,000 tons of municipal solid waste (MSW) to produce 1.5 million litres of bioethanol for use as fuel. The demonstration plant located in Babilafuente (Salamanca, Spain) uses W2B technology developed by Abengoa to produce second-generation biofuels from MSW using a fermentation and enzymatic hydrolysis treatment. During the transformation process, the organic matter is treated in various ways to produce organic fiber that is rich in cellulose and hemicellulose, which is subsequently converted into bioethanol. Currently, since Abengoa has filed for bankruptcy, the plant is idle.

In September 2014, Fulcrum Bioenergy Inc announced a $105m 'Biorefinery Assistance Program' loan guarantee from the USDA, which will support development of the proposed 10 MMgy Sierra BioFuels facility to convert MSW into syngas, followed by a Fischer Tropsch step to create second generation biodiesel and bio jet fuel. The Sierra BioFuels Plant will include a Feestock Processing Facility and a Biorefinery that will convert approximately 147,000 tons of prepared MSW feedstock into more than 10 million gallons of SPK jet fuel or diesel annually. Fulcrum has enteed into a long-term, zero-cost MSW feedstock agreements with Waste Management and Waste Connections, two of the largest waste service companies in North America, and a fuel off-take agreement with Tenaska BioFuels. The Sierra BioFuels Plant is expected to be one of the United States' first fully operational, commercial-scale MSW-to-renewable fuels production plants. In May 2015, Fulcrum awarded an engineering, procurement and construction contract to Abengoa for the construction of the Sierra Biorefinery. The $200 million fixed-price contract guarantees the schedule, cost and performance of the Sierra Biorefinery. However, as Abengoa has filed for bankruptcy, the future of Fulcrum´s Sierra BioFuels plant is unclear.

In June 2014, Enerkem inaugurated its commercial MSW-to-ethanol facility in Edmonton, Canada. Enerkem, through its affiliate Enerkem Alberta Biofuels, signed a 25-year agreement with the City of Edmonton to build and operate the plant that will produce and sell next-generation biofuels from non-recyclable and non-compostable municipal solid waste (MSW). Sorted MSW is shredded and then fed into a gasifier, where heat and pressure create syngas, which is then cleaned and conditioned prior to catalytic conversion to methanol and ethanol. With a production capacity of 38 million litres per year (10 million gallons per year), the Enerkem Alberta Biofuels facility is the world's first major collaboration of its kind between a metropolitan centre and a waste-to-biofuels producer. Future plans of Enerkem include building a commercial facility through VANERCO, a joint venture formed by Enerkem and GreenField Specialty Alcohols. The VANERCO commercial facility will be one of the first integrations between an existing, first generation ethanol plant and a new cellulosic ethanol plant. VANERCO will use Enerkem's exclusive technology to produce cellulosic ethanol from non-recyclable waste from institutional, commercial and industrial sectors as well as construction and demolition debris. The VANERCO facility will be located on the site of GreenField's current first-generation ethanol facility. Site preparation has started. Construction should begin in 2016. (See Enerkem´s presentation at SPM7 for more details.)

In July 2014, Fiberight announced that Andritz was to supply equipment, engineering, and field services for Fiberight's cellulosic ethanol plant in Blairstown, Iowa. Andritz technology will be used for continuous pre-treatment of municipal solid waste feedstock which will then be converted into cellulosic ethanol using Fiberight's existing fermentation and distillation processes.

Organic wastes and residues as feedstocks for biofuels production

Overview

Any organic residues / biological waste materials can potentially be converted to advanced biofuels by thermochemical, biochemical or chemical processes. Increasingly, processing or manufacturing facilities that convert biomass to food, building materials, paper, and other bioproducts take a biorefinery approach - maximising the conversion of feedstocks and waste streams into valuable byproducts, energy and biofuels.

Pulp and paper industry

Examples of other organic residues include black liquor from pulp and paper production (KRAFT process), and waste streams from the food, beverage and pharmaceutical industries. DME (Dimethyl ether) is being generated from black liquor. UPM and SunPine AB are developing production of renewable diesel from crude tall oil, a residual product of the pulp and paper industry.

Food and Beverage waste streams

St1 has bioethanol plants in Finland; an oil refinery in Gothenburg, Sweden; and service stations in Finland, Sweden and Norway. The company produces bioethanol from a variety of food industry waste streams:

- Biowaste from households
- Leftover dough from bakeries
- Expired bread and other organic waste from shops
- Waste from beer and other beverage production
- Waste and process residues from confectionery production
- Starch- and sugar-containing waste from the food industry

The objective of the IEE project FaBbiogas is to elaborate a solid information base on FaB (Food and Beverage) waste utilisation for biogas production and to prove the efficiency and feasibility of FaB waste-based biogas implementation projects. The EU project FABbiogas (Intelligent Energy Europe) project aspires to change the mindsets of all stakeholders in the waste-to-energy chain by promoting residues from FAB industry as a new and renewable energy source for biogas production.

Sewage sludge, manure or slaughterhouse residues are other feedstocks, which can be converted to biogas.

Waste gases as feedstocks for advanced biofuels

Overview

Waste gases from energy plants and industrial processes can potentially be captured and converted to advanced biofuels. A number of projects have been developed that capture carbon dioxide and use it for cultivation of algae, which is then converted to biofuels.

Historically, biogas (LFG) produced from landfill sites has been another potential source of renewable energy. However issues such as gas migration, the long lifecycle of landfill sites (requiring many decades of management), the risk of toxic leachates, and a lack of available land mean that increasingly, efforts are being made to reduce the amount of waste material being buried in Europe and globally.

A preferred option now is for Municipal Solid Waste to be separated (at source or waste management centres) into different fractions: putrescible waste, recyclable materials and Solid Recovered Fuel SRF (the fraction of MSW that cannot be recycled e.g. shredded textiles, wood, paper, card and plastics. The SRF and organic waste both have high potential for bioenergy and biofuel production via gasification and anaerobic digestion, respectively.

LanzaTech commercial ethanol facilities

Waste gases from industrial processes are also potential feedstocks for bioenergy and biofuels production. For example, LanzaTech, New Zealand, has developed a method for capturing carbon-rich waste gases from industrial steel production, which are then fermented and chemically converted for use as a jet fuel using microbes (developed via synthetic biology). The technology is being used in conjunction with Swedish Biofuels advanced processes for the conversion of alcohols into drop-in jet fuels.

In December 2014, LanzaTech announced a $60m equity investment from the New Zealand superannuation fund. In April 2015, China Steel Corp, Taiwan announced approval of a $46m (USD) investment in a LanzaTech commercial ethanol facility.

Feedstock Topics

Availability of biomass for advanced biofuels production

In Europe, proposals have been introduced to limit the amount of biofuels that can be grown on land suitable for food-crop production. Hence future expansion of biofuels production is dependent on cultivation of energy crops on marginal land, and mobilisation of waste streams (for example, from agriculture, forestry, bioindustry and domestic refuse collection). The actual amount of sustainable feedstock available depends on various factors:

- the potential amount of 'marginal' land types that may theoretically be available for energy crops
- the total amount of organic wastes and residues that are theoretically available across Europe

- competition for land for other uses such as, housing, conservation, animal grazing, recreation, etc
- the percentage of marginal land that it is feasible to exploit for biomass production for economic, logistic and enviromental reasons (relating to water, soil carbon, fertiliser inputs, biodiversity, etc)
- competing demand for biomass from bioenergy and bioproducts

Such issues have been the subject of a range of projects and studies on biomass availability in Europe.

Biomass potential

There are plenty of studies on biomass potentials, but most of these do not specify potentials that could be used for liquid biofuels. In the IEA Bioenergy ExCo Report of 2009 an enormous variation in the results of worldwide biomass potential assessment according to different studies is stated. In the same report a technical biomass potential of 1500 EJ/year is mentioned; speaking about a sustainable biomass potential the authors claim 200 – 500 EJ/year by 2050. In the so called “sustainability scenario” of Elbersen et al. (2012) the potential for 2030 is 353 Mtoe compared to the current 314 Mtoe, with the overall waste potential declining. Only a rise for agricultural residues and for secondary and tertiary forestry residues (e.g. saw dust, black liquor) is to be expected. On the other hand the authors of "Waste – Europe’s untapped resource" state that if all waste and residues were converted only to biofuels in the EU, 16% of road transport fuel could be provided in 2030 (technical potential of sustainably available feedstock from waste).

Other recent assessments of biomass potential include Global Bioenergy Supply and Demand Projections: A working paper for REMap 2030 published by IRENA in September, 2014.

Plant breeding and biomass yield

The amount of biomass required to replace a significant proportion of the fossil fuel used in transport runs into millions of tonnes. Hence, a crucial question is that of biomass yield. Higher yields obviously enable a similar amount of biofuel to be replaced using less land. However, land use efficiency may also be improved by selecting an overall production chain that can use a high yielding biomass crop.

For instance most oils seed crops only produce a few tonnes per hectare per annum, sugar and starch crops may generate 5 to 10 tonnes, while significantly greater yields come from woody plants – or from conventional crops such as cereals if the straw can be used. Greater utilisation of such materials depends on the development of advanced conversion technologies.

Plant breeding promotes the most essential traits for a bioenergy crop such as high yield of biomass, but also improvements such as single annual harvest, recycling more nutrients back into roots before harvest, delayed harvest or disease resistance. Many of the breeding and development efforts for bioenergy crops emphasize perennial crops and target lands that are marginal or less ideal for food or livestock production, such as land that is excessively wet or dry, acid soils, or highly erodible soils. As plant breeders develop crops dedicated to bioenergy, they use innovations such as hybridization, delayed flowering, genetic modification or genomics to reach their goals.

Even when higher yielding and novel feedstocks come to market, land availability still sets limits to what may be produced. Hence, suggestions have been made for the movement of biomass or biomass derived fuels from the more productive regions to the more industrialised countries (see logistics below).

See also Indirect Land Use Change ILUC

Projects such as the Landscape Biomass Project Iowa State University look at how to balance needs for food, feed, fuel and energy, by integrating advanced biofuels technologies and novel energy crops.

Competition for biomass

Competition for biomass is a key issue in the debate on biofuels. Biomass is used as food, materials (e.g. bioplastics, wood, textiles etc.) and for energetic use – all these applications require (biomass) resources. Factors influencing competition are raw material prices, prices of end products, policy, availability of land for feedstock or technological constraints. This brings along the following challenges for the biofuel development:

- Competition between sectors of the Bioeconomy could deter investors (too many options and none with an established market)
- Competition between sectors of the Bioeconomy could trigger a “supply bubble” (rising feedstock prices at stable or decreasing demand)
- Feedstock producers need to be reassured that additional costs deriving from mobilizing agricultural/forestry residues will generate stabile income and long-term benefits
- Lack of coherent national Bioeconomy development plans does not allow allocating resources according to needs, while the biomass markets are still rather volatile
- Resources for research and development funding are also affected by competition

Logistics of biomass production

For any proposed use of biomass a Life Cycle Analysis needs to be applied taking into account the total cost and energy balance from the source of the feedstock to its end use. The overall economic, environmental and energy cost of collection, handling, processing and transport needs to be assessed. Other factors include:

- The specific properties of biomass: low energy density, which often requires drying and densification; seasonal availability causing long storage and therefore high costs and problematic storage requiring further pre-treatment (e.g. pelletizing, torrefication) to lower transportation costs.
- Limited supply because of a lack of available and appropriately mechanized equipment and limited access to conversion structure and markets.
- At local level, planning issues, traffic movements and industrial development policies need to be taken into account. Generally, it is a benefit to develop a biofuel plant close to the point of feedstock production. However this has to be balanced against economies of scale of the biofuel production facility.

Preserving biodiversity, ecology and soil quality

Generally, a certain proportion of biomass (straw, stalks, fallen wood, etc) has to be left in situ to maintain forest or field ecology, and to maintain the condition of the soil, prevent erosion, and provide habitat, for example for beneficial insects and fungi, and to promote biodiversity.

In many potentially productive areas (globally), preserving biodiversity may offer greater environmental and economic benefit than clearing forest to produce energy crops. Hence mechanisms need to be put into place to recognise the value of biodiversity These include the use of payments for ecosystem services, such as Reducing Emissions from Deforestation and Degradation (REDD) and REDD-plus (which places a greater value on biodiversity rather than just the quantity of carbon held in the forest system).

The Sustainability section of this website discusses land availability, food vs fuel, iLUC and related topics in more detail.

Biofuels and Sustainability Issues

Introduction

Biofuels offer benefits in terms of GHG reduction and fossil fuel replacement. However, concerns about the overall sustainability of biofuels have been raised in terms of competition with food production, water use and other resource to produce biomass and in terms of the release of stored carbon and impacts on biodiversity if land is cleared to grow energy crops.

This section of the website presents the views of various organizations and research activities (see Reports) in regard to the following sustainability issues of biofuels:

- Certification and systems for verfiying origin of biofuels
- Initiatives to improve the sustainability of biofuels
- Environmental impact
- Land Availability
- Food vs Fuel
- Indirect Effects
- Bio-CCS (carbon dioxide capture and storage)
- **GHG reduction and Sustainable Production of Biofuels**

See below also for:

- Impact of fertilisers and biofuel policies on the Global Agricultural Supply Chain
- Archive reports
- List of sustainability links

European Policy and Standards for sustainable biomass and biofuels production

The Renewable Energy Directive

In the EU, biofuels sustainability is stipulated in the Renewable Energy Directive, which originally stated that use of biofuels must result in an overall GHG saving of 35%, in order to qualify towards the 10% biofuels target in the EU27 by 2020. This was set to rise to 50% from 2017 for existing production, and 60% for new installations from 2017. For plants already operating in January 2008, the new GHG requirement was set to start in April 2013.

In an amendment to the Renewable Energy Directive in September 2015 (2015/1513) these deadlines were brought forward to 60 % GHG saving for installation after 25 October 2015, and 50 % for existing installation after 1 January 2018.

Further sustainability criteria set in the directive are

- No biofuels feedstock from carbon rich or biodiverse land
- Food crop based biofuels are limited to a 7 % share in the transport sector
- Bench mark for the share in the transport sector of biofuels based on non-food crops of 0.5%
- Member States are obliged to guarantee compliance with these criteria (GHG, origin of feedstock)
- EC has to report on compliance with environmental and social sustainability criteria of major biofuel exporting countries.

The enforcement of these conditions requires the establishment of a transparent and rigorous certification system, based upon global standards that objectively quantify various sustainability criteria for such land types. In addition, sustainability standards should cover both direct and indirect impacts on the environment (water, biodiversity, etc) and socio-economic issues (food pricing, land availability, quality of life and social stability).

Read more on the Renewable Energy Directive and the EU legislation on biofuels

Certification and systems for verifying the origin of sustainable biofuels

As biofuels gain market share and international trading of biomass, raw materials and biofuels expands, the need to ensure socio-economic sustainability along the whole supply chain becomes more pressing. This includes aspects such as land use, agricultural practices, competition with food, energy efficiency and GHG emissions, life cycle analysis (LCA), etc.

A strategy to achieve sustainability includes the need for certification systems. Developing certification procedures for biomass feedstock to be used in biofuel production requires identification and assessment of existing systems followed by measures taken to improve them. Certification procedures need to be applicable at both global and local level and relate both to small farmers or foresters as well as large conglomerates.

Read more on Certification

Other projects and initiatives to improve the sustainability of biofuels

UFOP Video on biofuels sustainability and certification in Germany
GBEP sustainability indicators for biofuels

In May 2011, the Global Bio-Energy Partnership (GBEP) published a report on sustainability indicators for bioenergy. GBEP brings together public, private and civil society stakeholders in a joint commitment to promote bioenergy for sustainable development.

View GBEP sustainability indicators briefing note

View presentations from GBEP Events in 2011 covering GHG LCA, sustainable bioenergy for sustainable development and related topics.

In Europe, the sustainability of biofuels is the focus of the EC Joint Research Centre (JRC) project **Quality and Performance of Biofuels (BioF)** and projects such as BioGrace (see below). Sustainable biofuels in the EU are also subject to a certification scheme. More widely, the FACCEJPI - Joint Programming Initiative on Agriculture, Food Security and Climate Change aims to bring together national research in the EU covering the impact of climate change on crop production, forestry and aquaculture and *vice versa*. For example, methane produced by agricultural activities may influence man-made climate change, while at the same time weather due to increased sea temperatures may affect crop harvests. Hence ongoing research is required to optimise agricultural (and forestry) land use for food, feed or bioproducts in Europe, and to monitor and model the impact these have on the environment and food supplies.

BioGrace - Harmonisation of GHG calculations in the EU

View Presentation on BioGrace (1.3 Mb PDF) made by **Dina Bacovsky, Bioenergy 2020+** at EBTP SPM4 on 15 September 2011

BioGrace held a series of public workshops on biofuels GHG calculations focusing on all Member States. The workshops were held between February and June 2011 in Utrecht, Netherlands, Heidelberg, Germany, Paris, France, Athens, Greece, Stockholm, Sweden amd Madrid, Spain.

The EU funded project BioGrace (Contract No: IEE/09/736/SI2.558249) aimed to harmonise calculations of biofuel greenhouse gas emissions and thus supports the implementation of the Renewable Energy Directive (RED, 2009/28/EC)) and Fuel Quality Directive (FQD, 2009/30EC) into national laws.

IDB Biofuels Sustainability Scorecard

The Sustainable Energy and Climate Change Initiative (SECCI) and the Structured and Corporate Finance Department (SCF) of the Inter-American Development Bank (IDB) have created the IDB Biofuels Sustainability Scorecard based on the sustainability criteria of the Roundtable on Sustainable Biofuels (RSB). The primary objective of the Scorecard is to encourage higher levels of sustainability in biofuels projects by providing a tool to think through the range of complex issues associated with biofuels.

BIOSEA Project, Italy

In Italy, the BIOSEA project (optimization of biomass energy for economic and environmental sustainability) aims to optimise supply chains by making use of existing agricultural research and genetic engineering and LCA (Life Cycle Assessment) for a proper comparison between options and for the identification and elimination of critical points relating to economic sustainability and environmental processes.

Social Aspects of Biofuels Development

In September 2009, the Potsdam Institute, Germany, launched a 3-year project Biofuel as Social Fuel, which is analysing the societal impact of biofuel development, for example, the potential of technological innovation to enhance 'social progress'.

Biofuel Sustainability in the US

As in Europe, sustainability of biofuels is becoming increasingly important in the United States, and is addressed by the EPA and groups such as California Low Carbon Fuel Standards Sustainability Work Group.

Environmental impact

Some intensive modern farm methods used for food production have a range of negative effects on the environment, such as soil erosion, water shortage, pollution from pesticides and problems with over use of fertilizers (including eutrophication). Eutrophication, the decrease in the biodiversity of an ecosystem as the result of release of chemical nutrients (typically compounds containing nitrogen or phosphorous), is only one threat to biodiversity, which may also be impacted by the replacement of a natural ecosystem by monocultures, whether annual fields of rapeseed, sugar beet or cereals, or large areas of coppice or short rotation forest.

For example, palm oil is one of the cheapest sources of vegetable oil and is used widely in the food and cosmetics industry, and more recently as a feedstock for first generation biofuels. The clearing of biodiverse rainforest for expansion of palm plantations has been the subject of a number of protests and campaigns by conservation groups. Conservation scientitsts have expressed particular concerns over the release of stored carbon and destruction of habitat for endangered species [Source: Biofuel Plantations on Forested Lands: Double Jeopardy for Biodiversity and Climate and Conservation Biology].

The Convention on Biological Diversity suggests that the use of payment mechanisms to protect biodiversity (e.g. REDD Reducing Emissions from Deforestation and Degradation) may often be a better environmental and economic option than clearing biodiverse land to plant energy crops.

Competition for water resources is aother increasingly significant issue for biomass production.

Read more on Environmental impact.

Land availability

The amount of biomass required to replace a significant proportion of the fossil fuel used in transport runs into millions of tonnes. Hence, a crucial question is that of biomass yield. Higher yields obviously enable a similar amount of biofuel to be replaced using less land. However, land use efficiency may also be improved by selecting an overall production chain that can use a high yielding biomass crop. For instance most oils seed crops only produce a few tonnes per hectare per annum, sugar and starch crops may generate 5 to 10 tonnes, while significantly greater yields come from woody plants – or from conventional crops such as cereals if the straw can be used.

Greater utilisation of such materials depends on the development of advanced biofuels. Even if these methods come to market, land availability still sets limits to what may be produced.

Suggestions have been made for the movement of biomass or biomass derived fuels from the more productive regions to the more industrialised countries. Should this type of movement be encouraged?

Find out more about the constraints of land use on production of liquid biofuels.

Food versus fuel

The global population continues to grow, in places at an alarming rate, and will need to be fed and will expect to live an improved life style, consuming more energy. This raises questions of 'Food versus

Fuel'; how much land and other resources are available, how should they be used and what are the priorities?

The debate on Food versus Fuel has had a major impact on biofuels policy and gained media coverageA number of reports covering this issue are available in the EBTP reports database and the Food vs. Fuel page.

Read more...

Indirect Land Use Change (iLUC)

It has been suggested that growing energy crops on agricultural land may displace existing food-crop production, causing land use change in another location. This indirect Land Use Change (iLUC) might occur in a neighbouring area or even in another country hundreds of miles away, where an area of high biodiversity (and high levels of "stored carbon") might be cleared to make more land available for growing food crops.

In the US, this concept was the subject of a paper by Timothy Searchinger *et al,* Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change, published in Science in February 2008 [Vol. 319 no. 5867 pp. 1238-1240]. It has been suggested that increased use of rape seed oil for biodiesel production in Europe could reduce the amount available for the food industry, leading in turn to increased demands for imports of palm oil (potentially increasing deforestation in producer countries).

Since 2008, there has been much debate about the assumptions made and methods used to establish the impact of Indirect Land Use Change. There is a concensus among scientists that land use change is very complex and affected by a wide range of factors, not only biofuels. Nonetheless, public concerns have led to the amendment of EC biofuels policies and the role of biofuels in sustainable transport strategy.

Read more on iLUC...

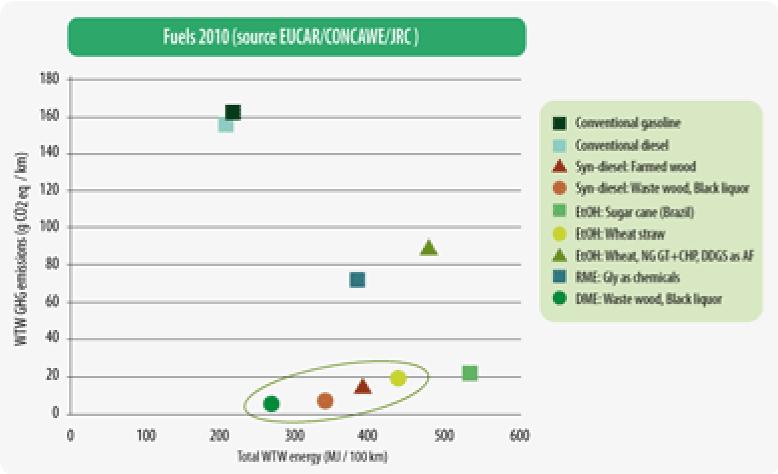
Impact of fertilisers and biofuel policies on the Global Agricultural Supply Chain

In November 2014, OECD published a report Fertiliser and Biofuel Policies in the Global Agricultural Supply Chain: Implications for Agricultural Markets and Farm Incomes.

This report analyses policies along the agricultural supply chain, in particular support measures for fertilisers and for biofuels. It uses the OECD Fertiliser and Biofuel Support Policies Database that covers polices in 48 countries (including the EU and its Members) and assesses the market effects of these policies with a computable general equilibrium model, MAGNET. This report finds that biofuel support policies generate additional demand for feedstock commodities and, therefore, higher incomes for crop farmers in subsidising and non-subsidising countries. In contrast, these policies increase costs to downstream industries, including livestock farmers, and to consumers. Fertiliser support policies reduce crop production costs and hence increase yields, production and incomes for crop farmers in subsidising countries. However, they lower crop farm incomes abroad, while livestock farmers in both country groups face lower feed costs and, in consequence, lower livestock prices.

GHG reduction and Sustainable Production of Biofuels

The development of sustainable liquid transport fuels, which can replace finite fossil fuels, is essential to guarantee the future security of energy supply in Europe. In common with all industrial processes, production of biofuels requires energy inputs and has an environmental impact. However, first generation biofuels (bioethanol and biodiesel) still offer benefits in terms of GHG reduction and fossil fuel replacement. When measuring overall sustainability of biofuels, other factors need to be taken into account, such as competition with food production, and release of stored carbon and impacts on biodiversity if land is cleared to grow energy crops. Such issues are being addressed by EC certification schemes, projects such as BioGrace, and the Roundtable on Sustainable Biofuels, among others, as well as development of advanced (2G) biofuels technology and new bioenergy crops that grow on land less suited to food production.



Well-to-wheel greenhouse gas emissions (in CO2-equivalents/km) versus total energy use for running a mid-size car over a distance of 100 km - View at larger size >>

Sustainable Advanced Biofuels

Second generation biofuels produced from lignocellulosic materials (e.g, straw, energy crops and forestry residues), could enable far greater reductions in GHG, and innovative fuels created from these feedstocks will count double towards the biofuels target of 10%.

Clearly, the type, location and environmental sensitivity of land used for cultivating biofuel feedstocks is critical, if expansion of biofuel production is to be sustainable and socially acceptable.

The EC Climate Change initiative stipulated that in order to meet sustainability criteria "old forest with no or limited human intervention cannot be used for biofuels cultivation, nor can 'highly biodiverse grasslands', or lands with a 'high carbon stock' like wetlands or 'pristine peatlands'"

The Directive on Renewable Energy (December 2008) states further that the EC has to report on compliance with environmental and social sustainability criteria of major biofuel exporting countries. And a bonus of 29g CO_2/MJ will be applied for biofuels derived from degraded/contaminated land.

Archive Reports

Recent reports on sustainability and biofuels are regularly added to the EBTP reports database, reflecting a range of views on the issue. Links to some notable archive reports are listed below.

Renewable Fuels Agency Review of the Indirect Effects of Biofuels

On 21 February 2008, the UK Secretary of State for Transport Ruth Kelly invited the Renewable Fuels Agency to undertake a Review of the Indirect Effects of Biofuels. This was done in the light of new evidence suggesting that an increasing demand for biofuels might indirectly cause carbon emissions because of land use change, and concerns that demand for biofuels may be driving food insecurity by causing food commodity price increases.

Roundtable on Sustainable Biofuels: Global Principles and Criteria for Sustainable Biofuels Production Version Zero (8.9 Mb - link updated April 2016)

In June 2007, the Steering Board of the Roundtable on Sustainable Biofuels (RSB) published draft principles for sustainable biofuels production, as the basis for a global stakeholder discussion around requirements for sustainable biofuels. A period of global consultation followed, and this document (Version Zero) presents the resulting draft standard – principles and criteria, along with key elements of the guidance for implementation.

Sustainability Standards for Bioenergy (1.5 Mb PDF) – Uwe R. Fritsche, Katja Hünecke, Andreas Hermann, Falk Schulze and Kirsten Wiegmann with contributions from Michel Adolphe, Öko-Institut e.V., Darmstadt. Published by WWF Germany, Frankfurt am Main, November 2006. Please note that the material in this report is copyright of WWF Germany, Frankfurt am Main and that any reproduction in full or in part of this publication must mention the title and credit the copyright holder.

Sustainability links

Better Sugarcane Initiative

Bureau Veritas

California Low Carbon Fuel Standards Sustainability Work Group

Council on Sustainable Biomass Production

Envrionmental Protection Agency

Ethical Sugar

EU sustainability criteria for the use of biofuels (used in transport) and bioliquids (used for electricity and heating)

Voluntary schemes verifying compliance with the EU's biofuels sustainability criteria

FACCEJPI - Agriculture, Food Security and Climate Change

GAVE - Climate Neutral Gaseous and Liquid Energy Carriers (Netherlands)

Global Bioenergy Partnership

IDB Biofuels Sustainability Scorecard

IEA Taskforce 40 Bioenergy Trade

iLUC Project

Inter-American Development Bank Biofuels Sustainability Scorecard

Low Carbon Vehicle Partnership LowCVP (UK)

Natural Resources Defense Council

Rainforest Alliance

Register of Biofuels Origination (RBO)

Renewable Transport Fuel Obligation (UK)

Roundtable on Sustainable Biofuels (RSB)

Roundtable on Suatainable Palm Oil

Roundtable on Responsible Soy Association

Sustainable Aviation Fuel Users Group SAFUG

Sustainable Food Laboratory - Responsible Commmodities Initiative (RCI) on Biofuels

United Nations Environment Programme (UNEP)

UNICA - Brazilian Sugarcane Industry Association

UNICA sustainable sugar cane initiative

University of Cambridge Programme for Sustainability Leadership (CPSL)

Plant breeding and biotechnology for innovative biofuels feedstocks and increased productivity

Plant breeding and biotechnology can be used to improve energy crops to increase yield, improve tolerance to pests and drought, to alter the characteristics of the plants (e.g. percentage of lignin, oil content, cell structure) making it more efficient to convert them to liquid biofuels. Plants may also be modified to produce specific chemicals, or to express enzymes that facilitate bioindustrial processing. See below for examples.

Reseachers at Michigan State University have identified a switch that regulates photosynthesis, and enables 'balanced plant metabolism'. A greater understanding of this switch mechanism could help to develop food and fuel crops that are more resiliant to environmental stress. (April 2015)

Syngenta has developed Enogen® corn (with 'corn Amylase trait') that increases the efficiency of ethanol production by 8% [Ref: Western Plains Energy]. The variety is currently supplied to 9 commercial ethanol plants in the US [Source: Syngenta April 2015]. See also Cellerate Process Technology.

Reseachers at the University of Manchester have manipulated two genes (PXY and CLE) in poplar trees to make them grow larger and faster (April 2015).

Virginia Tech has received a $1.4m grant (August 2014) to investigate optimising yields fom Populus spp. on poorer soils and under various environmental stresses. See also Hybrid Poplar for Bioenergy and Biomaterials Feedstock Production on Appalachian Reclaimed Mine Land (Amy Brunner et al, 2009).

In October 2013, UCLA published details of a synthetic glycolytic pathway (non-oxidative glycolysis, or NOG) that converts all six glucose carbon atoms into three molecules of acetyl-CoA (as opposed to the 4 carbon atoms converted naturally). This would potentially increase conversion efficiency of feedstock to ethanol by 50%. [Source: *Nature*, October 2013, Synthetic non-oxidative glycolysis enables complete carbon conservation].

In 2013, VIB Department of Plant Systems Biology, Gent, Belgium carried out a field trial in poplar trees in which the CCR-enzyme was suppressed to reduce the synthesis of lignin, and facilitate production of greater yields of ethanol. The technique is now being further developed to improve consistency and efficiency.

In July 2012, a paper published in Plant Cell by scientists at the Brookhaven National Laboratory suggest that a new enzyme (Engineered Monolignol 4-O-Methyltransferase) can reduce lignin content in cell walls making them easier to breakdown and convert into biofuels.

In September 2012, Purdue University, US, announced it has receieved a $5.2m grant to develop plants that produce phenylethanol, by modifying the metabolic route that normally converts phenyalanine to lignin. Initial research will be carried out using *Arabidopsis*, but the technique could eventually be applied to energy crops such as Switchgrass.

Partly supported by the PETRO program, Chromatin has engineered sweet sorghum to accumulate the fuel precursor farnesene (20%), a molecule that can be blended into diesel fuel.

Arcadia Biosciences, in collaboration with the University of California-Davis, is developing plants that produce vegetable oil in their leaves and stems (as opposed to seeds). Various projects are also looking at improving oil yields from modified strains of Camelina, and producing oils from modified Tobacco plants. University of Florida is working to increase the amount of turpentine in harvested pine from 4% to 20% of its dry weight.

Samuel Roberts Noble Foundation has also developed novel strains of switchgrass that contain lower amounts of lignin and hence boost biofuel yields by over a third [Source: Proceedings of the National Academy of Sciences].

Agrivida, Medford, Mass., uses protein-engineering expertise to produce low cost sugars from cellulosic feedstocks, such as corn stover, sorghum and switchgrass. Agrivida is developing both seeds engineered with pretreatment and cellulose-degrading traits, and processing techniques for activating the plants' cell wall-degrading enzymes in industrial and agricultural processes.

Research at Oregon State University suggest that modified trees with reduced height offer traits that could be beneficial for SRC and bioenergy.

In Singapore, Temasek Life Sciences Laboratory and JOil Pte Ltd. have developed Jatropha strains with 75% oleic acid content, compared to the typical 45% percent.

In the UK, the Centre for Novel Agriculturual Products, CNAP also carries out research on increasing biomass for biofuel production, biomass oils, and biorenewable products.

FUELS AND CONVERSION

Pretreatment

Torrefaction of biomass and 'biocoal' technologies

Overview

Torrefaction is a thermochemical process typically at 200-350 °C in the absence of oxygen, at atmopsheric pressure with low particle heating rates and a reactor time of one hour. The process causes biomass to partly decompose, creating torrefied biomass or char, also referred to as 'biocoal'. Biocoal has a higher energy content per unit volume, and torrefaction followed by pelletisation at the harvest sites facilitates transport over longer distances. It also avoids problems associated with decomposition of biomass during storage. Hence the benefits of torrefaction may outweigh the additional cost in many cases.

An overview of torrefaction technology and market potential is provided in the report: Wood torrefaction – market prospects and integration with the forest and energy industry *Carl Wilén, Kai Sipilä, Sanna Tuomi, Ilkka Hiltunen & Christian Lindfors, VTT, 2014*

EC Projects on Torrefaction and Biocoal

The NEWAPP "New technological applications for wet biomass waste stream products" project, supported by FP7, aims to develop hydrothermal carbonization HTC processes to convert wet biomass into biocoal at 'moderate' temperatures and pressures in the presence of water. The process also yields a water phase rich in plant nutrients.

FP7 Project SECTOR - Production of Solid Sustainable Energy Carriers from Biomass by Means of Torrefaction started in 2012 and runs for 42 months. The final project meeting is in Leipzig on 6-7 May 2015.

Torrefaction and 'biocoal' R&D and commercial demos/plants

In February 2014, Topell Energy, Essent, Nuon and GDF SUEZ, and ECN successfully completed a large-scale cofiring of torrified pellets at the Amer power plant, Geertruidenberg, Netherlands. See Commercial-scale biomass torrefaction demonstration. In November 2015, Blackwood Technology, Netherlands, acquired the world leading torrefaction technology and the team from Topell Energy.

Torrefaction is also being developed in the US. For example, in May 2012 Vega Biofuels (VB) announced plans to build a new bio-coal manufacturing facility in Georgia, US. Timber waste will be used as the feedstock. Zilkha Biomass Energy LLC and Valmet Corp. signed an agreement in early 2014 to develop steam exploded black pellets which can be used directly in coal-fired power stations. Zilkha is also providing technology to Thermogen in the US.

In Canada, Diacarbon Energy Inc is developing a pilot torrefaction bioreactor with support from the British Columbia Bioenergy Network. Solvay and New Biomass Energy are further developing an industrial-scale torrefaction operation in Quitman, US and aim to triple production to 250,00 tons by end of 2014.

Biochemical conversion

Conventional Ethanol

Bioethanol use in Europe and globally

This page is currently under development. Please follow the links below for up-to-date information on ethanol production and research worldwide.

Overview

First generation bioethanol is produced by distillation from crops such as wheat, corn, sugar cane and sugar beet. In Europe, wheat is the main crop grown for bioethanol production - accounting for 0.7% of EU agricultural land and 2% of Europe's grain supply [Source: ePure]. The EC has proposed to limit biofuel produced from "food crops" at 7% of energy use in transport, due to concerns about food price and land use impacts. However, there are conflicting studies and opinions on the issue (see the biofuels reports database) and biofuels producers suggest that the impacts of ethanol production from starch crops may have been exaggerated and the many benefits of biofuels (European fuel security, job and wealth creation, production of valuable byproducts, GHG reduction) have not been fully taken into account.

See Renewable ethanol: driving jobs, growth and innovation throughout Europe: State of the Industry Report 2014 published by ePure in June 2014.

See the EBTP ethanol fact sheet for more technical information.

Latest news, reports, expert opinion and data on bioethanol can be found through journals such as Ethanol Producer Magazine.

Extensive information on bioethanol in Europe is available from ePure - European Renewable Ethanol Association www.epure.org

Cellulosic ethanol (a second generation biofuel) can be produced from a wider range of feedstocks, including agricultural residues, woody raw materials or energy crops that do not compete directly with food crops for land use. This requires a more complex production process (cellulose hydrolysis), which is currently at the demonstration stage. Significant investment in R&D&D in Europe and the United States will lead to wider production of cellulosic ethanol on the commercial scale within the next decade. However, currently in the US and Europe most bioethanol is still produced from crops (for example, it was projected that in 2011, 40% of corn planted in the US was used as a feedstock for bioethanol, compared to just 7% a decade earlier).

Demand for ethanol is likely to increase over the next two decades in the US. The EPA indicates that E10 is now the norm for ethanol/gasoline blends in the US, there will be a mix of E10 and E15 by 2017 and by 2030 E15 will be the standard. In November 2014, the Renewable Fuels Association reported that already 2/3 of car manufacturers approve the use of E15 in their new vehicles.

In Brazil, which has the most mature market for fuel ethanol, the mandatory blend level of anhydrous ethanol was increased to 25% in May 2013.

In the EC, uncertainty over legislation in 2013 and 2014 continued to delay market development. However, the world's first commercial cellulosic ethanol plant, developed by Beta Renewables, went into production at Crecentino in 2013.

A number of pilot and demonstration plants are also developing novel routes to create bioethanol from commercial waste and MSW.

Ethanol can also be produced from energy crops, which may be grown on marginal land not currently used for food crops, using plant species that do not compete with food markets. In April 2013, work commenced on a 20 MMgy commercial ethanol plant in Florida using sweet sorghum as a feedstock. The plant is being built by Southeast Renewable Fuels LLC using the process technology of Uni-Systems do Brasil Ltda.

Use of plant breeding, novel crops and biotechnology to improve yields

Plant science is also being used to increase the production of first generation bioethanol, for example Enogen® corn developed by Syngenta.

Triticale has been tested as an alternative to wheat as a bioethanol feedstock. Trials in the UK in 2011 showed it offered greater yields at the same or lower levels of nitrogen inputs.

See the plant breeding and biotechnology page for further information and links.

Novel microbial fermentation

Although yeast strains are commercially used to produce ethanol, other microbes, such as *Zymomonas mobilis,* have also been investigated. *Zymomonas mobilis* uses the Entner-Doudoroff pathway to convert sugar to pyruvate, which is then fermented to produce ethanol. The organism offers potential benefits over yeast strains, including higher ethanol yields, greater ethanol tolerance, no need for additional oxygen and greater potential for genetic modification. *Z. mobilis* can also use nitrogen gas as a Nitrogen source with no reduction in ethanol yield.

Process efficiency improvements

The efficiency of ethanol production systems is being improved by innovation process technology such as the proprietary controlled flow cavitation process (CFC) developed by Arisdyne Systems Inc. which can boost ethanol yield by over 3 per cent by increasing the surface area available for enzyme interaction with corn slurry. The reduction in particle size using this technique, could similarly improve the efficiency of biodiesel production and biogas production.

Dual alcohol blends

Research is being carried out on dual-alcohol gasoline blends (e.g. 10% ethanol plus 10% methanol), which has a distillation curve close to that of pure gasoline, minimizing the impact on fuel volatility [Source: Distillation Curves for Alcohol-Gasoline Blends, V. F. Andersen et al, *Energy Fuels*, 2010, 24 (4), pp 2683–2691].

Cellulosic Ethanol (CE)

An introduction to cellulosic ethanol technology

- Introduction to Cellulosic Ethanol

Demonstration and flagship projects on cellulosic ethanol:

- Beta Renewables / Biochemtex commercial cellulosic ethanol plants in Italy, Brazil, US and Slovak Republic
- Poet-DSM Project Liberty commercial cellulosic ethanol plant in US

- Abengoa Hugoton, Kansas commercial plant and MSW to ethanol Demonstration Plant, Salamanca
- Clariant – sunliquid® cellulosic ethanol demonstration plant, Straubing
- Inbicon Biomass Refinery for production of Cellulosic Ethanol
- Maabjergenergy Concept, Denmark
- BioGasol Demonstration Plant - BornBioFuel2
- Conversion of MSW and cellulosic materials to ethanol via gasification and synthesis
- Futurol pre-industrial pilot for cellulosic ethanol
- Chempolis Biorefinery for cellulosic ethanol
- St1 / North Bio Tech Oy cellulosic ethanol plant, Kajaani, Finland
- Borregaard production of ethanol from spruce

EC-funded R&D and Demonstration on cellulosic ethanol

- BEST and CEG Plant Goswinowice to be funded under NER300 first call
- EC-funded projects on Cellulosic Ethanol
- FibreEtOH Project

Development of enzymes and processes for cellulosic ethanol production

- Enzymes for Cellulosic Ethanol production
- Petrobras Novozymes agreement on 2G ethanol from sugarcane bagasse
- TMO Process Demonstration Unit (PDU) for Cellulosic Ethanol
- ATENEA and PERSEO projects

Development of commercial cellulosic ethanol plants in North America and Brazil

- US Companies developing Cellulosic Ethanol plants
- Cellulosic Ethanol in Canada
- Commercial Scale Cellulosic Ethanol Plants in Brazil

Novel pathways to cellulosic ethanol

- Novel pathways to Cellulosic Ethanol
- Consolidated bioprocessing for production of Ethanol - Qteros and Mascoma

Use of Lignin

- Use of lignin - a by-product of lignocellulose conversion

Introduction to cellulosic ethanol

Cellulosic ethanol is chemically identical to first generation bioethanol (i.e. CH_3CH_2OH). However, it is produced from different raw materials via a more complex process (cellulose hydrolysis).

In contrast to first generation bioethanol, which is derived from sugar or starch produced by food crops (e.g. wheat, corn, sugar beet, sugar cane, etc), cellulosic ethanol may be produced from agricultural residues (e.g. straw, corn stover), other lignocellulosic raw materials (e.g. wood chips) or energy crops (miscanthus, switchgrass, etc).

These lignocellulosic raw materials are more abundant and generally considered to be more sustainable, however they need to be broken down (hydrolysed) into simple sugars prior to distillation. This may be achieved using either acid or enzyme hydrolysis. Both approaches have been the subject of continuing research interest since the 1970s, and large investments are being made in the US and Europe to speed up development of this route to bioethanol.

Cellulosic ethanol is now being produced on commercial scale in Europe, US and Brazil (see further details below). In October 2013, M&G officially opened the world's largest cellulosic ethanol production facility at Crescentino. In July 2013, Ineos Bio announced the start of production at its 8MMgy facility at Vero Beach, US.

Demostration plants for commercial scale production of cellulosic ethanol are also under development in Europe (e.g. Inbicon, Kalundborg and Abengoa, Salamanca).

In addition, a number of pilot plants are developing thermochemical/biochemical routes to create bioethanol from commercial waste and MSW.

Flagship (first-of-a-kind commercial) and demonstration cellulosic ethanol facilities

M&G commercial scale cellulosic ethanol plants in Italy, Brazil, US and Slovak Republic:

Crescentino (Italy)

The Beta Renewables commercial scale cellulosic ethanol plant at Crescentino was officially opened on 9th October 2013. It is currently the world's largest advanced biofuels refinery with a production capacity of 75 million litres of cellulosic ethanol annually. The shareholders of Beta Renewables are Biochemtex, a company of the Mossi & Ghisolfi Group (M&G), TPG Capital, and Novozymes.

The plant is based on the patented Proesa™ process, and uses Novozymes enzyme technology to convert local wheat straw, rice straw and Arundo donax to ethanol. Lignin, extracted during the production process, is used at an attached power plant, which generates enough power to meet the facility’s energy needs, with any excess green electricity sold to the local grid.

Prior to the construction of BioCrescentino, Proesa™ process was optimised at the Rivalta Scrivia (Alessandria) pilot plant, which has a capacity of 1t/day of biomass treated.

View short presentation on the opening of the commercial Crescentino Cellulosic Ethanol Refinery

Previously, a presentation on the commissioning of the Crescentino plant was made at EBTP SPM5 in February 2013.

Case study on the first commercial advanced ethanol plant in the EU, and how it was financed
Stefania Pescarolo, M&G Chemtex

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COMETHA Project - Industrial scale pre-commercial plant, Porto Marghera, Italy

COMETHA (2014-2018), supported by FP7, involves the construction and operation of an integrated industrial facility for the production of second generation bioethanol and other co-products from lignocellulosic feedstock. The project builds upon the technology and processes demonstrated at Crescentino. Innovations include:

- Proprietary biomass pre-treatment unit;
- SSCF technology for the simultaneous saccharification of cellulose and hemicellulose and co-fermentation of glucose and pentose, with the use of novel high-performance enzymes;
- High-efficiency integrated distillation and dehydration system;
- Optimisation of feedstocks including dedicated perennial crops (*Arundo donax*) and agricultural residues
- Detailed life cycle assessment

GranBio, Alagoas (Brazil)

Beta Renewables technology is also being used at the GranBio Commercial Scale Cellulosic Ethanol Plant in Alagoas, Brazil (see below for latest details), which began production in September 2014.

Canergy, Imperial Valley (United States)

In May 2013, Canergy LLC announced that BioChemtex/Beta Renewables technology would be used for a 30 MMgy cellulosic ethanol plant in Imperial Valley, California. Canergy's cellulosic advanced biofuel facility will begin production in 2016, and produce in excess of 30 million gallons per year of cellulosic ethanol from energy cane grown in the Imperial Valley of California.

In August 2012, it was announced that Chemtex International Inc. (Biochemtex) had received a conditional USDA loan guarantee to build a 20 MMgy cellulosic ethanol facility in eastern North Carolina using energy grasses as feedstock, also using Proesa™ technoloy. In July 2013, Chemtex International (Biochemtex) signed a long-term agreement with Murphy-Brown LLC, Warsaw, N.C., for supply of energy crops for the cellulosic ethanol facility at Clinton. The crops will be grown on land not used for grain production.

Strazske (Slovak Republic)

In October 2014, Beta Renewables and BioChemtex announced an agreement with Energochemica SE for the construction of a 55,000 metric ton commercial facility in **Strazske, Slovak Republic**, to produce cellulosic ethanol from non-food biomass. The plant will use enzymes from Novozymes and yeast from Leaf Technologies.

Fuyang (China)

In November 2013, Beta Renewables announced plans for a biorefinery in China that will convert straw and corn stover to ethanol and mono-ethylene glycol (MEG), which is used to produce polyester. The facility is a joint venture with Guozhen Group Co., and will be constructed in the Fuyang region, which has abundant agricultural residues available. The biorefinery will process 1 million metric tons of biomass per year, around 4 times the volume of BioCrecentino

Poet-DSM 'Project Liberty' - first commercial cellulosic ethanol plant in the US

POET-DSM Advanced Biofuels, LLC, is a 50/50 joint venture between Royal DSM, Netherlands, and POET, LLC. Based in Sioux Falls, South Dakota, the company is a cooperative effort to commercialize innovative technology to convert corn crop residue into cellulosic bioethanol.

In September 2014, Poet-DSM Advanced Biofuels LLC commenced production at the $275m 'Project Liberty' cellulosic ethanol facility. The plant will produce 20 MMgy per year of cellulosic ethanol from corn stover and cob, and shares infrastructure with the adjacent 50 MMgy ethanol plant.

Project Liberty construction timelapse.

Key facts about Poet-DSM Project Liberty:

- Capital costs are $275 million.
- Fuel from Project LIBERTY represents a GHG reduction of 85%-95% over gasoline.
- The plant employs more than 50 people directly, and biomass harvesting is creating another 200 indirect jobs in the community. In addition, hundreds of people were involved in the construction of the plant.
- The state of Iowa has estimated a $24.4 billion impact on the state over 20 years.
- Project LIBERTY will consume 285,000 tons of biomass annually from a 45-mile radius of the plant.
- Farmers remove approximately 1 ton of residue (~25%) per acre.
- Project LIBERTY will spend approximately $20 million annually purchasing biomass from area farmers, providing additional income to the farmers.
- Project LIBERTY will produce up to 25 million gallons of cellulosic bio-ethanol annually.

[Source: Royal DSM website]

Suomen Bioetanoli Oy commercial cellulosic ethanol plant, Myllykoski, Finland

Poet and DSM are in discussions with Suomen Bioetanoli Oy on how to utilize process, yeast and enzyme technology from the respective companies for conversion of cellulose to bioethanol in Finland. In December 2014, the Ministry of Employment and Economy in Finland granted €30m to Suomen Bioetanoli Oy to support development of a 90 MMly commercial cellulosic ethanol plant at Myllykoski [Source: www.tem.fi and Poet DSM].

Abengoa ceases production at commercial plant Hugoton, Kansas, US

The Abengoa Cellulosic Ethanol plant, Hugoton, Kansas © Copyright Abengoa 'the energy of change' blog

In December 2015, Abengoa ceased production at its Hugoton plant, due to financial difficulties. In November 2015, Abengoa announced that it was trying to reorganise over $9 billion in debts before 28 March 2016, to avoid being forced to file for insolvency. The company's NASDAQ shares fell sharply following the announcement. On 24 December 2015 Abengoa "signed with financial stakeholders, under Article 5 bis of the Spanish Insolvency Law, a loan that will serve as an economic injection of 106 M€. Abengoa is protected under Article 5 bis of the Spanish Insolvency Law which, for a period of three months extendable to four, allowing the company to protect and preserve the company’s value while it works on the design and development of an appropriated viability plan for its future. Abengoa trusts the viability plan will increase the confidence of stakeholders to focus all efforts in the future of the company." [Source: Abengoa website].

In October 2014, Abengoa Bioenergy Biomass of Kansas held the official opening of its commercial plant producing of 25 Mgal (100 ML) of cellulosic ethanol and 21 MW of renewable energy from biomass (mixture of agricultural waste, non-feed energy crops and wood waste). The plant is located to the west of Hugoton, state of Kansas, and aimed to create 65 permanent jobs. Feedstock purchases within a 50 mile radius of the plant were estimated to exceed $400m per annum. The construction of the Hugoton plant began in July 2011 and it started producing ethanol in September 2014.

In June 2013, Abengoas inaugurated its "W2B" MSW to cellulosic ethanol plant in Salamanca, Spain. The plant has a capacity to treat 25,000 tons of municipal solid waste (MSW) from which it will obtain up to 1.5 million liters of bioethanol for use as fuel. The demonstration plant located in Babilafuente (Salamanca, Spain) uses W2B technology developed by Abengoa to produce second-generation biofuels from MSW using a fermentation and enzymatic hydrolysis treatment. During the transformation process, the organic matter is treated in various ways to produce organic fiber that is rich in cellulose and hemicellulose, which is subsequently converted into bioethanol.

Abengoa 2G Ethanol Demo Plant in Salamanca

View at larger size >>

Previously, Abengoa provided its proprietary process technology and the process engineering design for a BCyL Biomass Plant in Salamanca. Managed by Abengoa, the biomass plant was completed in December 2008 and has been fully operational since September 2009. It was the world's first plant to utilize this technology on such a scale. It is located within the Biocarburantes de Castilla y León plant, meaning that both facilities share common services and process chains.

This plant has been used to improve the design of the commercial plants to be constructed over the coming years, assess operating costs, identify bottlenecks and streamline operations.

The plant capacity is 70 tpd of lignocellulosic, biomass such as wheat straw, and is able to produce over 5 MMl of fuel grade ethanol per year.

The production process involves:

- Preparation of biomass
- Thermochemical pretreatment
- Enzymatic Hydrolysis and fermentation with enzymes and yeast
- Distillation to produce ethanol and a solid co-product

Abengoa's demonstration plant was supported by the 5th Framework Programme.

Abengoa also heads the LED (Lignocellulosic Ethanol Demonstration) project funded by the European Commission and developed by a consortium of five companies from four different countries, with a plant in Arance, France.

In January 2012, Abengoa announced that its cellulosic ethanol technology would be used to produce ethanol from sugar cane cane straw and bagasse in Brazil, as part of the Industrial Innovation Program for the Sugar Energy Sector.

DuPont cellulosic ethanol facility, Iowa, US and planned plant in China

In December 2014, construction of the DuPont Cellulosic Ethanol LLC plant in Nevada, Iowa was nearing completion. The plant will produce 30MMgy of cellulosic ethanol from 590000 bales of corn stover. Murex LLC will market the ethanol. See Commercializing Advanced Renewable Fuel in Iowa for facts and figures.

In July 2015, DuPont also announced an agreement with Jilin Province New Tianlong Industry Co. Ltd, China, to develop a plant to produce cellulosic ethanol in Siping City, using residues from corn production in Jilin Province. The Chinese company will license cellulosic ethanol technology from DuPont and will use DuPont's Accellerase enzymes.

INEOS Bio, Indian River BioEnergy Center, US

Following earlier technical issues, in September 2014 INEOS Bio announced that the Indian River BioEnergy Center was being brought back on-line. The BioEnergy Center is a joint venture commercial demonstration project between INEOS Bio and New Planet Energy. At full capacity, it will have an annual output of eight million gallons (24kta) of cellulosic ethanol and six megawatts (gross) of renewable power.

Inbicon (DONG Energy) technology for commercial production of cellulosic ethanol

In June 2014, it was announced that Patriot Renewable Fuels is planning the first stage of a cellulosic ethanol project with Inbicon [Source: Inbicon website].

In December 2013, DONG Energy and Royal Dutch DSM announced the succesful demonstration of a combined fermentation of C6 and C5 sugars from wheat straw on industrial scale. The combined fermentation results in a 40% increase in ethanol yield per ton of straw, which can result in significant cost cuts in the production of second generation bio-ethanol. The joint work by DONG Energy and DSM was co-funded by the FP7 **KACELLE** project.

In March 2010, Great River Energy announced that it would use Inbicon technology in a $300m biorefinery to produce cellulosic ethanol primarily from 480 000 tons of wheat straw (and other agricultural residues) from a 70 mile radius. The refinery aimed to be operational by 2015. The lignin by-product was to be used to increase the efficiency of a nearby power plant [Source: Great River Energy].

In Autumn 2009, Inbicon a subsidiary of DONG Energy started the construction of a demonstration plant in Kalundborg, Denmark to showcase the company's second-generation technology for large-scale production of ethanol from straw.

The Kalundborg plant (at the Asnæs Power Station) also demonstrates energy integration with a power station. Steam from the power plant cooks the straw, and residual biofuel from the ethanol plant is burned by the power plant. Since the cellolosic ethanol plant produces more energy than it consumes to convert the biomass, the end result is an energy surplus that brings down the cost for both plants and demonstrates the efficiency and financial viability of the Inbicon process

The demonstration used 4 tonnes of straw per hour, equivalent to 30,000 tonnes of straw per year. Danisco Genencor & Novozymes were pre-qualified as suppliers of enzymes. The output will be 4300 tonnes / 5400 m^3 of ethanol per year. The plant was designed to produce 11,100 tonnes of molasses (65%DM) per year, which is currently used for feed, but could in future also be used for bioethanol or biogas production

DONG Energy signed a contract with Statoil, to purchase the first five million litres of Inbicon’s bioethanol.

Model of Inbicon demonstration plant for production of cellulosic ethanol from straw

View at larger size >>

Clariant – sunliquid® cellulosic ethanol demo, Straubing and FP7 SUNLIQUID Project to develop a large-scale demonstration plant

In recent years, Clariant (formerly Süd-Chemie), a global leader in the field of specialty chemicals headquartered in Switzerland, has been developing the sunliquid® process for the production of cellulosic ethanol from agricultural residues, which is ready to market.

Planned development of a large-scale demonstration plan (~€225 million) is partly supported by the EC FP7 SUNLIQUID Project (€23 million) 2014-2018, including participants from Austria, Germany and Hungary, with Clariant as the Coordinator.

In December 2014 Clariant announced positive results from its fleet testing sunliquid with Mercedes-Benz, whose BlueDIRECT engines are already able to use E20. During 2014, test fleet vehicles were fuelled with sunliquid at the Mercedes-Benz site in Stuttgart-Untertürkheim. At the Haltermann plant in Hamburg the cellulosic ethanol is mixed with selected components to form the innovative fuel, the specifications of which reflect potential European E20 fuel quality.

On 20 July 2012, the sunliquid demonstration plant was officially commissioned in the Lower Bavarian town of Straubing. The plant replicates the entire process chain on an industrial scale, from pre-treatment to ethanol purification, serving to verify the viability of sunliquid technology on an industrial scale. On an annual basis, up to 1,000 tons of cellulosic ethanol can be produced at this plant, using approximately 4,500 tons of wheat straw. Other feedstocks are also to be tested at a later stage.

Clariant sunliquid® demonstration facility

View at larger size >>

The biofuel obtained using this process is manufactured on an energy-neutral basis and boasts greenhouse gas savings of some 95% – 5% being attributable to the logistics chain which is calculated as fossil-based. The production costs can compete with those of first-generation bioethanol.

Firstly the feedstock, for instance wheat straw, undergoes mechanical and thermal pre-treatment. This results in the lignin separating from the cellulose and hemicellulose chains, allowing the enzymes to split into sugar monomers during the next step. The enzymes used have been optimised to a high degree by the company and specifically modified for each type of feedstock and the relevant process conditions. This ensures particularly efficient hydrolysis, giving rise to high sugar yields.

As a result of process-integrated enzyme production, enzyme costs can be reduced to a minimum. To this end, a small portion of the pre-treated feedstock is channelled off from the main mass to serve as a basic source of nutrients for special microorganisms which produce the enzymes. These are therefore created whenever and wherever needed, with no costs being incurred for transport, storage or processing and without being dependent on enzyme suppliers.

Clariant sunliquid® integrated enzyme production

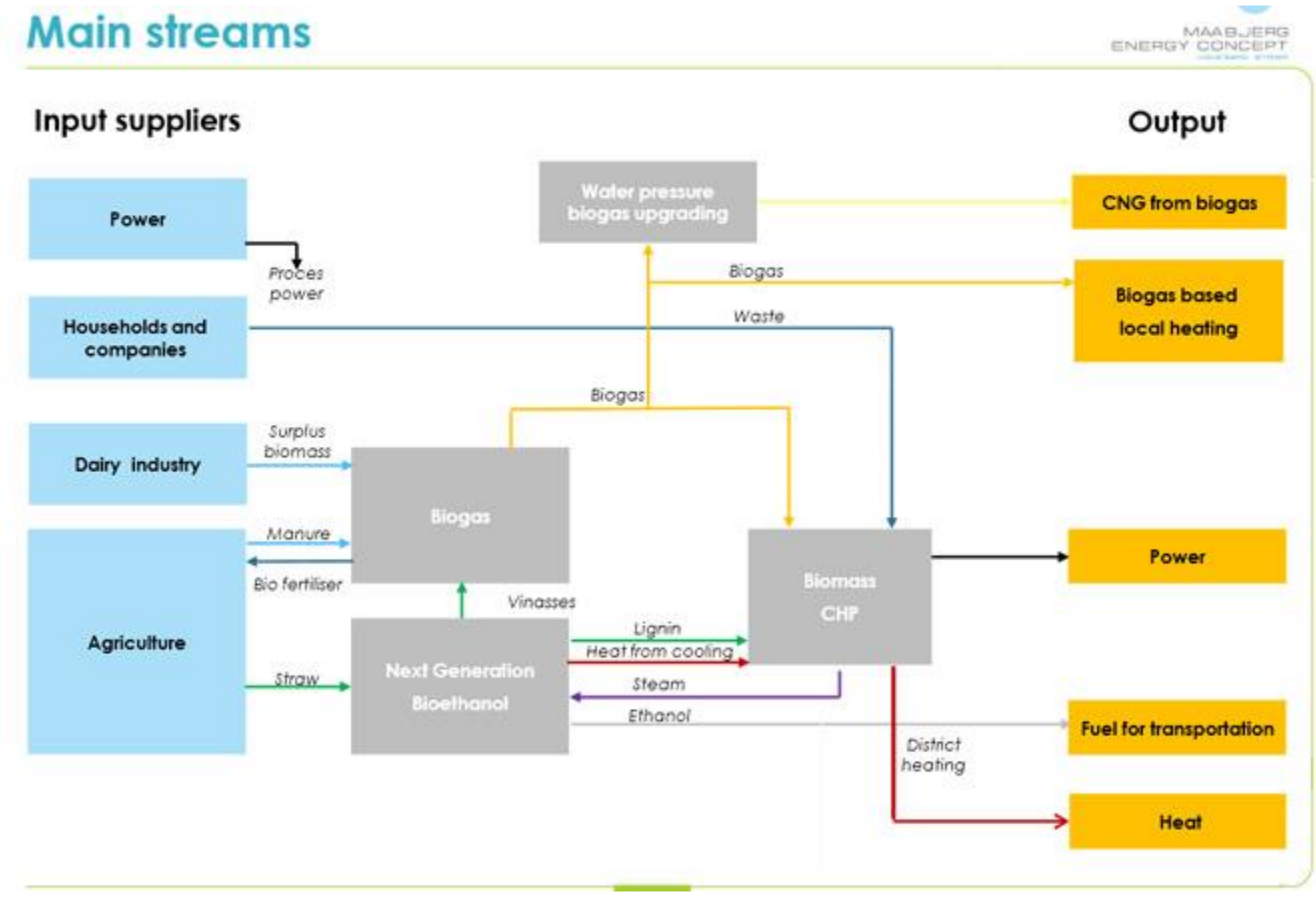
View at larger size >>

Following hydrolysis, any remaining solid matter (mainly lignin) is separated out and incinerated to generate energy, leaving a sugar solution containing C5 sugars in addition to glucose, a C6 sugar. The sunliquid process makes use of a special fermentation organism which simultaneously converts both C6 and C5 sugars into ethanol by way of a one-pot reaction, consequently producing around 50% more ethanol than comparable processes, which are only able to convert C6 sugars.

The final unit process consists of purifying the ethanol produced. This is usually carried out by means of classic distillation which, however, calls for high energy input. Clariant has developed an energy-efficient, adsorption-based separation process which, by comparison, offers energy savings of up to 50%. As a result of optimising this and other process design features, it is possible to generate the energy needed for the entire process from accumulated residue (mostly lignin). No additional fossil energy sources are required. The total ethanol yield lies between 20 and 25% (theoretical maximum: 27%).

Maabjerg Energy Concept, Denmark

View presentation on **[Maabjerg Energy Concept](#)** made by Niels Henriksen, DONG Energy at EBTP SPM6, October 2014



© Maabjerg Energy Concept / Dong Energy

In June 2014, it was announced that the Maabjerg Energy Concept project would receive 39 million under the second phase of NER300. The project involves commercial-scale production of second generation ethanol from plant dry matter in Holstebro, Denmark. The plant will produce 64.4 Ml of ethanol, 77,000 t of lignin pellets, 1.51 MNm3 of methane and 75,000 t of liquid waste annually, which will be transformed into biogas and injected into the national gas grid after its upgrade into methane. The process will use 250,000 t/year of locally sourced straw.

In May 2015, Dong Energy entered into an agreement to concerning divestment of the Måbjerg wase-to-energy CHP Plant to Struer Forsyning Fjernvarme A/S and Vestforsyning Varme A/S. The divestment does not change the plans for the biorefinery Maabjerg Energy Concept where the CHP plant will use the biofuel 'lignin' from the biorefinery. The realisation of the Maabjerg Energy Concept depends on whether the Danish government introduces a requirement stipulating that at least 2.5 % second generation bioethanol should be added to gasoline in order to "create a market for the sale".

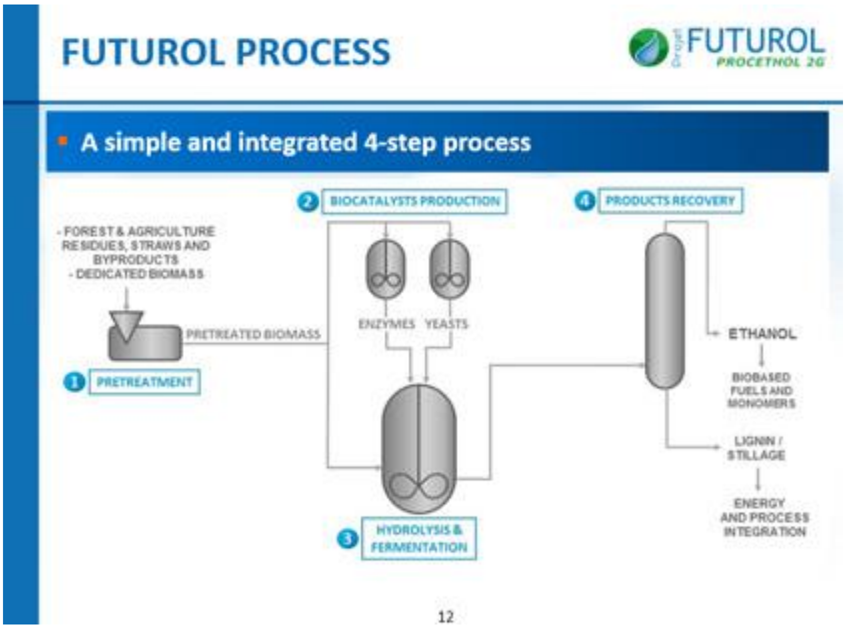
Futurol pre-industrial pilot plant for cellulosic ethanol production

Presentation on the FUTUROL pilot demonstration on cellulosic ethanol made by Frédéric Martel, Procethol at EBTP SPM6, Octobr 2014

In October 2011, the FUTUROL project announced the commissioning of its first pre-industrial pilot plant at Pomacle-Bazancourt, France. The plant, managed by Procethol 2G, validates research into second generation bioethanol carried out since 2008. The plant uses sustainable, local supply chains of feedstock including agricultural, forestry and other wastes. The plant on 1:1000 scale will produce 180,000 litres/year.

Futurol's one-pot process allows simultaneous enzymatic hydrolysis of biomass and C5/C6 sugars fermentation which provides:

- CAPEX and OPEX minimization via a simple and integrated process
- A unique synergy between biocatalysts
- Full C5 and C6 sugars conversion
- High ethanol yield and content



© Futurol Project: from presentation made at EBTP SPM6, October 2014

TMO Renewables Cellulosic Ethanol Technology

In October 2012 TMO Renewables Ltd signed a 25-year feedstock supply contract with Usina Santa Maria Cerquilho, and in April 2013 signed an MOU with the company to build and operate a bagasse-to-cellulosic ethanol plant in Brazil. A 10 MMgy plant was scheduled to go into production ~ 2014, followed by construction of a larger plant. TMO Renewables has been supported in this project by BB2E Ltd UK.

In August 2012, TMO Renewables signed a Memorandum of Understanding (MOU) with the authorities of Heilongjiang, China, to secure long term large volume biomass feedstock supply for future biofuel production facilities from Heilongjiang State Farm, the largest state owned farming corporation in China. In May 2011 TMO Renewables announced technology partnerships with COFCO and CNOOC New Energy Investment in China to produce ethanol from cassava.

In 2009, TMO Renewables Ltd celebrated the first year of operation of its Process Demonstration Unit (PDU), the UK's first Cellulosic Ethanol plant. The PDU processed a wide range of cellulosic feedstocks, to demonstrate the commercial viability of TMO's unique pretreatment and fermentation technology based on a strain of bacteria found in compost heaps.

In Spain, IMECAL is working with CIEMAT and FORD Spain on the PERSEO pilot plant to demonstrate production of bioethanol from MSW. These partners, as well as AVEN, are also operating the ATENEA pilot plant to demonstrate the conversion of citrus wastes into cellulolsic ethanol.

View ATENEA presentation from SPM2

View PERSEO presentation from SPM2

In Norway, Weyland has developed a version of the Strong Acid Process in which 98.5% of the acid can be recovered and recycled. Ethanol production by this method is competitive and virtually any type of cellulose containing feedstock can be processed. Coniferous wood, rice straw, corn cobs and bagasse have been successfully tested.

Chempolis biorefinery for cellulosic ethanol

In November 2014, Chemopolis signed a Memorandum of Understanding (MoU) with Indonesia International Institute for Life-Sciences (i3L) to jointly promote and develop commercial biorefinery projects. In October 2014, Chempolis signed a partnership agreement with Numaligarh Refinery Ltd for a 'bamboo ethanol' project in India. The planned facility will convert bamboo into cellulosic ethanol, furfural and acetic acid

Chempolis, Finland peviously invested €20m in a biorefinery to produce cellulosic ethanol (as well as biochemicals and fibres) from a wide range of non-food biomass, particularly straw and bagasse. The biorefinery was opened by the Finnish Prime Minister, Matti Vanhanen on 4 May 2010. The plant can process 25000 t/a of raw material, and will also be used for testing raw materials and producing samples of bioethanol. The biorefinery processes are designed to be self-sufficient (with virtually no GHG production) and low in water consumption. The Chemopolis formicobio™ technology combines selective fractionation and efficient enzymatic hydrolysis followed by rapid fermentation. The biosolvent is completely recoverable, and the process requires a low level of enzyme input. [Source: Chemopolis].

St1 / North Bio Tech Oy cellulosic ethanol plant, Kajaani, Finland

In summer 2014, North European Bio Tech Oy (NEB) announced it would be investing in a €40m 10m l/y cellulosic ethanol plant at Kajaani, Finland, using local sawdust as a feedstock. The plant will be implemented and operated by St1 Biofuels Oy. Construction is due to start in mid 2015, with production scheduled to start by mid 2016. In May 2015, Novozyme announced it would be supplying enzymes to the project, which uses ST1's propietary Cellunolix® process (incorporating steam explosion and enzymatc hydrolysis). The production capacity of the plant will be leased to North European Oil Trade Oy (a sister company to NEB).

Petrobras Novozymes agreement on 2G ethanol from sugarcane bagasse

In October 2010, Petrobras and Novozymes entered an agreement to develop a new route to produce second generation biofuel from sugarcane bagasse. The agreement covers the development of enzymes and production processes to produce second generation lignocellulosic ethanol from bagasse in an enzymatic process.

"The commercial potential of cellulosic ethanol in Brazil is substantial due to the great amount of sugarcane bagasse, a fibrous residue of sugarcane production, available in the country. Brazil is the world's largest sugarcane producer with an extraction capacity of approximately 600 million tons per year, currently yielding 27 billion liters (7 billion gallons) of ethanol. It is estimated that bagasse-to-ethanol technology can increase the country's ethanol production by some 40% without having to increase the crop area" [Source: Novozymes].

Conversion of MSW and cellulosic materials to methanol/ethanol via gasification and synthesis

Enerkem commercial-scale production of ethanol from MSW via gasification

In June 2014, Enerkem inaugurated its commercial MSW-to-ethanol facility in Edmonoton, Canada. Enerkem, through its affiliate Enerkem Alberta Biofuels, signed a 25-year agreement with the City of Edmonton to build and operate the plant that will produce and sell next-generation biofuels from non-recyclable and non-compostable municipal solid waste (MSW). Sorted MSW is shredded and then fed into a gasifier, where heat and pressure create syngas, which is then cleaned and conditioned prior to catalytic conversion to methanol and ethanol. With a production capacity of 38 million litres per year (10 million gallons per year), the Enerkem Alberta Biofuels facility is the world's first major collaboration of its kind between a metropolitan centre and a waste-to-biofuels producer.

Initially, the plant will convert syngas to methanol. In 2015, a methanol-to-ethanol conversion unit will be added.

In November 2014, Enerkem announced a partnership with AkzoNobel to exploe the potential for producing biochemicals from waste in Europe.

BioGasol

In April 2012 BioGasol announced a partnership with Sweetwater Energy Inc., who will integrate the BioGasol pretreatment technology (Carbofrac™) into its systems to maximise sugar production from non-food biomass.

The BioGasol process converts straw and other lignoicellulosic agricultural residues into ethanol, biogas, hydrogen and solid fuel with minimum use of water and low production costs. The process features a thermochemical pretreatment and a unique fermentation process based on proprietary microbes, which convert both C_6 and C_5 sugars to ethanol. In March 2009, the Danish Energy Agency (EUDP) awarded BioGasOl grant of 10.5 M Euros for the BornBioFuel2 demonstration plant on on Bornholm Island, using 27000 tonnes of dry feedstock to produce 7 Mio litres of ethanol per annum.

Pentoferm™ is BioGasol's proprietary technology that optimizes the utilization of C5 sugars. Pentoferm™ enables the conversion of C5 sugars into ethanol using the thermophilic bacterium

Pentocrobe™. With Pentoferm™ it is possible to achieve up to 40 percent higher ethanol yield from 1 tonne of biomass.

BioGasol previously formed a partnership wth Pacific Ethanol Inc to build the West Coast Biorefinery, in which BioGasol's technology was to be integrated with an existing corn-based bioethanol plant. The project was co-financed by the US DoE. The plant capacity was 5.8 tonnes of dry feedstock per hour (straw, hybrid poplar and cornstover), and aimed to produce 10 Mio litres of ethanol per year.

Range Fuels Two-Step Process

Also in the US, the Range Fuels Inc process uses heat, pressure and steam to convert cellulosic feedstocks (e.g. wood, grasses and corn stover) into syngas. In a second step the gas is passed over a proprietary catalyst to produce ethanol or methanol.

Two Cellulosic Ethanol projects to be funded under first NER300 call

BEST cellulosic ethanol project, Crescentino, Italy

On 18 December 2012 it was announced that the BEST project, Italy has been selected to receive counterpart funding of €28.4m under the first call for proposals of the NER300 funding programme for innovative low-carbon technologies. The Project concerns the design, construction and operation of an integrated biofuels demonstration plant in Crescentino (province of Vercelli, Piemonte region, Italy), at a distance of about 40 km from Turin. The Project envisages second generation technology conversion of lignocellulosic biomass from selected energy crops into ethanol. The Project proposes the cultivation and use of a new, autochthonous energy crop, Arundo donax (giant cane).The utilisation of wheat straw as an additional main lignocellulose biomass feedstock is also foreseen. The annual production capacity amounts to 51 Ml/year. Additionally, lignin will be produced as a by-product at some 165 t/year on wet basis.

CEG Plant Goswinowice, Poland

It was also announced that the CEG Plant Goswinowice, Poland has been selected to receive counterpart funding of €30.9m under the first call for proposals of the NER300 funding programme for innovative low-carbon technologies. The Project will demonstrate the production of second generation bioethanol from agricultural residues on a large commercial scale. The Project will make use of ~250000 t/year of wheat straw (75%) and corn stover (25%) sourced from the local agricultural area to produce 60 Ml/year of ethanol. The Project is located in Goswinowice in Poland close to an existing first generation ethanol plant. The Project plant and existing plant will be partially integrated. The co-products, lignin (70000 t dry matter lignin, moisture content 50-60%) and biogas (22.3 MNm3 biogas, 75% methane), will be sold as a fuel to the existing plant which in turn will provide steam for both plants.

[Source: SWD(2012) 224 final: NER300 - Moving towards a low carbon economy and boosting innovation, growth and employment across the EU]

EC-funded R&D on Cellulosic Ethanol

2G BIOPIC (Horizon 2020) - The purpose of the 2G BIOPIC project - Second Generation BIoethanol sustainable production based on Organosolv Process at atmospheric Conditions - is to demonstrate the performance, reliability and sustainability of the whole value chain of production of bioethanol from agricultural residues and wood. 2G BIOPIC (2015-2018) aims to design, construct and optimize a second generation (2G) demonstration plant with a capacity of 1 T of biomass/h. This 2G plant is based on the scale-up and optimization of bioethanol production from an already validated pilot plan scale (50Kg/h) achieved in a previous project (FP7 BIOCORE).

SUNLIQUID (FP7) aims to develop a large-scale lignocellulosic ethanol demonstration plan (~€225 million) with EC support of €23 million, 2014-2018. Includes participants from Austria, Germany and Hungary, with Clariant as the coordinator.

BABETHANOL - a collaborative research project between Europe and Latin America for the development of more sustainable processes for 2nd generation biofuel from lignocellulosic biomass (FP7 227498)

A short video presentation on the BABETHANOL project.

BABILAFUENTE- Project for the Production of 200 Million Litres of Bioethanol in Babilafuente (Salamanca) from Cereals and Lignocellulose (FP5 - NNE5 - 00685)

BIOCORE - Biocommodity refinery (FP7 BIOREFINE 241566)

BIO-HUG Novel bioprocesses for hemicellulose up-grading (FP5 - QLK3 - 00080) Further information

BIOLYFE Demonstrating large-scale bioethanol production from lignocellulosic feedstocks (FP7-239204)

DISCO Targeted DISCOvery of novel cellulases and hemicellulases and their reaction mechanisms for hydrolysis of lignocellulosic biomass (FP7)

FibreEtOH Bioethanol from paper fibres separated from solid waste, MSW (FP7 239341)

HYPEHigh efficiency consolidated bioprocess technology for lignocellulose ethanol (FP7 213139)

KACELLEKalundborg Cellulosic Ethanol Project (FP7). The aim is to bring the patented Inbicon Core Technology from a pre-commercial level to a near-commercial level, making the technology available in the market and attractive to investors (see also Inbicon Biomass Refinery below)

LED (Lignocellulosic Ethanol Demonstration) - Industrial solutions from a global bioethanol player

NEMO - Novel high performance enzymes and micro-organisms for conversion of lignocellulosic biomass to bioethanol

NILE- New Improvements for Ligno-cellulosic Ethanol (FP6 - 1982)

PROETHANOL2G - An EU-Brazil Collaborative project on Integration of Biology and Engineering into an Economical and Energy-Efficient 2G Bioethanol Biorefinery

Borregaard production of ethanol from spruce (SupraBio & EuroBioRef)

Cellulose producer, Borregaard, is involved in the development of biorefineries for the production of value-added products from wood, including bioethanol. Projects include supplying ethanol derived from spruce for 20 buses in Oslo. Borregaard was a key partner in the FP7 biorefinery projects Supra-Bio and EuroBioRef

The Borregaard demonstration biorefinery opened in April 2013, producing ethanol, lignin and added value biochemicals from wood, integrating a range of conversion technologies in a single facility.

FibreEtOH Project

The €16.26m collaborative FibreEtOH project ran from 2010-2013, with €8.65m support under FP7. The project was coordinated by UPM-Kymmenne. Other partners include AB Enzymes GMBH, Skandinavisk Kimiinformation AB, Poyry Forest Industry ConsulatingOY, Sila & Tikanoja OYJ, ST1 Biofuels, Roal and Valtion Teknillinen Tutkimuskeskus.

The innovative focus in the FibreEtOH project was to demonstrate for the first time globally in a commercial scale, a cost efficient paper fibre based ethanol production with high, > 70 % overall energy efficiency with high > 50 % green house gas reduction. 2nd generation ethanol production technology has been developed using mainly corn stover, straw or saw dust as raw material. So far reliable and cost efficient hydrolysis technology has been the bottleneck for large scale commercial success.

By using paper fibres separated from commercial and municipal solid waste or de-inking sludge at paper mills, the hydrolysis process was designed to be significantly easier as no pretreatment and special fractionation process was needed. The EtOH production cost was minimised by low price of the waste based raw material and the distillation steam compared to typical straw and wood EtOH production plants.

The results of the FibreEtOH project were published in Biomass and Bioenergy (Volume 46, November 2012, Pages 60–69). Ethanol and biogas production from waste fibre and fibre sludge – The FibreEtOH concept. The key results were as follows:

- Ethanol and biogas were produced in pilot scale
- Feedstocks were pulp and paper mill fibre sludge and waste fibre fractionated from solid recovered fuel
- Process was operated in continuous mode in high consistency conditions (substrate concentration 300 g kg^{-1}).
- Liquefaction of the materials with enzymes was fast without any pre-treatment
- Total ethanol yield of 48% was obtained with 27 h residence time

Enzymes for Cellulosic Ethanol production

A number of companies are developing enzymes for cellulose hydrolysis including Novozyme, Denmark, which produces cellulase and hemicellulase. In September 2012 Novozyme announced it was considering marketing a C5 yeast strain developed by Terranol, Denmark for use in advanced biofuel production (for example, from corn stover hydrolysate).

In June 2013, Direvo Industrial Biotechnology GmbH announced it has been granted US and European patents for 'polypeptides with cellobiohydrolase II activity'. These offer higher performance compared to currently available cellulase enzymes, says Direvo.

In 2009, Syngenta entered into a collaboration agreement with Proteus, France to develop CE enzymes.

Codexis works closely with Shell and Iogen on enhacing the efficiency of enzymes for cellulosic ethanol production.

Dyadic optimises C1 Platform Technology for the development of novel enzymes to convert biomass into fermentable sugars to produce cellulosic ethanol and butanol as well as chemicals, polymers and plastics. Dyadic is currently a party to non-exclusive license agreements with Abengoa Bioenergy New Technologies, Inc. and Codexis, Inc. Following a 4-year demonstration project between Dyadic and SEKAB-E Technology (see DISCO Project) a new enzyme for cellulosic ethanol production AlternaFuel CMAX™ has been succesfully developed.

Biométhodes has developed proprietary technologies within pretreatment and a unique enzyme solution for maximum cost reduction of ethanol production and valuation of all biomass compounds [Source: Biométhodes]. The company also aims to develop value-added applications for lignin. See also biohydrogen.

US Companies developing Cellulosic Ethanol plants and related technology:

Many of the companies developing cellulosic ethanol technology or demonstrations in the US are members of the Advanced Ethanol Council, which provides extensive information and data on the ethanol industry.

In July 2013, INEOS New Planet BioEnergy commenced commercial production at its 8M gallons-per-year cellulosic ethanol biorefinery at Vero Beach, Fla. This followed a $75 million loan guarantee from USDA. The plant also has a gross electricity production capacity of 6 MW. The feedstock for the process includes citrus and agricultural wastes, yard wastes and wood waste.

In September 2014, Poet-DSM Advanced Biofuels LLC commenced production at the $250m 'Project Liberty' cellulosic ethanol facility. The plant will produce 20 MMgy per year of cellulosic ethanol from corn stover and cob, and shares infrastructure with the adjacent 50 MMgy ethanol plant.

In May 2103, Canergy LLC announced that Chemtex/Beta Renewables technology would be used for a 25 MMgy cellulosic ethanol plant in Imperial Valley, California. Chemtex International Inc. has also received a conditional USDA loan guarantee to build a 20 MMgy cellulosic ethanol facility in eastern North Carolina using energy grasses as feedstock.

In December 2014, construction of the DuPont Cellulosic Ethanol LLC plant in Nevada, Iowa was nearing completion. The plant will produce 30MMgy of cellulosic ethanol from 590000 bales of corn stover. Murex LLC will market the ethanol. See Commercializing Advanced Renewable Fuel in Iowa for facts and figures.

Other examples of companies developing cellulosic ethanol technology include:

Cellerate, a collaboration between Syngenta and Cellulosic Ethanol Technologies LLC, a wholly owned subsidiary of Quad County Corn Processors. Cellerate enables corn kernel fiber to be converted into cellulosic ethanol, and the process technology can be readily added to existing ethanol plants as a bolt-on. In April 2015, Syngenta that Quad County Corn Processors has produced 1 million gallons of cellulosic ethanol using this technology. [Source: Syngenta 2014/2015].

In May 2013, American Process Inc. (API) announced investment from GranBio for cellulosic ethanol plants in the US and Brazil. API currently operates two demo plants in the US - the Alpena Biorefinery, and a facility in Thomaston, which uses API's 'American Value Added Pulping' AVAP process to convert a range of feedstocks to sugars.

Verenium (Vercipia). In September 2013, it was announced that Verenium would be acquired by BASF. In September 2010 BP Biofuels acquired the Verenium demonstration facilities in Jennings, LA, as well as cellulosic biofuels technology. In October 2012, BP announced that it has cancelled the planned construction of a commercial-scale cellulosic ethanol plant in Florida, and instead will focus on licensing its 2G technologies.

In January 2011, the USDA announced that "Coskata, Inc. received a letter of intent for a $250 million loan guarantee to construct and operate a cellulosic ethanol biorefinery facility. This 55-million gallon-per-year renewable biofuel project will use woody biomass to produce ethanol.

In Pontotoc, Miss., Enerkem Corporation received an $80 million loan guarantee to build and operate a biorefinery that will be capable of producing 10 million gallons of advanced biofuel (cellulosic ethanol) per year by refining some 100,000 metric tons of dried and post-sorted municipal solid waste through a thermo-chemical cellulosic process (see also Westbury demo below)." [Source: USDA].

California Ethanol & Power LLC Developing a facility able to produce 66 Mgy of ethanol, ~50 MW of electricity and 940M cubic feet of biogas, using sweet sorghum and sugar cane. The engineering will be led by Uni-systems do Brazil Ltda. Shell has signed a five-year offtake agreement for the electricity, biogas and ethanol [Source: CE&P October 2013].

Mascoma sold his Yeast Fermentation business to Lallemand Inc in 2014. Renmatix runs Mascomas plant in Rome.

ZeaChem Operates an existing 250,000 GPY integrated demonstration biorefinery, at the Port of Morrow, near Boardman, and hasin February 2012 received $12 from USDA to further develop/demonstrate its biorefinery systems.

GeoSynFuels developing demonstration of proprietary technology (5CS™ Process) to break down hemicellulose to 5 carbon sugar (xylose), leaving the cellulose (containing six carbon sugars) and lignin for power production. It is designed as a bolt-on platform for existing sugar cane or pulp mills. The benefits are lower Capex and Opex. In March 2014, GeoSynFuels acquired the demonstration plant assets of Western Biomass Energy, LLC.

Qteros

BlueFire Ethanol has developed commercial Concentrated Acid Hydrolyisis technology for conversion of cellulosic feedstock to sugars. BlueFire is currently in the process of developing two cellulosic ethanol facilities in Lancaster, California and Fulton, Mississippi. In October 2014, Bluefire announced an engineering, procurement and construction (EPC) contract for its 19 MMgy cellulosic ethanol plant in Fulton.

KL Energy Corp. is using its technology (based on a thermal-mechanical pretreatment process), in partnership with Petrobras, to convert sugarcane bagasse to ethanol. A demonstration plant has been operated in the US (exporting cellulosic ethanol to Brazil). The technology will be integrated in Brazil in future. KL Energy Corp. also aims to market its technology in the US and EU (France, Germany and Scandinavia) [Source: KL Energy Corp. website].

Abengoa Bioenergy - Constructing a commercial-scale cellulosic ethanol plant in Kansas due to start production in 2014.

Edeniq's Pathway™ enzyme platform combines the Cellunator™ and unique enzymes to produce cellulosic sugars. In January 2015, Edeniq announced it had secured $16m in funding to further commercialize it's technology which can increase efficiency of exising ethanol plants by 3-6%.

Previously in June 2012, Edeniq officially launched a Corn to Cellulosic Migration (CCM) pilot plant, which announced 1000 hours of continuous operation in May 2013.

Aemetis

Fiberight - Is developing commercial scale plants for conversion of MSW to ethanol

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POET Cellulosic Ethanol Pilot Plant, Scotland, SD, US, producing 20,000 gallons per year using corn cobs as feedstock. The $8m pilot plant is a precursor to the $200 million Project LIBERTY, a commercial-scale cellulosic ethanol plant that will begin production in 2011. View at larger size >>

Commercial Cellulosic Ethanol Plants in Brazil

Granbio Cellulosic Ethanol plant, Alagoas

Following a 20-month construction, Brazil's first commercial-scale cellulosic ethanol plant at São Miguel dos Campos, Alagoas, began production in September 2014, with current production capacity of ~22m gallons per annum. The cost of the plant was $190m with a further $75m spent on the co-generation system. The plant uses Beta Renewables / Biochemtex PROESA technoloy. Novozymes supplies the hydrolytic enzymes, and DSM yeasts are used for the fermentation.

In May 2013, BNDES provided a $149m loan to Bioflex Agroindustrial, a subsidiary of GranBio, for construction of the plant, which will convert bagasse and residual sugar cane straw into 2G ethanol. BNDES said "The use of straw and bagasse will allow industrial productivity of ethanol to reach around 10,000 liters per hectare, corresponding to an increase of up to 45 percent compared to current levels."

GranBio intends to build a new ethanol plant each year up to 2020 with a planned investment of US$1.7 billion.

Raizen / Iogen Cellulsoic Ethanol Plant

In December 2014, production commenced at the $100 million, 40 MMly Raízen Energia S/A commercial Cellulosic Ethanol plant at the Costa Pinto sugarcane mill. The 10MMgy plant, uses technology developed by Iogen Energy, a joint venture of Raízen and Iogen Corp, to convert bagasse into ethanol. Enzymes are supplied by Novozymes. Raizen plans to producing up to 1 billion liters of cellulosic biofuel from bagasse and cane straw by 2024.

Cellulosic Ethanol in Canada

In June 14, Enerkem inauguarated a commercial-scale MSW-to methanol/ethanol plant in Edmonton Canada.

VANERCO, a joint venture between Enerkem and GreenField, plans to develop a cellulosic ethanol plant at the GreenField ethanol plant in Varennes, Qubec. In September 2013 it was announced that the project will receive some initial funding from the SDTC NextGen Biofuels Fund.

In June 2012, Enerkem started production of cellulosic ethanol from waste at its pre-commercial demo facility in Westbury, Québec, which uses an innovative thermochemical conversion technology.

In January 2014 Iogen announced a new method to produce drop-in biofuels from biogas. It plans to introduce the technology (alongside ethanol production) at its CE plants to increase overall production efficiency. In November 2013, it was announced that construction had started on a 10MMgy facility in Brazil using cellulosic ethanol technology of Iogen Energy, a joint venture of Raízen and Iogen Corp.. On April 30, 2012 Royal Dutch Shell and Iogen laid off 150 employees at Iogen's headquarters in Ottawa. Plans for a 10 MMgy cellulosic ethanol plant in Manitoba were suspended.

Shell had previously worked with Iogen (and Codexis) and the federal government to get Canada's first commercial scale cellulose ethanol facility into production. Sustainable Development Technology Canada (SDTC), has been actively engaged in the transition of Iogen technology from development to commercialization.

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World's first filling station offering Cellulosic Ethanol - 10% blend from wheat straw.

Lignol Innovations ltd (a subsidiary of Lignol Energy Corporation, Canada) operates a Cellulosic Ethanol Development Centre in Vancouver, and is commissioning a pilot plant to produce bioethanol from lignocellulose (softwood, hardwood, agricultural residues). The technology is based on an ethanol-based organosolv process aquired from Repap Enterprises (bought by UPM Kymmene in 2000). Lignol has signed an agreement with the US DoE for construction of a commercial demonstration plant (up to $30m). The plant is being planned with Suncor Energy, and has a projected input capacity of 100 tonnes a day [Source: IEA Bioenergy].

Cellulosic Ethanol technology - Ongoing Research and Novel Pathways

In April 2015, Leaf Resources Ltd, Australia, launched Hybritech technology, based on it's Glycell pre-treatment process. Hybritch allows paper and pulp facilities to switch between pulp production and the production of cellulosic sugars, and is particularly suited to plants using the KRAFT process.

Xylome offers unconventional yeasts that can produce second generation ethanol (as well as biodiesel precursors) from cellulosic feedstocks. The company also modifies a range of unconventional yeasts for biosynthesis of advanced products. Unconventional yeasts have metabolic capabilities that go well beyond Saccharomyces in substrate utilization and product formation profiles (for example, those that are naturally able to ferment xylose and cellobiose).

Oklahoma State University Biobased Products and Energy Center (BioPEC) is developing hyprid gasification / fermentation pathways for production of ethanol, which it claims significantly lower the production cost of CE.

BE-Basic is developing a unique multi-purpose Bioprocess Pilot Facility BPF at Delft in the Netherlands, where companies, universities and knowledge institutions can investigate and learn how sustainable production processes respond to larger scales and how they can be scaled up. In January 2014 BPF announced it would be installing a prehydolysis system from Valmet.

In January 2014, French company Deinove announced the successful production of 9% ethanol from lignocellulosic feedstocks using *Deinococcus* bacteria in medium-sized (300 litre) bioreactors. The company now plans to develop the technology at industrial scale. The technology was developed through the Deinol project, which involved CNRS Montpellier and INSA Toulouse and the Tereos group (via its SYRAL and BENP Lillebonne subsidiaries). The Deinol project received €8.9m from the Strategic Industrial Innovation programme run by Oséo, the French state innovation agency. In November 2014, it was announced that Deinove had formed a partnership with Michigan State University to use its AFEX (ammonia-based pre-treatment) in production of cellulosic ethanol.

In February 2014, Aphios was granted US patents for its cellulosic biomass pretreatment method based on the Aosic process, in which "biomass is contacted with super fluids such as carbon dioxide with or without small quantities of polar cosolvents such as ethanol, both sourced from the downstream fermentation process. Pressure is released and fibers are made more accessible to enzymes as a result of expansive forces of super fluids (about 10 times those of steam explosion) and carbonic acid hydrolysis."

In February 2014, Leaf Energy, Australia, announced a succesful trial of Glycell Pretreatment Process, at the Andritz pilot plant, Springfield, Ohio. Leaf Energy is also working with Actinogen Ltd to exploit strains of Actinomycetes relevant to its technology.

Researchers at North Carolina State University are developing the use of protic ionic liquids, PILs, as a less-expensive method to remove lignin from cellulosic biomass.

In August 2013, US DOE Joint BioEnergy Institute announced the development of a 'one-pot' process for the ionic liquid pretreatment and saccharification of switchgrass.

Consolidated bioporcessing aims to simplify biofuel production pathways by integrating the steps of pre-treatment, hydrolysis and fermentation as far as possible. Companies working in this technology include Mascoma and Qteros.

The Qteros CBP platform leverages the natural advantages of the Q Microbe®, which produces virtually all the enzymes required to digest biomass into fermentable sugars and contains all pathways required for biomass conversion into ethanol. The result is a single-step conversion process that dramatically reduces the cost and complexity of producing cellulosic ethanol at commercial scale from a broad variety of non-food feedstocks [Source: Qteros].

Researchers at the University of Illinois have investigated the use of "switchable" butadiene sulfone in the presence of water as a potential pretreatment method to break down the cell wall in Miscanthus, and remove the lignin component. Subsequent recovery of the decomposition gases, reduces cost and environmental impact.

OSE0 (Strategic Industrial Innovation Programme), France awarded €8.9m to the €21.4m DEINOL project, which aims by 2014 to open up new pathways for lignocellulosic ethanol production in existing industrial installations, without the need for large additional capex. The OSEO award included Euro €6m to Deinove for the accelerated development of new biofuels production processes based on the bacteria *Deinococcus*. The other partners include CPBS (CNRS/University of Montpellier) and LISBP (INSA Toulose/CNRS/INRA),

Green Tech America is developing cellulosic ethanol technology using novel strains of yeast. The process is based on research by Laboratory of Renewable Resources Engineering (LORRE), Purdue University, which developed GM yeasts in the 1990s to convert glucose and xylose to ethanol.

In Austria, M-Real Hallein AG is developing a concept to produce bioethanol from wood sugars derived from sulfite spent liquor (SSL), a by-product of paper and pulp production.

In November 2009, Delft University published research on GM strains of *Saccharomyces cerevisiae* that have been engineered for use of acetic acid as an electron acceptor. The pathway would provide three major benefits for production of ethanol from lignocellulosic materials: elimination of glycerol, reduction of toxic acetic acid to ethanol, and increased ethanol yields. A patent was applied for and industrial partners were being sought to further invetigate the potential of the process.

Use of Lignin

The pretreatment processes described above breaks down lignocellulosic feedstocks into:

- hemicellulose, which is then hydrolysed by enzymes/acid to produce fermentable sugars for ethanol production
- lignin, the 'woody component'

Lignin has a number of potential uses, including:

- as a solid fuel
- as biofuel additives (e.g. conversion to oxygenated aromatics or esters)
- to add strength to concrete
- as an antioxidant
- to provide thermal protection to rubber

- for production of carbon fibre, asphalt mixes, plastics and polymers
- use as a paper sizing agent or board binder
- as a soil binder, as a dispersent for pesticide/herbicide applications, and similar agricultural uses

To improve the economics of cellulosic ethanol production in biorefineries, researchers are looking for ways to add value to lignin by conversion to other products (e.g. bio-oils containing aromatic compunds). Coversion technologies include use of solvents, hydrothermal depolymerisation, and super critical depolymerisation.

In 2015, The US National Renewable Energy Laboratory published a study in the journal *Energy and Environmental Science* on the conversion of lignin-derived compounds to adipic acid, which is used to produce nylon, plasticizers, lubricants, polyesters, etc.

In 2014, researchers at University of Wisconsin-Madison (funded by the Great Lakes Bioenergy Research Center), showed that high yields of the aromatics may be obtained by exposure of lignin to oxygen followed by treatment with a weak acid under mild conditions.

Reseachers at University of Tokyo have developed a technology using hydroxycyclopentadienyl iridium complexes as catalysts under hydrogen (dihydrogen) at atmospheric pressure to convert componens of lignin to aromatic chemicals [February 2015].

The University of Bath, UK has investigated ozonolysis in the presence of ethanol to depolymerise lignin, resulting in production of oxygenated aromatics. "Guaiacol, a potential antioxidant, was formed over short reaction times and was found to be completely miscible with low-sulphur petrol (ULSP), diesel, aviation kerosene and rapeseed methyl ester. The mainly aliphatic proportion of the bio-oil produced over 24h could be blended with the fuels replacing a maximum of 12-17wt.% of the hydrocarbon fuel." [Source: Renewable biofuel additives from the ozonolysis of lignin].

ETBE

Ethyl Tertiary Butyl Ether (ETBE) is produced from ethanol and isobutylene in a catalytic reaction. Blending with ETBE, improves the combustion characteristics of petrol, and ETBE is also more compatible with pipelines and engines than ethanol.

ETBE is produced from bioethanol (Bio-ETBE). Isobutylene is currently derived from fossil sources from either refining or from natural gas. ETBE provides improvements in air quality when blended into conventional gasoline. The EU maximum blending level specification for ETBE is 22% in E10 gasoline and 17.24% mass in E5 (equivalent to 2.7% mass of oxygen).

Bio-ETBE is extensively used in the EU in conventional vehicles and fuel distribution systems. This requires minimal investment in distribution system infrastructure. Bio-ETBE currently accounts for the majority of bioethanol destined for the EU gasoline market.

Tert-Amyl Ethyl Ether (TAEE) is also be derived from ethanol. Bioethers are also produced from biomethanol (e.g. MTBE, TAME).

Further information on ETBE and bioethers is available from the European Fuel Oxygenates Association

Biobutanol

Overview

Butanol is an alcohol that can be used as a transport fuel. It is a higher member of the series of straight chain alcohols with each molecule of butanol ($C_4H_{10}O$) containing four carbon atoms rather than two as in ethanol.

Butanol was tradionally produced by ABE fermentation - the anaerobic conversion of carbohydrates by strains of *Clostridium* into acetone, butanol and ethanol. However, cost issues, the relatively low-yield and sluggish fermentations, as well as problems caused by end product inhibition and phage infections, meant that ABE butanol could not compete on a commercial scale with butanol produced synthetically and almost all ABE production ceased as the petrochemical industry evolved.

However, there is now increasing interest in use of biobutanol as a transport fuel. 85% Butanol/gasoline blends can be used in unmodified petrol engines. It can be transported in existing gasoline pipelines and produces more power per litre than ethanol. Biobutanol can be produced from cereal crops, sugar cane and sugar beet, etc, but can also be produced from cellulosic raw materials.

Isobutanol ASTM standards

In October 2013, ASTM D7862 was announced for blends of butanol with gasoline at 1 - 12.5 % vol in automotive spark ignition engines. The specification covers three butanol isomers: 1-butanol, 2-butanol, and 2-methyl-1-propanol. The specification specifically excludes 2-methyl-2-propanol (that is, tert-butyl alcohol).

In December 2014, ASTM D7875, was approved: 'Standard Test Method for Determination of Butanol and Acetone Content of Butanol for Blending with Gasoline by Gas Chromatography'. The standard is primarily designed to ensure the purity of isobutanol manufactured for use as a fuel.

Commercial Development of biobutanol

A number of companies are now investigating novel alternatives to traditional ABE fermentation, which would enable biobutanol to be produced on an industrial scale. These are summarised below.

The two leading technology developers in this area, Gevo and Butamax, have been involved in a patent dispute. Up-to-date information on the respective positions of each company is available from their websites. The information presented on this page was believed to be accurate at the time of writing. However, neither the members of the European Biofuels Technology Platform, the Secretariat, the European Commission, nor any other individual or organisation involved with this activity, accept responsibility or liability whatsoever with regard to the material on this web page or the use to which it is put.

Gevo

Gevo white paper on iso-butanol

On 24 May 2012, Gevo commenced production at the world's first commercial-scale 18 MGPY biobutanol plant, developed by conversion of the former Agri-Energy corn ethanol plant in Luverne. A number of technical challenges have been overcome (e.g. improved batch turnaround times, avoidance of infections, etc) in the first months of operation, and the company was on target to produce 50,000 to 100,000 gallons per month of isobutanol by the end of 2014 [Source: Gevo]. The company reports that is getting close to the efficiency required for fully commercial operation. In March 2015, Praj Industries Ltd. signed a MOU to become a Gevo licensee.

In December 2013, Gevo announced that the U.S. Army succesful trials of a 50/50 blend of Gevo's ATJ-8 fuel in a Sikorsky UH-60 helicopter. The use of 16% isobutanol in UL 87A pumps has also been approved by Underwriter Laboratories, with no need for any equipment modification.

In September 2009, Gevo, Englewood, CO announced that Gevo Integrated Fermentation Technology (GIFT™) will be used in an ICM demonstration plant in St. Joseph, Missouri to produce one million gallons of biobutanol per year by retrofitting an existing ethanol plant. The process can utilise much of the existing ethanol production system, but uses cellulosic yeast strains engineered to produce butanol instead of ethanol. In 2009, Gevo entered a licensing agreement with Cargill granting the company exclusive rights to use Cargill's host organisms in Gevo Integrated Fermentation Technology. Total has also reportedly invested in Gevo. This technology built upon research by James Liao at the University of California, who developed E.Coli strains with genes coding for 2 enzymes that converted keto acides into aldehydes, and aldehydes into 1-butanol. When further manipulated, the microbes were able to produce butanol at much higher efficiencies, suitable for industrial production. In 2008, Gevo acquired an exclusive license to commercialize Liao's technology

Butamax Advanced Biofuels

Butamax Advanced Biofuels Fact Sheet

In October 2013, Butamax™ Advanced Biofuels LLC, and Highwater Ethanol LLC, a leading producer of first generation ethanol, commenced a retrofit of Highwater's ethanol plant in Lamberton, Minnesota for the production of biobutanol. In August 2014, phase one of the retrofit was completed, with the implementation of a proprietary Butamax technology to removes corn oil and prepare corn mash for fermentation.

Butamax and Highwater have entered into definitive agreements for license of Butamax's patented corn oil separation technology, which is an integral part of a full retrofit to biobutanol production.

In April 2012, Butamax entered into collaboration with leading biofuels engineering and construction company Fagen Inc. for commercial-scale biobutanol production (via retrofit of ethanol plants) using Butamax technology.

In December 2011 Butamax™ Advanced Biofuels announced agreement on commercialization principles with Highwater Ethanol, the first entrant to the Butamax Early Adopters Group [Source: Butamax™ website].

In June 2006, DuPont and BP formed a partnership to develop new biobutanol production technology using lignocellulosic feedstocks. In July 2009 the partnership was cleared to take over the US company Biobutanol LLC. In 2009, BP and DuPont formed Butamax™ Advanced Biofuels, Wilmington. Butamax's business model is to offer current ethanol producers proprietary biobutanol technology to permit improved biofuels growth and plant profitability.

In November 2009, BP and DuPont announced the formation of Kingston Research Ltd and the establishment of a £25 million advanced biofuels research centre in Hull for demonstration of biobutanol technology (which was scheduled to become operational in 2010).

The Abengoa method for production of butanol via catalytic condensation

The Abengoa production method involves catalytic condensation of ethanol to produce butanol through the Guerbet ($2CH_3$-CH_2OH◊CH_3- CH_2-CH_2-CH_2OH + H_20) reaction. The company has developed and patented a catalyst that enables the manufacture of biobutanol competitively. In November 2013, Abengoa announced that it has produced butanol with 99.8% purity and plans to start commercial-scale produciton of butanol in 2015.

The process allows a butanol plant to be built as an 'add on' to an existing commercial ethanol plant, enabling the production of butanol without having to halt the ethanol production process

Green Biologics

In the UK, Green Biologics has developed butanol-producing GM microbial strains and will integrate these into a novel fermentation process. This technology advance should result in a step change in the economic viability of the fermentation and enable the large scale production of Green Biologics' Butafuel™ product.

In January 2015, Green Biologics announced it has raised $76m towards acquisition and conversion of a 21 MMgy plant (Central MN Ethanol Co-op) based in Little Falls, Minnesota. Initially the facility will continue to produce ethanol, but aims to start production of of n-butanol and acetone in 2016.

In January 2012, Green Biologics Limited announced a merger with butylfuel™ Inc., US. The new company will operate under the Green Biologics name with headquarters in the UK, but with a strong operational presence and commercial focus in the US contributed by Green Biologics, Inc. [Source: Green Biologics]. Previously, Green Biologics was also involved in biobutanol development in India and China.

Cobalt Technologies

In April 2013, it was announced that Cobalt Technologies, Naval Air Warfare China Lake Weapons Division, Show Me Energy Cooperative and NREL will cooperate in a $2.5m pilot plant for conversion of 'switchgrass butanol' to military-grade jet fuel. In March 2012 it was announced that Albermale would manufacture biojet fuel from butanol, provided by Cobalt, using NAWCWD's alcohol to jet technology. Cobalt and Rhodia have formed a partnership to develop a demonstration plant in Brazil to convert sugarcane bagasse and other non-food feedstocks into biobutanol.

Other developments and demonstrations in butanol production

Other companies developing butanol technology include Tetravitae Bioscience, and METabolic EXplorer, France.

Global R&D on production of butanol and use as a transport fuel

The USDA ARS has carried out studies showing that barley straw and corn stover can be converted to butanol with high efficiency via Separate Hydrolysis, Fermentation and Recovery (SHFR) or by Simultaneous Saccharification, Fermentation and Recovery (SSFR). Gas stripping can be used to recover high yields of butanol from the SSFR process [Source, Quereshi et al, ARS Bioenergy Research Unit]. See also Closing In on Butanol for Biofuel.

Butalco GmBH, Switzerland is developing new production processes for biobutanol based on genetically optimised yeasts together with partners in downstream processing technologies.

Optinol has developed a "patented non-GMO clostridium strain that naturally and prolifically favors the production of butanol, without acetone or ethanol". The technique has been developed by researchers at Louisiana State University, US. Optinol says the method can produce butanol at cost parity with bioethanol.

In August 2013, The United States Department of Agriculture (USDA) awarded Microvi Biotechnologies a grant to "develop a breakthrough technology to dramatically improve the yield and performance of biobutanol processes. The technology overcomes toxic and inhibitory effects on butanol producing microorganisms, a major bottleneck in scaling existing biobutanol processes." [Source: Microvi website].

The Wass Research Group, University of Bristol, UK, is developing improved catalysts with yields of 95% offering lower-cost conversion of ethanol to butanol, and potentially enabling ethanol producers to avoid high retrofit costs. Researchers now plan to scale-up the current lab technology as a first step towards commercialisation [Ref: Catalytic Conversion of Ethanol into an Advanced Biofuel: Unprecedented Selectivity for n-Butanol, Prof. Duncan F. Wass etal, Angewandte Chemie International Edition, Volume 52, Issue 34, pages 9005–9008, August 19, 2013].

University of Michigan is developing a method for butanol production from cellulosic plant material using a combination of *Trichoderma reesei* and *E. coli* in a bioreactor. See 'Design and characterization of synthetic fungal-bacterial consortia for direct production of isobutanol from cellulosic biomass', *Proceedings of the National Academy of Sciences* [19 August 2013].

Archive 'research notes' on biobutanol production

It was reported that State corporation, Russian Technologies, will begin construction of a biobutanol factory in the Irkutsk region in spring 2011. The factory will use wood chips and other timber byproducts [Source: Moscow Times].

In the 1980s, hydrolyzates of lignocellulosic material were used to produce butanol on an industrial scale in Russia, and the processes developed have also attracted renewed interest from butanol researchers (the technology pathway for the new biobutanol factory was not mentioned in the news release).

In November 2009, researchers at UCLA announced that modified strains of *Synechococcus elongatus* could produce isobutyraldehyde and isobutanol directly from carbon dioxide [Source: Nature Biotechnology 27].

Research was also being carried out into the production of 2,3 butanediol (a potential biofuel) from agricultural residues (e.g. hydrolysis of hemicellulose-rich fractions by *Trichoderma harzianum* followed by fermentations using *Klebsiella pneumoniae*). Improved fermentation efficiency was one of the focuses of the FP7 SUPRABIO project.

Various biobutanol researchers are working with modified *Clostridium* strains.

Hydrolysis of cellulosic raw materials prior to butanol conversion potentially offers greatly increased yields. In research published by the USDA in 2007, wheat straw was hydrolyzed to lignocellulosic component sugars (glucose, xylose, arabinose, galactose, and mannose) prior to their conversion to butanol, by *Clostridium beijerinckii* P260. The rate of production of wheat straw hydrolysate to butanol was 214% over that from glucose.

Ongoing genetic research focused on 'gene knock-out' systems in *Clostridium* strains, whereby the enzymes that catalyse competing reactions (which produce Acetone, Ethanol, etc) are 'removed'.

Research into the ABE fermentation process has addressed issues of end-product inhibition and control of phage infection, but this technology has now been superceded by more advanced biotechnology, which are now being demonstrated at commercial-scale (as described above).

Biogas/Biomethane for use as a transport fuel

Contents

Overview

Production of biogas

Biogas is a mixture of biomethane CH_4 (65-70%) and CO_2 (30-35%) and small amounts of other gases. It is created by anaerobic digestion of organic wastes such as sewage, manure, food wastes, landfill, etc. This is an established technology. After removal of contaminants, biomethane is the same as natural gas, and can be used as a transport fuel in the form of Liquid Natural Gas (LNG) or Compressed Natural Gas (CNG).

Bio-SNG (Bio Synthetic Natural Gas) is produced by gasification of lignocellulosic (woody materials). A number of Bio-SNG demonstration projects are discussed on the Bio-SNG page of this website.

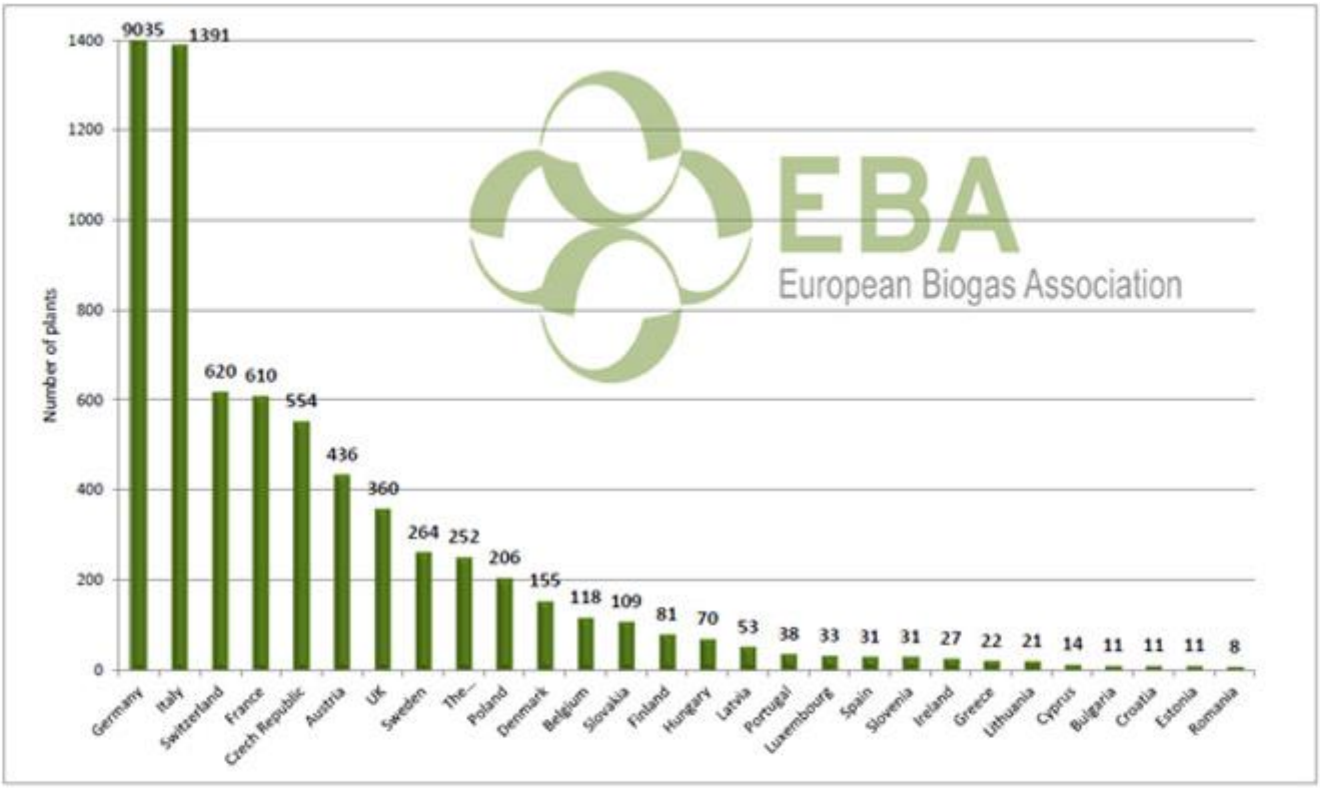
Biogas may also be produced form lignocellulosic feedstocks, such as straw, following pre-treatment with steam and enzymes. See VERBIO straw project.

Anaerobic Digestion technology is well established, hence biogas is often categorised as a 'first generation' biofuel. However, biogas derived from organic wastes does not compete with food production, and is considered to be sustainable.

Biogas production statistics for Europe

The latest EurObserv'ER Biogas Barometer report estimates about 13.4 million tonnes oil equivalent (m toe) of biogas primary energy were produced during 2013 - 1.2 m toe more than in 2012 representing a 10.2% growth.

The latest news and statistics on biogas production and use in Europe are available from the European Biogas Association website. In 2013, there were over 14500 bigas plants in Europe with an installed capacity of 7857 MW [Source: EBA website].



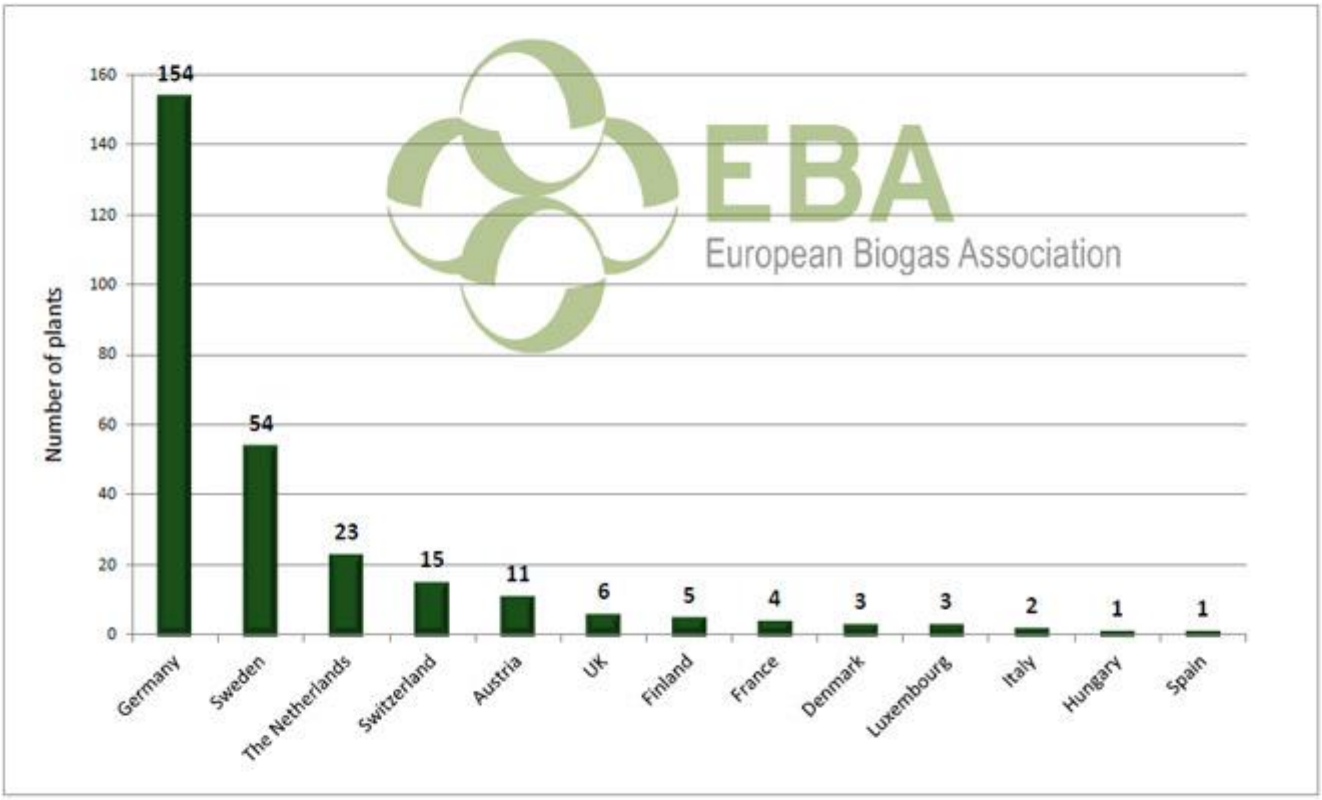
14 563 biogas plants in Europe with total installed capacity of 7 857 MWel (2013)

© Copyright 2014 European Biogas Association

In 2013, the fastest growth was seen in Central Europe: Hungary, the Czech Republic, Slovakia and Poland where an increase of 18% in the number of biogas plants in the region was recorded. Biogas plants in UK, France and Sweden, continue to develop at a steady. However, there are concerns over foreseen changes in support schemes across Europe. The Czech Republic and Cyprus have already ceased support for biogas plants, while German and Austrian biogas plant operators are facing local caps [Source: EBA 2014].

Biomethane production statistics

Production of biomethane (cleaned biogas, which is equivalent to natural gas) is also increasing in Europe. In 2013 there were 282 plants with a total annual production of 1.303 billion m^3. The number of biomethane filling stations doubled in 2013 with 10% of the total produced biomethane in Europe now used in transport [Source: EBA 2014].



282 biomethane plants in Europe
producing 1.303 billion m^3 of biomethane annually (2013)

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Use of biomethane in transport

Developing use of biomethane for transport is the focus of several projects such as BIOMASTER, MADEGASCAR, GasHighWay, BioGas Max, Urban Biogas, Green Gas Grids and Baltic Biogas Bus, which aim to increase its use in the market.

View presentations from the Final conference of Green Gas Grids, Urban Biogas and BIOMASTER

Biomethane for transport was also one of the options supported by the European Green Cars Initiative (a €5 billion PPP boost to the European car industry).

Biogas is used globally in waste to energy plants, and is increasingly being converted to natural gas for injection into pipelines or use in vehicles. For example, in the US, Waste Management Inc. operates 2 plants in California and Ohio (with a third announced in October 2013) to convert landfill gas to liquified natural gas. Waste Management also produces over 500 MW of electricty from biogas, and its subsidiary Wheelabrator Inc. has a capacity of almost 670 MW. Waste Managment also uses bioCNG to power a fleet of 100 trucks.

In March 2014, Waste Management Inc., Ventech Engineers International LLC, NRG Energy Inc. and Velocys plc formed a joint venture to produce renewable fuels and chemicals from biogas and natural gas using smaller-scale gas-to-liquids (GTL) technology. The joint venture's first facility will be at East Oak, Oklahoma. Velocys, will supply the Fischer-Tropsch reactor and catalyst.

Demonstrations on biogas production in Europe

VERBIO Straw to biogas project, Germany, to be supported under the NER300 first call

On 18 December 2012 it was announced that VERBIO Straw project, Germany, has been selected to receive counterpart funding of €22.3m under the first call for proposals of the NER300 funding programme for innovative low-carbon technologies. The Project will be built as an extension to an existing ethanol-biogas plant in Schwedt, Germany, to produce biogas. The Project will have a design capacity of 25.6 Mm3(S) of biogas containing 12.8 Mm3(S) of methane and make use of 70000 t/year of straw. The process comprises raw material handling, biomass pre-treatment of biomass by steam and enzyme successively, production of biogas by anaerobic fermentation, and biogas post-treatment. The produced gas will be cleaned to natural gas quality and fed into the grid. The Project is planned to be located in a refinery site of PCK Raffinerie GmbH (Refinery Site) and it benefits from the existing site infrastructure.

[Source: SWD(2012) 224 final: NER300 - Moving towards a low carbon economy and boosting innovation, growth and employment across the EU]

EC Projects related to use of biomethane in transport in Europe

- BIOSURF
- BIOMASTER
- BioWALK4Biofuels
- MADEGASCAR
- GasHighWay
- FaBbiogas
- BioGas Max
- BIOGASFUEL
- Urban Biogas
- Green Gas Grids
- Baltic Biogas Bus

BIOSURF

BIOSURF is an EU-funded project under the Horizon 2020 programme. The BIOSURF consortium consists of 11 partners from 7 countries and strives to increase the production and use of biomethane (from animal waste, other waste materials and sustainable biomass), for grid injection and as transport fuel, by removing non-technical barriers and by paving the way towards a European biomethane market. BIOSURF intends:

- To develop a value chain analysis from production to use depending on the territorial, physical and economic features (specified for different areas, i.e., biofuel for transport, electricity generation, heating & cooling);

- To analyze, compare and promote biomethane registering, labelling, certification and trade practices in Europe, in order to favor cooperation among the different countries and across border markets on the basis of the partner countries involved;
- To address traceability, environmental criteria and quality standards, so aiming to reduce GHG emissions and indirect land-use change (iLUC), to preserver biodiversity and to assess the energy and CO2 balance;
- To identify the most prominent drivers for CO2-emissions along the value chain as an input for future optimization approaches; and
- To exchange information and best practices all along Europe concerning biomethane policy, regulations, support schemes and technical standards.

[Source: European Biogas Association].

BIOMASTER

The BIOMASTER Project (supported by Intelligent Energy Europe) aims to engage with people and processes to enable a significant breakthrough in the uptake of biomethane for transport. The four participating regions in BIOMASTER, Malopolska Region (Poland), Norfolk County (United Kingdom), Skåne Region (Sweden) and Trentino Province (Italy), are working together to promote biomethane production, its grid injection and use for transport. They are undertaking a joint initiative involving all these key components of the biomethane chain, stimulating investment, lobbying to remove non-technological barriers and mobilising action for uptake.

View Reports, newsletters and documents on BIOMASTER

BioWALK4Biofuels: Use of macroalgae for biogas production

The FP7 project BioWALK4Biofuels aims to develop an innovative system for the treatment of biowaste and use of GHG emissions to produce biofuels, through the use of macroalgae.

BIOGASFUEL

The Eureka BIOGASFUEL project is developing a dual-fuel supply system for diesel engines using alternative fuel. The research programme on fuel will assess the possibility of using biogas as a fuel for compression ignition engines of non-road vehicles and machines used in agriculture.

FaBbiogas

The objective of the IEE project FaBbiogas is to elaborate a solid information base on FaB (Food and Beverage) waste utilisation for biogas production and to prove the efficiency and feasibility of FaB waste-based biogas implementation projects. The EU project FABbiogas (Intelligent Energy Europe) project aspires to change the mindsets of all stakeholders in the waste-to-energy chain by promoting residues from FAB industry as a new and renewable energy source for biogas production. Project outputs will support the diversification of energy sources within FAB companies, leading to wide-spread valorization and efficient integration of FAB residues into energy systems and boosting the realization of a growing number of biogas projects in Austria, Czech Republic, France, Germany, Italy and Poland.

Other EU and global reseach on biogas production and use in transport

Pretreatment of agricultural residues for enhanced production of biogas

Researchers at the Fraunhofer Institute IKTS, Germany, have developed the first-ever biogas plant to run purely on agricultural wastes. This demonstrates that pretreatment with enzymes can greatly increase biogas yields from cellulosic residues such as corn stalks.

In China, 3 pilot facilities have been built to demonstrate the production of biogas from rice straw pretreated with Sodium Hydroxide. With 23 day anaerobic digestion at mesophilic temperature of 35°C, rice straw pretreated with 10% NaOH at 20°C for 24 hours had the biogas yield of 0.6 L /g VS, 50% higher than the biogas yield from untreated straw. After enzymatic hydrolysis using cellulase from *Trichoderma reesei* ATCC 26921 and cellobiase from *Aspergillus niger*, the pretreated straw had the reducing sugar yield of 298 mg glucose/g VS, 185% higher than the untreated straw (Source: Dong Yang et al, published April 2009 American Society of Agricultural and Biological Engineers)

MagneGas™ technology

In the US, MagneGas has developed a technology to produce a mix of hydrogen and carbon monoxide from sewage and other liquid organic wastes using a patented technology called Plasma Arc Flow™, based on flowing the target liquid waste through a submerged electric arc between two electrodes. The arc decomposes the liquid molecules into atoms and forms a plasma around the tips of the electrodes at about 10,000°F / 5,500 C. The Plasma Arc Flow moves the plasma away from the electrodes and controls the formation of MagneGas that rises to the surface for collection. MagneGas is composed of hydrogen (55-65%), carbon monoxide (30-35%), carbon dioxide (1-2%), water vapor (2%), and trace gases (0.5-1%). The gas mixture can be used in a similar way to natural gas or can be co-combusted with existing hydrocarbon fuels.

Small-scale biogas production and CHP

Biogas can be produced via anaeobic digestion of farm or food processing wastes, and converted to heat and power on site. For example, in Europe companies such as ENER-G offer small-scale CHP (4kWe to over 10MWe) from biogas, with around 170MWe currently installed (May 2015).

Further links on biogas R&D&D and use in transport in Europe and globally

The following links provide further information on EC R&D&D on Biogas production and its use as a transport fuel:

European Biogas Association

NVGA Europe (Natural Gas Vehicle Assocation) - promoting the use of Bio-CNG, LNG and L-CNG

Farmagas

Biogas Regions

UK Anaerobic Digestion and Biogas portal

Biomethane Transport Forum UK

Biogas as a Road Transport Fuel Report

IEA Task 37 - Energy from Biogas and Landfill Gas

Biogas Upgrading to Vehicle Fuel Standards and Grid Injection

Use of natural gas as a transport fuel in Europe

Gas is widely used as a transport fuel in many European countries, notably Italy, which boasts 650,000 gas powered vehicles. Sweden is a world leader in upgrading and use of biomethane for transport, and has many 'biogas vehicles', including private cars, buses, and even a biogas train and a biogas powered touring car team.

The Netherlands is also expanding it's use of natural gas vehicles, and in September 2010 opened its 50th CNG filling station.

In February 2014 Cambi AS inaugurated a facility near Oslo to convert 50,000 tonnes of food waste to biogas, and produce LNG as a transport fuel for a local bus fleet. The biogas liquefaction plant was delivered by Wärtsilä Corporation and will produce fuel for 135 buses. The plant is operated on behalf of EGE (Waste-to-Energy Agency) and the City of Oslo.

New techniques are being developed to increase the methane content in 'product gas', so that it is suitable for direct injection into the grid. For example **ETW Energietechnik** in Germany, which uses Pressure Swing Absorption (PSA) technology developed by Schmak Carbotech.

In December 2013, the UK National Grid and Future Biogas announced an £8m anaerobic digestion project at Lindholme. The system will convert 35,000 metric tons of biomass into 12,000 cubic metres of biomethane for injection into the natural gas network. In February 2014, Iona Captial and Scotia Gas Networks announced an investment in a joint venture Keithick Biogas, the first biogas-to-grid project in Scotland, UK.

To promote the potential of biomethane as a transport fuel, E.ON has entered the 2009 Swedish Touring Car Championship (STCC) with two gas-driven Volkswagen Sciroccos. E.ON is Sweden's leading player in biogas. The company produces biogas, builds refueling stations and sells biogas. View at larger size >>

Liquefied biogas as a transport fuel in Sweden

In Summer 2012, a new liquefied biogas plant in Lidköping, Sweden, started operation. The plant produces transport fuel for cars, trucks and buses, in both gaseous and liquefied form, and is run by Lidköping Biogas AB, owned by Göteborg Energi AB and the Municipality of Lidköping. Swedish Biogas International Lidköping AB owns and operates the biogas production plant.

View video presentation on Sweden's first plant for liquefied biogas

Liquid biomethane from landfill to fuel commercial delivery vehicles in the UK

The UK's largest retailer, Tesco, is commissioning 25 Iveco EcoDaily light commercial vehicles fuelled by sustainable liquid biomethane for its online retail and delivery service tesco.com. The fuel is made by UK company, Gasrec (the first commercial producer of Liquid Biomethane in Europe), and is created by extracting naturally occurring methane from organic waste in landfill sites and converting it to a high quality, clean fuel. [Source: Gasrec].

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In the UK, the University of East Anglia (UEA) Low Carbon Innovation Centre (LCIC) and Hardstaff Group (Nottingham, UK), have modified a standard Optare Solo single-deck diesel midibus from the Anglian Bus fleet. Originally powered entirely by diesel, the Mercedes-Benz engine has been adapted to run for 60-80 per cent of the time on biomethane.

Biopropane

In September 2014, Neste Oil announced plans to build a biopropane unit at its refinery in Rotterdam. In addition to the unit itself, the investment will include storage tanks and pipework. The project will start immediately and the plan is to begin sales of biopropane at the end of 2016. The total value of the investment is approximately EUR 60 million.

The new unit will purify and separate biopropane from the sidestream gases produced by the refinery. The process will increase the added value of this sidestream significantly, as the gas in question has been sold as fuel for power plant use up until now. When the new unit is complete, biopropane production is expected to total 30,000-40,000 t/a. Biopropane has a comparable set of properties to fossil propane and is suitable for use in existing liquefied petroleum gas (LPG) applications [Source: Neste Oil].

Sustainability of biomethane

Methane Slip and certification

If methane is accidentally released into the atmosphere, it is much more damaging than carbon dioxide as a GHG. In 2008, the Naturemade certification system was initiated in Switzerland to guarantee the ecological quality of the biomethane injected into the grid. To qualify, the emission of biomethane (also known as 'methane slip') must not exceed 1% of the total biomethane generated by a plant [Source: BioGas Max].

Thermochemical conversion

Biomass to Liquids (BtL)

Introduction

The term Biomass to Liquid BtL is applied to synthetic fuels made from biomass through a thermochemical route. The objective is to produce fuel components that are similar to those of current fossil-derived petrol (gasoline) and diesel fuels and hence can be used in existing fuel distribution systems and with standard engines. They are also known as synfuels.

Biomass is pretreated and then converted to synthesis gas via gastification. The resulting syngas is then cleaned prior to conversion to liquid biofuels, typically via Fischer Tropsch or the Mobil Process outlined below.

Although the individual steps for production of BtL are well known (and have been demonstrated successfully at industrial scale), integrating the various technologies for commercial production of BtL has proved challenging. In recent months some promising industrial scale demonstration projects have been cancelled due to uncertainty surrounding the regulatory environment for advanced biofuels in Europe. However, R&D&D on Biomass-to-Liquid continues, as outlined below.

Note: Some European demonstration projects on gasification have been discontinued in recent months for various reasons, however summary information on the 'project history' and technology developed is retained on this page for reference purposes.

BtL demonstration projects in Europe

BA GreenSky project shelved, citing lack of government support

On 6 January 2016, British Airways announced that it has been forced to shelve its GreenSky project to create 16m gallons of jet fuel from waste every year, partly due to a lack of government support [Source: The Guardian, UK]. British Airways planned to use 600,000 tonnes of MSW (collected in London) to produce over 50000 tonnes of biojet fuel and 50000 tonnes of biodiesel annually. The GreenSky project was to have used Solena's Plasma Gasification (SPG) technology, which can process 20-50% more waste than conventional gasification technologies, and Velocys technology for production of the jet fuel.

The BioTfuel BtL demonstration project

BioTfueL is a joint project launched by five French partners and Uhde. BioTfueL aims to integrate all the stages of the BTL process chain and bring them to market. This involves the drying and crushing of the biomass, torrefaction, gasification, purification of the synthesis gas and its ultimate conversion to second generation biofuels using Fischer-Tropsch synthesis.

The project will use Uhde's proprietary PRENFLOTM™ gasification process with direct quench (PDQ). The procees can utilise a wide range of feedstocks, allows high energy efficiency and enables very pure synthesis gas to be produced.

The overall budget for the BioTfueL project is 112.7 million euro. The project includes the construction and operation of two pilot plants in France to produce biodiesel and biokerosene based on biomass gasification.The plants are scheduled to go into operation in 2012 [Source: Uhde GmbH].

Bioliq Pilot Plant at Karlsrhue

The bioliq® pilot plant at Karlsruhe Institute of Technology (KIT) is running successfully along the complete process chain. All stages of the process have now been interconnected: Flash pyrolysis, high-pressure entrained flow gasification, hot gas cleaning, and synthesis. In March 2015, Air Liquide announced it has provided key technologies for the pyrolysis of biomass and gas synthesis as well as the oxygen supply needed for the gasification process.

CEA / Air Liquide - SYNDIÈSE-BtS project, Bure-Saudron

Air Liquide and CEA, France, are developing an innovative process for converting biomass into synthesis gas - the SYNDIÈSE-BtS project, Bure-Saudron. CEA is developing a novel mechanical pretreatment processes for biomass, which will reduce energy consumption compared to thermochemical pretreatments. Air Liquide is developing techniques to convert the pretreated biomass to syngas in an oxy-burner at 1300-1400° C. In May 2013, the began development of a pilot plant to test the concept at 1 tonne per hour.

In 2009, CEA announced a BtL pilot plant in Bure Saudron using 75000 tonnes of foresty and agricultural residues to produce ~23000 tonnes/year of biofuel (diesel, kerosene and naptha). This project added hydrogen during the synthesis stage to optimise the ratio with carbon monoxide [Source CEA].

Fulcrum Bioenergy - Sierra Biofuels MSW to Jet Fuel and Diesel facility

In May 2105, Fulcrum Bioenergy Inc., announced it has awarded a $200m engineering, procurement and construction (EPC) contract to Abengoa for the construction of the 10 MMgy Sierra BioFuels facility to convert MSW into syngas, followed by a Fischer Tropsch step to create second generation biodiesel and bio jet fuel.

In September 2014, Fulcrum Bioenergy announced a $105m 'Biorefinery Assistance Program' loan guarantee from the USDA, as well as a $70 million grant under the US DoD Defense Protection Act, which will support development.

Fulcrum has entered into a long-term, zero-cost MSW feedstock agreements with Waste Management and Waste Connections, two of the largest waste service companies in North America, and a fuel off-take agreement with Tenaska BioFuels. The Sierra BioFuels Plant is expected to be one of the United States' first fully operational, commercial-scale MSW-to-renewable fuels production plants.

In Summer 2014, Cathay Pacific Airways announced that it is investing in Fulcrum Bioenergy Inc., the parent company of Fulcrum Sierra BioFuels, LLC, and has negotiated a long-term supply agreement with Fulcrum for 375 million gallons of sustainable aviation fuel over 10 years. This would represent about 2 % of the airline's annual fuel consumption. [Source: Fulcrum Bioenergy website & USDA Press Release].

Cool Planet 'Reformate' commercial facility, Louisiana, US

Cool Planet (with investors including BP, Google Ventures, ConocoPhillips and GE), is using a thermo-mechanical fractionation system (pyrolyzer) to convert wood waste and energy crops into hydrocarbon chains (gases). These are converted via catalysts to high-octane, renewable gasoline blendstocks (known as "Reformate"), which can be used to enhance the energy content of gasoline, diesel, and jet fuel. Pine chips will be the feedstock source for the Cool Planet facility, but the process can use almost any type of renewable cellulosic material. BioChar is produced as a by-product for soil enhancement and carbon sequestration [Source: Cool Planet].

In February 2014, Cool Planet Energy Systems broke ground on a commercial facility 'Project Genesis' in Alexandria to produce 10m gallons per years of renewable gasoline. In October 2014, it was announced USDA has reached an agreement with Silicon Valley Bank to provide a $91 million Biorefinery Assistance Program loan guarantee to Cool Planet to help the company finish construction of the plant. A $168m investment for three production facilities in Louisiana was originally announced by Cool Planet in September 2013.

Velocys / Red Rock Biofuels

In July 2015, Red Rock announced an ageement to supply FedEx Express with 3m gallons p.a. of bio jet fuel from 2017. Red Rock also has agreements to supply Southtwest Airlines. In October 2014, it was announced that Red Rock Biofuels had been awarded a $70m USDD biofuels contract to use woody biomass to produce 12m gallons of advanced biofuels using Velocys Fischer-Tropsch technology.

UPM Stracel BTL

A final decision on whether or not the UPM Stracel BtL facility will proceed is reportedly pending, due to ongoing uncertainty over the regulatory environment for advanced biofuels in Europe.

On 18 December 2012 it was announced that the UPM Stracel BTL project, France, had been selected to receive counterpart funding of €170m under the first call for proposals of the NER300 funding programme for innovative low-carbon technologies. The Project concerns the construction and operation of a second generation Biomass-to-Liquid (BtL) plant on the Strasbourg site of the UPM Group, which already owns and operates a paper mill on the same site (Stracel). The Project is based on a prototype developed in cooperation with the technology provider using a gasification process. The Project is based on the application of novel pressurized oxygen blown biomass gasification technology. The BtL plant will be integrated into the paper & pulp production line, enabling exchanges of energy and products. The plant will use about 1 million tonnes of woody biomass and will have an annual output of 105 000 tons of biofuel. Using mainly wood feedstock, the Project aims to produce and sell biodiesel (80%) and bionaphtha (20%). The proposed technical solution is based on the following main components: feedstock handling, gasification, raw gas cleaning, gas-to-liquid conversion, liquid treatment and storage, and power generation.

Discontinued BtL Projects

Ajos BTL

In February 2014, The Board of Directors of Vapo Oy made the decision to freeze project planning for the biodiesel plant planned for Ajos in Kemi. According to the companys's press release: *The final, decisive blow to the project was that the EU’s climate and energy strategy published in January did* *not agree on new binding limits for the share of the renewable component in traffic fuels after 2020. "In this situation it is not possible to conclude long-term commitments, which would have created the financial preconditions for Vapo's biodiesel project."*

It was also announced that the AJos BtL project, Finland, has been selected to receive counterpart funding of €88.5m under the first call for proposals of the NER300 funding programme for innovative low-carbon technologies.The Project concerns the design, construction and operation of a biofuel-to-liquid (BtL) plant in northern Finland, with a gasification capacity of 320 MW and an annual output of 115000 t/y of biofuel using close to 950000 t/y of woody feedstock and 31000 t/y of tall oil. The technical solution is based on the following main components: biomass pre-treatment, gasification island (comprising two gasification lines of 160 MW each and an air separation unit), gas cleaning and compression, gas-to-liquid conversion (Fischer-Tropsch) including refining, processing and storage of products. The Project will produce and sell biodiesel and bionaphta in the Baltic Sea area, with a focus on Finland and Sweden. Principal off-takers are expected to be diesel and petrol retailers.

[Source: SWD(2012) 224 final: NER300 - Moving towards a low carbon economy and boosting innovation, growth and employment across the EU]

The preparation work in the project had been carried out by the Forest BtL Project established by Metsäliitto and Vapo.

Linde Engineering Dresden GmbH had signed an agreement with Forest BtL Oy, Finland for licensing of Carbo-V® biomass gasification technology (see also Choren archive informaiton below).

NSE Biofuels BtL Demonstration Plant

NSE Biofuels Oy - a joint venture between Neste Oil and Stora Enso operated a BtL demonstration plant at Stora Enso's Varkaus Mill in Finland. The output was 656 t/a from a 12 MW gasifier. As well as providing test data and operating experience, the plant also reduced greenhouse gas emissions as wood-based gas from the plant replaced oil in the pulp mill's lime kiln, making the Varkaus integrate virtually fossil fuel free. NSE Biofuels (in partnership with Foster Wheeler and VTT) planned to develop a commercial production plant at one of Stora Enso's mills with a projected output capacity of 100000 t/a and a potential launch date of 2016.

However, in August 2012 Neste Oil and Stora Enso announced that they had decided not to progress with their plans to build a biodiesel plant, for which the two companies had applied for funding under the EC's NER 300 programme. Although the technology has worked well at the demonstration plant (above), the project was not among those listed [in the NER300 intermin report] as scheduled to receive funding. Even with public funding, significant investment would also have been required for the commercial plant. [Source: Neste Oil website].

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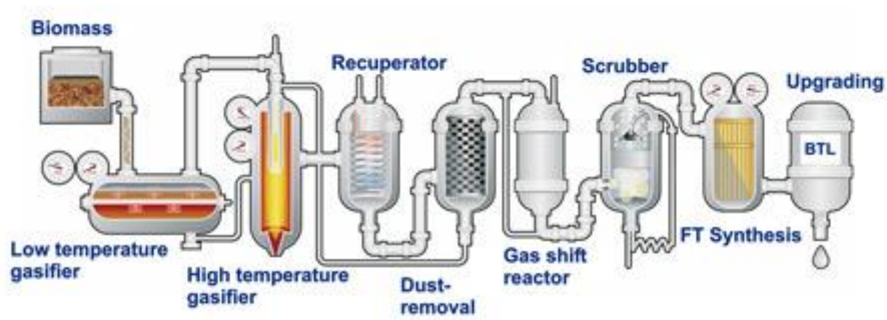
The NSE Biofuels BtL demonstration plant.

Choren gasification technology sold to Linde

Previously, the world's first commercial BtL Plant was under construction in Frieberg Saxony, utilising the Choren Carbo-V ® Process. Choren Industries filed for insolvency in July 2011. A new investor for Choren Components was announced in October 2011. On 9 February 2012 Choren's biomass gasification technology was sold to Linde Engineering Dresden, who will further develop the Choren Carbo-V® technology used to produce syngas.

The Choren Carbo-V ® Process



© Copyright Choren
The Choren Carbo-V ® Process View at larger size>>

The Carbo-V® Process is a three-stage gasification process resulting in the production of syngas:

- low temperature gasification,
- high temperature gasification and
- endothermic entrained bed gasification.

The Fischer-Tropsch (FT) process is then used to convert the synthesis gas into an automotive fuel SunDiesel®.

The Choren plant used the proprietary Shell Middle Distillate Synthesis (SMDS) technology. Syngas production is followed by a modified version of the Fischer-Tropsch process. This favours the production of long chain waxy molecules, which are unsuitable for transport fuels, but substantially reduces the amounts of unwanted smaller hydrocarbons or gaseous byproducts. The hydrocarbon synthesis step is followed by a combined hydro-isomerisation and hydrocracking step to produce the desired, lighter products [Source: Shell Middle Distillate Synthesis: Fischer Tropsch catalysis in Natural Gas Conversion to High Quality Products, J. Ansorge, Shell International Oil Products B.V.].

The SMDS process has been implemented on a commercial scale at the $18 billion fossil gas-to-liquids (GTL) plant, developed by Qatar Petroleum and Shell, with a capacity of 260,000 barrels oil equivalent a day.

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Reactor being delivered to the Choren BTL plant.

View at larger size>>

The Choren website listed a number of advantages for SunDiesel®:

- High cetane number and therefore much better ignition performance than conventional diesel fuel,
- No aromatics or sulfur and significantly reduces pollutants from exhaust emissions,
- Can be used without any adjustment to existing infrastructure or engine systems,
- Largely CO_2-neutral.

SunDiesel® demonstration fuel station at Choren BtL plant

View at larger size>>

Presentation on Choren BtL plant from EBTP SPM2

European Research on BtL, thermochemical conversion and 'sustainable biodiesel'

In Summer 2013, VTT TRC Finland published a 126pp study Liquid transportation fuels via large-scale fluidised-bed gasification of lignocellulosic biomass. 20 individual BTL plant designs were evaluated based on their technical and economic performance.

In February 2013, a presentation on **Status update of selected demonstration plants (thermochemical value chains)** was made at EBTP SPM5.

BRISK is a €10.84M four-year initiative with €8.98M funded under EC FP7 (Ref: 284498). BRISK aims to develop a European Research Infrastructure for Thermochemical Biomass Conversion, supporting R&D on innovative processes to convert sustainable feedstocks (agricultural/forestry wastes and energy crops) into liquid, gaseous or solid fuels.

The €3.73m DIBANET project is being co-ordinated by Carbolea at the University of Limerick and is a response to the Energy 2008 Call - "Significant enhancement of the cooperation between key researchers & industries from the EU & Latin America in the field of biofuels". DIBANET stands for the "Development of Integrated Biomass Approaches NETwork" & the title of the Project is "The Production of Sustainable Diesel Miscible Biofuels from the Residues & Wastes of Europe & Latin America". There are 13 partners in the group, 6 from the EU & 7 from Latin America (LA). The total budget for the project is €3.7m. DIBANET will develop technologies to help towards eliminating the need for fossil diesel imports in the EU & LA by advancing the art in the production of ethyl-levulinate from organic wastes and residues. Ethyl levulinate (EL) is a novel diesel miscible biofuel (DMB) produced by esterifying ethanol with levulinic acid.

The Cutec institute Cutec operates a pilot plant to investigate the thermochemical conversion of different types of biomass to synthesis gas and the separation of elements of the biomass step-by-step via a hot gas filter, water-based scrubber, sulferox scrubber, etc.

Greasoline® technology converts oily and fatty raw and waste materials to hydrocarbon mixtures consisting of chemical substances occurring in fossil gasoline, kerosene and diesel fuels. These products may be used as fuels and fuel components but also as chemical raw materials. The procedure was developed at the Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT in Oberhausen, Germany. The GREASOLINE project was supported under FP6. In contrast to biodiesel, the product is chemically identical with fossil fuels. [Source: Fraunhofer Instiute].

In 2009, a demonstration facility - The Dutch Biorefinery Initiative (DBI) - was initiated in the Port of Rotterdam by WUR and ECN with support from the Netherlands government. This included a 10 MWth entrained-flow gasification based syngas production platform for heat and power, base chemicals and BtL. Information on this project was included in the IEA Bioenergy Task 42 publication on Biorefineries

US and Canadian research and demonstration on thermochemical conversion

In the US, Primus Green Energy has started construction of a $7m demonstration plant to produce drop-in fuels using proprietary technology based on an enhanced version of the Mobil Process. Gasification is followed by Carbon dioxide separation and scrubbing of the syngas, before a four-stage catalytic system to produce the drop-in biofuel.

In April 2013 Frontline Bioenergy received $4.2m in DOE funding for a pilot facility integrating a gasification unit, novel conditioning processes and FT to produce military biofuels.

Haldor Topsoe and Andritz Carbona, along with GTI/Uhde (Morphysorb capture of acid gases) and Phillips 66 (engine testing) have developed a 20 bbl/day wood to gasoline demonstration plant at Des Plaines, Illinois, integrating all the steps from woody biomass to gasoline production in a single facility. The project uses Topsoe Integrated Gasoline Synthesis (TIGAS), using wood pellets supplied by UPM-Kymmene. Andritz provides the gasification technology. The project has been supported by the U.S. Department of Energy (DOE), Golden Field Office, under its Integrated Biorefinery Platform program [Source: Haldor Topsøe A/S June 2013].

CRI Catalysts is the exclusive worldwide licensor of IH^2 Technology, which was developed at the Gas Technology Institute (GTI) in Des Plaines, IL. This technology directly converts virtually any biomass to high quality (ligno)cellulosic hydrocarbon gasoline, diesel or jet fuels and/or blend stocks via a two stage thermochemical process. The IH2 process technology uses specially tailored CRI catalysts in both the Hydropyrolysis and Hydroconversion stages.

Purdue University has developed H2Bioil technology, whereby biomass is rapidly heated in the presence of pressurised hydrogen. Catalysts are then used to convert the gas to "biogasoline" molecules.

Syntroleum has developed Fischer-Tropsch and Bio-Synfining® technologies to convert fats, biomass, natural gas, coal, and other carbon bearing feedstocks into liquid fuels. Syntroleum has a worldwide license under ExxonMobil's GTL patents to produce and sell fuels from natural gas or other carbonaceous substances such as coal. The company also has a joint venture Dynamic Fuels LLC to convert animal processing wastes to biofuels.

In the United States, Maverick Synfuels has developed a modular system to produce methanol from syngas and then convert it to olefins, and in turn biofuels or other bioproducts.

Biomass to Liquid - the basics

BtL fuels may be produced from almost any type of low-moisture biomass, residues or organic wastes such as short rotation trees, perennial grasses, straw, forest thinnings, bark from paper-pulp production, bagasse, waste paper or reclaimed wood or fibre based-composites.

It is estimated that over 4m^3 of BtL-fuels can be produced per hectare of land per annum. Hence, in future if 4-6 million hectares of land were used to grow energy crops, one could replace 20-25 % of the liquid transport fuel currently used.

The advantage of the BtL route to liquid transport fuels lies in the ability to use almost any type of biomass, with little pre-treatment other than moisture control. This is because the feedstock is gasified in the first stage of the process. The gas produced is then treated further to clean it, remove tars, particulates and gaseous contaminants, and to adjust the ratio of the required gases (hydrogen and carbon monoxide) to that required. The result is a balanced syngas that can be used in the second, catalytic, stage. Syngas may also be obtained by pyrolysis to form charcoal. The hot charcoal is then reacted with steam to produce watergas.

The two main catalytic processes for BtL production are Fisher-Tropsch and the Mobil Process

Fisher-Tropsch

The Fischer-Tropsch process is a catalyzed chemical reaction in which carbon monoxide and hydrogen are converted into liquid hydrocarbons of various forms. Generally the catalysts used, for the following reaction, are based on iron and cobalt.

$(2n+1)H_2 + n(CO) \rightarrow C_nH_{2n+2} + nH_2O$

The FT process is an established technology and is already applied on a large scale from coal or natural gas. Developed in the 1920s in Germany, it was used by both Germany and Japan during World War II and later by South Africa and to a lesser extent in the United States.

One problem is the high capital cost of the multistage process. This may be greater when biomass is used as feedstock, since the scale of operation may be limited by the distance over which biomass can be transported to the factory at an economic price. Hence, the economy of scale is decreased compared to a large coal or gas-based operation. Running and maintenance costs are also comparatively high.

Mobil Process

This is a two stage catalytic process. In the first stage LINK methanol is produced. The methanol is then used as feedstock to generate hydrocarbons of varying chain length, using a zeolite catalyst. In the conversion, a number of reactions take place in the gas phase. The conversion is initiated by the removal of water to produce dimethyl ether:

$2CH_3OH(g) \rightarrow CH_3OCH_3(g) + H_2O(g)$

This is followed by various other reactions in which further molecules of water are removed resulting in gradual increase in chain length.

These reactions include the following.

$2CH_3OCH_3(g) + 2CH_3OH(g) \rightarrow C_6H_{12}(g) + 4H_2O(g)$

$3CH_3OCH_3(g) \rightarrow C_6H_{12}(g) + 3H_2O(g)$

As a result of other dehydration reactions occuring in parallel a mixture of hydrocarons is produced of which about 80% is suitable for petrol production. The mixture contains (w/w) around 50% highly branched alkanes, 12% highly branched alkenes, 7% cycloalkanes and 30% aromatics. This process has been commercialised by Methanex in New Zealand using methanol produced from natural gas.

Methanol

Introduction

Currently, most methanol is produced by the catalytic conversion of syngas (a mix of carbon monoxide, carbon dioxide and hydrogen) from fossil sources. Information on methanol use is available from the International Methanol Producers and Consumers Association IMPCA and from the Methanol Institute.

Biomethanol can be produced from a wide range of biomass feedstocks via a thermochemical route similar to the Fisher-Tropsch process for BtL. It can be blended in petrol at 10-20%. In China, M10 and M85 are already used in thousands of vehicles. Methanol has also been investigated for use as a fuel in shipping.

View Fact sheet on methanol

Biomethanol demonstration projects

BIOMCN commercial production of biomethanol

BioMCN, Netherlands, is the first company in the world to produce, market and sell industrial quantities of biomethanol, using glycerin as a feedstock. BioMCN continus to develop innovative processes for the production of biomethanol using various feedstock, including crude glycerine, green gas, biomass and CO_2.

Enerkem MSW to Methanol plant (coupled with conversion to ethanol)

In June 2014, Enerkem inaugurated its commercial-scale MSW to methanol plant in Edmonton, Canada. The facility converts MSW to syngas, which is converted to methanol. In 2015 a methanol-to-ethanol conversion unit will be added.

The City of Edmonton will supply 100,000 dry metric tons of sorted MSW per year. The sorted MSW to be used is the ultimate residue after recycling and composting, which is saved from being landfilled. The commissioning of the facility has begun. Operations will start in 2014 with the production of biomethanol. A methanol-to-ethanol conversion module will be added after.

Enerkem’s project partners, namely the City of Edmonton and Alberta Innovates – Energy and Environment Solutions, contributed $20 million to the project. The project has been selected by

Alberta Energy to receive $3.35 million in funding, as part of the Biorefining Commercialization and Market Development Program. In addition, Waste Management and EB Investments have invested equity in the project with Enerkem Inc. This facility is part of a comprehensive municipal waste-to-biofuels initiative in partnership with the City of Edmonton and Alberta Innovate.

MTO/OCP Methanol to Olefins / Olefin-Cracking-Process demonstration plant

An industrial-scale demonstration plant funded by Total in Feluy, Belgium, used the Methanol-to-Olefins (MTO) process developed by UOP/Hydro and the Olefin Cracking Process (OCP) developed jointly by Total and UOP, followed by downstream polymerization to produce polymers. Olefins can also potentially be used as building blocks for advanced biofuels.

Woodspirit project selected for support under first NER300 call

On 18 December 2012 it was announced that the Woodspirit project, Netherlands, has been selected to receive counterpart funding of €199m under the first call for proposals of the NER300 funding programme for innovative low-carbon technologies. The Project will demonstrate the production of bio-methanol in large commercial scale using biomass torrefaction and entrained flow gasification as the new core technologies. The output of the Project is 516 Ml/y bio-methanol, which is equivalent to 413000 t/y. The plant will be located in the Netherlands next to the existing plant of the Project sponsor in Oosterholm, Farmsum. The Project will make use of 1.5 Mt/y of imported wood chips. The bio- methanol will be used as a petrol additive for partial replacement of mineral fuel. The main components of the new complex include a fuel receiving and processing facility, gasification island to produce raw syngas, the syngas cleaning area and the methanol plant including bio-methanol synthesis and purification plants.

[Source: SWD(2012) 224 final: NER300 - Moving towards a low carbon economy and boosting innovation, growth and employment across the EU]

VärmlandsMethanol AB

VärmlandsMethanol AB is in the process of building a biomass-to-methanol plant in Hagfors, Sweden. VärmlandsMetanol will gasify biomass (forest residue) and then convert and purify the syngas into fuel grade methanol. The plant will produce 300 t/day fuel grade methanol and also deliver district heating water with a thermal duty of 15 MW.

SUPER METHANOL Project

The SUPER METHANOL project on Reforming of Crude Glycerine in Supercritical Water to produce Methanol for Re-Use in Biodiesel Plants (FP7-212180) aims to produce methanol from crude glycerine, and re-use the methanol in the biodiesel plant. This will improve the energy balance, carbon performance, sustainability and overall economics of biodiesel production. The work expands on expertise generated by the consortium on reforming of glycerine in supercritical water, and to produce a synthesis gas suitable for direct once-through methanol synthesis (GtM - Glycerine to Methanol). Producers will be less dependent on the methanol spot price, there is a (partial) security of methanol supply, and their by-product is used as a green, sustainable feedstock

METHAPU project - us of Methanol as a shipping fuel

The FP6 METHAPU project (Validation of renewable methanol based auxiliary power systems for commercial vessels) is invesitgating the use of Methanol and solid oxide fuel cell (SOFC) technology for shipping

Global R&D on methanol

GEM Gasoline Ethanol Methanol blends

Abengoa, Methanex and other partners are collaborating in the development of GEM Fuels (gasoline/ethanol/menthanol blends) for use in racing cars.

Research has previously been carried out on 'dual-alcohol' gasoline blends (e.g. 10% ethanol plus 10% methanol), which has a distillation curve close to that of pure gasoline, minimizing the impact on fuel volatility [Source: Distillation Curves for Alcohol-Gasoline Blends, V. F. Andersen et al, *Energy Fuels*, 2010, 24 (4), pp 2683–2691].

Maverick Synfuels modular system for syngas-to-methanol

In the United States, Maverick Synfuels has developed a modular system to produce methanol from syngas and then convert it to olefins, and in turn biofuels or other bioproducts. In March 2014, Maverick annnounced a partnership with Plant Process Equipment Inc., to manufacture and sell small-scale plants to convert waste gas to methanol at low-cost. In September 2014, the modular system became commercially available.

Demonstration of BioDME - Dimethyl ether as an advanced biofuel at industrial scale

Introduction

Dimethyl ether (DME) can be produced by catalytic dehydration of methanol, or from syngas. Above -25°C or below 5 bar, DME is a gas. Hence its use as a transport fuel is similar to that of LPG.

View Fact sheet on dimethyl ether BioDME

BioDME

The initial BioDME project to demonstrate production of BioDME from lignocellulosic biomass at industrial scale, involved a consortium of Chemrec, Haldor Topsøe, Volvo, Preem, Total, Delphi and ETC. The project was supported by the Swedish Energy Agency and the EU's Seventh Framework Programme. Dimethylether (DME) was produced from black liquor through the production of clean synthesis gas and a final fuel synthesis step. In order to check technical standards, commercial possibilities and engine compatibilities the BioDME has been tested in a fleet of Volvo trucks.

In February 2013, Luleå University of Technology's holding company took over Chemrec and its gasification plant. LTU is entering a long-term partnership with Chemrec and also the Danish company Haldor Topsö, a world leader in catalytic processes. In addition, there is a related consortium being formed by both industrial and public actors.

In April 2012, Chemrec signed a cooperation agreement with China Tianchen Engineering Corporation, TCC, to provide an integrated offering of Chemrec plants on a global lump-sum turn-key basis and co-market the Chemrec black liquor gasification technology – a route to 2nd generation biofuels or green power.

The signing took place in Stockholm in the presence of the prime ministers of China, Wen Jiabao, and of Sweden, Fredrik Reinfeldt. Under the agreement, Chemrec and TCC will develop an offering to provide industry standard design, engineering, procurement and construction (EPC) services as well as overall performance guarantees to support project financing for black liquor gasification plants. TCC will also assist in procuring plant financing [Source: Chemrec].

Previously, in January 2011, the EU approved a grant of up to SEK 500 million (49 million, $73 million) by the Swedish Energy Agency for industrial scale demonstration of the Chemrec technology for production of BioDME and Biomethanol. The plant was scheduled to be built at the Domsjö Fabriker biorefinery in Örnsköldsvik. This follows the original approval of the investment grant by the Swedish Energy R&D Board in September 2009. However in May 2012, Domsjö withdrew from the black liquor gasification demonstration.

The Domsjö plant aimed to supply well over 2000 heavy trucks with fuel. With fully implemented renewable fuels production at all pulp mills in Sweden, half of all heavy road transport could be propelled by BioDME and biomethanol. Potentially, this could reduce Swedish fossil carbon dioxide emissions by 10% or about 6 million tons and replace fossil fuel imports worth approx. SEK 10 billion (1 billion, $1.5 billion) annually. However, this relies on securing further sources of investment and a supportive framework for commercial-scale production of BioDME in Sweden.

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Volvo BioDME truck View at larger size >>

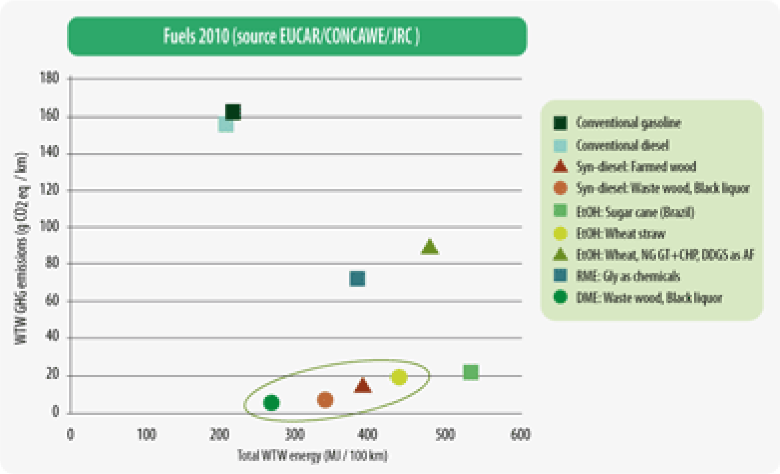
On September 18, 2009, His Majesty King Carl XVI Gustaf of Sweden broke ground for the world's first BioDME production plant at the Smurfit Kappa paper mill in Piteå, Sweden. The pilot plant was inaugurated in 2010 with a capacity of about 4 tons (1,600 gallons) per day using forest residues as feedstock. The estimated cost of the plant was around SEK 150 million (EUR 14 million, USD 20 million).

In October 2010 Chemrec was named a GoingGreen Silicon Valley Top 100 Winner was also included in the prestigious 2010 Global Cleantech 100.

Chemrec development plant in Piteå, producing high-quality synthesis gas which will be converted to second generation biofuels with low GHG emissions View at larger size >>

Inside the Chemrec gasification plant View at larger size >>

In Well to Wheel tests, BioDME is shown to generate substantially lower Greenhouse Gas Emissions than fossil fuels and first generation biofuels (see below).



Well-to-wheel greenhouse gas emissions (in CO2-equivalents/km) versus total energy use for running a mid-size car over a distance of 100 km - View at larger size >>

Bio-SNG (Synthetic Natural Gas) and Gasification Technologies

Bio-SNG is produced by gasification of cellulosic materials (e.g. forestry residues, energy crops), whereas "biogas" is produced by a biological process - anaerobic digestion of organic materials (e.g. manure, organic waste).

Bio-SNG is typically produced via an initial gasification step followed by gas conditioning, SNG synthesis and gas upgrading. Bio-SNG can be used in a similar way to biomethane (biogas) generated via anaerobic digestion. Syngas may also be converted into liquid advanced biofuels. Syngas may be converted to diesel, ethanol (e.g. Fulcrum Bioenergy) or other fuel molecules (e.g. via Methanol To Gasoline technology).

Biomass Gasification Technology Assessment (US 2012)

In November 2012 an extensive Biomass Gasification Technology Assessment was produced by M. Worley and J. Yale, Harris Group Inc. on behalf of NREL. The goal was to solicit and review the technical and performance data of gasifier systems and develop preliminary capital cost estimates for the core equipment. Specifically, the assessments focused on gasification and tar reforming technologies that are capable of producing a syngas suitable for further treatment and conversion to liquid fuels.

Bio-SNG Projects in Europe

GoBiGas Phase 2, Sweden, to be supported under the first NER300 call

The GoBiGas facility was inaugurated on 12 March 2014. The facility converts waste wood to SNG via gasification, followed by gas cleaning and methane production. In December 2014, methane produced by GoBiGas was injected into the natural gas grid.

On 18 December 2012 it was announced that GoBiGas Phase 2, Sweden, had been selected to receive counterpart funding of €58.8m under the first call for proposals of the NER300 funding programme for innovative low-carbon technologies. The Project will demonstrate the large-scale conversion of low-quality wood into high quality synthetic natural gas (SNG) by indirect gasification at atmospheric pressure, gas cleaning, methane production (via nickel catalyst), pressurization and injecting the product into the regional gas network. The Project will make use of forestry feedstock, which consists of pulpwood and forest residues harvested from the surrounding areas of Gothenburg, the Lake Vänern and Baltic region. The volume of ~0.5 Mt/year of wet biomass will be used in the Project, which has an installed capacity of ~100 MWth to produce 800 GWh/year of gas (SNG).

[Source: SWD(2012) 224 final: NER300 - Moving towards a low carbon economy and boosting innovation, growth and employment across the EU]

View Videos Part 1 and Part 2 about the project on the GoBiGas You Tube page.

SNG Demonstration in Güssing

The Biomass CHP Plant Güssing, which started operation in 2002, has a fuel capacity of 8 MW and an electrical output of about 2 MWel with an electrical efficiency of about 25 %. Wood chips with a water content of 20 – 30 % are used as fuel. The plant consists of a dual fluidized bed steam gasifier, a two-stage gas cleaning system, a gas engine with an electricity generator, and a heat utilization system, offering a complete value chain demonstration from woody biomass to SNG.

Commercial bio-sng plants are expected to be in the scale of 20 to 200 MW. In the initial conversion step i.e. in the biomass gasification process wood chips are converted into a syngas or more general into a product gas. The FICFB gasification process has operated in Güssing since 2002 for a combined heat and power (CHP) plant and in this time has been in operations for many 10000s of hours. The product gas is delivered at ambient pressure, has a high content of CH4, higher hydrocarbons and tars. This product gas is suitable for SNG production.

The final conversion step consists of three individual steps, i.e. gas conditioning, SNG synthesis and gas upgrading. R&D work over the first 8 years at Güssing focused on gas conditioning and SNG synthesis. The pilot scale showed that fluidized bed SNG synthesis is possible. The whole process chain reaches high conversion efficiencies and has the potential for lower investment and lower operation costs than conventional SNG synthesis technology.

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[Source: SWD(2012) 224 final: NER300 - Moving towards a low carbon economy and boosting innovation, growth and employment across the EU]

View Videos Part 1 and Part 2 about the project on the GoBiGas You Tube page.

Gaya Demonstration Project

The Gaya Demonstration project, supported by the EC, aims to demonstrate a commercial pathway for gasification and methanation of residues (e.g. wood, straw) to produce synthetic biomethane at the industrial scale.

Dong Pyroneer Plant, Denmark

DONG Energy has developed a new technology 'Pyroneer' that converts biomass to gas at low temperature. In 2011, it established a 6MW demonstration plant adjoining Asnæs Power Station near Kalundborg.

UK waste-to-energy gasification plants: Birmingham Bio Power Plant and Hoddesdon

In December 2013 it was announced that work will begin on a 10.3 MW biomass gasification plant in Tyseley, UK. The plant will be developed by Carbonarius, a joint venture of O-Gen UK and UNA Group, with a £47.8m investment by the UK Green Investment Bank and Foresight Group. The plant will be built and operated by MWH, based in Broomfield, US, and will use the biomass gasification process of the Canadian firm Nexterra Systems to convert 67,000 metric tons of locally-sourced woodwaste into power. The feedstock will be supplied by JM Envirofuels Ltd.

Foresight Group and the U.K. Green Investment Bank plc have invested £30m in a £60m ~10MW Waste to Energy gasification facility in Hoddesdon, Hertfordshire, using refuse derived fuel (RDF) as a feedstock. The gasification technology will be designed by Biomass Power Ltd., and constructed by Bouygues Energy & Services. The plant will begin opeations in 2017.

Waste-to-energy gasifier Lahti, Finland

160 MW thermal waste gasifier in Lahti, Finland, uses Solid Recovered Fuel SRF (the fraction of MSW that cannot be recllced) as a feedstock. This mainly consists of shredded textiles, wood, paper, card and plastics, etc. that would otherwise be destined for landfill. The gas is cooled and cleaned before being passed to the boiler.

Cortus WoodRoll® Technology Sweden

Cortus has built an integrated production flow plant where the drying, pyrolysis and gasification of different biofuels is run at the scale of 500 kW. In February 2012, it was announced that the plant had succeeded to produce synthesis gas from biomass without traces of hydrocarbons. This 'breakthrough' facilitates the use of the synthesis gas for more cost-effective fuel production.

Following the success of these trials, the aim is to construct a ten times larger demonstration plant in Köping. The plant is constructed in cooperation with Torkapparater AB, Concordance AB, AGA Gas AB, ÅF and Sandvik Heating Technology, among others. Funding comes from the Swedish Energy Agency, Triple Steelix, Movexum and Cortus.

BioProGReSS - Biomass Product Gas Reforming Solutions (BESTF)

BioProGReSs is a 3 year 5.3M Euro project. The goal is to develop, implement and demonstrate advanced syngas cleaning based on chemical looping reforming in both a pilot and an industrial scale bioSNG plant. In addition a novel measuring technique developed at TU Berlin will be tested and implemented in order to monitor and control the gasification process.

Bio-SNG project (FP6)

Demonstration of the Production and Utilization of Synthetic Natural Gas (SNG) from Solid Biofuels (Bio-SNG) (TREN/05/FP6EN/S07.56632/019895)

The objective of the Bio-SNG project (2006-2009) was to demonstrate SNG (Synthetic Natural Gas) production from solid biofuels and to integrate this Bio-SNG into the existing energy infrastructure (i.e. fuel station for vehicles, natural gas grid).

It has been demonstrated, that the entire process chain (wood to Bio-SNG) is feasible and fulfils the expectations in terms of efficiency. Such technology can be applied in the energy industry for the production of sustainable fuel as a replacement of fossil fuel. The interested potential user of such technology is the energy sector, particularly the natural gas industry (distributors). Since the EU decided to replace fossil fuels partially, this technology can fill part of the gap. The technology is not yet fully mature, but a first small industrial scale project will allow the technology to achieve maturity. Such a project is being planned. The project was started upon a granted base patent which has been extended. Patent rights have not yet been granted.

In order to run the catalyst of the process, the synthesis gas needs to be purified from sulphur to a very large extent. A process stage has been developed in order to remove sulphur containing tars to an extent not yet known using biogenic solvents which can be regenerated. Such a process cannot only be applied for Bio-SNG production but also for other synthesis gases (e.g. from coal) or for other downstream processes (e.g. Fischer Tropsch). Patent protection has been applied for.

E.ON Bio2G Project

The E.ON Bio2G project in Sweden involved the design, erection and commissioning of a gasification plant with 200MW output. Commissioning is planned for 2015 pending planning approval.

KIT DemoSNG Technology

Karlsruhe Institute of Technology (KIT), Germany, has developed a novel scalable technology using a 'honeycomb' nickel catalyst to produce methane and water from carbon dioxide, carbon monoxide and hydrogen. The 'DemoSNG' system is to be tested at a biomass gasification plant in Köping, Sweden [Source: KIT, December 2014].

Concord Blue / Blue Tower Gasification Technology

In Germany, Blue Tower (Concord Blue) is developing gasification technology to convert a wide range of wastes to energy via gasification system with up to 80% efficiency.

The ECN/HVC Project for BioSNG

ECN has been developing a system for the conversion of dry lignocellulosic biomass into natural gas quality gas: BioSNG or Substitute Natural Gas from biomass. Technology choices have been based on the desire to have large-scale BioSNG plants with high overall efficiency. The ECN concept is based on so-called MILENA indirect gasification and OLGA tar removal.

The ECN concept offers 70% efficiency from biomass to BioSNG. A lab-scale system is available at ECN. A 1 MW pilot system at ECN is under commissioning for the two main parts of the system: the MILENA gasifier and the OLGA tar removal. HVC is a waste company, which is expanding its activities towards renewable energy. Joining the development of the BioSNG-concept perfectly fits in with HVC's ambitions in the medium and long term. HVC intends to realize two demonstration plants to demonstrate the ECN-concept.

The first demo plant will be a ~10 MW CHP plant to demonstrate the combination of the MILENA and OLGA-processes. The second demo plant will be a ~50 MW SNG plant in which the MILENA and OLGA are up-scaled and further gas cleaning and methanation will be added. These additional units will be supplied by a large EPC, which will soon be involved in the development.

Bio-SNG Demonstrations in the United States

Gasification for production of cellulosic ethanol

Enerkem, Fulcrum Bioenergy Inc, Range Fuels Inc and others are developing processes for production of ethanol, using gasification as a first step. See the Cellulosic Ethanol page for further details.

Sundrop Fuels

Sundrop Fuels has announced a partnership with ThyssenKrupp Uhde (Germany) to produce 50mgy of drop in biofuels (renewable gasoline) at a plant near Alexandria, Louisiana. The plant will combine natural gas and biomass (forest residues) using a commercial XTL process that integrates ThyssenKrupp Uhde's High Temperature Winkler gasification process and gas cleaning, followed by methanol synthesis and methanol-to-gasoline (MTG) technology (licensed from Exonn Mobil).

In July 2013 IHI E&C International Corporation, a US subsidiary of Tokyo - based IHI Corporation, was announced as contractor of choice for Sundrop's Alexandria facility. The combined commercial and demonstration plant will annually produce about 60 million gallons of finished gasoline from natural gas while providing the platform for Sundrop Fuels to prove its proprietary gasification technology for production of 'green gasoline'.

Rentech

The Rentech Inc. Port St. Joe Renewable Energy Project (Port St. Joe Project), in Florida, is an advanced-stage renewable power project that would employ a Rentech-SilvaGas biomass gasifier to provide synthesis gas to a combined–cycle power plant. The project is designed to produce approximately 55 megawatts net of renewable low-carbon base load electric power (RenPower™) from approximately 930 dry tons per day of woody biomass.

Vista International Technologies

Vista International Technologies is entering the testing phase of its pilot waste-to-energy (WTE) project which uses its patented thermal gasifier technology - a low-temperature gasification process that can produce syngas from a wide range of feedsocks, including municipal solid waste (MSW) and biomass.

Bio-oil (via pyrolysis / thermochemical conversion) and Tall Oil for production of advanced biofuels

Introduction

This page covers biofuels produced from:

Tall oil - a byproduct of the KRAFT process for wood production;

Bio-oil (bio-crude) - produced in dedicated facilities by pyrolysis and thermochemical conversion.

Bio-oil production

A number of research projects and companies are developing innovative processes to turn a wide range of biomass (forestry residues, crop residues, waste paper and organic waste) into stable, concentrated bio-oil (biocrude) that is compatible with existing refinery technology and can be converted into advanced biofuels.

For example, in the HTU® (hydrothermal upgrading) process, originally developed by Shell, biomass is treated with water at high temperature and pressure (300-350°C & 120-180 bar) to produce bio-crude. This can be separated by flashing or extraction to heavy crude (suitable for co-combustion in coal power stations) and light crude, which can be upgraded by hydrodeoxygenation (HDO) to advanced biofuels (Source: Biofuel BV presentation).

Updates on fast pyrolysis are included on the PyroKnown website, which is dedicated to sharing knowledge and learning about biomass fast pyrolysis. See PyroWiki, PyroWebinar, PyroMovies, PyroLearn.

Tall oil

Tall oil, a residual product of the pulp and paper industry, is also being used to produce biodiesel. The first commercial-scale facilities are being developed in Europe.

Definitions of 'Fast Pyrolysis Bio-oil' FPBO

In January 2014, a REACH Fast Pyrolysis Bio-Oil (FPBO) consortium was formed in Europe, and determined the following definition for FPBO: "Liquid condensate recovered by thermal treatment of lignocellulosic biomass, at short hot vapour residence time (typically less than about 10 seconds) typically at between 450 - 600°C at near atmospheric pressure or below, in the absence of oxygen."

The consortium is managed by Linnunmaa Oy and the lead registrant is Fortum. Properties and composition of FPBO, along with further details of the FPBO REACH consortium, were published in PyNe Newsletter 34 produced by IEA Task 34.

Standards for fast pyrolysis bio-oil

CEN/TC 19/WG 41 is currently developing standards for fast pyrolysis oils in response to EC mandate M/525 (2013). Three standards will be developed for replacement of heavy fuel oil, light fuel oil and for use of bio-oils in stationary combusiton engines. Later, two furtrher technical specifications may also be introduced for use of fast pyrolysis oils as gasfication feedstocks and for mineral oil refinery co-processing, as and when required.

Commercial production of advanced biofuels from Tall Oil

UPM announces world's first biorefinery for production of biodiesel from wood

View presentation made at EBTP SPM6, October 2014, by Sari Mannonen, UPM Biofuels on **Biorefinery for production of advanced wood-based biofuels**.

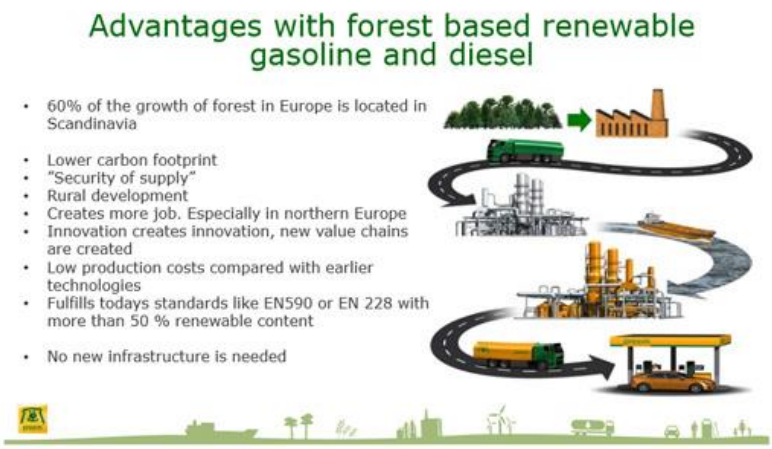
The UPM Lappeenranta Biorefinery, producing wood-based renewable diesel from forestry residue, started commercial production in January 2015.

In November 2012 UPM announced that it had commenced construction of a biorefinery producing biofuels from crude tall oil at UPM's Kaukas mill site in Lappeenranta, Finland. This followed an initial announcement of the project in 1 February 2012. The industrial scale investment is the first of its kind globally. The biorefinery will produce annually approximately 100,000 tonnes of advanced biodiesel. UPM's total investment will amount to approximately EUR 150 million. UPM has not applied for a public investment grant for the project.

UPM's advanced biodiesel, UPM BioVerno, will decrease greenhouse gas emissions of transport up to 80% in comparison to fossil fuels. The product's characteristics correspond to those of the traditional oil-based fuels and highly complement today's vehicles and fuel distribution systems.The construction of the biorefinery will offer work for nearly 200 people for approximately two years. When production commences, the biorefinery will directly employ nearly 50 people and indirectly about 150 people. [Source: UPM].

SunPine production of biodiesel from Tall Oil

View presentation made at EBTP SPM6, Octopber 2014, by Sören Eriksson, Preem on **Advanced biofuels and new feedstocks**.



SunPine AB has pioneered a "Wood to Wheel" renewable diesel process technology using crude tall oil, a residual product of the pulp and paper industry, as feedstock. The company, created in 2006, is owned by Preem, Sveaskog, Södra and KIRAm AB, and operates a €23 million plant in Piteå.

Tall oil can be extracted from pine, spruce and birch. During the pulping process resinous substances in the wood are dissolved and form calcium soaps. This soap is skimmed from the black liquor and subsequently washed and acidified to form crude tall oil. The yield of tall oil diesel from the crude tall oil is high, up to 65-70 percent. The remaining 30-35% becomes pitch fuel, a renewable fuel oil which is returned to the pulp mills. Also other residual products such as sodium and sulfur are returned to a pulp mill. The SunPine production process does not generate any waste. In the future it is also planned to extract other useful substances, such as resin acids and sterols.

The SunPine process step-by-step:

1. Crude Tall Oil is mixed with biomethanol and sulphuric acid. Via the esterification a crude tall oil diesel component is built.
2. In a destillation tower the component is destilled to the main product crude tall oil (CTO) and the by-product pitch fuel.
3. The crude tall oil is then upgraded to a high quality diesel fuel at Preem refinery in Gothenburg.
4. The by-product pitch fuel is a green fuel oil. In the future it is also planned to extract other useful substances, such as resin acids and sterols.

[Source: www.chemrec.se]

Industrial scale demonstration of pyrolysis technology

Fortum Bio-oil plant at Joensuu

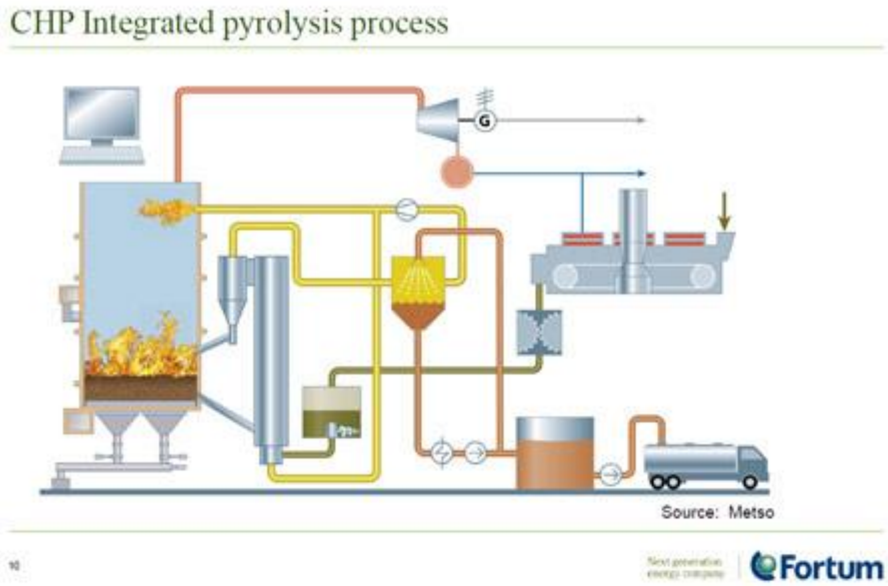
In March 2014, it was announced that Fortum, UPM and Valmet will work together on a five-year project LignoCat (Lignocellulosic Fuels by Catalytic Pyrolysis) to develop and commercialize integrated catalytic pyrolysis technology to produce biofuels from cellulosic feedstocks. The project is funded by Tekes - the Finnish Funding Agency for Technology and Innovation.

In March 2012, Fortum, Finland announced an investment of ~ EUR 20 million to build a bio-oil plant, based on fast pyrolysis technology, connected to the Joensuu CHP plant, which will be the " first of its kind in the world on an industrial scale."

The integrated plant aims to produce electricity and district heat and 50,000 tonnes of bio-oil per year. The bio-oil raw materials include forest residues and other wood based biomass. Construction of the bio-oil commenced during 2012, and the plant started production in November 2013. Bio-oil production will increase the energy wood consumption at Joensuu power plant almost doubling the use from the existing 300,000 m^3 per year. Savon Voima will begin using the bio-oil in its standby heat station in Iisalmi, Finland, at the start of 2014. [Source: Fortum]

From concept to demonstration: developing an advanced biofuel project - Presentation from EBTP SPM5 February 2013

Jukka Heiskanen, Head of R&D, Fortum



Empyro Fast Plyrolysis Plant

On 20 May 2015, [BTG - Biomass Technology Group BV] announced the opening of the [Empyro] 25 MWth polygeneration pyrolysis plant to produce electricity, process steam and fuel oil from woody biomass. Construction of the plant in Hengelo, Netherlands started in early 2014. Empyro BV is jointly owned by BTG BioLiquids, Tree Power, the province of Overijssel and a private investor. The project was initially supported by the EC FP7 Empyro project.

BTG's fast pyrolysis technology was originally based on the rotating cone reactor (RCR). Biomass particles at room temperature and hot sand particles are introduced near the bottom of the cone, where the solids are mixed and transported upwards by the rotating action of the cone. In the current process 70 wt.% bio-oil and 30 wt.% char and gas are produced as primary products [Source: BTG].

Green Fuel Nordic biorefinery

Green Fuel Nordic Oy plans to build up to 20 biorefineries in Finland, each producing 90,000 tons of RFO (Renewable Fuel Oil). The first GFN biorefinery is under construction in Iisalmi, using Rapid Thermal Processing™ RTP technology.

NER300 projects in Estonia and Latvia

2 pyrolysis projects using wood waste were selected for counterpart funding under the second phase of NER300 (in Summer 2014). These included a fast pyrolysis plant in Estonia to convert 130,000 tonnes of wood chips to pyrolysis oil, and a CHP pyrolysis facility in Latvia using 100,000 tonnes of wood chips. Both plants plan to export pyrolysis oil to replace heavy fuel oil in Sweden and Finland.

Ensyn, Canada, commercial pyrolysis process

In Canada, Ensyn is using Rapid Thermal Processing (RTP)™ technology to generate high yields of pyrolysis oil (typically 65-75wt% pyrolysis oil from dried lignocellulosic biomass). Ensyn's commercial process is currently used for production of chemicals and food flavourings (100 tonnes of wood per day). Up to end of 2014, 37m gallons of product had been produced using Ensyn RTP technology [Source IEA Task 34 / PyNe newsletter Jan 2015]. Current strategic relationships include UOP, Fibria Celulose, Chevron Technology Ventures, Petrobras/NREL and Credit Suisse.

bioCRACK, Austria

The bioCRACK process represents a new biomass-to-liquid concept to generate advanced biofuel by liquid-phase pyrolysis. A liquid heat carrier vacuum gas oil (VGO), an intermediate heavy oil product from the vacuum distillation, is used. From autumn 2012 a fully integrated pilot plant at Schwechat Refinery, Austria, with a nominal biomass capacity of 100 kg/h, was in continuous operation, generating data for up-scaling the technology to an industrial scale.

IEA Task 34 / PyNe - updates on the latest Pyrolysis R&D&D

Recent developments in fuels and chemicals from pyrolysis are regularly published by PyNe IEA Bioenergy Task 34 on Pyrolysis (which evolved from the Pyrolysis Network).

In particular, Pyne publishes updates on pyrolysis developments by country, and developments with pyrolysis priority topics.

View PyNe newsletters for latest R&D&D news.

EU-funded Research relevant to Biocrude/Bio-oil

BIOCOUP - Co-processing of upgraded bio-liquids in standard refinery units (FP6 - 518312)

BIOCAT - Catalyst Development For Catalytic Biomass Flash Pyrolysis Producing Promissing Liquid Bio-Fuels
(FP5 – ENK6 - 00510)

CASCATBEL - CAScade deoxygenation process using tailored nanoCATalysts for the production of BiofuELs from lignocellullosic biomass aims to design, optimize and scale-up a novel multi-step process for the production of second-generation liquid biofuels from lignocellulosic biomass in a cost-efficient way through the use of next-generation high surface area tailored nano-catalysts (FP7).

EMPYRO - Polygeneration through pyrolysis: Simultaneous production of oil, process steam, electricity and organic acids (FP7 - 239357)

Further links and reports on combustion, pyrolysis and gasification of biomass are provided by the ThermalNet project (funded under Altener, IEE). The final report of ThermalNet - Thermal Biomass Conversion - was published in November 2009.

Research and Demonstration developments in bio-oil / biocrude

ExxonMobil announced in October 2014 it is establishing two research projects with Iowa State University on fast pyrolysis of biomass. CENUSA Bioenergy, led by Iowa State University and supported by a $25m funding from USDA National Institute of Food and Agriculture, previously developed fast pyrolysis technology to convert energy grasses into bio-oil for production of advanced biofuels.

In February 2015, the Australian Renewable Energy Agency announced $5.2m funding for the Renergi pilot bio-oil facility in Perth. The $12.9m project aims to be operational be end of 2017.

Researchers at Purdue University, US, have demonstrated a new method to produce bio-oil via fast-hydropyrolysis-hydrodeoxygenation (H2Biooil), which involves adding hydrogen to the biomass-processing reactor, and uses a new platinum-molybdenum catalyst and innovative reactor design. Biomass along with hydrogen is fed into a high-pressure reactor and heated rapidly (within a second) to 500° C. The technique has proved succesful at lab scale with a wide variety of biomass. The researchers previously invented an approach called "hybrid hydrogen-carbon process" or H2CAR [Source: Rakesh Agrawal et al, Purdue University].

In 2014, University of the Basque Country has continued development and demonstration of conical spouted bed technology for biomass flash pyrolysis, offering more stable operation and higher bio-oil yields.

NextFuels is developing a pilot facility in Asia, based on Shell's hydrothermal process, to convert palm waste to 'green crude' [Source: NextFuels, August 2013].

In Sienna, Italy, Coll'Energia has announced it will use Envergent's RTP™ technology for a power plant converting wood residues to power via pyrolysis, enabling the plant to generate 10% more power from the same amount of biomass. The 12.8 MW power plant will generate 100m kWh from 85000 tonnes of biomass per annum, potentially saving 35000 tonnes of CO_2 emissions.

In 2013 the Agricultural Research Service (ARS) was awarded a $6.86 million Biomass Research and Development Initiative (BRDI) grant from the National Institute of Food and Agriculture (NIFA) to lead a 14 member industry/ university consortium on the “FarmBio3“ project 'Distributed On-Farm Bioenergy, Biofuels and Biochemicals Development and Production via Integrated Catalytic Thermolysis'.

The Fraunhofer UMSICHT Department of Biorefinery and Biofuels, is also investigating the potential for on-farm conversion of biomass residues to bio-oil.

In the United States, KiOR has developed a proprietary (catalytic pyrolsis) technology platform to convert biomass feedstocks into renewable crude oil, which can be converted, using standard refinery equipment, into gasoline, diesel and fuel oil blendstocks. KiOR developed a commercial facility in Columbus, Mississippi. In March 2014, KiOR announced that it would idle the Columbus plant due to financial difficulties. In November 2014, KiOR Inc. filed a voluntary petition for Chapter 11 bankruptcy (the filing does not include the Columbus biorefinery).

Pacific Northwest National Laboratory is invesigating the "reaction blocking" effects of the bio-product phenol when upgrading bio-oil to biofuels via catalysts. Researchers found that phenol is converted to ketones, which form long chains and slow down reactions on the surface of the metal catalysts. Water molecules were found to play an important role in the formation of ketones.

In the US, Blue Sun Energy, ARA Inc. and Chevron Lummus Global operate a Biofuels Isoconversion (BIC) demonstration facility in St. Joseph, Mo (4200 gallons per day). ARA’s patented Catalytic Hydrothermolysis (CH) process converts plant oils into a high quality crude oil intermediate. CLG’s Isoconversion Catalysts upgrade the 'biocrude' into drop in biojet fuel and advanced biodiesel.

In April 2013, Mercurius Biorefining received $4.6m funding from US DOE for a pilot plant to demonstrate its patent-pending Renewable Acid-hydrolysis Condensation Hydrotreating (REACH) technology to produce 'green crude' as an intermediate for advanced biofuel production. The company produces diesel and jet fuel hydrocarbons through a solid-bed-catalytic process analogous to that used for conversion of crude in the petroleum industry.

Battelle has developed a mobile catalytic pyrolysis unit for converting wood waste into bio-oil. A one-ton-per-day pilot system is being evaluated using pine waste in West Jefferson, Ohio.

Dynamotive Energy Systems Corporation has demonstrated a neutral fast pyrolysis technology that uses medium temperatures and oxygen-free conditions to turn dry waste biomass into BioOil® for power and heat generation (and conversion into transport fuels).

The Bionic Group has developed microwave liquefaction and catalytic depolymerisation technologies for converting biogenic wastes to light oils, which can then be converted to biofuels.

In April 2012, US DoE announced up to $15m funding for demonstration of biomass-based oil precursors (biocrude) for renewable transportation fuels.

Green EnviroTech Holdings Corp. (GETH) processes recovered plastic and tyres and produces light sweet crude oil as one end product.

The University of Massachusetts Amherst has granted exclusive global rights to Anellotech for its catalytic fast pyrolysis (CFP) technology for producing biogasoline and other biohydrocarbon fuels from waste biomass.

The Huber Biofuesl Research Group carries out R&D on Catalytic Fast Pyrolysis and has developed a pilot plant for Pyrolysis Oil Production and Upgrading

See also Ensyn (Canada).

The Pyrogrot project, Sweden (previously selected for NER300 funding) to be discontinued

On 16 December 2013, BillerudKorsnäs announced that it would not continue to develop the Pyrogrot project. The company's press release stated that: "Technical solutions are at hand for the production of pyrolysis oil but the commercial environment at current conditions, and as assumed in the short to mid-term future development, is not solid enough."

On 18 December 2012 it was announced that Pyrogrot project, Sweden, has been selected to receive counterpart funding of €31.4m under the first call for proposals of the NER300 funding programme for innovative low-carbon technologies. The Project concerns the construction and operation of a plant for the production of pyrolysis oil using forest residues as feedstock. The design capacity was 160000 t/year of pyrolysis oil with the energy content estimated at about 750 GWh.

[Source: SWD(2012) 224 final: NER300 - Moving towards a low carbon economy and boosting innovation, growth and employment across the EU]

Oleochemical conversion

Straight Vegetable Oils (SVO) / Pure Vegetable Oil (PPO)

Diesel engines can be modified to run on Straight Vegetable Oils (SVO), otherwise known as Pure Vegetable Oils (PVO) or Pure Plant Oil (PPO). Waste Vegetable Oils (WVOs) - waste cooking oil from the food industry - are often viewed as being sustainable.

Decentralised small-scale production occurs in many European countries, including Germany, France, Netherlands and UK, for use in agriculture, private vehicles or municipal vehicles.

PVO is addressed by the FP7 project 2ndVegOil - second generation vegetable oil (2008-2011), which has worked on PVO engine development for agricultural vehicles, among other topics. A follow-up project has PraxTrak: Climate protection with pure plant oil fuel as a co-product of animal fodder production funded by financed by the German Ministry for Nutrition, Agriculture and Consumer Protection, started on 1 July 2012. Under the lead of John Deere, the developments done in 2ndVegOil will be further fine-tuned with the aim to produce a fully pure plant oil-fuelled tractor. The kick-off meeting took place on 16 July 2012 at the John Deere European Technology Innovation Center in Kaiserslautern/ Germany.

Further information on SVO/PVO/PPO:

Fuels and biofuels: Pure plant oil fuel for diesel engine concepts - Requirements and test methods

Demonstration of 2nd Generation Vegetable Oil Fuels in Advanced Engines - The 2nd VegOil Project

Pure plant oil as fuel: Technical aspects and legislative context

Facts and figures on Pure Plant Oil provided by Solar Oil Systems

Straight Vegetable Oil - the French Experience

Biodiesel (FAME) production and use in Europe

Overview

Fatty Acid Methyl Esters (FAME) are esters of fatty acids. The physical characteristics of fatty acid esters are closer to those of fossil diesel fuels than pure vegetable oils, but properties depend on the type of vegetable oil. A mixture of different fatty acid methyl esters is commonly referred to as biodiese. FAME has physical properties similar to those of conventional diesel. It is also non-toxic and biodegradable.

For further technical information please see the FAME Fact Sheet.

First generation (conventional) biodiesel is typically produced from oil crops (rape, palm, soy, etc.). Increasing use of crops for biofuels production has raised concerns about sustainability, which is an important crosscutting issue for all Working Groups of the EBTP. The sustainability section of this website includes information and links on land use issues, biofuels certification and environmental impacts.

The short report Rapeseed opportunity or risk for the future produced by UFOP in 2013 provides a producers' perspective on use of rape seed for biodiesel production in Euorpe. UFOP also produces a monthly bulletin "Market Information - Oilseeds and Biofuels," which is now available in English. The annual report 2012 of the German Öl-Wärme-Institut (OWI) offers a detailed overview of the current state of research in the area of oil heating and the usage of FAME as a blend component.

Following a previous study by Greenpeace, UFOP carried out a study in July 2013 to investigate the raw material composition of the fatty acid methyl ester, offered by public filling stations as the blend component in Diesel (B7).

New energy crops (e.g. Jatropha) are now being cultivated on a large scale in several countries (e.g. India) for production of biodiesel. Other oil crops, such as Camelina and *Salicornia bigelovii,* are also being developed as 'sustainable' biodiesel feedstocks. Such crops can be grown on marginal land and hence do not directly compete with land used for food production. Biodiesel can be produced from waste fats and oils such as Used Cooking Oil (UCO) or waste animal fats.

Advanced biodiesel can be produced via a number of routes, for example, gasification of lignocellulosic feedstocks or biogenic wastes to produce syngas, which is then converted to BtL (biomass to Liquid) via the Fischer Tropsch process (which converts a mix of CO and hydrogen into liquid hydrocarbons). Plant sugars can be converted into biodiesel (and drop-in transport fuels) via catalysis or biotechnology. Residues from the pulp/paper or forestry industry (e.g. tall oil) can also be used to produce biodiesel. System are being developed to cultivate algae on an industrial scale so that the oil can be extracted and converted to liquid fuels. These new technologies will take several years to reach their commercial potential, but can make an important contribution to low-carbon transport in Europe and to the developing European bioeconomy (creating new jobs and wealth, while reducing reliance on fossil fuels and GHG emissions).

Up-to-date information and statistics on biodiesel production in Europe is available from the European Biodiesel Board

European R&D&D on biodiesel

ECOBRIBER process for biodiesel production with improved efficiency

In Spain, Ecoproductos Ibericos SA (ECOPRIBER) and INMASA have developed and patented two efficient processes for the production of biodiesel. The first method (with methyl acetate) does not produce glycerin as a byproduct and the second method improves the efficiency of the conventional processes with methanol. These technologies enable higher production and profitability ratios with investment, operation and maintenance costs notably lower than those required with current technologies.

Greasoline® Technology for conversion of oily feedstocks and fats to diesel and gasoline

Greasoline® technology converts oily and fatty raw and waste materials to hydrocarbon mixtures consisting of chemical substances occurring in fossil gasoline, kerosene and diesel fuels. These products may be used as fuels and fuel components but also as chemical raw materials. The procedure was developed at the Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT in Oberhausen, Germany. In contrast to biodiesel, the product is chemically identical with fossil fuels. [Source: Fraunhofer Instiute].

Use of B100 in Agricultural Engines

In June 2012, German engine producer DEUTZ AG, Cologne, in cooperation with UFOP, annoucned provision of a warranty for use of B100 in the new agripower-engine.

View technical sheet

E-Diesel (Diesel/ethanol blends)

The ethanol-diesel blend, better known as e-diesel, is obtained by mixing bioethanol with traditional diesel oil, in a percentage that varies between 5 and 15%, and an additive that ensures the stability of the mixture. It can be used in traditional diesel oil motors with slight modifications or without them. Compared with regular diesel fuel, e-diesel can significantly reduce the emissions of particles and other contaminants, and improve cold start-up properties. It is currently in the development stage, and not yet commercially available. ABNT is working to reduce the main technical and regulatory barriers for its commercialization.

These barriers include:

- Low flashpoint and tank volatility.
- Instability of the micro-emulsion (separation of ethanol phases and diesel at low temperatures).
- Guarantee from the Original Equipment Manufacturer (OEM), by generating data in real tests.
- Lack of process standardization that allows its registration according to the standards on emissions and health.

The use of e-diesel will further expand the market for ethanol applications.

E-diesel has been mainly tested in the USA and Brazil and currently in Spain and Europe. Fleet demonstrations indicate that the e-diesel can be easily handled and used with proper staff training. No significant operational or material problems have been reported. The main differences in the handling of e-diesel compared with conventional diesel oil are based on ensuring that water is not added to the fuel. In order to ensure a correct performance of the fuel, a quality control system of the ethanol, the diesel oil, and the final blend are necessary, as well as the establishment of a fuel specification. [Source: Abengoa Bioenergy].

Biodiesel developments in the United States and globally

A wide range of Biodiesel Fact Sheets are avilable from www.biodiesel.org in the United States.

In the United States, some corn ethanol producers are also starting to produce corn oil, which can be readily converted to biodiesel. For example, in October 2013 Pacific Ethanol began commercial production of corn oil using the Edeniq Oil Plus™ process.

In June 2012, Piedmont Biofuels "cut the ribbon" at its new biodiesel refinery, which uses FaESTER enzymatic biodiesel technology. The plant, supported by a $1.2m DoE innovation grant, uses enymes (from Novozyme), as opposed to the conventional sodium methoxide, to catalyse production of biodiesel.

In June 2012, POET announced that it's network of plants is now using its corn oil technology to produce feedstock for 31 million gallons of biodiesel.

In May 2012, UOP, a Honeywell company, announced a licensing agreement with Emerald Biofuels LLC to produce 85 mg/year of Honeywell Green Diesel™ from non-food oils and animal fats. Honeywell Green Diesel is a drop-in fuel that is "identical" to fossil diesel.

In January 2011, the US DoE announced a conditional $241 million loan guarantee for Diamond Green Diesel, LLC, the proposed joint venture between Valero Energy Corporation and Darling International Inc., for an industrial scale plant to produce biodiesel primarily from waste animal fats.

JetE LLC has successfully converted corn oil, a coproduct of ethanol production, into drop-in green diesel and jet fuels, using a modular biorefinery system that facilitates distributed production [Source: JetE].

Wake Forest University, North Carolina has developed a sugar-based catalyst that enables more cost-effective conversion of low quality waste fats into biodiesel.

In October 2013, Sweetwater announced a 15 year $250m project to provide "biomass sugars" to Naturally Scientific for production of high-value vegetable oils. Naturally Scientific operates a pilot in

Nottingham, UK, and also has developed processes for converting CO_2 into C3 sugars. The technology could potentially be used for production of advanced biofuels.

Under the 2012 Joint Call on "Green Technologies" of KORANET (Cooperation between Korea and the European Research Area), the PROMOFUEL Project focuses on new feedstocks for advanced biodiesel production, using 'rubber seed oil' and fish oil as representative of novel non-food feedstocks with high unsaturation. The project involves a collaboration between University of Coburg, Germany and the Korean Institute oif Energy Research. In particular PROMOFUEL aims to improve stability of novel biodiesel feedstocks as well as study the influence of feedstock type on engine emissions.

TransBiodiesel enzyme-based transesterfication

In Israel, TransBiodiesel has developed enzyme based transesterification systems for production of biodiesel, which can be used with a variety of oils and fats as feedstocks.

HVO/HEFA

This web page is currently under development.

Overview

Hydrotreating is an alternative process to esterification to produce diesel from biomass. Hydrotreated Vegetable Oils HVO are commonly referred to as renewable diesel. Hydrotreating (hydroprocessing) can use a wide range of waste fats and oils as feedstocks, hence the synonym **HEFA Hydroprocessed Esters and Fatty Acids** is increasingly applied.

HEFA are straight chain paraffinic hydrocarbons that are free of aromatics, oxygen and sulfur and have high cetane numbers. HEFA offers a number of benefits over FAME (Fatty Acid Methyl Esters), such as reduced NOx emission, better storage stability, and better cold properties. Properties are similar to biomass-to-liquid (BTL) diesel fuels produced by Fischer-Tropsch (FT) synthesis, hence HEFA can typically be used in all diesel engines. [Source: Hydrotreated Vegetable Oil (HVO) as a Renewable Diesel Fuel; Hannu Aatola et al, Seppo Mikkonen, 2008)

HEFA has also been approved for use as an aviation (bio jet) fuel.

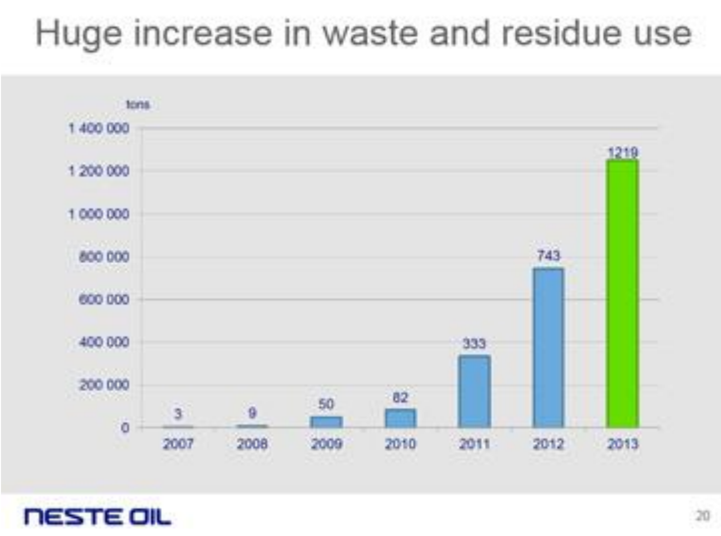
Commercial production of HEFA/HVO is carried out by Neste Oil in Europe and Asia, and by companies such as Renewable Energy Group Inc, US. The main focus is now on feedstock diversification (see figure below showing increase in use of waste oils and fatty acids as a feedstock by Neste Oil).

Commercial production of HEFA

Neste Oil NexBTL facilities

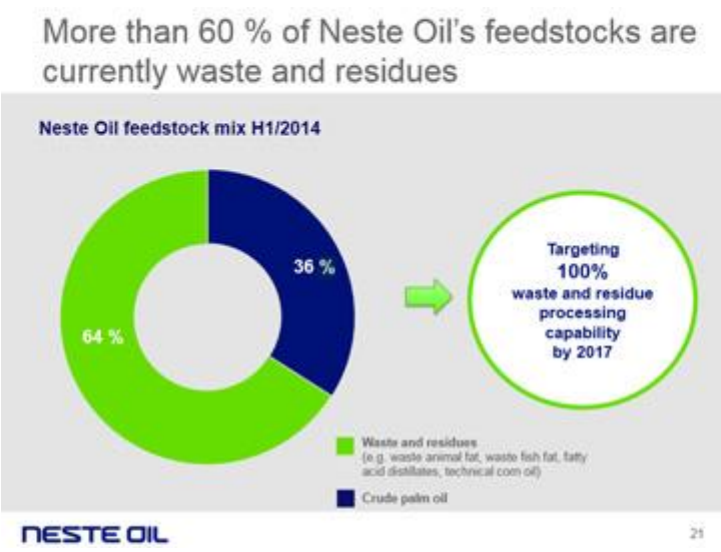
Neste Oil has developed the NexBTL process for production of "Renewable Diesel Fuel". The company has 4 facilities (Finland, Singapore and Rotterdam) that are able to produce HEFA from a wide range of oils. The crude palm oil used by the company to produce renewable diesel today is 100% certified and traced back to the plantation where it originally comes from. A major challenge is sourcing and certifying of alternative feedstocks, such as Used Cooking Oils. In April 2014, Neste Oil introduced its own sustainability verification system (approved by the EC) to accelerate the utilisation of waste oils and fats.

View presenation from EBTP SPM6, October 2014, covering **Large-scale chemical conversion of oils and residues in Rotterdam** made by Petri Lehmus, NesteOil.



Neste Oil has operated a HEFA (renewable diesel) production facility in Rotterdam since 2007 and has rapidly increased the amount of wastes and residues used as feedstocks.

© Copyright Neste Oil (from pesentation made at EBTP SMP6, October 2014)



Wastes and residues include animal fats, fatty acid distillates, technical corn oil. Algal oils could be used in the future.

© Copyright Neste Oil (from presentation made at EBTP SMP6, October 2014)

Total La Mède Biorefinery, France

In April 2015, Total S.A. announced an investment of €200m to convert the La Mède oil refinery in southern France to a biorefinery producing renewable diesel from UCO and other feedstocks.

Plans for Eni Venice Refinery

In March 2014 Eni announced plans to convert Venice refinery into a "green refinery" to produce HVO ("green diesel", using the Ecofining™ process develope with Honeywell-UOP. The facility will be able to produce HVO as well as naphtha, LPG and, potentially, bio jet fuel. The plant aims to start producing 300,000 tonnes of HVO in 2014 using palm oil, but in future plans to use waste animal fats and oils, algal oils and other wastes as feedstocks.

EcofiningTM is a two-stage process:

- during the first stage of hydrodeoxygenation of vegetable oil, the oil, or more generally the biological feedstock, is transformed into a blend of linear C16-C18 paraffins;
- in the second isomerization stage, the paraffin isomers are transformed to give the product the necessary cold properties and meet the specifications of diesel fuel, with bionaptha and bioLPG as by-products.

HVO/HEFA production in the United States

Companies in the United States, such as Renewable Energy Group Inc also produce HVO on a commercial basis.

In 2013, the Four Motors motor racing team, Germany, worked with UFOP on trials of an "Rmax" blend, composed of equal parts of rapeseed methyl ester (biodiesel) and rapeseed oil-HVO. The race car is a Volkswagen Scirocco, dubbed "BioRocco", which is constructed from biocomposites and biopolymers.

© Copyright UFOP
View at larger size >>

Use of HEFA as an aviation fuel

HEFA is approved for use as an aviation fuel under ASTM D7566-14, Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons. A revised standard was approved on July 1, 2011 allowing up to 50 percent bioderived synthetic blending components (HEFA) to be added to conventional jet fuel.

HEFA is currently used for testing purposes in commercial passenger flights [Source: Aireg]. HEFA is also an important component of the European Advanced Biofuels Flight Path Initiative.

Other biofuels technologies

Process innovation relevant to advanced biofuels and bioenergy production

Overview

Various innovative technologies and process innovations can be used in the production of biofuels to improve efficiency, boot yields, overcome technical issues and reduce operating costs. Examples include:

Ethanol/corn oil production process

Cellerate™ Process Technology is a new process technology designed to enable dry grind ethanol plants to convert corn kernel fiber into advanced and cellulosic ethanol, increasing a plant's ethanol production.

TransFerm Yield+ developed by Lallemand Biofuels & Distilled Spirits and Mascoma LLC Lallemand (US Patent: 8,956,851 B2) is an advanced strain of *Saccharomyces cerevisiae* that expresses glucoamylase (GA) enzyme and reduces glycerol production. It is used in the production of fuel ethanol from liquefied grains. Fuel ethanol production facilities using TransFerm Yield+ may experience a yield gain of up to 4% in ethanol, a reduction in glycerol of approximately 30% and may reduce separately purchased GA enzyme. The technology is curently used in ~50 ethanol plants.

ICM Fiber Separation Technology™ removes fibre during ethanol processing, allowing increased ethanol and oil recovery yields.

Solenis is developing chemical additives to improve the separation of corn oil in the ethanol production process, greatly increasing the volume of oil produced and reducing the amount of solids in the oil (Patent No. US 8,841,469 B2).

U.S. Water offers a COR™ additive designed to increase the removal of corn oil from mechanical separation systems at dry-mill ethanol plants

Flow cavitation process (CFC) developed by Arisdyne Systems Inc. can increase yields in corn ethanol production. Powerful cavitation forces completely fracture the corn structure particles, exposing additional entrapped starch molecules within the cellular structure, thus enhancing hydrolyzed enzymatic efficiency in the "mash". Arisdyne has also developed technology for improved removal of phosphatide "gums" in vegetable oil refining.

Catalytic membane reactors and related technologies

Demcamer - an FP7 project to develop innovative multifunctional Catalytic Membrane Reactors (CMR) based on new nano-architectured catalysts and selective membranes materials to improve their performance, durability, cost effectiveness and sustainability (lower environmental impact and use of new raw materials) over four selected chemical processes (Autothermal Reforming (ATR), Fischer-Tropsch Synthesis (FTS), Water Gas Shift (WGS), and Oxidative Coupling of Methane (OCM)) for pure hydrogen, liquid hydrocarbons and ethylene production.

FLUIDCELL - The FLUIDCELL project aims at the Proof of Concept of an advanced high performance, cost effective bio-ethanol m-CHP FC system for decentralized off-grid, by improving technology developments from previous EU projects. The improvements will be achieved by development of a) better system integration using a fluidized bed catalytic membrane reactor working at low temperature (<500°C) b)innovative materials;Pd pore filled (PdPF) membrane, low temperature autothermal ethanol steam reforming (AESR) catalysits and c) most advance FC technologies. Low temperature allows lower thermal duty, higher compactness, use of less expensive materials and long term stability.

SusFuelCat - Sustainable fuel production from wet biomass with new catalysts. SusFuelCat aims to improve the production of hydrogen from wet biomass using the process of aqueous phase reforming. The aim is to develop New catalytic materials that are stable, decrease production costs and improve the yield of hydrogen.

Pass through distillation and related technologies

Pass through distillation - a novel technology offering low-energy distillation at room temperature.

Drystill has invented a disruptive and revolutionary, chemical- separation platform, based on thermally-integrated, evaporation and gas absorption (TIEGA™) principles. This low temperature / low energy distillation process (demonstrated at pilot scale) offers potential cost and energy savings for production of first and second genertaion biofuels. At the heart of Drystill's technology is its novel, patented apparatus called a stripper/absorption module (SAM).

Bioenergy/'biocoal' technology

Rotawave produces microwave processors that can be used in various bioenergy applications, for example Targeted Intelligent Energy System (TIES), a processor that transforms biomass into a consistent quality biocoal.

Potential applications of nanotechnology in bioenergy

Potential applications of nanotechnology in bioenergy - a Masters thesis by Jason Kramb, Department of Physics, University of Jyväskylä, Finland. The major nanotechnology areas which were reviewed are nanostructured coatings (wear resistant, corrosion resistant, low friction and anti-icing), nanomembranes for gas separation, nanostructured catalysts for emission reductions, thermoelectrics and thermophotovoltaics. Basic economic analyses were also performed to determine conditions for economic viability of the nanotechnology solutions. Currently nanotechnologies are too costly to be implimented for large-scale bioenergy production but could be applied in the future.

Catalytic Chemistry - novel processes to produce hydrocarbon biofuels

A number of novel pathways are being developed for producing advanced biofuels, via catalytic chemistry. The aim is to produce petrochemical replacements - synthetic fuels that can be used in conventional engines ('Drop-in' biofuels). Advanced catalytic pyrolysis is covered by the page on bio-oil and biocrude.

Chemical Catalysis

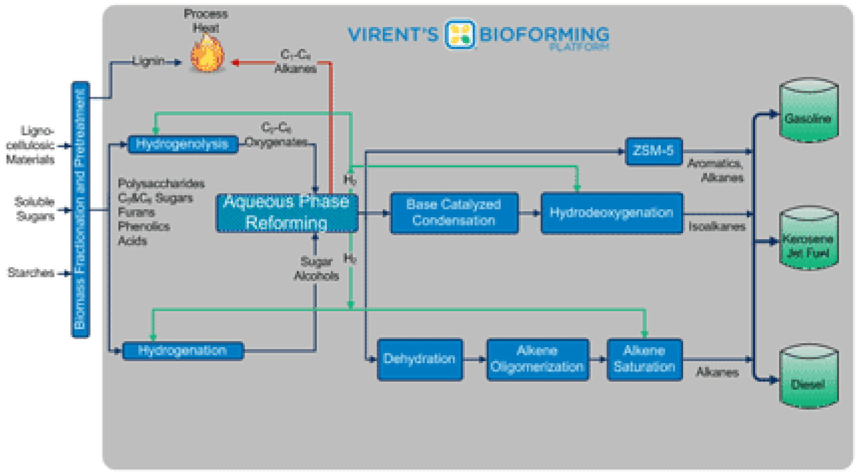
In February 2012, Shell announced the construction of an advanced biofuels pilot plant at the Westhollow Technology Center in Houston, USA, which will produce drop-in biofuels using a thermo-catalytic process technology licensed from its commercial partner Virent.

Previously, in March 2010, Virent and Shell announced the world's first biogasoline demonstration plant based on Virent’s BioForming® process. The demonstration plant in Madison, WI can produce up to 38,000 litres (10,000 U.S. gallons) per year, which will be used for engine and fleet testing. In June 2010, Virent announced that it has secured $46.4m from Cargill and Shell to accelerate biofuel scale-up.

Virent’s BioForming® process can convert a wide range of feedstocks, including non-food and home grown energy sources, into the variety of fuels and chemicals now made from fossil fuels. The BioForming® process, is based on the novel combination of Virent’s core APR technology with conventional catalytic processing technologies such as catalytic hydrotreating and catalytic condensation processes, including ZSM-5 acid condensation, base catalyzed condensation, acid catalyzed dehydration, and alkylation. Like a conventional petroleum refinery, each of these process steps in the BioForming platform can be optimized and modified to produce a particular slate of desired hydrocarbon products. For example, a gasoline product can be produced using a zeolite (ZSM-5) based process, jet fuel and diesel can be produced using a base catalyzed condensation route, and a high octane fuel can be produced using a dehydration/oligomerization route.

(Source: www.virent.com)

Virent Technology Whitepaper (August 2008, 869 kb)



Virent’s BioForming® process View at larger size >>

In the Netherlands, Avantium Furanics are developing processes - proprietary "YXY" technology - that use catalytic dehydration/esterification of carbohydrates (e.g. cellulose, hemi-cellulose, starch and sucrose) to produce furan derivatives that can substitute hydrocarbons deived from petroluem. These furanic building blocks may be used to create biofuels, biopolymers and other products. The process also yields heat and power. Avantium is currently focused on production of PEF (Polyethylene furanoate) from FDCA (furan-dicarboxylic acid), but is also developing the use of furanics as advanced biofuels. The company successfully conducted a range of engine tests using blends of diesel and

Furanics (in different ratios), as well as blends of gasoline and Furanics. Avantium has since collaborated with DAF Trucks and Volkswagen for more extensive engine testing programmes.

The 50M Euro CatchBio project (Catalysis for Sustainable Chemicals from Biomass) involves public-private partnership R&D on use of chemical catalysis on biomass feedstocks (2008-2015) to produce advanced biofuels and novel biochemicals.

In the US, Midori Renewables have developed a patented reusable solid catalyst to convert cellulosic biomass into sugars.

Vertimass LLC, a California-based start-up company, has licensed an Oak Ridge National Laboratory technology that directly converts ethanol into a hydrocarbon blend-stock for use in transportation fuels, using an inexpensive zeolite catalyst. This overcomes the ethanol belnd wall. The drop-in blend-stock can also be used in jet fuel and diesel.

Aqueous phase hydrodeoxygenation (APHDO) using solid heterogeneous catalysts to convert aqueous carbohydrate solution into targeted gasoline range products or chemicals, has been developed at the Huber Biofuels Research Group, University of Wisconsin.

Production of HMF, DMF, Levulinic acid, GVL gamma-valerolactone via Catalysis

Researchers at the University of Wisconsin, Madison, have been researching the conversion of cellulosic materials to 5-hydroxymethylfurfural (HMF), which can then be converted to alkenes (building blocks for synthetic fuels). The process requires expensive ketones and also produces levulinic acid and formic acid. Less costly catalysts can be used to convert these acids into gamma-valerolactone (GVL). GVL can be catalysed into butene, which is readily converted into transport fuels, with an overall efficiency of 95% (GVL -> fuel). Research is now focused on finding a highly efficient route from cellulose to GVL.

Hydroxymethylfurfural can be converted to 2,5-Dimethylfuran (DMF) which has potential for use as biofuel. In June 2012, researchers at University of Delhi published A Catalytic Method of Rapid DMF Biofuel Synthesis in The Berkley Energy Review. See also DMF - A New Biofuel Candidate published by Guohong Tian, Ritchie Daniel and Hongming Xu University of Birmingham and Newcastle University, UK. [Ref: Biofuel Production- Recent Developments and Prospects, Dr. Marco Aurelio Dos Santos Bernardes (Ed.), ISBN: 978-953-307-478-8, InTech].

The EC FP7 project DIBANET is developing the production and use of levulinic acid to make diesel miscible fuels sustainably (via esterification of ethanol with levulinic acid over solid acid catalysts). Further information is available in the latest DIBANET Newsletter. The project aslo offers an elearning portal covering hydrolysis and thermal processing topics related to the project.

Techniques for production of levulinic acid as 'biogasoline' are also being developed by University of California at Davis.

KU Leuven, Centre for Surface Chemistry and Catalysis, Netherlands, has developed a chemical catalytic process for converting sawdust into saturated hydrocarbon chains (HMF). See Direct catalytic conversion of cellulose to liquid straight-chain alkanes, *Energy & Environmental Science*, September 2014. The catalytic reaction proceeds at elevated temperatures under hydrogen pressure in the presence of tungstosilicic acid, dissolved in the aqueous phase, and modified Ru/C, suspended in the organic phase. Tungstosilicic acid is primarily responsible for cellulose hydrolysis and dehydration steps, while the modified Ru/C selectively hydrogenates intermediates *en route* to the liquid alkanes.

Researchers at the University of Science and Technology of China have developed a new catalytic route for the conversion of biomass carbohydrates into gamma-valerolactone (GVL) without using an external H_2 supply. A model experiment with glucose provided gamma-valerolactone in 48% yield. [Source: Angewandte Chemie International Edition *Vol 48, Iss 35, 6529-6532, 23/07/09*]

Shell has also reportedly tested blends of ethyl valerate (EV) derived via hydrogenation of gamma-valerolactone (GVL) into valeric acid followed by esterification. "Petrol blended with 10-20% EV would largely meet European petrol specificiations (EN 228). EV also leads to an increase in octane rate (RON and MON) of the fuel, without affecting other characteristics, such as corrosion and plaque formation. The fuel density and oxygen levels also increase. EV also reduces the volatility and levels of aromates, olefines and sulphur." [Source GAVE]

See also Jean-Paul Lange et al (2010) Valeric Biofuels: A Platform of Cellulosic Transportation Fuels. *Angewandte Chemie International Edition*.

Since 2007 Maine Bioproducts has operated a pilot plant in Gorham, Maine to demonstrate the Biofine process, which involves high-temperature dilute-acid-catalyzed hydrolytic breakdown of cellulose to form levulinic acid.

Synthetic biology, 'modified metabolism' and biotechnology for production of advanced biofuel molecules

A range of biotechnology techniques, already used in development of therapeutics and bioproducts, are being developed or investigated for production of advanced biofuel molecules or improvement of energy crops. These techniques involve complex biology at the cellular and genetic level, and require detailed explanation. As a broad introduction to the topic, this page includes selected links to advanced biofuels R&D and demonstration projects covering:

- Synthetic biology - "designing" microorganisms that are able to produce novel fuel molecules or improve process efficiency by combining characteristics in a single microbe or overcome process issues (for example, improving tolerance to a toxic metabolic byproduct:

  See Joint BioEnergy Institute - Biofuels Toxicity & Tolerance Group.

  In April 2014, NYU Langone Medical Center's Institute for Systems Genetics, announced the synthesis of the first functional chromosome in yeast, paving the way for production of novel biochemicals, including advanced biofuels, in future. See Sc2.0

- Metabolic modification - optimising cell processes to increase production of a specific substance that can be more readily converted to advanced biofuel molecules.

The journal Biotechnology for Biofuels is a good source of information and recent research articles in this area.

R&D&D on biotechnological pathways to advanced biofuels

See also Process Innovation page for commercial use of biotech to improve productivity of etahnol production.

Total Amyris Biosolutions

Amyris Inc is developing technology based on synthetic biology to produce added value biofuels (renewable biodiesel and jet fuel) from sugar cane, and has established 'joint undertakings' for production facilities in Brazil.

In December 2013 Total and Amyris, announced a joint venture 'Total Amyris BioSolutions BV' to produce and sell advanced biofuels. In August 2013, Amyris announced increased production and sales of farnesene from its facility in Brazil. The company also announced that it has secured further funding worth $60m. In October 2012 Amyris entered a collaboration agreement with Microbiogen for improvement of base yeast strains for biofuels production. On 19 June 2012, Azul Brazilian Airlines, completed a demonstration flight using jet fuel produced from sugarcane using Amyris technology.

"On 30 November 2011, Total and Amyris announced an agreement to expand their ongoing research and development collaboration to accelerate the deployment of Biofene® and develop renewable diesel based on this molecule produced from plant sugars. The ambitious R&D programme, launched in 2010 and managed jointly by researchers from both companies, aims to develop the necessary stages to bring the next generation renewable fuels to market at commercial scale. Total has committed to contribute $105 million in funding for an existing $180 million program. In addition, Total and Amyris have agreed to form a 50-50 joint venture company that will have exclusive rights to produce and market renewable diesel and jet fuel worldwide, as well as non-exclusive rights to other renewable products such as drilling fluids, solvents, polymers and specific biolubricants. The venture aims to begin operations in the first quarter of 2012" [Source: Amyris Press Release].

In July 2011 Amyris Brasil S.A., a subsidiary of Amyris, Inc., announced it will begin supplying up to 160 city buses in the Brazilian city of São Paulo with Amyris renewable diesel derived from sugarcane (Diesel de Cana™). Vehicle manufacturers in Brazil have issued warranties for the use of 10% Amyris renewable diesel blends in Brazil. The renewable diesel derived from plant-based sugars does not require engine or infrastructure modifications.

In March 2012, it was announced Amyris fuels would be used for performance testing with VW TDI Clean Diesel Technology.

Global Bioenergies / Audi

In January 2014, the French company Global Bioenergies announced a collaboration with Audi to develop isobutene-derived isooctane (for gasoline engines) via synthetic biology. An initial pilot plant was supported by a 5.2m Euro investment under the Investissemements d'avenir programme. Global Bioenergies is now developing a pre-commercial pilot plant at the Fraunhofer CBP in Leuna near Leipzig, Germany, to produce high-purity isobutene.

Joule / Audi

Joule has partnered with Audi AG to accelerate the commercialization of its biofuels, Sunflow-E (ethanol) and Sunflow-D (diesel). In April 2013, Joule announced advances in the development of Sunflow-G and Sunflow- J processes for gasoline and jet fuel, respectively. In September 2012 Joule announced the commissioning of its first SunSprings™ demonstration plant in Hobbs, New Mexico, where the company will prove its scalable platform for advanced biofuel production. The Joule process uses optimized microorganisms that act as living catalysts to produce fuel, rather than first producing biomass and later extracting lipids or sugars for subsequent multi-step conversion into fuel. Joule says that its process uses a fraction of the land and capital investment required for algae-derived or agricultural biofuels. *"Joule aims to show that its uniquely modular system can achieve replicable results whether installed across one or thousands of acres – opening the door to near-term deployment by eliminating scale-up costs and risks that have hamstrung biofuels for years*." [Source: Joule website].

Renewable Energy Group Inc.

In January 2014, LS9 was acquired for ~$61m by Renewable Energy Group Inc. LS9 is engineering a wide range of DesignerMicrobes™ that are used in a proprietary 1-step fermentation process to produce renewable fuels and sustainable chemicals. The technology enables the rapid and widespread adoption of renewable transportation fuels. Patent-pending UltraClean™ fuels are custom engineered to have higher energetic content than ethanol or butanol; to have fuel properties that are essentially indistinguishable from those of gasoline, diesel, and jet fuel; and to be distributed in existing pipeline infrastructure and run in any vehicle. [Source: LS9].

100% sugar cane biodiesel (B100) produced by LS9, has been used succesfully in Brazil by Man Latin America, who ran tests in Summer 2013 in trucks with Euro 5 engines. The results, publicised in October 2013, showed a decrease of 15% in NOx emissions, 77% in particulate matter, and 42% in black smoke.

Gevo isobutanol production

See also Gevo (cellulosic yeast strains engineered to produce butanol) on the butanol page.

Use of biotechnology for production of advanced biofuels with algae

Please see the Algae and aqauti cbiomass page for more infromaiton on Synthetic Genomics (engineered algae), Algenol Biofuels, and Solazyme (heterotrophic algae modified to increase oil yield using standard fermentation equipment).

Other recent R&D&D on biotechnology for biofuels

OPX Biotechnology OPXBIO has patented its Efficiency Directed Genome Engineering (EDGE) technology platform, which promises to more rapidly, rationally, and robustly engineer microbes and develop cost-effective bioprocesses. In April 2015, the technology was acquired by Cargill. It can be used to accelerate the production of a range of non-food biomaterials, for example fatty acids for conversion into renewable diesel. View the infographic on BioAcrylic production.

In the Netherlands, the 120M Euro Public/Private BE-Basic project is developing advanced genomics technologies and bioprocess engineering for bioproducts, including advanced biofuels.

In the US, the Joint BioEnergy Institute (JBEI) has identified a three-gene cluster in *Micrococcus luteus* that encodes enymes that catalyze key steps in the conversion of plant sugars into hydrocarbons. When introduced into *Escherichia coli*, the genes enabled synthesis of long-chain alkene hydrocarbons from glucose.

The JBEI has also conducted research with Lawrence Livermore National Laboratory to introduce tolerance to ionic liquids in bacteria (so they may grow normally in presence or absence of ionic liquids). This facilitates the use ionic of liquid pretreatment of cellulosic biomass, a part of JBEI's biofuel production strategy.

ARPA-E's Electrofuels program in the U.S. (Microorganisms for Liquid Transportation Fuel), involves a number of institues that are researching the use of varous microbes to produce electrofuels from carbon dioxide and water. Electrofuel technology enables electricity from renewable sources to be converted into liquid and gaseous fuels, to facilitate energy storage and use in transport.

The Energy Biosciences Institute (California / Illinois) has identified pathways used by *Neurospora crassa* to digest cellodextrins and xylodextrins released from plant cell walls by its secreted enzymes. Five N.crassa genes have been introduced to yeast. A hot water pretreatment is required to release the xylose from the plant cells The Institute is involved in a number of other biotech RTD projects relating to biofuels [Source: Energy Biosciences Institute 2015].

Georgia Institute of Technology and the JBEI have engineered a bacterium to synthesize **pinene**, a hydrocarbon produced by trees that could potentially replace high-energy rocket fuels.

University of Georgia has developed a strain of yeast *Saccharomyces cerevisiae* strain AJP50 (PCT/US2009/043358) that can produce higher yields of ethanol from pretreated pinewood. Research was funded by C2 Biofuels LLC and DoE [2015].

The Adams Laboratory at University of Georgia is also researching *Caldicellulosiruptor bescii*, an anaerobic microbe capable of breaking down plant components (cellulose, sugars, and lignin). Promising studies have been carried out using Switchgrass. Several open access papers on *Caldicellulosiruptor bescii* and related research are available via the *Bioechnology for Biofuels* journal online.

Researchers at the Colorado School of Mines have engineered *Synechococcus sp. PCC 7002* to produce the plant terpenoids limonene ($C_{10}H_{16}$) and α-bisabolene ($C_{15}H_{24}$), which can be used as hydrocarbon precursors for biofuels and oher industrially biochemicals. Colorado School of Mines is a partner of the Colorado Center for Bioefining and Biopoducts.

The Energy Biosciences Institute at Berkley is researching microbial production of 1-Undecene and related fuel-like molecules. EBI discovered the first microbial aliphatic medium-chain 1-alkene (MCAE) biosynthetic enzyme, UndA, which was able to convert medium-chain fatty acids (C10-C14) into their corresponding terminal olefins using an oxygen-activating, non-heme iron dependent mechanism. This paves the way pave the way for tailored bioconversion of renewable raw materials to MCAE-based biofuels.

Researchers at UCLA have successfully introduced enzymes to *Ralstonia eutropha* to enable the microorganism to produce isobutanol and 3-methyl-1-butanol in an electrobioreactor using carbon dioxide as the carbon source and electricity for energy. Formic acid is used as an energy carrier. The research is supported by ARPA-E's PETRO program.

VG Energy (a majority owned subsidiary of Viral Genetics) is developing commercial applications of Metabolic Disruption Technology MDT in the energy sector. MDT, which was primarily developed to treat diseases, is now being used to increase production of oils from algae and seeds, for use as feedstocks for biodiesel.

Aalto University in Finland is developing microbial methods for production of butanol and has a research project with Neste Oil to convert lignocellulosic wastes to microbial oil (using yeasts and molds). In November 2012 it was announced that a pilot plant would be constructed by Neste Oil to develop a commercial process for production of mircobial oil from wastes using proprietary technology (patents applied for). Waste and residues are first broken down into various sugars, which are used by the microbes to grow and produce oil [Source: Neste Oil and Aalto University websites].

In the UK, Shell and BBSRC have supported research at the University of Exeter to develop strains of *E.coli* that produce drop-in biodiesel molecules 'on demand'. Currently research is at the lab scale, but could offer potential for future scale-up [Source: University of Exeter Press Release, May 2013].

At the University of Texas in Austin, researchers have developed modified strains of the yeats *Yarrowia Lipolytica* that produce 90% cell mass as lipids, which can then be converted to biofuel [Source: Nature Communications 5, Article number: 3131 (2014)].

Biohydrogen

Information on biohydrogen

The latest news and information on development of hydrogen technology in Europe is available from the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) a unique public private partnership supporting research, technological development and demonstration (RTD) activities in fuel cell and hydrogen energy technologies in Europe. Its aim is to accelerate the market introduction of these technologies.

Production of biohydrogen

Hydrogen for use as a transport fuel can be produced from fossil fuels as well as renewable sources (biohydrogen).

Steam reforming

Biohydrogen may produced by steam reforming of methane (biogas) produced by anaerobic digestion of organic waste. In the latter process, natural gas and steam react to produce hydrogen and carbon dioxide.

Fermentation

Biohydrogen may also be produced by fermentation. Fermentation of renewable materials by bacteria may take place in light (photofermentation) or in the absense of light (dark fermentation). Research is focused on increasing yields of biohydrogen from various strains of bacteria.

Cell-free enzymatic process for production of Biohydrogen

Biométhodes and Virginia Tech are currently developing a cell-free enzymatic process for production of 3rd Generation biohydrogen.

Microbial Fuel Cells

In the US, researchers at Penn State University in the US, have developed a microbial electrolysis cell to produce hydrogen from renewable resources. The method uses bacteria called "exoelectrogens" to break down acetic acid - produced by fermenting cellulose, glucose or other organic matter.

Abstracts from Microbial Fuel Cells: First International Symposium. The Pennsylvania State University, University Park, PA. May 27-29, 2008.

Production of biohydrogen by Algae

Algae (e.g. *Chlamydomonas reinhardtii*) also produce hydrogen under anaerobic conditions, and novel techniques are also being developed to increase yields via this route.

EU-funded projects on biohydrogen

The FP7 project PLANT POWER - living plants in microbial fuel cells for clean, renewable, sustainable, efficient, in-situ bioenergy production, is investigating microbial fuel cells, which might be used as future large-scale Europe wide green energy providers. Such a system can produce in-situ 24 hours per day green electricity or biohydrogen without harvesting the plants.

Previous EC Projects relevant to Hydrogen

HYVOLUTION Non-thermal production of pure hydrogen from biomass (FP6 - 19825)

CHRISGAS - Clean Hydrogen-rich Synthesis Gas (FP6 - 502587)

Biomass and Waste Conversion in Supercritical Water for the Production of Renewable Hydrogen (FP5 – ENK6 - 00555)

BIOHYDROGEN: A novel bioprocess for hydrogen production from biomass for fuel (FP5 - QLK5 - 01267)

SYSAF - The EC Joint Research Centre action on Systems for Alternative Fuels also covers use of hydrogen in transport

HySYS - Research on low-cost components for fuel cell (FC-) systems and electric drive systems which can be used in future hybridised FC-vehicles (medium term objective) and ICE vehicles.

HyTRAN - Hydrogen and Furel Cell Technologies for Road Transport

HyLights

StorHy - Hydrogen Storage Systems for Automative Applications

US Research on hydrogen from sustainable resources

In the US, researchers at NREL Researchers at NREL are developing advanced processes to produce hydrogen economically from sustainable resources. These R&D efforts include:

- Biological Water Splitting
- Photoelectrochemical Water Splitting
- Conversion of Biomass and Wastes
- Solar Thermal Water Splitting
- Renewable Electrolysis

See also the Hydrogen from Coal Plan (2.8Mb PDF covering the concept of coal-biomass hydrogen production).

Use of biohydrogen

Hydrogen market development

Currently most hydrogen is produced from fossil fuels (e.g. steam reforming of natural gas). Prototype hydrogen vehicles have been developed, but there is currently no significant infrastructure for distributing hydrogen as a transport fuel, and in-vehicle storage capacity is still an issue. In addition, hydrogen fuel cells are expensive to produce and fragile, and have a relatively short service life. Extensive research is being carried out on chemical storage of hydrogen.

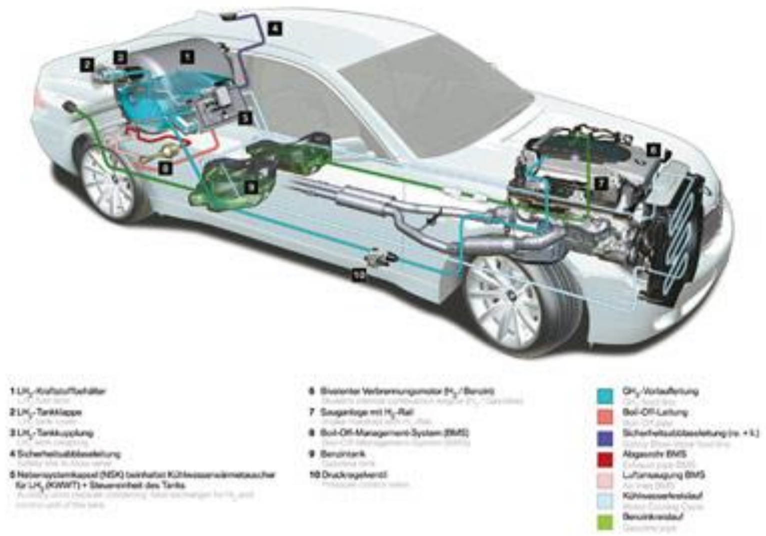
Hydrogen powered cars

Honda plans to deliver about 200 FCX Clarity hydrogen-powered fuel cell vehicles to customers in the first three years of its fuel cell lease program.

Use of hydrogen in combustion engines

BMW has developed liquid-hydrogen combustion engines and released a limited run of 100 bivalent (gasoline/hydrogen) BMW Hydrogen 7 cars to demonstrate technical feasibility. There are no immediate plans for larger-scale production.

BMW Hydrogen 7 View larger image



BMW Hydrogen 7 View larger image

Biomass heat and power and bioelectricity for transport

Overview

Heat and Power in Europe

In 2012, final energy consumption within the EU-28 was 1,104.5 Mtoe, with a share of 21.8 % of electricity and 4.4 % of heat. In electricity generation renewables accounted for 24.2 % (798.7 TWh) of total generation. From this share of renewables, 18.7 % came from biomass and renewables (149.4 TWh) (EC 2014). The primary energy production from biomass in the EU was 82.3 million metric tons of oil equivalent (Mtoe). This included 79.5 TWh of electricity and 68 Mtoe heat (EurObserv'ER 2013).

Combined Heat and Power CHP

The simultaneous generation of electricity and heat is called cogeneration or combined heat and power (CHP). In contrast to thermal power plants, CHP uses the waste heat, which is emitted during electricity generation, and therefore increases the efficiency of the process up to over 80 %. Common CHP plant types are gas turbines and engines, biofuel engines (adapted reciprocating gas engine or diesel engine), wood gasifiers, combined cycle power plants and steam engines.

Cogeneration systems are often integrated in pulp and paper mills, refineries, chemical plants and biorefineries. Bioelectricity can be used within the production process (i.e. to power the biorefinery) and/or be exported to the grid, potentially for use by electric vehicles.

Biomass resources for CHP

Different kinds of biomass resources can be used as fuel for cogeneration plants to produce heat and electricity. Biomass may be co-fired in coal power plants or combusted in smaller dedicated biomass energy plants, where there is a reliable local supply of feedstock. Typically 10 % of biomass can be used for co-firing, higher percentages may be enabled by the use of biocoal, produced via torrefaction. Biomass may also be converted into carbon-rich gases (biogas by anaerobic digestion or BioSNG via gasification), which can be used in gas engines and turbines in CHP plants.

The use of liquid biofuels, such as biodiesel, ethanol, biocrude-oil or vegetable oil, for stationary decentralized energy generation is not very common. It is technically possible to feed biofuels to power and heat generation systems, but the economics of such processes are not positive (ETA 2003). Liquid biofuel production is highly energy intensive and the product costs are high compared to other resources. Therefore, although sustainable, biofuels are not favoured for use as fuel in CHP plants.

Availability of biomass for bioenergy

700m tonnes of coal are used in Europe every year and there are only 300m tonnes of wood produced. So even if every piece of wood was used for biocoal production, this would still not meet current energy demand. As in other areas of bioenergy, feedstock availability (rather than technology issues) may ultimately be the limiting factor to production capacity.

See the forestry page for information on the EU forestry strategy and related R&D.

View pages on the availability of biomass and sustainability.

The rising demand for wood from the bioenergy sector led to a 30% increase in wood price in the UK in the 3 years up to 2010. Energy generator subsidies for wood fibre is causing concern for other industries, for example, chipboard manufacturers, who have seen sharp rises in costs.

Certification of sustainable biomass in the EU

The Sustainable Biomass Partnership SBP Framework of standards and processes enables producers of woody biomass to demonstrate that they source their raw material responsibly and that it complies with the regulatory, including sustainability, requirements applicable to European power generators burning woody biomass to produce energy.

Under the SBP Framework the Biomass Producer, typically a pellet mill, is certified by a SBP-approved Certification Body. To become SBP-approved, a Certification Body must first provide evidence that it meets the SBP requirements regarding its existing accreditations and it must also demonstrate that it has sufficient resources and competence to manage the certification programme.

Commercial development of bioenergy (combined heat and power) facilities

EurObserv'ER Solid Biomass Barometer for 2012 estimates that primary energy production from biomass in the EU was 82.3 million metric tons of oil equivalent (Mtoe). This included 79.5 terawatt hours (TWh) of electricity and 68 Mtoe heat. Use of biomass for heat and power is also developing rapidly in the United States: the Federal Energy Regulatory Commission's Office of Energy Projects reported 777 MW of new biomass capacity in 2013.

Examples of large scale bioenergy projects in Europe

A number of new large-scale bioenergy CHP plants are now being constructed in Europe and around the world. For example, in November 2014, it was announced that Abengoa will be developing a €315m biomass power plant producing 215MW of 'bioelectricity' on behalf of Belgian Eco Energy (Bee) at Ghent, Belgium. The feedstock includes wood chips and agro-residues.

A 69MW plant based at a Smurfit Kappa Group paper facility in France commenced operation in September 2012. In 2014 the Bio Golden Raand 49.9MW biomass power began operations at the port of Delfzijl, Netherlands. The plant is operated by Eneco and was developed by Ballast Nedam Industriebouw and Metso Power Oy. Also in Netherlands, the Essent power plant in Geertruidenberg co-fires 34% biomass in one of its units.

In 2015, the number of large biomass power plants in Europe continues to increase. In the UK, the £150m Rotherham Biomass Plant will use a B&W Vølund-designed multi-fuel boiler with a DynaGrate fuel combustion system, a dry flue gas desulfurization system and will burn waste wood to generate approximately 40MW of electricity. The contract to build the plant has been awarded to Interserve The Nokianvirran Energia biomass boiler plant, Finland, will use a 68MW HYBEX boiler supplied by Valmet, including fluidized bed technology, flue gas purification equipment, and the plant's electrification and automation system. The new steam heat station will be built by Nokia.

In July 2013, RWE npower closed the 750MW biomass power station at Tilbury, UK, citing a lack of investment capacity and technical difficulties in converting the plant to use biomass in place of coal. However, work continues on the £400m, 300MW Tees Renewable Energy Plant (Tees REP) in North East England, which will generate around 2.4 TWhrs of electricity from biomass each year, enough to power 600,000 homes. It will enter commercial operation in 2016. There are also plans to convert the 400MW Lymington coal-fired power plant to biomass, with investment support from DECC (Department of Energy and Climate Change). However a planned 100MW plant at Port of Blyth in Northumberland ceased development in March 2014, with RES citing inconsistent UK energy policy as a key factor.

In June 2010, the world's largest biomass co-firing project was commissioned at the Drax coal power station, which has an installed power cpacity of 4000 MWe and provides 7% of the UK's electricity. The plant aims to use 10% biomass (1.5m tonnes per year). In October 2012, Drax and Centrica cancelled plans for new biomass plants, both citing lack of government support. Drax is proceeding with a smaller £700m project that will convert half of its existing 4,000 MW coal-fired plant at Selby, North Yorkshire, to biomass. This follows a decision by the government to reduce subsidies for new-build biomass plants and instead focus on conversion of coal planbts to biomass.

In December 2013 it was announced that work will begin on a 10.3 MW biomass gasification plant in Tyseley, UK. The plant will use the biomass gasification process of the Canadian firm Nexterra Systems to convert 67,000 metric tons of locally-sourced woodwaste into power.

The Biomass CHP Plant Güssing, which started operation in 2002, has a fuel capacity of 8 MW and an electrical output of about 2 MWel with an electrical efficiency of about 25 %. Wood chips with a water content of 20 – 30 % are used as fuel. The plant consists of a dual fluidized bed steam gasifier, a two-stage gas cleaning system, a gas engine with an electricity generator, and a heat utilization system.

In Summer 2012, CHO Power completed construction of a demonstration facility in Morcenx, France to gasify 37,000 tonnes of ordinary industrial waste and 15,000 tonnes wood chips per annum, generating power for EDF.

In December 2011, CHO Power SAS (a subsidiary of Europlasma) and Sunrise Renewables announced plans to build 4 high temperature plasma gasification facilities at UK docks to convert waste wood into clean syngas. The Syngas will be cleaned further and the tar removed, prior to power production via gas engine generators.

A market study by CHO Power in 2012, estimated that by 2030 107 advanced gasification plants will need to be built in the UK as well as 126 advanced gasification plants in France to meet EU targets for renewable energy.

The demonstration plant at Skive Fjernvarme in Denmark converts wood to combined heat and power (CHP) production via gasification, generating 120k MWh of district heating and 22k MW of electricity. "A single bubbling fluidized bed (BFB) gasifier and related equipment converts wood pellets to fuel gas for three reciprocating engines in a combined heat and power (CHP) in the CHP plant. The engines generate electrical energy (two MW each) from which the heat is recovered for the community's district heating needs. Two gas boilers in the facility can also utilize the biomass-derived gas providing additional district heat."

REACT Energy is developing two biomass gasification CHP demonstrations in Newry, Northern Ireland (2-4 MW) and Enfield, England (12 MW), with further 12MW installations planned in Plymouth and Derbyshire, UK. Gasification technology for Phase 1 of the project in Newry was provided by Zeropoint. GE Jenbacher engines are now being installed by Clarke Energy.

In March 2014, Xergi announced it will be developing the lagest biogas plant in France at Hagetmau, which each year will convert 153,000 tons of biomass to biogas, which will be used to generate 37.8 million kWh of electricity.

Biomass use in North America

At end of 2014, the US had 13,447.1 MW of biomass capacity (8,330.3 MW from wood and wood waste, 2,069.1 MW from landfill gas, 2,230.7 MW from MSW, and 817 MW from other waste biomass). A further 211.1 MW of biomass capacity is scheduled to be added in 2015 [Source: EIA].

In Canada, the Thunder Bay Generating Station, operated by Ontario Power Generation, will be converted from coal to biomass. The plant aims to be operational in 2015.

Use of an Externally-Fired Gas Turbine EFTG allows a wider range of biomass resources to be used, and has been investigated for decentralised production of power at a smaller scale. In Canada, Nexterra Systems has developed a proprietary fixed-bed, updraft gasifier for generating decentralised heat and power from biomass with high efficiency (up to 10 MW). The technology is being implemented in a number of niche projects in North America. In September 2012 a commercial demonstration of a CHP system using Nexterra's technology (with wood waste as a feedstock) was launched at the University of British Columbia. The system combines Nexterra's gasification and conditioning technologies with a GE Jenbacher internal combustion engine.

The $2billion Clean Coal Power Initiative is (among other activities) developing IGCC technology for coal power. A number of US DoE awards were made for research into biomass-coal gasification, as well as hydrogen production.

EC projects on Bioenergy R&D&D

The FP7 DEBCO project - DEmonstration of large scale Biomass Co-firing and supply chain integration - will develop and demonstrate innovative approaches to the co-utilisation of biomass with coal for large-scale electricity production and/or CHP, at more competitive costs and/or increased energy efficiency. The aim is the development, demonstration, and evaluation of innovative and advanced co-firing technologies.

Also see the pages on bio-SNG and biogas for more details of relevant projects on biofuel and bioenergy production via gasification and anaerobic digestion.

Torrefaction and related pretreatment technologies

Typically 10% of biomass can be used for co-firing [Source: IEA Clean Coal] - avoiding issues such as slagging and fouling (although these issues also depend on the feedstock type). Higher percentages of biomass in co-firing may be enabled by torrefaction [Source: Torrefaction for biomass co-firing in existing coal-fired power stations; Bergman et al 2005). Torrefaction is a thermochemical process typically at 200-350 °C in the absence of oxygen, at atmopsheric pressure with low particle heating rates and a reactor time of one hour. The process causes biomass to partly decompose, creating torrefied biomass or char, also referred to as 'biocoal'.

Biocoal has a higher energy content per unit volume, and torrefaction followed by pelletisation at the harvest sites facilitates transport over longer distances. It also avoids problems associated with decomposition of biomass during storage. Hence the benefits of torrefaction may outweigh the additional cost in many cases.

Further information is available on the torrefaction page.

History of higher efficiency power generation via gasification of biomass

Biomass integrated combined cycle gasification (BIGCC)-gas turbine technology (BIG-GT) potentially offers much higher efficiences than conventional CHP, and was investigated in the late 1990s and the early 2000s. Several demonstration plants were built. However, at the current time, biomass gasification technologies for heat and power are not always considered to be competitive with combustion [Source: ThermalNet].

The Värnamo plant in Sweden was the world's first IGCC plant and was designed to generate 6 MW of electricity and 9 MW of heat for district heating from wood chip. The Växjö Värnamo Biomass Gasification Centre (VVBGC) was upgraded under the EU CHRISGAS project in 2004-2010 and there were plans for it to continue as a "centre of excellence" on biomass gasification, supporting the development of industrial scale biomass gasification in Sweden. However in February 2011 funding partners withdrew.

In 2001, a demonstration plant was comissioned in Brazil with support from the EU-BRIDGE (EU-Brazil Industrial Demonstration of Gasification to Electricity) project. This demonstrated that the power output of biomass to energy plants in the Brazillian sugar industry could potentially be greatly increased via gasification. IGCC was also the basis of the Arable Biomass Renewable Energy (ARBRE) project in the UK. This project was halted due to a combination of technical and financial issues.

In the United States, several biomass gasification plants were demonstrated in the late 1990s (e.g. Vermont Gasifier). As in Europe, the technology was not commercialised at the time. However development of biomass gasification technology continues (as detailed below). See also the Bio-SNG page for details of new industrial-scale gasification projects.

Electric vehicles for road transport

There are a wide range of electric and hybrid vehicles now available across Europe. Many Member States offer tax incentives and grants to promote electric cars. For more information on electric vehicles and infrastructure in various countries, please see IEA-HEV (IEA Hybrid Electric Vehicals Implementing agreement).

European Green Cars Initiative

The European Green Cars initiative is one of the three PPPs included in the Commission's recovery package. The envelope for this initiative is foreseen at €5 billion to boost to the automotive industry in a time of economic hardship, and support the development of new, sustainable forms of road transport. Of this financial envelope, €4 billion will be made available through loans by the European Investment Bank (EIB), and €1 billion through support to research, with equal contribution from the Seventh Framework Programme for Research (FP7) and from the private sector.

Research on electric and hybrid vehicles, within this initative, includes:

- High density batteries
- Electric engines
- Smart electricity grids and their interfaces with vehicles

Electric HGVs

In the UK, the retailer TK Maxx has introduced a small fleet of aerodynamic, battery-powered ten-tonne delivery truck has a range of over 120 miles. The retailer plans to introduce 10 further trucks to deliver to its stores in the UK, Germany and Poland. The company also uses biodiesel blends (based on WVO).

© TK Maxx. For improved efficiency, the TK Maxx electric delivery lorry features the aerodynamic "teardrop design", a registered design of Don-Bur

'Electrofuels'

Electrical energy generated by fossil fuels, nuclear and renewable souces (wind, solar, hydro, etc) can potentially be converted to liquid and gaseous fuels (e.g. diesel, kerosene, buanol, etc) for use in transport. Electrofuels are produced from carbon dioxide and water. For example, see ARPA-E's Electrofuels program in the U.S. (Microorganisms for Liquid Transportation Fuel). See also Sunfire, Germany, which develops systems for the production of renewable synthetic fuels (e.g. methane gas, diesel or kerosene) using regenerative electricity (*recycling*).

Bioenergy and Carbon Capture and Storage

The concept of Bioenergy and Carbon Storage (Bio-CCS or BECCS) has been suggested as a means of producing carbon negative power (i.e. removing carbon dioxide from the atmopshere via biomass conversion technologies and storage underground). Carbon capture and storage (CCS) technology is currently at a demonstration phase, and current research is focused on reducing the costs of CCS so that it can be applied to a new generation of clean coal power stations. However, CCS could potentially be appled to a wider range of energy plants, including those incorporating co-firing or co-gasification of sustainable biomass feedstocks (agricultural and wood wastes and energy crops), or even 100% biomass energy plants, biofuel production facilities or biorefineries.

The potential for future synergies between CCS and bioenergy/biofuels production is the focus of the Bio-CCS Joint Task Force led by the Zero Emissions Platform with contributions by EBTP.

Further information on Bio-CCS

Bioelectricity vs. Biofuels?

A widely publicised study by the University of California published in Science in May 2009 suggested that bioelectricity produces an average 81% more transportation km and 108% more emissions offsets per unit area crop land than cellulosic ethanol.

These findings do not address the issue that electricity needs to be stored in batteries, which currently have limited capacity or the requirements for upgrading of the electricity infrastructure to enable large scale recharging of electric vehicles at regular intervals (or in millions of homes overnight). However, electric vehicles and electrified public transport may be the preferred option for urban transport strategies, where journeys are much shorter and where local congestion and air quality issues are also important considerations. Electricty is not an option for aviation, which requires liquid fuels.

A wide range of advanced technologies are being developed for second generation biofuels. However, as these are not yet widely available at commercial scale, any direct comparison of bioelectricity with current 2G biofuels may be considered as premature. However, it is clear that advanced biofuels and plug-in and hybrid vehicles will have a vital role to play in the future of sustainable transport in Europe.

END USE

Biofuels for use in road transport

Contents

Post-2020 Visions and National Plans for Sustainable Transport

In December 2015, ECN published a report, comissioned by EBTP, on Post-2020 Visions and National Plans for Sustainable Transport. The EBTP has also produced a draft Position Paper on Post-2020 Transport Strategies in Europe, focusing on the pivotal role of advanced biofuels in national and European transport strategy.

A key message of the EBTP position paper is that "*Next to RD&D and innovation support, a clear EU obligation for advanced biofuels is required. Such an obligation should be gradually increased in the period from 2021 to 2030. The obligation can be defined as an absolute amount e.g. in terms of energy or greenhouse gas reduction, or as a relative share of biofuels in transport energy demand or liquid/gaseous transport fuels demand, and it can be applied to Member States or to fuel blenders.*"

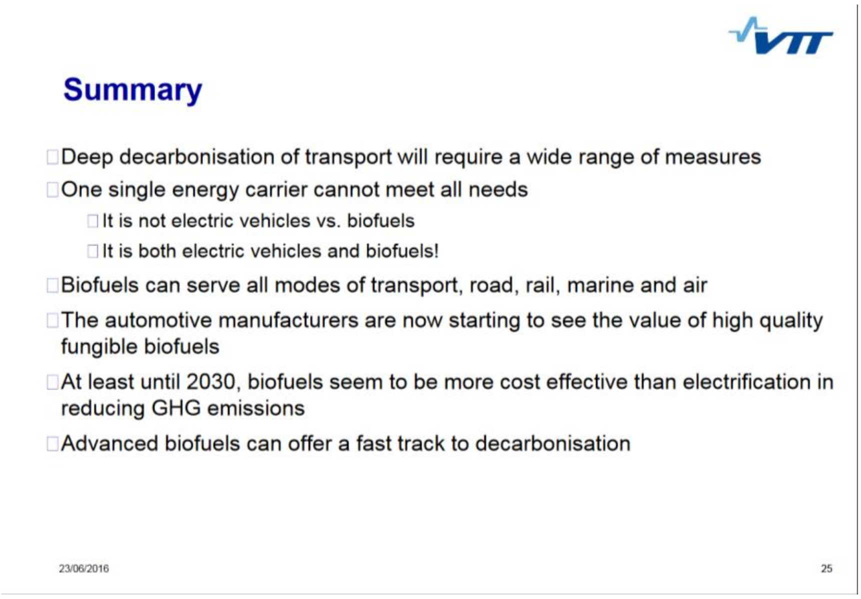
Key findings of the ECN report were as follows:

- In all Member States, ambitions beyond 2020 are still in the phase of visions and plans, and have not yet been translated into formal legislation.
- Not all the Member States have issued national plans beyond 2020. Only Finland, Germany, the Netherlands, Poland, and the UK have issued national plans in this regard.

- Timeframes and horizons regarding the action plans for sustainable transport are diverse among Member States. These vary from 2020 and up to 2050.
- There is a major difference in the availability of data among national plans, which diverges between qualitative and quantitative data. Moreover, a major difference among the national plans is found with regards to the level of in-depth data.
- The status of the policy documents varies from: visions, targets and national strategies.
- The aim of the policy documents varies from one Member States to another, according to their national preferences. For some Member States the aim is to modernize or update the transport system, while for others the aim is to decarbonize the system or lower the emissions related to transport.

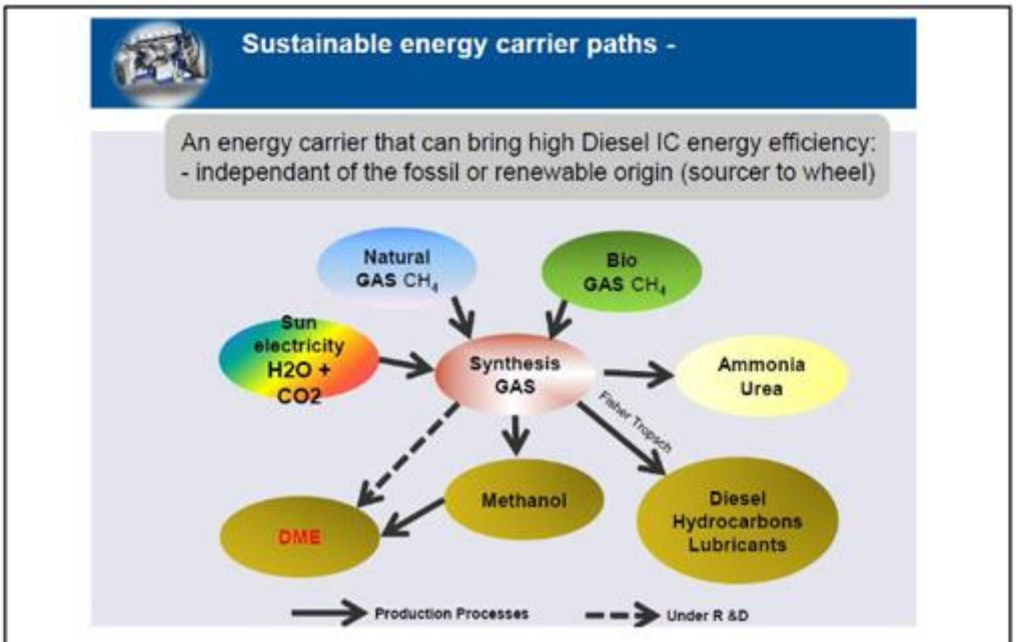
SPM7 presentation on the role of advanced biofuels in future transport options

Presentation made at EBTP SPM7, June 2016, by Nils-Olof Nylund, EBTP Working Group Chair ‘End use and distribution’, VTT on The role of advanced biofuels in future transport options



SPM6 presentation on fuel and technology alternatives for commercial vehicles

Presentation made at EBTP SPM6, October 2014, by Nils-Olof Nylund, VTT on **Fuel and technology alternatives for commercial vehicles**.



Source: Staffan Lundgren/Volvo 2014

Overview

Current status

In 2010 the worldwide annual road energy consumption was 1,698 Mtoe – the largest consumers were the USA with 30 %, EU-28 with 18 % and China with 8 %. The forecast is that while the US and EU-28 will be able to reduce their road energy consumption by 2050, China and India will become the largest consumers (AMF 2012).

Final energy consumption in EU road transportation with 297.6 Mtoe in 2011 takes a share of 81.7 % of final energy consumption of the transport sector. Road transport accounts for the greatest amount of energy consumption in transport. 95.3 % of this energy comes from petroleum products, and only 4.7 % from biofuels (EC 2013).

Therefore road transport needs major "de-carbonizing" actions. There is no single fuel solution for the future of mobility - all main alternative fuel options must be pursued, from liquid and gaseous biofuels to electricity.

Road transportation can be divided into passengers and goods transport in the EU. In 2011 the passenger vehicle stock was 278 Mio. with 5,334 billion pkm in the EU Member States and the goods vehicle stock was 34 Mio. with 1,734 billion tkm. The majority of intra-EU passenger transport (83 %) is accounted for by road transport, whereas 43 % of freight transport is by road (EC 2013).

Alternative fuels for road transport

In the EU, road transport biofuels account for 4.7 % (13,985 ktoe) of final energy consumption, divided into biodiesel (10,644 ktoe), biogasoline (2,892 ktoe) and other liquid biofuels (422 ktoe) (EC 2013). Biofuels are largely compatible with today's engines and vehicles and can be blended with current fossil fuels to a certain extent. Figure 1 shows the main alternative fuels and their possible coverage for road transportation in different travel ranges.

Figure 1: Coverage of transport modes and travel range by the main alternative fuels (COM (2013) 17)

For road transport, the most promising biofuels are liquid and drop-in biofuels, such as B7, E10, E20, lignocellulosic drop-in gasoline and diesel and HVO/CHVO as well as PPO/SVO (Pure Plant Oil/ Straight Vegetable Oil), used in fleets. Conventional bioethanol and biodiesel are commercially available across all Member States of the EC, and are widely used in fuel blends for passenger and freight vehicles on Europe's roads.

The most suitable biofuel-vehicle components for a liquid biofuel strategy to 2030 and beyond are depicted in figure 2. More information on the respective advanced biofuels can be found in the [fuels and conversion] section.

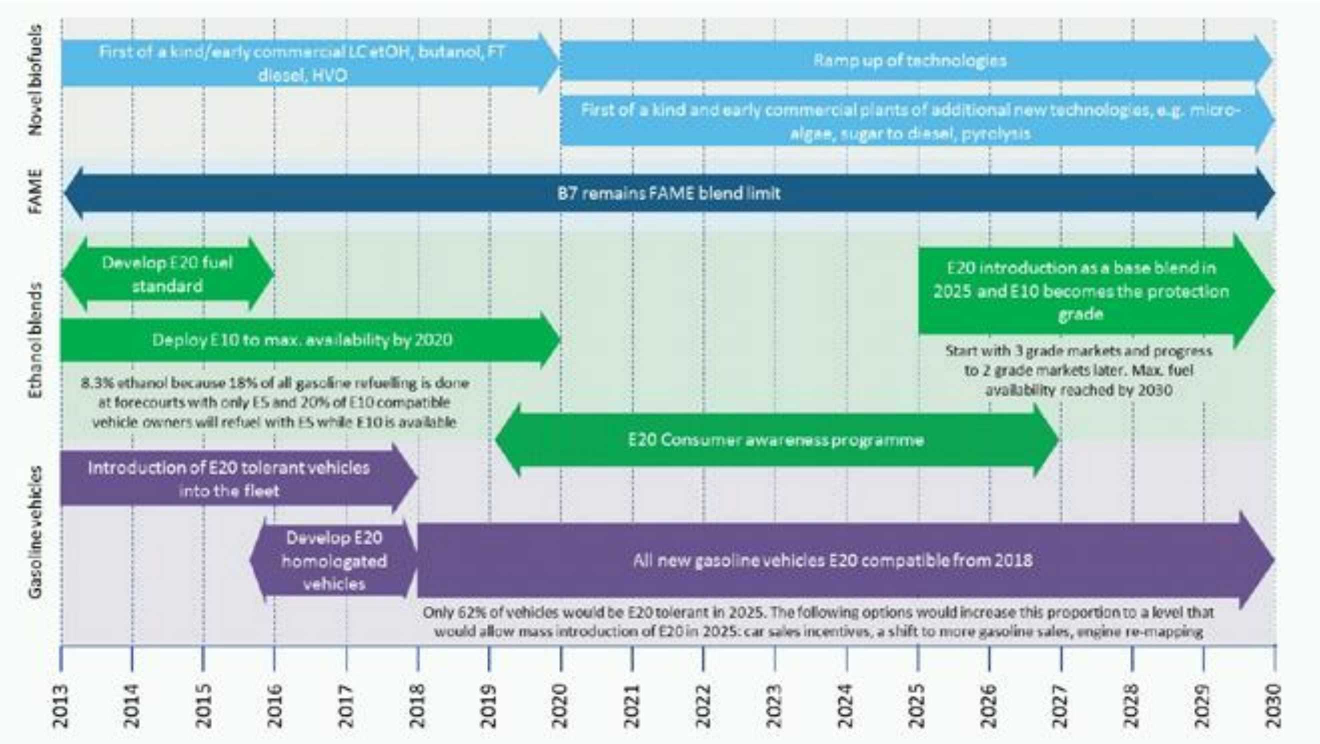


Figure 2: Components of a harmonised Auto-Fuel biofuel roadmap for the EU to 2030 (E4Tech 2013)
View image at larger size

Future perspectives for biofuels in road transport

The promotion of biofuels is a political priority and part of the European energy-climate policy. The EC Directive 2009/28/EC on the promotion of the use of energy from renewable sources introduced a binding target of 10 % share of renewable energy in transport by 2020. For this target, biofuels will make a substantial contribution. In addition, Directive 2009/30/EC allows for the blending of ethanol into petrol up to 10 % (v/v) and for a FAME content of 7 % (v/v) in diesel.

In 2013, the European Parliament stated its intention to place a 6 % cap on first-generation biofuels and a 2.5 % incorporation threshold of advanced biofuels, produced from waste or algae, but these initial ambitions were cut down in the draft directive on the change of land use (June 2014). This agreement imposes a minimum level of 7 % of final energy consumption in transport in 2020 for first-generation biofuels and does not provide for a binding incorporation target for advanced second and third generation biofuels. The agreement is still in a draft version, a final decision is expected for 2015 (EurObserv'ER 2014).

Future expansion of biofuels in road transport up to 2020 and beyond depends on a favourable regulatory environment for advanced biofuels value chains, in particular to support:

- availability of more diverse feedstocks including energy crops, wastes and residues
- demonstration of innovative thermochemical, biochemical and chemical conversion technologies at commercial scale
- market development of advanced biofuels through support mechanisms at national and EC level

Global expansion of biofuels use in road transport also depends on the ongoing development of:

- CI and DI engines able to use higher blends of ethanol and diesel
- the development of drop-in biofuels with properties 'near-identical' to their fossil fuel counterparts. Drop-in fuels can be used in standard engines at much higher blend levels than conventional biofuels, or even at 100% with similar performance.

Passenger Transport by Road

Since 2010, 842 Mio. passenger light-duty vehicles (passenger cars) have been on the road worldwide. EU-28 countries hold 28 % of the world's passenger vehicle stock, the US holds 25 % and Japan, Korea, China and India hold together 16 % (AMF 2012). In 2011 the EU passenger vehicle stock was 242 Mio. passenger cars (483 cars/ 1000 inhabitants), 820,000 buses and coaches and 34 Mio. powered two-wheelers (EC 2013).

In 2011, total passenger transport activities in the EU (including intra-EU air and sea transport) are estimated to have amounted to 6,569 billion pkm. The data for the different passenger transport modes for 1995-2011 is depicted in figure 3. 83.1 % of this amount came from passenger road transportation. Passenger road transportation can be divided into cars (light duty vehicles), buses and coaches (heavy duty vehicles) and powered two-wheelers. The main part of road passenger transportation is done with light duty vehicles (88.4 %; 4,822 billion pkm); buses and coaches (9.4 %, 512 billion pkm) and powered two-wheelers (2.3 %, 123 billion pkm) play a secondary role (EC 2013).

Figure 3: Passenger transport by mode (EU27 as in 2010, prior to advent of EU28)

Freight road transport

The vehicle stock for commercial freight vehicles in the EU is much lower than for passenger transportation, in 2011 34 Mio. commercial freight vehicles were on the road.

In 2011, total goods transport activities in the EU (including intra-EU air and sea transport) are estimated to have amounted to 3,824 billion tkm. The distribution of goods transports to the respective transport modes is given in figure 4. Road transport accounted for 45.3 % (1,734 billion tkm), followed by intra-EU maritime transport with 36.8 %. Rail transport accounted for 11 %, inland waterways for 3.7 % and oil pipelines for 3.1 %. Intra-EU air transport only accounted for 0.1 % of the total.

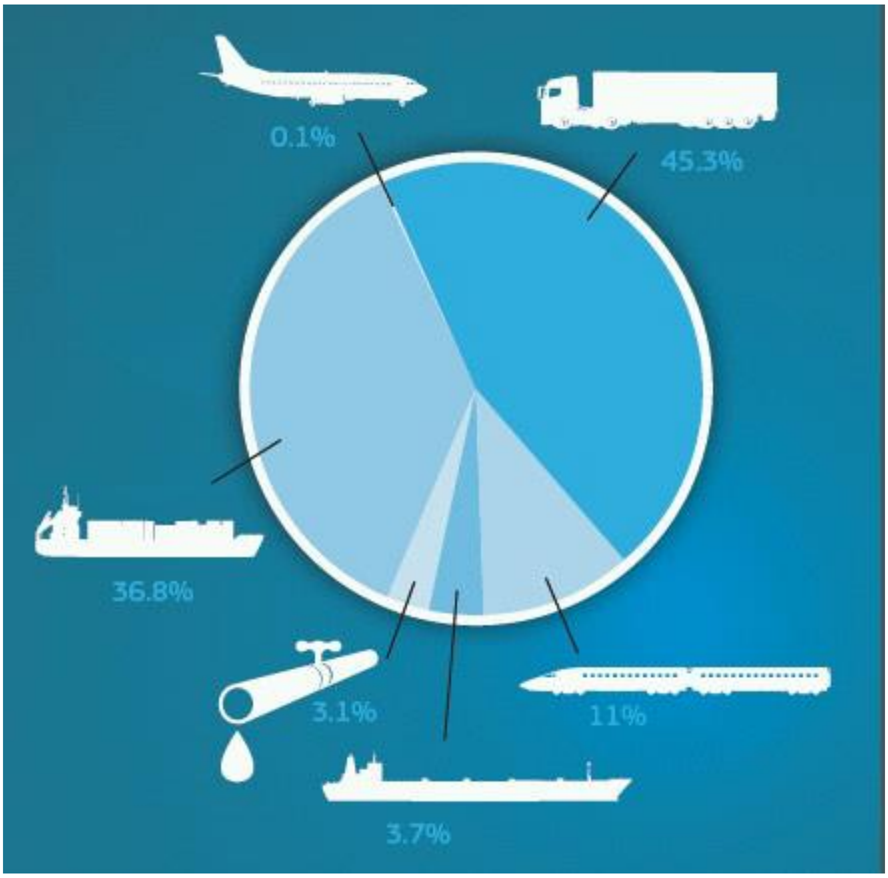


Figure 4: Freight transport in %, based on tkm (EC 2013)

Also, in future freight transport over short and medium distances (below some 300 km) will, to a considerable extent, remain via trucks and heavy duty vehicles. Besides encouraging alternative transport solutions (rail, waterborne transport), it is therefore important to improve truck efficiency. This can be done via the development and the uptake of new engines and cleaner fuels, the use of intelligent transport systems and further measures to enhance market mechanisms.

EC activities on sustainable road transport

It is recognised that liquid transport fuels from renewable sources are just one aspect of the transition to a more sustainable transport system. On 24th January 2013 the EC published COM(2013) 17 [Clean Power for Transport: A European Alternative Fuels Strategy](), which encompasses Biofuels as well as LNG, SNG, electricity and hydrogen. See also the Press Release Europe Launches Clean Fuel Strategy

Under Horizon2020, R&D&D relating to advanced biofuels is included within the Secure, Clean and Efficient Energy work programme. Wider sustainable transport R&D (including gas and hybrid/electric road vehicles) is covered by the Smart, green and integrated transport work programme.

Following the introduction of the directive on the promotion of clean and energy efficient vehicles, the EC launched a Clean Vehicle Portal to advise buyers (domestic and public and private fleet managers) on the environmentasl impact of all new vehicles. This takes into account energy consumption, CO_2 emissions and pollutant emissions over the lifetime of each vehicle (from manufacture to disposal). The website also includes useful information on procurement rules and incentive schemes for clean vehicles and EU-wide information about market-shares of clean vehicles.

The Clean Urban Transport pages on the EC Mobility and Transport website discuss recent policy, reports and research in this area.

The 'Transport GHG: Routes to 2050?' project, commissioned by DG Climate Action, has now entered it's second phase and will continue to develop an understanding of potential impacts of transport GHG reduction policies, and evaulate various potential pathways. Project reports and the SULTAN illustrative scenarios tool, which was developed as part of the project, are also available on the website.

As part of the Commission's modern industrial policy, the CARS 21 (Competitive Automotive Regulatory System for the 21st century) process, which was initially launched in 2005, aims to make recommendations for the short-, medium-, and long-term public policy and regulatory framework of the European automotive industry. This framework enhances global competitiveness and employment, while sustaining further progress in safety and environmental performance at a price affordable to the consumer. Among other topics, CARS 21 addresses alternative fuels.

Links, reports and references

- CARS 21 (Competitive Automotive Regulatory System for the 21st century)
- Clean Urban Transport page on the EC Mobility and Transport website
- COM (2011) 144: White paper – Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system
- COM (2013) 17: Clean Power for Transport: A European alternative fuels strategy
- Directive 2009/33/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of clean and energy-efficient road transport vehicles
- ERTRAC 2009: ERTRAC Road Transport Scenario 2030+
- Climate and Clean Air Coalition CCAC
- COM (2013) 17: Clean Power for Transport: A European alternative fuels strategy
- Directive 2009/28/EC: Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC

- Directive 2009/30/EC: Directive 2009/30/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 98/70/EC as regards the specification of petrol, diesel and gas-oil and introducing a mechanism to monitor and reduce greenhouse gas emissions and amending Council Directive 1999/32/EC as regards the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EEC
- A harmonized Auto-Fuel biofuel roadmap for the EU to 2030, E4tech (UK) Ltd
- EU transport in figures – statistical pocketbook 2013, EC 2013
- EurObserv'ER Biofuels Barometer
- IEA-AMF 2012: IEA Advanced Motor Fuels – Annual Report 2012
- Report of the European Expert Group on Future Transport Fuels
- ERTRAC Road Transport Scenario 2030+
- Reducing Transport Greenhouse Gas Emmissions - Trends and data 2010 (OECD)

Previous EU-funded research and resources on use of biofuels in road transport

The following EU-funded projects cover R&D on biofuel end use in road transport (a more comprehensive list of related biofuels R&D projects are included on the funding page):

TRIP - Transport Research and Innovation Portal. TRIP is the hub for European transport research and innovation.

BEAUTY - Bio-ethanol engine for advanced urban transport by light commercial & heavy-duty captive fleets (DG Research)

BEST - BioEthanol for Sustainable Transport

OPTFUEL - Optimised fuels for sustainable transport (paving the way for large scale BtL production).

RENEW- Renewable Biofuels for Advanced Powertrains

2NDVEGOIL - Demonstration of 2nd generation vegetable oil fuels in advanced engines

Off-road use of biofuels in Europe

Overview

Non-road engines are used for purposes other than for passenger or goods transport. These cover an extremely wide range of applications and include non-road equipment and non-road vehicles.

Non-road engines can be divided into (adapted from EPA 2014 and EC 2014):

- Small spark-ignition engines: these are typically found in lawn and garden machines, in light duty industrial machines and in light logging machines, all fuelled with gasoline. Lawn and garden machines comprise hedge trimmers, brush cutters, lawn mowers, garden tractors, snow blowers and others. Examples for light duty industrial machines are generator sets, welders and pressure washers. Light logging machines are chainsaws, log splitters and shredders.
- Spark-ignition engines >19 kW: these include forklifts, generators, compressors and many other farm, industrial and construction applications which are running with gasoline, propane or natural gas.
- Land-based recreational vehicles: these are snowmobiles, dirt bikes or off-highway motorcycles and all terrain vehicles (ATVs) which are used for recreational purposes.
- Land-based compression ignited engines: Non-road diesel engines are used in a variety of machines including excavators, other construction equipment, farm tractors and other agricultural equipment, heavy forklifts, airport ground service equipment, snow groomers, and utility equipment (generators, pumps, compressors). Small diesel engines < 19 kW are mostly used for small agricultural or industrial machines used in private households or farms. Diesel engines > 560 kW are heavy construction equipment and heavy mining equipment.

In Europe, the emission regulations are specifically clarified on the mobility by using the term non-road mobile machinery. Diesel and spark emission engines installed in these non road mobile machinery contribute greatly to air pollution by emitting carbon oxide (CO), hydrocarbons (HC), nitrogen oxides (NOx) and particulate matters. Emissions from these engines are regulated before they are placed on the market by six directives: the "mother" Directive 97/68/EC, and the amendments: Directive 2002/88/EC, Directive 2004/26/EC, Directive 2006/105/EC, Directive 2011/88/EU, and the most recen amendment Directive 2012/46/EU (EC 2014).

The use of biofuels for non-road application is technologically possible – the used fossil fuels (propane, gasoline, diesel) could be blended with biofuels. To run purely on biofuels, the engines of non-road machines and vehicles need to be adapted to the respective biofuel.

Initiatives in support of off-road biofuels in Germany and UK

At the moment the use of biofuels in non-road engines is limited. However, a number of schemes have been introduced to encourage greater use.

In Germany, the Bavarian government has recently started the so called "RapsTrak200-Programm" (Promotion of agricultural and forestry machinery based on rapeseed oil or vegetable oil fuel) running fo 3 yars from 2015. Farmers can apply for up to 7.5k Euro towards buying a tractor (or off-road machinery) using rape seed oil as fuel. The use of biodiesel and rape seed oil in the agriculture sector is still energy tax free. The programme is supported by Bavarian Centre of Technology and Renewable resources (TFZ).

In the UK, the extension of the Renewable Transport Fuel Obligation to cover Non-Road Mechnical Machinery NRMM has encouraged greater use of biofuels for this purpose. UK biofuels suppliers, such as Ennovor Biofuels, now market biodiesel for non-road use.

For example, EnPlant is specified for use as B100 manufactured according to EN14214 using any blend of waste oils, animal fats or vegetable oils. It is designed for use in mobile power generation equipment and non-road mobile machinery and plant. Ennovor Biofuels' EnPlant biodiesel has comparable performance to petroleum-based diesel fuels and qualifies for the Renewable Obligation Credit for off-road plant and machinery. EnPlant cites the following benefits in the UK of using B100 for generators, plant and equipment:

- Up to 2 Renewable Transport Fuel Certificates (RTFCs) per litre when used for non-road mobile machinery (NRMM)
- Reduced engine wear as a result of natural improved fuel lubricity and no engine modifications required
- 80% reduction in greenhouse gas (GHG) emissions
- All year round freezing point reduced to -15 degrees Centigrade, depending on the blend and additives
- Improved safety, as EnPlant is non-hazardous when spilled

[Source: Ennover Biofuels website].

References and links

RapsTrak200-Programm

UK Government Response to: Consultation on the implementation of the transport elements of the Renewable Energy Directive - Non Road Mobile Machinery

Non-Road mobile machinery (NRMM) emissions: Directives and current status of NRMM legislation

EC 2009: Impact Assessment Study Reviewing Directive 97/68/EC - Emissions from non-road mobile machinery

EPA 2014: United States Environmental Protection Agency: Non-road Engines, Equipment, and Vehicles

Biofuels for Air Transport

Contents

Biofuels in Aviation - An Overview

Current status

Global energy consumption in the transport sector accounted for approximately 2,300 Mtoe in 2009, with 10 % of it consumed by global aviation (figure 5, AMF 2011). In the EU (2011) intra-EU air transport accounted for 13.9 % of final energy consumption in transport sector, which corresponds to 50.5 Mtoe (EC 2013).

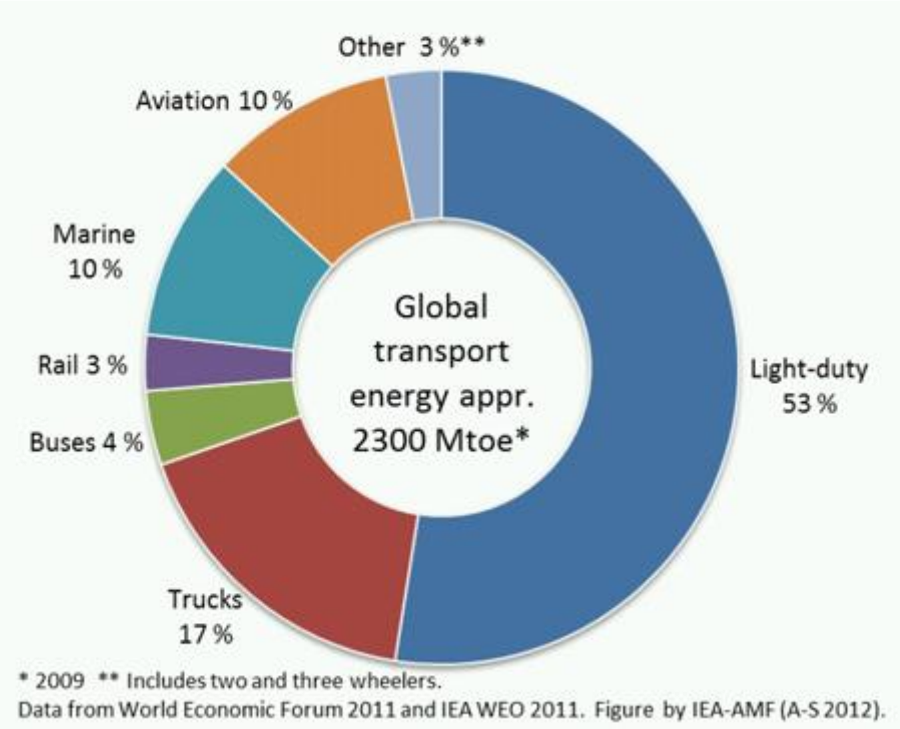


Figure 5: Global view on transport modes 2009 (AMF 2011)

Air transport is more important for transporting passengers than for goods. In 2011, intra-EU air transport contributed to passenger transportation with 8.8 % or 575.1 billion pkm. In comprison, only 0.1 % of freight was transported via intra-EU air traffic (EC 2013).

Alternative fuels for air transportation

Traditional jet fuel is a hydrocarbon, almost exclusively obtained from the kerosene fraction of crude oil. Two types of fuels are used in commercial aviation: Jet-A and Jet A-1. Fuel specifications for aviation fuels are very stringent.

For aviation, advanced liquid biofuels are the only low-CO2 option for substituting kerosene, as they have a high specific energy content. Gaseous biofuels and electrification are definitely no option for air transportation. Advanced biofuels for aviation should use a sustainable resource to produce a fuel that can be considered as substitute for traditional jet fuel (Jet A and Jet A-1), while not consuming valuable food, land and water resources.

A big challenge facing the use of biofuels in aviation is the high quality standards requirements. Safety and fuel quality specifications are of tremendous importance in the aviation sector, however, these are not limiting the use of biofuels. The technical requirements for aviation biofuels are: a high performance fuel, that can withstand a range of operational conditions; a fuel that does not compromise safety; a fuel that can directly substitute traditional jet fuel aviation; a fuel that meets stringent performance targets (ATAG 2009).

ASTM-certified biofuels represent no technical or safety problem in flights. Currently, the following fuel categories are approved by the standard:

- Hydrogenated Esters and Fatty Acids (HEFA)
- Fischer-Tropsch (FT) based on biomass (BtL - biomass to liquid)
- Renewable Synthesized Iso-Paraffinic (SIP) fuel (renewable farnesane hydrocarbon)

Other options incldue ATJ Alcohol to Jet Fuel and Hydrogenated Pyrolysis Oils (HPO).

Globally, various sustainable feedstocks and conversion technologies for production of biofuels for aviation are currently being developed by research organisations, airlines, fuel producers and aircraft manufactuers. In the short term, HEFA appears to be the most promising alternative to supply significant amounts of biofuel for aviation. In the medium term, the most promising alternative is drop-in FT-fuels.

The aviation industry is unlikely to rely on just one type of feedstock. Aircrafts will be powered by blends of biofuels from different types of feedstocks along with jet fuel. Biomass sources for advanced bio-jet fuels include oil crops such as Jatropha and Camelina, waste fats and oils, and, in the longer term, biomass sugars, algae and halophytes (IEA Bioenergy 2012, ATAG 2009, EBTP 2014).

Testing of biofuels is crucial to determine suitability for aviation. In the testing process, which aims to maintain the highest standards in safety, biofuels must undergo dozens of experiments in the laboratory, on the ground and in the air (ATAG 2009). Many major airlines and air forces have been involved in some kind of test flights with biofuels and the number of these demonstration flights continues to grow and indicate the increasing interest in biofuels for aviation. Biofuels have been used in commercial passenger flights since the Autumn of 2011, and several subsequent biofuels test flights are included on this page.

Future perspectives for biofuels in air transport

Aviation is one of the strongest growing transport sectors and this trend will continue. In the period up to 2030, global aviation is expected to grow by 5 % annually according to International Air Transport Association IATA (See IATA Fact Sheet on Alternative Fuels). The demand for aviation fuels is expected to increase by approximately 1.5-3 % per year. (IEA Bioenergy 2012). For the EU, aviation transport is expected to grow at an average rate of 3 % annually until 2050, with a fuel consumption growth of 2 % annually (EC 2011 Update 2013).

There is policy at EU level for the production and use of biofuels in the aviation sector and several initiatives established:
The White Paper – Roadmap to a Single European Transport Area (COM (2011) 144) aims to reach a share of 40 % use of sustainable low carbon fuels in aviation by 2050.

The High Level Group on Aviation Research sets ambitious goals including a 75 % reduction in CO2 emissions and a 90 % reduction in NOx emissions per passenger kilometer in 2050 (EUR 098 EN 2011). The same document also claims that Europe should be established as a centre of excellence on sustainable alternative fuels, based on a strong European energy policy.

The International Air Transport Association is committed to achieve carbon-neutral growth starting 2020 and a 50 % overall CO2 emissions reduction by 2050 (EUR 098 EN).

The EC, in coordination with Airbus, leading European airlines (Lufthansa, Air France/KLM, & British Airways) and key European biofuel producers (Neste Oil, Biomass Technology Group and UOP), launched an initiative to speed up the commercialisation of aviation biofuels in Europe. The European Advanced Biofuels Flight path is a roadmap with clear milestones to achieve an annual production of two million tonnes of sustainably produced biofuel for aviation by 2020. The Biofuels Flight Path initiative is a shared and voluntary commitment by its members to support and promote the production, storage and distribution of sustainably produced drop-in biofuels for use in aviation.

Drivers with potentially the greatest impacts on the development of biojetfuels use in the medium term might be (IEA Bioenergy 2012):

- Overall jetfuel demand (growth of aviation sector, specific jetfuel demand)
- Overall biojetfuel availability (availability of advanced biojetfuel production technologies, infrastructure and logistics for large scale production, progress in plant breeding)
- Environmental effects (Carbon burden of jetfuels, carbon burden of biojetfuels, effects of additional greenhouse effects)
- Market development (development of oil price, development of biojetfuel prices, development of CO2 prices and/or further regulations, further regulations for other emissions forcing the greenhouse effect)
- International trade (standards for biojetfuel quality, sustainability certification for biojetfuels)

At present several hurdles prevent commercial deployment of advanced biofuels: lack of reliable overall biofuel policy, lack of policy incentives for aviation biofuels, lack of long term off-take agreements between the biofuel producers and the aviation industry, and lack of financing.

To help address this, a number of EC-funded R&D projects and initiatives have been initiated to map a way forward for the introduction of sustainable biofuels to help reduce dependence on fossil fuels in air transport and reduce GHG emissions by the air industry.

EC R&D and Support for Aviation Biofuels

FlightPath 2050: Europe's Vision for Aviation

A broad vision for sustainable aviation in the EC is covered by the report FlightPath 2050: Europe's Vision for Aviation produced by the High-level Group on Aviation Research.

High Biofuel Blends in Aviation (HBBA) Study and BioJetMap Workshop

A High Biofuel Blends in Aviation (HBBA) Study and BioJetMap Workshop was held in Brussels on 11 February 2015:

Day One Presentations (zip folder)

- Background and fuels used
- Properties of biokerosene
- Material Compatibility
- Effects on emissions

Day Two Presentations (zip folder)

- Aviation biofuels - achievements to date
- Scale of Opportunity and Challenges
- Sustainable Aviation Fuels - The Airbus Approach
- Potential impact of bio-based kerosene on refining
- What FAO Thinks and Does about Sustainable Bioenergy
- Update on the EU Legislative Framework
- How to achieve a level playing field
- Harmonisation of sustainability standards

- Sustainable fuels in aviation - Feasibility study on deployment of aviation biofuels in Finland
- Bioport Holland

BioJetMap

The BioJetMap is a Biokerosene flight database and web application initiated in 2012, and further developed under the HBBA study project. The scope is global and historical. Its time-enabling traces the evolution of the aviation biofuels sector through successive demonstration, test and commercial flights. Its sortable tabular indexes enable exploration by feedstock, biofuel, and airline.

European Advanced Biofuels Flight Path Initiative

The EC, in coordination with Airbus, leading European airlines (Lufthansa, Air France/KLM, & British Airways) and key European biofuel producers (Neste Oil, Biomass Technology Group and UOP), launched an initiative to speed up the commercialisation of aviation biofuels in Europe.

Biofuels FlightPath 4th Workshop: "Financial mechanisms for advanced biofuel flagship plants" was held on 20 March 2012.

Biofuels FlightPath 3rd Workshop: "The role of a European Civil Aviation Network in the promotion of aviation sustainable fuel and the deployment of the Biofuels Flight Path" was held on 12 December 2012.

The 2nd Biofuels FlightPath Workshop **Progress and benchmarking of paraffinic value chains** was held on 20 Septmber 2011 in brussels. Presentations and more information are available online.

The initiative, labelled "European Advanced Biofuels Flight path" is a roadmap with clear milestones to achieve an annual production of two million tonnes of sustainably produced biofuel for aviation by 2020. The "Biofuels Flight path" is a shared and voluntary commitment by its members to support and promote the production, storage and distribution of sustainably produced drop-in biofuels for use in aviation. It also targets establishing appropriate financial mechanisms to support the construction of industrial "first of a kind" advanced biofuel production plants.

The Biofuels Flight path is explained in a technical paper, which sets out in more detail the challenges and required actions. The key findings of the technical paper were presented to the stakeholders during a Workshop "**Achieving 2 million tonnes of biofuels use in aviation by 2020**" held in Brussels on 18 May 2011.

Launch of the European Advanced Biofuels Flightpath

Technical paper - 2 million tons per year: A performing biofuels supply chain for EU aviation (6 Mb)

The lauch of the Flightpath initiative was challenged by the NGO, Friends of the Earth in the publication Flying in the Face of Facts.

Inclusion of Aviation in the EU Emission Trading Scheme ETS

It has been announced that all flights in and out of EU airports are to be included in the EU Emissions Trading Scheme for 2012 (a scheme based on a "cap and trade" system for emissions allowances). The decision to include international flights is being legally challenged by some US airlines. From 2013, at least half the total number of ETS allowances is expected to be auctioned. It has been argued that money raised should be reinvested in R&D&D in sustainable technologies. For example in the aviation sector, proceeds from ETS could potentially be used to support the demonstration of advanced biojetfuels at the industrial scale.

ITAKA - Initiative Towards sustAinable Kerosene for Aviation

View presentation made at EBTP SPM7, June 2016, by Inmaculada Gomez Jimenez, ITAKA, on the **Decarbonisation**

of transport in the aviation sector

In December 2012, the EC launched the ITAKA project, which will look at removing the barriers to the use of sustainable biofuels in aviation and contribute to the EC's 'Biofuel Flight Path Initiative' annual production target of two million tonnes of biofuel for aviation by 2020.

The project aims to produce sustainable renewable aviation fuel and to test its use in existing logistic systems and in normal flight operations in Europe. The project will also link supply and demand by establishing relationships among feedstock growers and producers, biofuel producers, distributors, and airlines.

As feedstock, ITAKA targets European camelina oil and used cooking oil, in order to meet a minimum of 60% on greenhouse gas emission saving compared to the fossil Jet A1. The project aims to certify the entire supply chain of the renewable aviation fuel, based on the Roundtable on Sustainable Biofuels (RSB) EU RED standard. In addition, the production and use of camelina as a biofuel feedstock will also be assessed with regards to its contribution to food and feed markets and its potential impact on direct and Indirect Land Use Change (ILUC).

The research will also evaluate the economic, social and regulatory implications of the large-scale biofuels utilisation in aviation. Consortium members include feedstock production (BIOTEHGEN and Camelina Company España); renewable fuel production (Neste Oil and RE-CORD); fuel logistics (CLH and SkyNRG); air transport (Airbus, EADS IW UK, Embraer and SENASA); and sustainability assessment (EADS IW France, EPFL and MMU).

CORE Jet-FUEL - Coordinating research and innovation of jet and other sustainable aviation fuel

The FP7 Project **CORE Jet-FUEL** - Coordinating research and innovation of jet and other sustainable aviation fuels - links initiatives and projects at the EU and Member State level, serving as a focal point in this area to all public and private stakeholders. CORE-JetFuel addresses competent authorities, research institutions, feedstock and fuel producers, distributors, aircraft and engine manufactures, airlines and NGOs. Activities are dividided into for 4 broad areas covering feedstocks, conversion, end-use, and policies and market development. The CORE-JetFuel Final International Conference took place on the occasion of the EU Sustainable Energy Week (EUSEW) on 16-17 June 2016 in Brussels.

BIOREFLY

The FP7 project BIOREFLY (2014-2018) involves the industrial-scale demonstration of 2,000 t/y bioefinery processes to convert lignin to aviation fuel:

- Validation at pre-commercial scale on novel competitive technologies for lignocellulosic-based aviation fuel production
- Design, construction and operation of a first-of-a-kind paraffinic fuel industrial facility
- Address the complete value chain, including the conversion of lignocellulosic energy crops and agro residues into biofuel
- Test of jet fuel use in turbines and engines including demonstration flights, as steps towards ASTM validation

The major steps in the process are catalytic depolymerization of lignin -> separation -> hydrogenation ->dehydration -> distillation -> jet fuel

FORUM-AE - Forum on Aviation and Emissions

The **FORUM-AE Forum on Aviation and Emissions** is a technical and scientific forum addressing all issues associated with emissions from aviation: impacts, technical solutions and regulation, and support for European research and innovation.

SWAFEA: Sustainable Way for Alternative Fuel and Energy in Aviation

SWAFEA was a 26 month study (starting May 2009) with €5.1m funding from DG-TREN involving 19 partners from aviation and fuel industries, airlines, research and consultancy to develop a vision and road map for sustinable deployment of alternative fuels and energies in aviation

ALFA-BIRD

ALFA-BIRD gathers a multi-disciplinary consortium that aims to develop the use of alternative fuels in aeronautics, with key industrial partners from aeronautics (engine manufacturer, aircraft manufacturer) and fuel industy, and research organization covering a large spectrum of expertise in fields of biochemistry, combustion as well as industrial safety. Bringing together their knowledge, the consortium will develop the whole chain for clean alternative fuels for aviation. The most promising solutions will be examined during the project, from classical ones (plant oils, synthetic fuels) to the most innovative, such as new organic molecules. Based on a first selection of the most relevant alternative fuels, a detailed analysis of up to 5 new fuels will be performed with tests in realistic conditions.

BioTfuel is a 112.7m Euro joint project launched in 2010 by six partners. BioTfueL aims to integrate all the stages of the BTL process chain and bring them to market. The project includes the construction and operation of two pilot plants in France to produce biodiesel and biokerosene (bio-jet fuel) based on biomass gasification. Partner include:

- **Axens** in the design of catalytic processes, especially Fischer-Tropsch synthesis.
- **IFP Energies Nouvelles** and the **French Alternative Energies and Atomic Energy Commission** (CEA) in research and innovation.
- **Sofiprotéol** in sourcing.

- **ThyssenKrupp Uhde** in gasification technology.
- **Total** in the development of industrial projects and the formulation of transportation fuels.

SOLAR-JET (Solar chemical reactor demonstration and Optimization for Long-term Availability of Renewable JET fuel) is an FP7 project to demonstrate production of keroene and other fuels from CO2 and water using concentrated solar power.

Clean Sky JTI

The Clean Sky JTI is one of the largest European research projects ever, with a budget estimated at €1.6 billion, equally shared between the European Commission and industry, over the period 2008 - 2013. This public-private partnership will speed up technological breakthrough developments and shorten the time to market for new solutions tested on Full Scale Demonstrators.

"Clean Sky will demonstrate and validate the technology breakthroughs that are necessary to make major steps towards the environmental goals sets by ACARE - Advisory Concil for Aeronautics Research in Europe - the European Technology Platform for Aeronautics & Air Transport and to be reached in 2020:"

- 50% reduction of CO2 emissions through drastic reduction of fuel consumption
- 80% reduction of NOx (nitrogen oxide) emissions
- 50% reduction of external noise
- A green product life cycle: design, manufacturing, maintenance and disposal / recycling

This will be achieved by technologies in areas such as loads and flow control, Aircraft Energy Management, NOx and CO2 reduction, rotorcraft, regional aircraft, trajectory management, smart fixed-wing aircraft, etc.

Global initiatives and National activities in support of sustainable aviation biofuels

Sustainable Aviation Fuel Users Group, SAFUG

The Sustainable Aviation Fuel Users Group was formed in September 2008 Support and advice is provided by leading environmental organisations including the Natural Resources Defense Council and the Roundtable on Sustainable Biofuels (RSB). The group is focused on accelerating the development and commercialization of sustainable aviation biofuels. Members include several of the world's major airlines. Affiliates include aircraft manufacturers, such as Boeing and Airbus, as well as fuel developers such as, UOP, a Honeywell Company. SAFUG members agree to contribute to robust sustainability and certification regimes via the RSB global multi-stakeholder process. All members subscribe to a sustainability pledge stipulating that any sustainable biofuel must perform as well as, or better than, kerosene-based fuel, but with a smaller carbon lifecycle.

National Initiatives on Sustainable Aviation

In January 2014 it was announced that Boeing, Etihad Airways, Takreer, Total and the Masdar Institute of Science and Technology are collaborating an a new initiative 'BIOjet Abu Dhabi: Flight Path to Sustainability' to develop biojet fuel capacity in the **United Arab Emirates**.

In a related project, the Sustainable Bioenergy Research Consortium is developing an Integrated Seawater Energy and Agriculture System (ISEAS) to cultivate the halophyte *Salicornia* as a sustainable feedstock for biofuel productio.

In the **Netherlands**, KLM, SkyNRG, Neste Oil, Schiphol Group, Port of Amsterdam and the Dutch government have developed the BioPort Holland supply chain.

In **Norway**, Oslo Airport is developing a hub to receive and supply biojet fuel. From March 2015, Statoil Aviation will deliver 2.5m litres of biofuel produced from UCO (enough for ~3000 flights with 50% biojet). Statoil Aviation has entered into supply agreements with Lufthansa Group, SAS and KLM.

In **Spain**, the bioqueroseno initiative - Spanish Initiative for the Production and Consumption of Biokerosene for Aviation - has its origins in the 2009 ICAO Conference on Alternative Fuels for Aviation, and was launched in October 2011. The initiative brings together several Spanish ministries as well as compnaies active in production of raw materials, refining technologies, aeronautical logistics and sustainability, with a strong involvement from Airbus. Spain also actively participates in SUSTAF.

In February 2014, Airbus announced the formation of a consortium in **Malaysia** to ensure the sustainability of future biojet feedstocks. Partners include AMIC Aerospace Malaysia Innovation Centre, MiGHT Malaysian Industry-Government Group for High technology, University Putra Malaysia, CIRAD, France, and BioTech Corp, Malaysia.

In June 2011, a group of 20 airlines, aviation companies, universities and biofuel producers lauched AIREG the Aviation Initiative for Renewable Energy in Germany. It aims at coordinating research activities and fostering the market introduction of "climate friendly" aviation fuels in **Germany**.

The AUFWIND project, Germany, was launced in 2013 and involves twelve partners from research and industry, who are developing microalgae as a basis for the production of biokerosene. Key questions addressed are the economic and ecological feasibility of the process. The Federal Ministry of Food, Agriculture and Consumer Protection (BMELV) is funding the project with € 5.75 million via its project management organization FNR (Fachagentur Nachwachsende Rohstoffe). Total funding for the project amounts to some € 7.4 million.

In the **United States**, the USDA and FAA have developed a Feedstock Readiness Tool (FSRL) to track the availabuility of potential feedstocks for bio jet fuel, with tha aim of improving supply chains and matching them to appropriate conversion technologies. Also n the US, the Commercial Aviation Alternative Fuels Initiative (CAAFI) "seeks to enhance energy security and environmental sustainability for aviation by exploring the use of alternative jet fuels. CAAFI is a coalition of airlines, aircraft and engine manufacturers, energy producers, researchers, international participants and U.S. government agencies. Together these stakeholders are leading the development and deployment of alternative jet fuels for commercial aviation."

In August 2013, Airbus and RT-Biotekhprom signed a cooperation agreement to analyze the availability of sustainable feedstock for aviation biofuels in **Russia**. Airbus is developing sustainable supply chains for biojet fuel feedstocks globally.

In February 2014, the Civil Aviation Administration of **China** granted Sinopec the first "certificate of airworthiness" for biojet fuel.

Recent publications and links on biofuels in aviation

The Air Transport Action Group ATAG has produced two publications that provide a useful overview of progress, issues and opportunities for biofuels in aviation:

Powering the future of flight - The six easy steps to growing a viable aviation biofuels industry

Beginner's Guide to Aviation Biofuels

In August 2012, IEA Bioenergy Task 40 published the report The Potential Role of Biofuels in Commercial Air Transport - BioJetFuel, which provides a good overview of the current situation and issues affecting the development of biofuels for use in aviation.

The Long Haul to Alternative Aviation Fuels a presentation by Dr. Charles Cameron, Head of Technology, Downstream BP Refining & Marketing made in June 2012.

In June 2013, Qantas and Shell published a report **Australian feedstock and production capacity to produce sustainable aviation fuel**, concluding that significant public subsidies will be required for commercial development of aviation biofuels to be economically viable.

FlightPath 2050: Europe's Vision for Aviation

COM (2011) 144: White paper – Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system

EC 2011 Update 2013: 2 million tons per year: a performing biofuels supply chain for EU aviation – August 2013 Update

EC 2013: EU transport in figures – statistical pocketbook 2013

EUR 098 EN 2011: Flightpath 2050 – Europe's Vision for Aviation

Links to other reports on aviation biofuels can be found below and in the EBTP reports database.

Standards for renewable jet fuels

So far. five aviation biofuels have been approved to meet ASTM International standards. These aviation biofuels are:

- Alcohol to Jet Synthetic Paraffinice Kerosene (ATJ-SPK): created from isobutanol derived from feed stocks such as sugar and corn.
- Synthesized Iso-parafins (SIP) (renewable farnesene hydrocarbon): developd by Total and Amyris, produced by converting plant sugars into farnesene using an 'industrial synthetic biology platform'. In September 2014, Lufthansa made the first scheduled flight in Europe using a 10% blend of farnesene in Germany. In December 2014, Amyyris biojet fuel was approved for use in Brazil by the national regulator ANP.
- Hydro-processed Esters and Fatty Acids Synthetic Paraffinic Kerosene (HEFA-SPK): made from vegetable oil-containing feedstock
- Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK)
- Fischer-Tropsch Synthetic Kerosene with Aromatics

R&D and demonstration on sustainable advanced biofuels for aviation

British Airways GreenSky project shelved, citing lack of government support

On 6 January 2016, British Airways announced that it has been forced to shelve its GreenSky project to create 16m gallons of jet fuel from waste every year, partly due to a lack of government support [Source: The Guardian, UK]. British Airways planned to use 600,000 tonnes of MSW (collected in London) to produce over 50000 tonnes of biojet fuel and 50000 tonnes of biodiesel annually. The GreenSky project was to have used Solena's Plasma Gasification (SPG) technology, which can process 20-50% more waste than conventional gasification technologies, and Velocys technology for production of the jet fuel.

Fulcrum Bioenergy Sierra Biofuels Plant

In May 2015, Fulcrum Bioenergy Inc., announced it has awarded a $200m engineering, procurement and construction (EPC) contract to Abengoa for the construction of the 10 MMgy Sierra BioFuels facility to convert MSW into syngas, followed by a Fischer Tropsch step to create second generation biodiesel and bio jet fuel.

In September 2014, Fulcrum Bioenergy announced a $105m 'Biorefinery Assistance Program' loan guarantee from the USDA, as well as a $70 million grant under the US DoD Defense Protection Act, which will support development. The Sierra BioFuels Plant will include a Feedstock Processing Facility and a Biorefinery that will convert approximately 200,000 tons of prepared MSW feedstock into more than 10 million gallons of SPK jet fuel or diesel annually. In Summer 2014, Cathay Pacific Airways announced that it is investing in Fulcrum Bioenergy Inc., the parent company of Fulcrum Sierra BioFuels, LLC, and has negotiated a long-term supply agreement with Fulcrum for 375 million gallons of sustainable aviation fuel over 10 years. This would represent about 2% of the airline's annual fuel consumption. [Source: Fulcrum Bioenergy website & USDA Press Release].

See also the BtL page for additional information.

Lufthansa collaborations on developing aviation biofuels

In April 2014, Lufthansa made an agreement to evaluate alcohol-to-jet fuel (ATJ) produced by Gevo, using isobutanol.

In September 2012 Lufthansa signed a collaboration agreement with Algae.Tec Ltd. for an industrial-scale algae to aviation fuel production facility in Europe.

Image © Neste Oil: Over 1000 flights have been made by Lufthansa using a blend of Neste Oil "NexBTL"

Neste Oil has also carried out pioneering work with Lufthansa in the area of aviation biofuels. Neste Oil's "NexBTL renewable aviation fuel" was used on a total of 1,187 flights between Frankfurt and Hamburg during a six-month trial. The trial concluded in January 2012 with an intercontinental flight, flown as a regular scheduled service, between Frankfurt and Washington D.C. Lufthansa and Neste Oil presented the results of the trial at their joint stand at International Green Week in Berlin. [Source: NesteOil].

The co-operation and technical trials are set to continue, and Lufthansa will now focus on the sustainability, availability, and certification of raw materials.

Petrixo / Honeywell biorefinery planned for UAE

In July 2014, Petrixo Oil & Gas (Dubai) announced that it would use Honeywell UOP technology (based on hydrogenation of fats and oils) to produce biojet fuel and biodiesel at an $800m biorefinery planned for the UAE. The refinery would process around 500,000 tonnes of feedstock.

US DoD Advanced Drop-In Biofuels Production Project

In May 2013, the US Department of Defense invested $16m with three companies to support facilities for production of bio jet fuels for fighter jets and destroyers by 2016, as part of the Advanced Drop-In Biofuels Production Project (Defence Production Act). The recipients of the funding were Fulcrum Brighton Biofuels LLC, Emerald Biofuels LLC, and Natures BioReserve LLC.

ARA / Blue Sun Energy renewable jet fuel demonsration

In January 2013, ARA and Blue Sun Energy Inc signed an ageement for the design, construction, and operation of a Biofuels ISOCONVERSION™ Process (BIC) demonstration system using the ARA and Chevron Lummus Global process for the production of certification quantities of 100% drop-in renewable jet, diesel, and gasoline. The Biofuels ISOCONVERSION™ process includes patented Catalytic Hydrothermolysis (CH) reactor technology, developed by Applied Research Associates (ARA), which utilizes water as a catalyst to quickly and inexpensively convert plant and algal oils into stable intermediate oil products, which are very similar to petroleum crude oil. The intermediate oils are processed with hydrogen using CLG's ISOCONVERSION™ catalysts to produce renewable jet fuel and diesel. The resulting fuels contain high-density aromatic, cycloparaffin, and isoparaffin hydrocarbons. See also ReadiFuels website for further information. In October 2012, Aemetis signed a technology licence agreement with Chevron Lummus Global for the production of fungible renewable biojet and diesel fuel.

LanzaTech / Swedish Biofuels

LanzaTech, New Zealand, has developed a method for capturing carbon-rich waste gases from industrial steel production, which are then fermented and chemically converted for use as a jet fuel using microbes (developed vis synthetic biology). The technology is being used in conjunction with Swedish Biofuels AB advanced processes for the conversion of alcohols into drop-in jet fuels. Under a project funded by the U.S. Government Defense Advanced Research Projects Agency (DARPA), Swedish Biofuels AB have produced a jet fuel prototype, 100% biological, SB-JP-8, equivalent to petroleum based JP-8.

Other RTD and demo activities

In March 2012 it was announced that Albermale would manufacture biojet fuel from butanol, provided by Cobalt, using NAWCWD's alcohol to jet technology.

In April 2012 Agrisoma Biosciences announced that Resonance™ *(Brassica carianata*) will be evaluated as a feedstock for Honeywell Green Jet Fuel™.

Aliphajet has developed a catalytic process for producing jet fuel and other biofuels from plant oils or animal fats, and in July 2012 joined the Advanced Biofuels Association (ABFA).

EADS has partnered with IGV GmbH on the use of algae-based biofuels in aviation. An IGV photobioreactor, which multiplies microalgae, was also exhibited at the Berlin Air Show. In 2012, IGV GmbH signed a contract with Bioalgostral SAS (BAO) for the delivery and establishment of an industrial plant for the production of biofuels from microalgae with a total volume of 82000 L [Source: IGV].

Airbus previously teamed with Honeywell Aerospace; UOP, a Honeywell Company; International Aero Engines (IAE); and JetBlue Airways to pursue development of a sustainable second-generation biofuel for use in commercial aircraft.

In August 2008, The world's first algal based jet fuel was produced by Solazyme. It passed the most critical ASTM D1655 specification tests.

In January 2009, the Defense Advanced Research Projects Agency (DARPA) awarded Science Applications International Corporation (SAIC) a $25m contract to develop an integrated process for developing Jet Fuel (JP-8 replacement) from algae.

A 100% renewable jet fuel produced by the Energy & Environmental Research Center (EERC), University of North Dakota, under a $4m contract with DARPA has been tested by the AFRL and met JP-8 specification criteria.

Arizona State University Laboratory for Algae Research & Biotechnology, Heliae Development, LLC and Science Foundation Arizona are also collaborating in the development of kerosene-based jet fuel derived from algae.

The Virent BioForming® Process for catalytic conversion of plant sugars into liquid hydrocarbon fuels could also potentially be used to produce jet fuel from sustainable feedstocks.

Recent demonstration flights with bio jet fuel

On 31 March 2016, **KLM Royal Dutch Airlines** launched a series of around 80 biofuel flights from Oslo to Amsterdam operated with an EMBRAER 190. The remaining flights will be operated over the following period of five to six weeks, marking yet another step in the right direction towards making aviation more sustainable. Embraer will be conducting measurements during these flights to gauge the efficiency of biofuel in comparison with kerosene.

In May 2015, Gevo Inc. announced it has signed a strategic alliance agreement with Alaska Airlines to purchase Gevo's renewable jet fuel and fly the first-ever commercial flight on alcohol-to-jet fuel (ATJ). The demonstration flight is expected to occur after Gevo receives ASTM International certification for its fuel, sometime in mid to late 2015.

to purchase Gevo's renewable jet fuel Test flights of advanced biojet fuel have continue globally in 2013. In August, LAN Colombia successfully completed a flight using a blend of jet fuel derived from Camelina in an Aibus A320.

In June 2012, Air Canada flew its first flight using biofuels (from recycled cooking oil supplied by SkyNRG). The flight from Toronto to Mexico City, supported by Airbus, coincided with the G20 meeting. On 19 June 2012, Azul Brazilian Airlines, completed a demonstration flight using jet fuel produced from sugarcane using Amyris technology.

In April 2012 Porter Airlines, All Nippon Airways and Qantas all carried out successful demonstration flights using biojet fuel.

In March 2012 Airbus, Boeing and Embraer signed a collaboration agreement to accelerate the commercialization of sustainable biojet fuel.

The Dutch airline KLM planned to use 50% biokerosene derived from recycled cooking oil (collected in the EU and refined in the US) on 200 flights between Paris and Amsterdam, starting in Autumn 2011.

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Thomson Airways passenger plane being fuelled with sustainable avaiation biofuel View at larger size >>

On 6 October 2011 a Boeing 757-200 operated by Thomson Airways carried 232 passengers from Birmingham Airport, UK to Arrecife, using a sustainable biofuels blend in one engine. The biofuel was supplied by SkyNRG, Netherlands, who is advised by an independent Sustainability Board consisting of two leading NGOs and a leading Government scientific institute. For Thomson Airways, SkyNRG partners with US refiner Dynamic Fuels and uses Used Cooking Oil as a feedstock.

The flight illustrates the potential for further use of aviation biofuels, in combination with improved efficiency, to reduce emissions from aviation and reduce dependence on fossil fuels. The challenge now facing the airline industry is to source commercial quantities of sustainable biojet fuels.

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A Virgin Atlantic 747-400 prepares for take-off from London Heathrow to Amsterdam using a sustainable biofuel blend composed of babassu and coconut oils blended with kerosene-based jet fuel. Boeing partnered with GE, Imperium Renewables and Virgin Atlantic to conduct the first commercial flight using sustainable biofuels as part of its efforts to guide the industry toward fuels that have a low-carbon-lifecycle footprint to help reduce impacts to climate change

In June 2010, the first flight by an airplane using 100% algal biofuels was demonstrated by EADS at the Berlin Air Show. The microalgae oil was produced by Biocombustibles del Chubut S.A. at its plant in Puerto Madryn, Argentina, and then refined and converted into biofuel by VTS Verfahrenstechnik Schwedt in Germany.

Details of some previous demonstration flights are included below.

ACCESS II: Testing of atmospheric emissions from jet engines using alternative fuels

NASA has signed separate agreements with the German Aerospace Center (DLR) and the National Research Council of Canada (NRC) to conduct a series of joint flight tests to study the atmospheric effects of emissions from jet engines burning alternative fuels. The Alternative Fuel Effects on Contrails and Cruise Emissions (ACCESS II) flights are set to begin 7 May 2014 and will be flown from NASA's Armstrong Flight Research Center in Edwards, California.

Previous Demonstration flights using biofuels

Below are details of some earlier test flights of biofuels. In 2010/2011 testing was carried out in a number of different planes with various bio jet fuel blends, and several airlines and their partners are now investigating production of aviation biofuels on the commercial scale.

In Spring 2011, Interjet and Airbus conducted the first jatropha-based biofuel test flight in Mexico. An The Airbus 320 jet successfully flew from Mexico City International Airport to Angel Albino Corzo of Tuxtla Gutierrez airport in the southern State of Chiapas. One of the aircraft’s two engines was fuelled with a 30 percent blend of biojet fuel by Honeywell UOP.

In June 2010, the first flight by an airplane using algal biofuels was demonstarted by EADS at the Berlin Air Show. EADS has partnered with IGV GmbH in the development of algae-based biofuels. An IGV photobioreactor, which multiplies microalgae, was also exhibited at the Berlin Air Show.

In February 2008, Virgin Atlantic carried out a test flight of a Boeing 747 Jumbo from London to Amsterdam with a 20% blend of coconut and babassu oil in one of the aircraft's fuel tanks. However, at that time, the company had no immediate plans to use similar mixtures in commercial flights.

Also in February 2008, an Airbus A380 used a 40% blend of GTL (gas to Liquid) in a flight from Bristol to Toulose, paving the way for future use of BTL. "Analysis of data from the A380's historic flight powered by an alternative fuel derived from gas (GTL) has shown that use of the GTL blend had no adverse impact on the engine, aircraft systems or materials, and that it behaved like conventional kerosene."

In December 2008, a blend of 2nd Generation biofuel from Jatropha was used in one Rolls Royce engine for a two hour test flight of an Air New Zealand Boeing 747-400.

Bio-Derived Synthetic Paraffinic Kerosene (Bio-SPK) has been used by Boeing in flight tests of several different aircraft between 2006 and 2009. Performance was as good as (or better than) Jet A fuel.

In January 2009, Japan Airlines (JAL) used a 50:50 blend of Jet A fuel and 2nd generation synthetic kerosene, mainly produced from Camelina, in one Pratt & Whitney engine of a Boeing 747-300. View JAL press release

Biofuels in Aviation - Older Studies and Reports

A 2003 study by Imperial College - The Potential for Renewable Energy Sources in Aviation - investigated renewable alternatives to kerosene, the fuel currently used by jet aircraft. This concluded that bioethanol cannot be used for air transport due to its low energy density, and because it doesn't combust effectively in 'thin air' at high altitude. The Imperial study also concluded that methanol and biogas are unsuitable for air transport for both technical and safety reasons. However, hydrogen, Fischer-Tropsch (FT) kerosene and biodiesel could all theoretically be used in aviation.

More recently, research has focued on production of 'bio jet oil' via a number of novel routes such as catalytic pyrolysis / refining and catalysis of plant sugars.

The 2007 report Alternative Technology Options for Road and Air Transport published by ETAG (European Technology Assessment Group) for the European Parliament, suggested that due to tighter operational and safety criteria for novel aviation fuels, biofuels will predominantly be used in the road transport sector for the forseeable future. However, this assessment was made before the successful test flights of Boeing and AIRBUS aircraft, and the landmark ASTM Aviation Fuel Subcommittee decision to establish a specification for synthetic aviation fuels.

The establishment of SAFUG and increasing investments in biojet fuel R&D indicate that biofuels are now most definitely on the radar of major airlines.

The **ICAO Workshop on Aviation and Alternative Fuels (WAAF)** held on 10-12 February 2009 included 30 presentations, with several covering use of biofuels.

In the UK, the Sustainable Aviation strategy group brings together researchers, airlines and other stakeholders contributing to a number of key documents proposing a way forward for sustainabile air travel.

In July 2009, a research summary was published by Policy Exchange, UK entitled Green Skies Thinking - promoting the development and commercialisation of sustainable jet fuels

A Boeing lab technician conducts automated freeze-point testing on jet fuel samples at the Boeing Commercial Airplanes Fuels and Lubricants Test Laboratory in Seattle. Boeing is exploring second-generation biofuel testing to identify renewable alternative fuel sources for aviation uses as part of the company's environmental initiative.

Use of Biofuels in Shipping

Contents

Recent R&D&D and initiatives on use of Advanced Biofuels in Shipping

Methanol-fueled ships

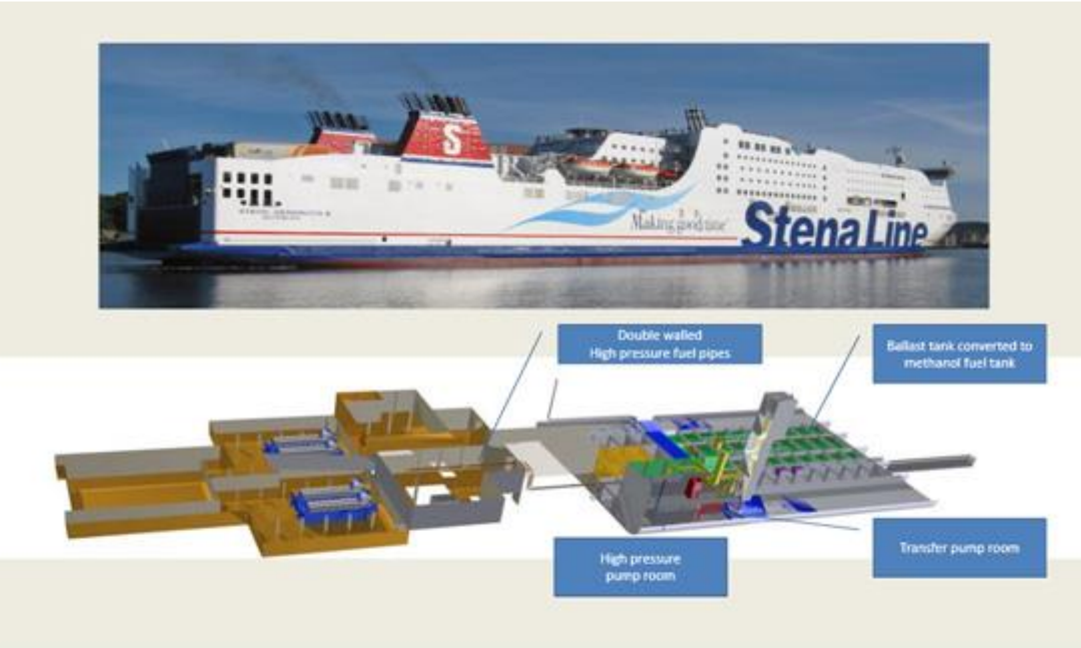
The world's first ocean-going ships capable of operating on methanol are about to be delivered to operator Waterfront Shipping Co. In a ground breaking event, three methanol-propelled tankers were delivered in April 2016 from South Korean and Japanese shipyards. Another four methanol-burning ships are scheduled to enter service in October 2016.

The seven 50,000 dwt product tankers will be used to replace older vessels and expand Waterfront's fleet of methanol carriers. The new ships each have MAN B&W's dual-fuel, two-stroke engines ME-LGI, which can run on methanol, fuel oil, marine diesel oil or gasoil. Two of the vessels will be owned by Westfal-Larsen Management (WL), three by Mitsui OSK Lines (MOL) and the other two by a joint venture between Marinvest and Skagerack Invest and Waterfront. The ships are constructed by Hyundai Mipo Dockyard and Minaminippon Shipbuilding Co.

Stena Line launches the world's first methanol ferry

In March 2015, Stena Line launched the world's first methanol powered ferry, the Stena Germanica, on the Kiel–Gothenburg route. The Stena Germanica's fuel system and engines have been adapted in the Remontova shipyard Gdansk, Poland, in a collaboration between Stena Line and Wärtsilä. The cost of the project was 22M Euros with 50% support from the EU *Motorways of the Seas* project. Dual fuel technology is used, with methanol as the main fuel, but with the option to use Marine Gas Oil (MGO) as backup.

View presentation made at EBTP SPM6, October 2104, by Per Stefenson, Stena Rederi AB on **the use of biofuels in the maritime sector**.



TEN-T Project on Methanol: the marine fuel of the future

The TEN-T programme consists of hundreds of projects – defined as studies or works – whose ultimate purpose is to ensure the cohesion, interconnection and interoperability of the trans-European transport network, as well as access to it. As part of Priority Project 21: Motorways of the Seas, pilot tests on Methanol as a marine fuel of the future will be carried out on the passenger ferry Stena Germanica operating between the ports of Gothenburg and Kiel. The Stena Germanica is the world's second largest Ro-Pax ferry. The running of the Stena Germanica on methanol will allow the vessel to comply with the new Sulphur Emission Control Area rules ahead of the 2015 deadline.

The 22M Euro project is receiving 50% funding under the EC TEN-T programme. The project particpants consist of Stena Aktiebolag, Wärtsilä Finland OY, Stena Oil AB, Port of Kieland Göteborgs Hamn AB. The engine supplier is MAN and methanol will be supplied by Methanex.

The proposed "action" will provide the real "live test" to prove the feasibility of methanol as a future fuel for shipping, deliver the engine conversion kit which can be further implemented on other ships, and provide the important and ultimate piloting culmination of many years of research. In addition to retrofitting the vessel, the pilot action will also create the appropriate port infrastructure for the supply of methanol for bunkering: a bunker vessel and a storage tank will be built to carry methanol, as well as the corresponding facilities in both ports.

See also the FP6 METHAPU project (below), which investigated methanol and solid oxide fuel cell (SOFC) technology for shipping.

LLoyds Register / Maersk test programme on biodiesel for marine engines

Biodiesel is a good candidate as a shipping fuel, being biodegradable, non-toxic and essentailly free of sulphur and aromatics. It can be used in many marine applications with little or no need for engine modification [Source: www.biodiesel.org].

Lloyd's Register is involved in a two year programme to test the suitability of biodiesel for use in powering marine engines. The feasibility study will take place on board the Maersk Line container ship, *Maersk Kalmar*. Collaborators in the biodiesel project are Maersk Line, Maersk Tankers, Maersk Supply Service, Maersk Drilling, Maersk Ship Management, Lloyd's Register's Strategic Research Group, and a consortium of Dutch subcontractors. The project is being part-funded by the Dutch government and co-ordinated by Maersk Maritime Technology (MSM) [Source: Lloyds Register].

GLEAMS Glycerine Fuel for Engines and Marine Sustainability

GLEAMS (Glycerine Fuel for Engines and Marine Sustainability) is a Technology Strategy Board project under the Marine Vessel Efficiency competition in the UK. The project aims to develop technology for use of Glycerine (a by-product of biodiesel production) as a marine fuel for a wide range of shipping. GLEAMS Members include: Aquafuel Research Ltd, Gardline Marine Sciences Ltd, Lloyd's Register EMEA, Marine South East Ltd, Redwing Environmental Ltd.

Partnership for drop-in shipping fuels from wood in Denmark

In September 2013, Steeper Energy and Port of Frederikshavn, together with Aalborg University, announced a partnership to produce up to 100,000 tons p.a. of drop-in marine biofuels using wood. The sulphur-free biofuel will comply with SECA regions – Sox Emission Control Areas, which comes into force in January 2015. "Steeper Energy's proprietary technology Hydrofaction™ uses 'super critical' chemistry to transform low-energy density organic feedstocks into valuable high-energy density products." [Source: Steeper Energy website].

Tests of algal biofuels in shipping

In December and January 2011, Maersk and the US Navy both tested biofuels based on algal oils. The navy plans to continue the tests throughout 2012 as part of its "great green fleet" initiative and aims to cut its fossil oil use by 50% by 2020.

Currently Solazyme has a contract to provide 450000 gallons of algal biofuels for ongoing US Navy trials.

Maersk envisages in the region of 10% of the world's shipping fleets could be powered by biofuels by 2030 [Source: *The Guardian*, 14-01-12].

LNG as Marine Fuel

Qatar and Royal Dutch Shell have agreed to develop liquefied natural gas (LNG) as a marine fuel for use by the world's largest container shipping company. Qatargas, the world's largest LNG producer, said the three companies signed a memorandum of understanding which sees Qatargas 4, a joint venture between Qatar Petroleum and Shell, producing the fuel for use by Maersk Line. Most shipping companies currently use heavy fuel oil, or bunker fuel, to propel their vessels although LNG as marine fuel has been used by some ships in the past decade.

DNV GL, an international energy and shipping certification agency, says while most of the industry will continue to use heavy fuel oil for now, LNG is being used more, in part because it more easily meets current and proposed emission rules. In a 2015 report, DNV GL said 63 LNG-fuelled vessels were already operating globally with another 76 ships being built that would use the new fuel. In contrast, Maersk has just under 600 ships operating, including some of the biggest in the world.

Biomethane is also gaining interest in the marine industry. Operators are looking increasingly seriously at using liquefied natural gas as an engine fuel. The Rolls-Royce Bergen K gas engine has been certified to power the world's first major car and passenger ferries running on LNG. There is a need for LNG storage facilities at ports to facilitate use of this technology.

Methanol and solid oxide fuel cell (SOFC) technology for shipping

The FP6 METHAPU project (Validation of renewable methanol based auxiliary power systems for commercial vessels) studied the use of methanol as a shipping fuel. The consortium consisted of

- Wärtsilä, Finland
- Wallenius Marine, Sweden
- Lloyd's Register, United Kingdom
- University of Genoa, Thermochemical Power Group, Italy
- Det Norske Veritas (DNV), Norway

The strategic objectives of the METHAPU project were:

- Assess the maturity of methanol using technology on board a commercial vessel
- Validate marine compatible methanol running solid oxide fuel cell technology
- Innovate necessary technical justifications for the use of methanol on board cargo vessels involved in international trade in order to support the introduction of necessary regulations to allowing the use of methanol as a marine fuel
- Assess short-term and long-term environmental impacts of the application
- Enable future research activities on larger marine compatible solid oxid fuel cell (SOFC) units and methanol based economy

In May 2010 the METHAPU fuel cell system, comprising the methanol tank container and the fuel cell room were installed onboard the car carrier M/V Undine A major aim of the project was to support the introduction of necessary regulations to allow the use of methanol as a marine fuel. The specific components of the technology validated were methanol fuel bunkering, distribution, storage system and methanol consuming SOFC unit. [Source: METHAPU project website].

Use of butanol in smaller marine crafts

In February 2012 it was announced that The U.S. Coast Guard was collaborating with Oak Ridge National Laboratory (US DoE) to test butanol blends in marine craft. Ethanol is already blended with gasoline in small boat engines, but this three-year test anticipates the potential availability of butanol at industrial scale.

In July 2013, Gevo started to supply the U.S. Coast Guard R&D Center with isobutanol-gasoline blends.

Overview

Current status

In global transport approximately 2,300 Mtoe of energy were used in 2009, with 10 % of it consumed by marine transport (AMF 2011). In the EU, inland navigation accounted for 1.6 % of final energy consumption in the transport sector (EC 2013).

In water transport, different modes according to the transport distance can be divided: inland navigation, short-sea and maritime transport. Within Europe 40,600 km inland waterways and intra-EU maritime transport are used. In passenger transport intra-EU maritime plays a secondary role with 37 billion pkm, which corresponds to 0.6 % of total passenger transport in the EU in 2011. Intra-EU maritime freight transport is the second most important mode with 36.8 % (1,408 billion tkm), additionally inland waterways account for 3.7 % with 141 billion tkm (EC 2013).

Alternative fuels for shipping

Today, the feedstocks for marine fuels are crude oil or natural gas, used to produce residual (heavy) fuels and higher quality distillate fuels. The latter are used in emission protection areas and are known as ULSD – Ultra Low Sulfur Diesel. Electrification is not possible in water transport, therefore only gaseous and liquid biofuels would be alternative fuels - for example, BioLNG, methanol, hydrogen and biomass-derived products equivalent or substitutes for marine distillates and residual fuel.

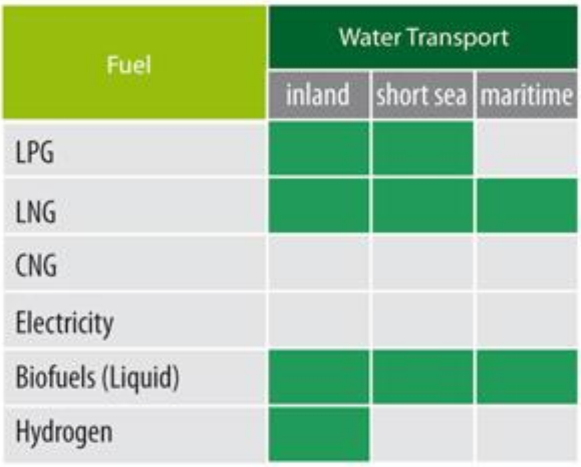


Figure 1: Coverage of travel range by main alternative fuels (COM (2013) 17)

Biofuels are one of the options to lower carbon intensity in the propulsion of ships and to reduce the effect of emissions to local air quality. But the shipping sector is still in a very early stage of orientation towards biofuels. Currently no significant consumption of biofuels for shipping takes place within the EU. There are R&D initiatives investigating the possibilities (as shown below). For example, under the TEN-T Priority Project 21: Motorways of the Seas, pilot tests on Methanol as a marine fuel of the future are currently being carried out. Biomethanol potentially could be used as well as methanol from fossil sources.

For diesel engines, biodiesel (FAME), vegetable oil and hydrotreated vegetable oil, dimethyl ether, gas-to-liquid and biomass-to-liquid fuels could be used. For otto engines, biogas (LNG) and hydrogen could be used as biofuels. Conventional and advanced biodiesel could be used as Bio-MDO (marine distillates), straight vegetable oil could be used as alternative for HFO and LSHFO (two categories of residual fuel of different sulphur contents), biogas would be an alternative for LNG. Bio-hydrogen could also be used (Lloyds Register 2014).

Depending on the type of biofuel, the usage in the shipping sector could be done easily (drop-in fuels) or with huge modifications (new-build). Although there is not many practical experience with biofuels in ships, technical compatibility of biofuels with marine engines (both diesel-cycle and gas-fired engines) seems high and integration manageable.

The most promising option, from a technical point of view, seems to be small percentage biodiesel blends (up to 20 %) with marine diesel oil or marine gas oil (MDO/MGO), besides the 100 % replacement of heavy fuel oil (HFO) by straight vegetable oils (Ecofys 2012). The benefits of biodiesel compared to fossil fuels include possible blending up to 100 %, reduced soot emissions, no negative impacts on engines, higher cetane numbers and no bacterial formations in biofuel storage tanks.

Future perspectives for biofuels in shipping

Water transport is among the fastest growing modes in the transport sector, and will be in future of certain importance, as it is a relatively low-energy mode of long-distance transport.

Future of maritime transport is very important for the European Union for intra-EU transport and global transport, and therefore goals for maritime transport were defined. The EU set ten goals for a competitive and resource efficient transport system for achieving the 60 % GHG emission reduction target. One of the goals is that 30 % of road freight over 300 km should shift to other modes such as rail or waterborne transport by 2030, and more than 50 % by 2050. Another goal is to reduce the EU CO2 emissions from maritime transport by 40% (if feasible 50%) by 2050 compared to 2005 levels, as the environmental record of shipping can and must be improved by both technology and better fuels and operations (COM (2011) 144).

References and reports on use of biofuels in shipping

Global Marine Fuel Trends 2030 - Lloyds Register Marine & UCL Energy Institute

Potential of Biofuels for Shipping - Ecofys / EMSA 2012

In March 2014, U.S. D.o.T. Maritime Administration (MARAD) released a report comparing ultralow sulfur diesel (ULSD) and a 76/33 blend of ULSD and drop-in biodiesel produced from sugar by Amyris Inc. The study determined that the diesel blend reduced air emissions without any significant difference in engine performance, fuel economy, air emission. View the full report Renewable Diesel for Marine Application (22Mb PDF).

AMF 2013: IEA Advanced Motor Fuels – Alternative Fuels for Marine Applications

COM (2011) 144: White paper – Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system

COM (2013) 17: Clean Power for Transport: A European alternative fuels strategy

EC 2013: EU transport in figures – statistical pocketbook 2013

Biofuels for rail transport

This web page is currently under development

Overview

Current status:

Railway transport is very energy efficient. Final energy consumption for railway transport in the EU was 7.3 Mtoe in 2011, which represents 2 % of total energy consumption for transport. In passenger transport 6.3 % of km were done by rail (407.1 billion pkm), whereas 11 % of goods transport were done per rail (420 billion tkm). The railway network in EU (2010) was 212,800 km with 112,000 km of electrified rail lines. In 2011 the vehicles stock of locomotive and railcars amounted to 59,269 (EC 2013).

Alternative fuels for rail transport

In rail transport various alternative fuels could be used, such as liquefied natural gas, electricity, liquid biofuels and hydrogen (see figure 6). As the highly travelled parts of the railway network are electrified, the majority of alternative fuels in rail transport comes from renewable electricity. Only 20 % of EU railway operations comes from diesel traction (UIC 2007), and for this share biodiesel could be an alternative fuel. Other biofuels are of secondary importance, possible fuels would be BtL and HTU diesel, biogas and biomethane, bioethanol and biobutanol and biomass used for electricity generation in CHP systems.

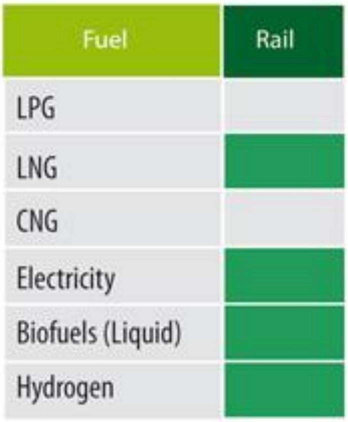


Figure 6: Coverage of rail transportation by the main alternative fuels (COM (2013) 17)

The most promising option for biofuels in rail transportation sector is biodiesel. The global consumption of liquid fuel by the railways, which is mostly diesel, is likely to be up to 34,000 million litres (1.380 PJ). The EU only accounts for 15 % of the industrialised countries' use of diesel on the railways, whereas the consumption is dominated by the US (70 %). In the US the consumption of liquid fuels by railways was growing (from 1990 to 2002), in the EU and in Canada liquid fuel consumption was decreasing (UIC 2007).

Biodiesel is technologically feasible for blending in diesel traction systems, but there is relatively little experience with using biodiesel in railways. Details of a few trials of biodiesel in rail transport globally are included below. There are potential advantages and disadvantages of using FAME in rail transport, which are given in figure 7.

Beneficial aspects	Adverse aspects
• Reduce gaseous (except nitrogen oxides) and particulate emissions • Minimal sulphur content • Higher cetane number and flash point • Higher denisty/viscosity • Improved lubricity • Biodegradable and low toxicity	• Reduced energy content (by approx. 8-10%) • Increased fuel consumption • Increased nitrogen oxide • Poor low temperature starting & operation • Poor oxidation stability and water absoprtion characteristics • Incompatability with certain elastomers and natural runners • More rapid lubricating oil degradation • Degradation during long-term storage

Figure 7: Advantages and disadvantages of using biodiesel in rail transport (UIC 2007)

Most engine manufacturers appear to be willing to include B5, but they are less willing to include use of higher blends like B10, B15, B20 or even B100 (UIC 2007). Additionally tax incentives for biofuels are not so significant, since rail often pays relatively less duty on its fuel compared to road transport. Therefore it would be quite a challenge to enhance biodiesel use in rail transport.

Future perspectives in rail transport

Rail transport is one of the transportation modes which will be strengthened and increased in the future. The EU set ten goals for a competitive and resource efficient transport system for achieving the 60 % GHG emission reduction target. One of the goals is that 30 % of road freight over 300 km should shift to other modes such as rail or waterborne transport by 2030, and more than 50 % by 2050. Another goal concerning rail transport is that by 2050 a European high-speed rail network should be completed and the majority of medium-distance passenger transport should go by rail (COM (2011) 144).

Trials and use of biodiesel in rail transport globally

A number of European rail operators have carried out bench and field trials on rail vehicle and engines (e.g. French SNCF, German DB, Czech CD, Hungarian MAV).

In 2010/2011 Amtrak began a one-year trial of B20 in a diesel locomotive opreating in the southern states of the US. Montana State University carried out a similar trial on the BNSF railway in 2011. The trials could help establish a mandate for use of biodiesel blends in locomotives in the US.

In August 2012 Indian Railways announced plans for 4 biodiesel plants.

References and links of biofuels and rail transport

In 2007 the International Union of Railways UIC in association with the UK Association of Train Operating Companies ATOC published a short report Railways and Biofuel. The reports concluded: "Test results from railways in Europe and India reveal that biodiesel is technical feasible for use in railway traction units engines in lower blends. However, there are potential disadvantages of using higher blends, e.g. increased fuel consumption and lower engine power." UIC also organised the first ‘Railways and Biofuel Workshop’ in July 2007.

COM (2011) 144: White paper – Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system

COM (2013) 17: Clean Power for Transport: A European alternative fuels strategy

EC 2013: EU transport in figures – statistical pocketbook 2013

Biomass heat and power and bioelectricity for transport

Overview

Heat and Power in Europe

In 2012, final energy consumption within the EU-28 was 1,104.5 Mtoe, with a share of 21.8 % of electricity and 4.4 % of heat. In electricity generation renewables accounted for 24.2 % (798.7 TWh) of total generation. From this share of renewables, 18.7 % came from biomass and renewables (149.4 TWh) (EC 2014). The primary energy production from biomass in the EU was 82.3 million metric tons of oil equivalent (Mtoe). This included 79.5 TWh of electricity and 68 Mtoe heat (EurObserv'ER 2013).

Combined Heat and Power CHP

The simultaneous generation of electricity and heat is called cogeneration or combined heat and power (CHP). In contrast to thermal power plants, CHP uses the waste heat, which is emitted during electricity generation, and therefore increases the efficiency of the process up to over 80 %. Common CHP plant types are gas turbines and engines, biofuel engines (adapted reciprocating gas engine or diesel engine), wood gasifiers, combined cycle power plants and steam engines.

Cogeneration systems are often integrated in pulp and paper mills, refineries, chemical plants and biorefineries. Bioelectricity can be used within the production process (i.e. to power the biorefinery) and/or be exported to the grid, potentially for use by electric vehicles.

Biomass resources for CHP

Different kinds of biomass resources can be used as fuel for cogeneration plants to produce heat and electricity. Biomass may be co-fired in coal power plants or combusted in smaller dedicated biomass energy plants, where there is a reliable local supply of feedstock. Typically 10 % of biomass can be used for co-firing, higher percentages may be enabled by the use of biocoal, produced via torrefaction. Biomass may also be converted into carbon-rich gases (biogas by anaerobic digestion or BioSNG via gasification), which can be used in gas engines and turbines in CHP plants.

The use of liquid biofuels, such as biodiesel, ethanol, biocrude-oil or vegetable oil, for stationary decentralized energy generation is not very common. It is technically possible to feed biofuels to power and heat generation systems, but the economics of such processes are not positive (ETA 2003). Liquid biofuel production is highly energy intensive and the product costs are high compared to other resources. Therefore, although sustainable, biofuels are not favoured for use as fuel in CHP plants.

Bioelectricity in transport

In electric vehicles (EVs) a highly efficient electric motor is used for propulsion, which can be supplied by electricity from the grid, favourably from low-CO_2 energy sources. Besides EVs, there are hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs) and fuel cell vehicles (FCVs) (for more information see: IEA-HEV). Hybrid electric vehicles combine internal combustion engines and electric motors, saving oil and reducing CO2 emissions.

Major obstacles to market uptake are the lack of recharging points with a common plug, long recharging times and limited driving ranges. The main issues which limit the driving range of vehicles considerably are high costs, low energy density and heavy weight of batteries. The advantages of EVs are that no noise and no pollutants are emitted and therefore EVs are the preferred option for urban transport, where distances are very short and where local congestion and air quality issues are important considerations.

It is important to have a balanced mix of alternative fuels and drive systems to fulfill the needs of the different transport modes. Advanced biofuels and plug-in and hybrid vehicles will have a vital role to play in the future of sustainable transport in Europe.

Availability of biomass for bioenergy

700m tonnes of coal are used in Europe every year and there are only 300m tonnes of wood produced. So even if every piece of wood was used for biocoal production, this would still not meet current energy demand. As in other areas of bioenergy, feedstock availability (rather than technology issues) may ultimately be the limiting factor to production capacity.

See the forestry page for information on the EU forestry strategy and related R&D.

View pages on the availability of biomass and sustainability.

The rising demand for wood from the bioenergy sector led to a 30% increase in wood price in the UK in the 3 years up to 2010. Energy generator subsidies for wood fibre is causing concern for other industries, for example, chipboard manufacturers, who have seen sharp rises in costs.

Certification of sustainable biomass in the EU

The Sustainable Biomass Partnership SBP Framework of standards and processes enables producers of woody biomass to demonstrate that they source their raw material responsibly and that it complies with the regulatory, including sustainability, requirements applicable to European power generators burning woody biomass to produce energy.

Under the SBP Framework the Biomass Producer, typically a pellet mill, is certified by a SBP-approved Certification Body. To become SBP-approved, a Certification Body must first provide evidence that it meets the SBP requirements regarding its existing accreditations and it must also demonstrate that it has sufficient resources and competence to manage the certification programme.

Commercial development of bioenergy (combined heat and power) facilities

EurObserv'ER Solid Biomass Barometer for 2012 estimates that primary energy production from biomass in the EU was 82.3 million metric tons of oil equivalent (Mtoe). This included 79.5 terawatt hours (TWh) of electricity and 68 Mtoe heat. Use of biomass for heat and power is also developing rapidly in the United States: the Federal Energy Regulatory Commission's Office of Energy Projects reported 777 MW of new biomass capacity in 2013.

Examples of large scale bioenergy projects in Europe

A number of new large-scale bioenergy CHP plants are now being constructed in Europe and around the world. For example, in November 2014, it was announced that Abengoa will be developing a €315m biomass power plant producing 215MW of 'bioelectricity' on behalf of Belgian Eco Energy (Bee) at Ghent, Belgium. The feedstock includes wood chips and agro-residues.

A 69MW plant based at a Smurfit Kappa Group paper facility in France commenced operation in September 2012. In 2014 the Bio Golden Raand 49.9MW biomass power began operations at the port of Delfzijl, Netherlands. The plant is operated by Eneco and was developed by Ballast Nedam Industriebouw and Metso Power Oy. Also in Netherlands, the Essent power plant in Geertruidenberg co-fires 34% biomass in one of its units.

In 2015, the number of large biomass power plants in Europe continues to increase. In the UK, the £150m Rotherham Biomass Plant will use a B&W Vølund-designed multi-fuel boiler with a DynaGrate fuel combustion system, a dry flue gas desulfurization system and will burn waste wood to generate approximately 40MW of electricity. The contract to build the plant has been awarded to Interserve The Nokianvirran Energia biomass boiler plant, Finland, will use a 68MW HYBEX boiler supplied by Valmet, including fluidized bed technology, flue gas purification equipment, and the plant's electrification and automation system. The new steam heat station will be built by Nokia.

In July 2013, RWE npower closed the 750MW biomass power station at Tilbury, UK, citing a lack of investment capacity and technical difficulties in converting the plant to use biomass in place of coal.

However, work continues on the £400m, 300MW Tees Renewable Energy Plant (Tees REP) in North East England, which will generate around 2.4 TWhrs of electricity from biomass each year, enough to power 600,000 homes. It will enter commercial operation in 2016. There are also plans to convert the 400MW Lymington coal-fired power plant to biomass, with investment support from DECC (Department of Energy and Climate Change). However a planned 100MW plant at Port of Blyth in Northumberland ceased development in March 2014, with RES citing inconsistent UK energy policy as a key factor.

In June 2010, the world's largest biomass co-firing project was commissioned at the Drax coal power station, which has an installed power cpacity of 4000 MWe and provides 7% of the UK's electricity. The plant aims to use 10% biomass (1.5m tonnes per year). In October 2012, Drax and Centrica cancelled plans for new biomass plants, both citing lack of government support. Drax is proceeding with a smaller £700m project that will convert half of its existing 4,000 MW coal-fired plant at Selby, North Yorkshire, to biomass. This follows a decision by the government to reduce subsidies for new-build biomass plants and instead focus on conversion of coal planbts to biomass.

In December 2013 it was announced that work will begin on a 10.3 MW biomass gasification plant in Tyseley, UK. The plant will use the biomass gasification process of the Canadian firm Nexterra Systems to convert 67,000 metric tons of locally-sourced woodwaste into power.

The Biomass CHP Plant Güssing, which started operation in 2002, has a fuel capacity of 8 MW and an electrical output of about 2 MWel with an electrical efficiency of about 25 %. Wood chips with a water content of 20 – 30 % are used as fuel. The plant consists of a dual fluidized bed steam gasifier, a two-stage gas cleaning system, a gas engine with an electricity generator, and a heat utilization system.

In Summer 2012, CHO Power completed construction of a demonstration facility in Morcenx, France to gasify 37,000 tonnes of ordinary industrial waste and 15,000 tonnes wood chips per annum, generating power for EDF.

In December 2011, CHO Power SAS (a subsidiary of Europlasma) and Sunrise Renewables announced plans to build 4 high temperature plasma gasification facilities at UK docks to convert waste wood into clean syngas. The Syngas will be cleaned further and the tar removed, prior to power production via gas engine generators.

A market study by CHO Power in 2012, estimated that by 2030 107 advanced gasification plants will need to be built in the UK as well as 126 advanced gasification plants in France to meet EU targets for renewable energy.

The demonstration plant at Skive Fjernvarme in Denmark converts wood to combined heat and power (CHP) production via gasification, generating 120k MWh of district heating and 22k MW of electricity. "A single bubbling fluidized bed (BFB) gasifier and related equipment converts wood pellets to fuel gas for three reciprocating engines in a combined heat and power (CHP) in the CHP plant. The engines generate electrical energy (two MW each) from which the heat is recovered for the community's district heating needs. Two gas boilers in the facility can also utilize the biomass-derived gas providing additional district heat."

REACT Energy is developing two biomass gasification CHP demonstrations in Newry, Northern Ireland (2-4 MW) and Enfield, England (12 MW), with further 12MW installations planned in Plymouth and Derbyshire, UK. Gasification technology for Phase 1 of the project in Newry was provided by Zeropoint. GE Jenbacher engines are now being installed by Clarke Energy.

In March 2014, Xergi announced it will be developing the lagest biogas plant in France at Hagetmau, which each year will convert 153,000 tons of biomass to biogas, which will be used to generate 37.8 million kWh of electricity.

Biomass use in North America

At end of 2014, the US had 13,447.1 MW of biomass capacity (8,330.3 MW from wood and wood waste, 2,069.1 MW from landfill gas, 2,230.7 MW from MSW, and 817 MW from other waste biomass). A further 211.1 MW of biomass capacity is scheduled to be added in 2015 [Source: EIA].

In Canada, the Thunder Bay Generating Station, operated by Ontario Power Generation, will be converted from coal to biomass. The plant aims to be operational in 2015.

Use of an Externally-Fired Gas Turbine EFTG allows a wider range of biomass resources to be used, and has been investigated for decentralised production of power at a smaller scale. In Canada, Nexterra Systems has developed a proprietary fixed-bed, updraft gasifier for generating decentralised heat and power from biomass with high efficiency (up to 10 MW). The technology is being implemented in a number of niche projects in North America. In September 2012 a commercial demonstration of a CHP system using Nexterra's technology (with wood waste as a feedstock) was launched at the University of British Columbia. The system combines Nexterra’s gasification and conditioning technologies with a GE Jenbacher internal combustion engine.

The $2billion Clean Coal Power Initiative is (among other activities) developing IGCC technology for coal power. A number of US DoE awards were made for research into biomass-coal gasification, as well as hydrogen production.

EC projects on Bioenergy R&D&D

The FP7 DEBCO project - DEmonstration of large scale Biomass Co-firing and supply chain integration - will develop and demonstrate innovative approaches to the co-utilisation of biomass with coal for large-scale electricity production and/or CHP, at more competitive costs and/or increased energy efficiency. The aim is the development, demonstration, and evaluation of innovative and advanced co-firing technologies.

Also see the pages on bio-SNG and biogas for more details of relevant projects on biofuel and bioenergy production via gasification and anaerobic digestion.

Torrefaction and related pretreatment technologies

Typically 10% of biomass can be used for co-firing [Source: IEA Clean Coal] - avoiding issues such as slagging and fouling (although these issues also depend on the feedstock type). Higher percentages of biomass in co-firing may be enabled by torrefaction [Source: Torrefaction for biomass co-firing in existing coal-fired power stations; Bergman et al 2005). Torrefaction is a thermochemical process typically at 200-350 °C in the absence of oxygen, at atmopsheric pressure with low particle heating rates and a reactor time of one hour. The process causes biomass to partly decompose, creating torrefied biomass or char, also referred to as 'biocoal'.

Biocoal has a higher energy content per unit volume, and torrefaction followed by pelletisation at the harvest sites facilitates transport over longer distances. It also avoids problems associated with decomposition of biomass during storage. Hence the benefits of torrefaction may outweigh the additional cost in many cases.

Further information is available on the torrefaction page.

History of higher efficiency power generation via gasification of biomass

Biomass integrated combined cycle gasification (BIGCC)-gas turbine technology (BIG-GT) potentially offers much higher efficiences than conventional CHP, and was investigated in the late 1990s and the early 2000s. Several demonstration plants were built. However, at the current time, biomass gasification technologies for heat and power are not always considered to be competitive with combustion [Source: ThermalNet].

The Värnamo plant in Sweden was the world's first IGCC plant and was designed to generate 6 MW of electricity and 9 MW of heat for district heating from wood chip. The Växjö Värnamo Biomass Gasification Centre (VVBGC) was upgraded under the EU CHRISGAS project in 2004-2010 and there were plans for it to continue as a "centre of excellence" on biomass gasification, supporting the development of industrial scale biomass gasification in Sweden. However in February 2011 funding partners withdrew.

In 2001, a demonstration plant was comissioned in Brazil with support from the EU-BRIDGE (EU-Brazil Industrial Demonstration of Gasification to Electricity) project. This demonstrated that the power output of biomass to energy plants in the Brazillian sugar industry could potentially be greatly increased via gasification. IGCC was also the basis of the Arable Biomass Renewable Energy (ARBRE) project in the UK. This project was halted due to a combination of technical and financial issues.

In the United States, several biomass gasification plants were demonstrated in the late 1990s (e.g. Vermont Gasifier). As in Europe, the technology was not commercialised at the time. However development of biomass gasification technology continues (as detailed below). See also the Bio-SNG page for details of new industrial-scale gasification projects.

Electric vehicles for road transport

There are a wide range of electric and hybrid vehicles now available across Europe. Many Member States offer tax incentives and grants to promote electric cars. For more information on electric vehicles and infrastructure in various countries, please see IEA-HEV (IEA Hybrid Electric Vehicals Implementing agreement).

European Green Cars Initiative

The European Green Cars initiative is one of the three PPPs included in the Commission's recovery package. The envelope for this initiative is foreseen at €5 billion to boost to the automotive industry in a time of economic hardship, and support the development of new, sustainable forms of road transport. Of this financial envelope, €4 billion will be made available through loans by the European Investment Bank (EIB), and €1 billion through support to research, with equal contribution from the Seventh Framework Programme for Research (FP7) and from the private sector.

Research on electric and hybrid vehicles, within this initative, includes:

- High density batteries
- Electric engines
- Smart electricity grids and their interfaces with vehicles

Electric HGVs

In the UK, the retailer TK Maxx has introduced a small fleet of aerodynamic, battery-powered ten-tonne delivery truck has a range of over 120 miles. The retailer plans to introduce 10 further trucks to deliver to its stores in the UK, Germany and Poland. The company also uses biodiesel blends (based on WVO).

© TK Maxx. For improved efficiency, the TK Maxx electric delivery lorry features the aerodynamic "teardrop design", a registered design of Don-Bur

'Electrofuels'

Electrical energy generated by fossil fuels, nuclear and renewable souces (wind, solar, hydro, etc) can potentially be converted to liquid and gaseous fuels (e.g. diesel, kerosene, buanol, etc) for use in transport. Electrofuels are produced from carbon dioxide and water. For example, see ARPA-E's Electrofuels program in the U.S. (Microorganisms for Liquid Transportation Fuel). See also Sunfire, Germany, which develops systems for the production of renewable synthetic fuels (e.g. methane gas, diesel or kerosene) using regenerative electricity (*recycling*).

Bioenergy and Carbon Capture and Storage

The concept of Bioenergy and Carbon Storage (Bio-CCS or BECCS) has been suggested as a means of producing carbon negative power (i.e. removing carbon dioxide from the atmopshere via biomass conversion technologies and storage underground). Carbon capture and storage (CCS) technology is currently at a demonstration phase, and current research is focused on reducing the costs of CCS so that it can be applied to a new generation of clean coal power stations. However, CCS could potentially be appled to a wider range of energy plants, including those incorporating co-firing or co-gasification of sustainable biomass feedstocks (agricultural and wood wastes and energy crops), or even 100% biomass energy plants, biofuel production facilities or biorefineries.

The potential for future synergies between CCS and bioenergy/biofuels production is the focus of the Bio-CCS Joint Task Force led by the Zero Emissions Platform with contributions by EBTP.

Further information on Bio-CCS

Bioelectricity vs. Biofuels?

A widely publicised study by the University of California published in Science in May 2009 suggested that bioelectricity produces an average 81% more transportation km and 108% more emissions offsets per unit area crop land than cellulosic ethanol.

These findings do not address the issue that electricity needs to be stored in batteries, which currently have limited capacity or the requirements for upgrading of the electricity infrastructure to enable large scale recharging of electric vehicles at regular intervals (or in millions of homes overnight). However, electric vehicles and electrified public transport may be the preferred option for urban transport strategies, where journeys are much shorter and where local congestion and air quality issues are also important considerations. Electricty is not an option for aviation, which requires liquid fuels.

A wide range of advanced technologies are being developed for second generation biofuels. However, as these are not yet widely available at commercial scale, any direct comparison of bioelectricity with current 2G biofuels may be considered as premature. However, it is clear that advanced biofuels and plug-in and hybrid vehicles will have a vital role to play in the future of sustainable transport in Europe.

POLICY AND SUSTAINABILITY

Deployment of advanced biofuels

Societal Benefits of Biofuels in Europe

Overview

In recent years, much media coverage of the biofuels industry in Europe has focused on the environmental impacts of some types of biofuels. Media coverage is often driven by vigorous campaigns by groups who are broadly against the use of biomass feedstocks (particularly crops) to produce transport fuels. Subsequent public concerns have led politicians and administrators at EU and national level to change their biofuels policies. While a debate on sustainability issues is necessary as production and use of biofuels expands globally, it needs to be informed by reliable scientific data, and take into account the many benefits offered by sustainable biofuels production.

Rather than viewing production of food, bioenergy and non-food bioproducts as competing activities, it is more benefical (in terms of technolology, land use and economics) to develop synergies between these sectors in a balanced and integrated bioeconomy. Taking this holistic approach to sustainable production of renewable transport fuels offers a range of benefits to European society:

Reduction of European dependency on fossil fuel imports

The EC communication on European Energy Security Strategy COM(2014) 330 final, published in May 2014, highlights the need to reduce reliance on fuel imports to the EU. The European Union is strongly dependent on fossil fuels for its transport needs and is a net importer of crude oil. At the same time, concerns are increasing about climate change and the potential economic and political impact of peak oil production. In addition, there is a geopolitical threat to energy supplies and fuel price stability due to conflicts in the Middle East, and more recently the eastern borders of Europe. To reduce dependency on fossil fuels imports, meet 2020 targets for renewable energy sources in transport, and radically cut GHG emissions, the EU has adopted measures to encourage the production and use of sustainable biofuels.

Although European energy security now and in the future is the single biggest driver for biofuels production, biofuels offer many other benefits to society, ranging from GHG reduction and improvement in air quality, to job and wealth creation, rural development and fuel price stability.

Fuel Price Stability

Reducing dependence on imports of fossils fuels, and deriving fuel from diverse biomass feedstocks, has helped to stabilise the costs of transport fuels in Europe. Studies suggest that the wider availability of biofuels in European fuel markets can protect consumers from severe fluctuations in crude oil price. See: Biodiesel as a motor fuel price stabilization mechanism (PDF).

Reduction of Greenhouse Gas Emissions

In the very simplest terms, biofuels are produced from plants that remove carbon dioxide from the air when they grow and return it to the air when they are combusted. So there is no net increase in atmospheric carbon. This is in contrast to fossil fuels that use carbon sources that have been stored in the ground for millions of years, and have been released into the atmosphere in vast quantities, mainly in the last century. The resultant increase in atmospheric carbon has led to 'man-made' climate change (although it should be remembered that the earth's climate is dynamic and is affected by a number of other natural phenomenon e.g cyclic solar activity).

Substituting fossil fuels with biofuels has clearly been shown to reduce man-made Greenhouse Gas (GHG) emissions. However, the comparison between GHG emissions of fossil fuels and biofuels is not staightforward. For example, the energy required to produce, fertilise and transport feedstocks and then convert them into liquid fuels also has to be taken into account. Common methods (see BioGrace) have been developed to harmonise calculations of greenhouse gas emissions from bioenergy in Europe and determine the "GHG balance" of producing different biofuels from different feedstocks.

A report published in November 2014 Greenhouse gas impact of marginal fossil fuel use (PDF), suggested that the GHG reduction **benefits of biofuels may be under-estimated by 50%** as they are calculated using an average fossil fuel comparator rather than figures for production of marginal fossil fuels (which require much greater energy inputs). The report was produced by Ecofys on behalf of the European Oilseed Alliance (EOA), the European Biodiesel Board (EBB) and the European Vegetable Oil and Proteinmeal Industry (FEDIOL).

Globally, there are concerns that clearing of forestry to plant energy crops releases the carbon stored in plants and the soil, increasing GHG emissions. However, biofuels only account for a small proportion of global deforestation - underlying poverty, subsistence farming, logging, cattle ranching and commercial food production are major causes. See NASA overview on causes of deforestation. However there have been specific concerns, for example, over palm oil production for biofuels in parts of Asia.

To address this, biofuels certification schemes have been introduced in the EU, to ensure that biofuels are derived from sustainable feedstocks. However, these are at different stages of implementation in various Member States.

Taking into account the 'energy balances' and the challenges faced with sustainable feedstock production, biofuels already help reduce production of millions of tonnes of GHG by transport in Europe each year. Improvements in sustainability, production efficiency and use of advanced biofuels will continue to improve GHG reduction levels. And with a supportive regulatory framework, the benefits can be achieved even faster!

Jobs, wealth creation and rural development in Europe and globally

The production of biomass feedstocks and their conversion to heat and power, transport fuels and bioproducts, creates new opportunities for:

- farmers and forestry workers who are able to diversify into energy crop production and/or processing of agroforestry wastes;
- engineers and construction workers who build and opeate advanced biofuels biorefineries;
- companies who market and distribute biofuels;
- research companies who develop and licence innovation process technologies;
- thousands of people in support industries who benefit from the wealth that biomass, bioenergy and biofuels production generates in rural communities;

See Renewable ethanol: driving jobs, growth and innovation throughout Europe: State of the Industry Report 2014 published by ePure in June 2014.

In the United States, the economic output of the 'renewable fuels industry' is estimated at $184 billion. It supports over 852,000 jobs and $56 billion in wages and generates about $14.5 billion in local and state tax revenue every year [Source: National Corn Growers Association, April 2014].

Developing countries can also potentially benefit from sustainable development of bioenergy feedstocks and biofuels. The challenges and opportunities are outlined in reports such as Sustainable Biomass Production and Use - Lessons Learned from the Netherlands Programe on Sustainable Biomass (NPSB) 2009-2013, Netherlands Enterprise Agency.

Conversion of wastes from food, forestry, agriculture and other bioindustry to fuels

Bioindustrial activity - production of food, feed, forestry products and other bioproducts - creates millions of tonnes of waste (solid, liquid and gaseous) that previously had to be disposed of and were potential pollutants. The move towards biorefineries, which use all parts of a feedstock in cascading processes, has helped to replace products and energy derived from fossil fuels, and create valuable 'low-carbon' fuels for heat and power and transport.

Reduction of tailpipe pollution from vehicle transport

Various studies have shown that diesel produced from biomass produces less pollutants in exh aust gases than fossil diesel. See the TNO report Impact of biofuels on air pollutant emissions from road vehicles. The use of ethanol blends has helped enable the removal of lead and other carcinogens from gasoline, with significant benefits to public health.

Reduction of military dependence on imported fossil fuels

Much pioneering activity in advanced biofuels development has been carried out by the military, to ensure future supplies of transport fuels that are not dependent on fossil imports. A country cannot be defended without reliable fuel supplies. In a volatile and rapidly changing world, where remaining fossil sources are concentrated in areas of political instability, feedstock diversity is an increasingly important strategic issue for national security.

European Biofuels Markets

Introduction to European Biofuels Markets

Development of sustainable advanced biofuels is part of the **Strategy for a Sustainable European Bioeconomy** proposed by the European Commission in February 2012 to shift the European economy towards greater and more sustainable use of renewable resources and processes (for food, feed, energy and industry).

The plan focuses on three key aspects:

- developing new technologies and processes for the bioeconomy;
- developing markets and competitiveness in bioeconomy sectors;
- pushing policymakers and stakeholders to work more closely together.

In 2009 the EU bioeconomy had a turnover of nearly €2 trillion (2012) and employed more than 22 million people, 9% of total employment in the EU. The statistic included agriculture, forestry, fisheries, food and pulp and paper production, as well as parts of chemical,biotechnological and energy industries. Each euro invested in EU-funded bioeconomy research and innovation was estimated to trigger €10 of value added in bioeconomy sectors by 2025.

Market development of advanced biofuels for road transport, aviation and shipping

Information on market development initiatives are provided on the individual pages covering road transport, shipping and aviation. See the EBTP deployment database , which collates information on initiatives and supports to accelerate use of advanced biofuels at national and international level.

Statistics and market information are available from:

- ESBF - European Sustainable Biofuels Forum
- EBB European Biodiesel Board
- ePure - European Renewable Ethanol Association

There has been a specific focus on development of alternative aviation fuels within the European Union - partly because liquid biojet fuels are currently the only alternative to fossil fuels for air transport (i.e. electrification is not an option). In 2011 the EC, in coordination with Airbus, leading European airlines (Lufthansa, Air France/KLM, & British Airways) and key European biofuel producers (Neste Oil, Biomass Technology Group and UOP), launched an initiative to speed up the commercialisation of aviation biofuels in Europe. The initiative, labelled "European Advanced Biofuels Flight path" is a roadmap with clear milestones to achieve an annual production of two million tonnes of sustainably produced biofuel for aviation by 2020. Further information is provided on the aviation biofuels page.

Policy-driven development of biofuels markets in the EU

In recent years, market development of biofuels in Europe has been driven by binding targets set in the Renewable Energy Directive for 10% of renewables in transport energy use by 2020. Public concerns over land use issues have led to the amendment of the Renewable Energy Directive in 2015 (EU/2015/1513) which caps the use of conventional biofuels derived from crop plants at 7%. At the same time it obliges Member States to implement a target for biofuels from non-food feedstock of at least 0,5% in transport energy in 2020. As a further incentive the amendment rules the double-counting of the energy contents of advanced biofuels towards the renewable energy target of 10%. Hence the future expansion of biofuels markets in Europe is dependent on the commercial deployment of advanced biofuels that use wastes, residues and energy crops (grown on marginal land) as feedstocks. In addition, electricity from renewable resources for rail transport is counted 2,5 times and for road transport 5 times the energy content.

However, no targets for biofuels are included in a policy framework for climate and energy in the period from 2020 to 2030. This represents is some 'contradiction' in policies as the European Energy Security Strategy COM(2014) 330 final, published in May 2014, highlights the need to reduce reliance on fuel imports to the EU. The important role played by biofuels is included in COM(2013) 17 Clean Power for Transport: A European Alternative Fuels Strategy.

ePure position during the negociation of the RED amendment

In 2013, in preparation of the amendment of the Renewable Energy Directive, ePure, the association of the European ethanol producing industry, published a study on the double counting proposal. Double Counting, Half Measures: Study on the effectiveness of double counting as a support for advanced biofuels. The study concludes with alternative measures to accelerate deployment of advanced biofuels:

- Increasing the weighting of advanced biofuels towards the target for 10% renewables in transport will not help reducing GHG emissions from transport by 2020;
- A dedicated sub-target for innovative advanced biofuels technologies, with high enough penalties to prevent buy-outs;
- A strong, long-term and stable framework beyond 2020;
- Dedicated investment support for first-of-its-kind plants.

JEC biofuels programme

The JEC research collaboration started in 2000 bringing together

- Joint Research Centre of the European Commission, (IET institute)
- EUCAR, the European Council for Automotive R&D
- CONCAWE, the Oil Companies' European Organisation for Environment, Health and Safety

The JEC research collaboration provides scientific facts to European institutions, Member States and sector stakeholders relating to the energy use and efficiency and emissions from a broad range of road vehicle powertrain and fuel options.

The JEC Biofuels Programmes (2008-2010; 2011-2014) assessed the possible biofuel implementation scenarios for achieving EU renewable energy targets in the transport sector by 2020. These scenarios were assessed by modelling and other analyses.

In 2014 the JEC consortium came up with a revised version of its first report of 2011. The reference scenario and three fuel demand scenarios have been re-developed and tested on the legislative concepts proposed by EU institutions to modify the RED and FQD regulation with a view to including ILUC concerns. The revised reference scenario has been compared to the outcomes of the JEC Biofuels Study in 2011 to identify and characterise the main drivers behind different results on the capacity to attain the RED and FQD targets. The main conclusions to be drawn from the analysis performed in this revised version of the JEC Biofuels study using the F&F model and a revised bottom-up supply outlook for advanced biofuels are:

- None of the scenarios, tested against the legislative concepts, will achieve the RED and FQD targets.
- The introduction of an accounting cap on conventional biofuels towards achieving the RED target will diminish the potential impact of higher biofuel blends. It will also affect the use of drop-in fuels from such sources to blend beyond the current (diesel) grade.
- ´Switching to low-ILUC risk feedstocks has the potential to have a major impact on achieving the FQD and RED targets but is expected to be limited by feedstock availability.

Examples of older EC Projects on development of markets for biofuels

BIODIENET - Developing a network of actors to stimulate demand for locally produced biodiesel from used cooking oils (EIE/06/090/S12.448899)

Further information

BioDieNet aimed to involve Energy Agencies across Europe in the local production and distribution of biodiesel from used cooking oils (UCO), stimulating demand for higher concentrations of this biofuel. The 17 partners in 10 regions will form a network to share expertise and experience and provide specific, practical information, education, dedicated tools and support to help set up and maintain projects which result in greater uptake of locally-produced biodiesel by public and private vehicle fleets as well as individual vehicle owners.

BIODIESEL CHAINS - Promoting favourable conditions to establish biodiesel market actions (EIE/05/113/S12.420022)

Website

The Biodiesel Chains project aims to understand & promote favourable conditions for the establishment of biodiesel market chains in selected countries which have had limited developments to date. The work focuses on countries – Greece, Belgium, Poland, Cyprus, Romania & Bulgaria – that are making limited progress in creating markets to achieve European liquid biofuel policies & targets.

BIOFUEL MARKETPLACE - Web-based Biofuel Marketplace for Supporting the e-commerce of Biofuel Products and Technologies (EIE/05/022/S12.420009)

Further information

The Biofuel Marketplace project will act as an interactive web-based forum where Europe's biofuel actors can promote their technologies, exchange ideas, sell and buy biofuel products, disseminate results of national, international and European research activities and raise the awareness both of the public and the professional community. The on-line supply and demand information system is expected to encourage the further exploitation of the EU biofuels potential.

BIOGASMAX - Biogas Market Expansion to 2020 (FP6 - 019795)

Further information

The overall goal of this project is to reduce dependency on oil, reduce greenhouse gases and direct emissions through increased and more efficient production, distribution and use of biogas in the transport sector generated from a wide variety of feedstock available in urban areas and regions in Europe. The project adopts the well-to-wheel approach to identify the potential for efficiency gains and cost optimisation to ensure market expansion. It aims to prove the technical reliability, cost-effectiveness, environmental and societal benefits of biogas fuels and perform large-scale demonstrations to optimise industrial processes, experiment and benchmark new and near-to market techniques and expand biogas fleets as well as to identify and assess ways to remove technical, operational, organisational/institutional barriers, which can inhibit or prevent alternative motor fuels and energy efficient vehicles from entering the market.

BIOMOTION Biofuels in Motion (IEE)

Further information

Aims to increase the use, knowledge and acceptance of biofuels. An international cluster of relevant actors and seven biofuel information centres will be established. A number of highly visible examples, or "beacons", will be used to demonstrate the use of various raw materials for the production of different biofuels on a commercial scale. The BioMotion Tour, with vehicles powered by several types of biofuels, will show the advantages of using biofuels. The project should encourage the development of biofuel supply chains and highlight market opportunities, particularly in rural areas. In addition to professional advice, the project contains specific motivation and PR actions aimed at particular target groups in accordance with the motto: Bio fuels in Motion by Information and Motivation.

BIOPROM Bioenergy-Promotion - Overcoming the non-technical barriers of project-implementation for bioenergy in condensed urban environments (Altener EIE-04-38585)

Further information

This project aimed to overcome non-technical constraints of the realisation of bio-energy projects in densely populated urban areas and to bring bioenergy projects on their way by establishing a network of actors and stakeholders of the bioenergy sector in five European regions. Biogas, biofuel, wood chip and wood pellet projects are considered within the project. The five different EU regions involved in this project lie in France, Slovenia, Austria and Germany.

BOOSTING BIO - Boosting Bioenergy in Europe (Altener EIE-04-38592)

Further information

The main aim of this project was to boost bioenergy use in Europe through targeted actions in 2005 and 2006, developing a vision for bioenergy in 7 EU Member States and consultation with policy makers and private companies. The vision for bioenergy will be worked out with a strategy to develop bioenergy further, based on a market analysis where financial instruments will be taken into account. This strategy will be integrated with views from national decision makers and industries in order to evaluate it.

CAB-CEP (BIOFUELS CITIES) - Biofuel Cities European Partnership (FP6 - 020085)

Website

The Biofuel Cities project develops and maintains the 'Biofuel Cities European Partnership' in order to demonstrate the broadscale use of new and innovative biofuel technologies. Biofuel Cities covers the complete chain from feedstock to biofuels production, distribution and utilisation in vehicle fleets. The 'Biofuel Cities European Partnership' is set up with the aim to become a permanent institution.

CARBON LABELLING - Carbon Efficiency Labelling & Bio-Blending for Optimising benefits of Biodiesel & Additive Use (EIE/06/015/S12.442654)

Website

The Carbon Labelling project implements several labelling measures in Europe which focus on transportation products and services with low CO2 emissions. The project promotes biodiesel, fuel efficiency improvements and ‘low carbon’ freight services. This first European carbon labelling initiative helps meeting greenhouse gas reduction targets of the European Union, reduces petroleum dependence and helps to combat climate change.

ELOBIO Effective and Low-disturbing Biofuels (EIE-07-139-S12.467616)

Website

This project develops low-disturbing policy options, enhancing biofuels but minimising the impacts on e.g. food and feed markets, and markets of biomass for power and heat. The project consists of a review of current experiences with biofuels and other RE policies and their impacts on other markets, iterative stakeholder-supported development of low-disturbing biofuels policies, model-supported assessment of these policies' impacts on food & feed and lignocellulosic markets, and finally an assessment of the selected optimal policies on biofuels costs and potentials.

HyLights - Hydrogen for Transport in Europe (FP6 - 019990)

Website

This is a coordination action that aims to accelerate the commercialisation of hydrogen and fuel cells in the field of transport in Europe on the basis that hydrogen enables the transport sector to phase in renewable energies on the path to cleaner mobility. HyLights will draw on a network of relevant experts. For this purpose an European Partnership for Hydrogen in Transport (EPHT) will be established to extend the reach of the European Hydrogen and Fuel Cells Platform (HFP).

MADEGASCAR - Market development for gas driven cars (IEE)

Further information

MADEGASCAR (Market development for gas driven cars) is a project operating from September 2007 to January 2010, funded by the IEE programme. The project aims at developing the market for gas driven vehicles – natural gas and biomethane fuelled vehicles – with the overall goal to increase the number of energy efficient and alternative fuelled vehicles in European countries. The project will address existing barriers by creating more acceptance on the consumer side, educating fleet owners as well as car dealers, incentive programmes and by awareness raising and information activities. On the other side activities for a better supply infrastructure (fuel stations) and market structure, including the integration of biogas, will be carried out.

PREMIA - R&D, demonstration and incentive programmes effectiveness to facilitate and secure market introduction of alternative motor fuels (FP6 - 503081)

Further information

This a Specific Support Action that aims to assess the effectiveness of measures to support the market introduction of alternative motor fuels, taking into account the national context of member states. Three categories of fuels are envisaged: bio fuels, natural gas and hydrogen. Certain alternative fuels are closer to market maturity than others. Bio fuels could achieve market maturity rather soon (estimated up to 2010), while hydrogen is much further away (estimated up to 2020). Although a general European approach is most obvious, country-specific conditions and constraints may require different approaches in different countries. The strategy to introduce alternative motor fuels is best adapted to the specific country legislation, the available resources (e.g. land for bio fuels), supply opportunities and available energy sources and available infrastructure - so especially for the new member Countries a specific approach may be needed.

PRO-BIODIESEL Overcoming Non-Technological Barriers For Full-Scale Use of Biodiesel In Europe (Altener EIE-05-111)

Further information

The general objective of this project was to promote biodiesel as a competitive and commercial product in the European fuel market, using the broadest range of raw materials both from North and South-Europe and considering all the agents involved. One of the aims was to successfully put in the market 35,000 t/year of biodiesel, which represents an increases of 2.3% biodiesel on the production of EU-25 in 2003.

REFUEL Renewable Fuels for a Sustainable Europe (Altener EIE-05-042)

Further information

The object of this project is to develop a roadmap for biofuels to reach a target market penetration in 2030 in an effective way. It expects to deliver a meaningful road map that is consistent with EU policies and which has been discussed and agreed by a wide range of stakeholders resulting in a biofuels scenario consistent with a target market penetration in 2030 together with a design of the required supply chain and market structure, the assessment of costs and potentials and the short and long term barriers to implementation.

VIEWLS: Clear Views on Clean Fuels - Data, Potentials, Scenarios, Markets and Trade of Biofuels (FP5-NNE5–00619)

Further information

The aim of this project was to bring together information and future perspectives concerning the use of biofuels for transportation. It aimed to assist policy makers, NGO's and industrial decision makers in the selection of optimal pathways for the development and market introduction of biofuels in Europe. The project has now ended and many of the features have been transferred to the coordination project Biofuel Cities

ZERO REGIO - Lombardia & Rhein-Main towards Zero Emission: Development & Demonstration of Infrastructure Systems for Alternative Motor Fuels (Bio-fuels and Hydrogen) (FP6 - 503190)

Further information

This project has the overall objective of developing low-emission transport systems for European cities. The specific objectives of the project are to demonstrate the use of hydrogen as an alternative motor fuel, produced as primary or waste stream in a chemical plant or via on-site production facilities; development of infrastructure systems for alternative motor fuels (bio-fuels & hydrogen) and integrating them in conventional refuelling stations. This will include demonstration of 700 bar refuelling technology for hydrogen blends of bio-fuels in fuel flexible vehicles, demonstration of alternative fuels via. automobile-fleet field tests at two different urban locations in the EU, Rhein-Main, Germany and Lombardia, Italy and demonstrating ways and prospects for faster penetration of low-emission alternative motor fuels in the market at short and medium term.

Investing in European fuel security - funding commercial deployment of advanced biofuels

Overview

Development of advanced biofuels currently carries a number of risks for potential investors, including:

- Long-term sourcing of reliable supplies of feedstocks (waste streams, residues and energy crops), which do not currently all have well-developed supply chains;

- Deployment of innovative conversion technologies with high capex and opex, which have not been proven under commercial conditions;
- Dependence on a stable and supportive long-term regulatory framework (including consistent policy and financial incentives) at national or EC level.

Due to a combination of these risk factors, it is currently less attractive for investors to develop advanced biofuels projects in Europe. And European technology developers are increasingly looking at opportunities outside the EU in North and South America and China.

While policy uncertainties have had an impact on advanced biofuels investments in Europe, on a positive note institutional investors are increasingly moving towards renewable energies and away from fossil fuel investments, which offers a potential opportunity for companies developing advanced biofuels and bioenergy technologies (see below).

Impact of policy on European investment in advanced biofuels

Risk sharing through Public Private Partnerships between industry, Member States and investors is seen as the best way forward.

EC initiatives and programmes such as NER300, Horizon2020, EIBI, ERA-NET+, BBI offer public co-funding towards the capital costs of industrial-scale demonstrations of advanced biofuels and bioenergy. The Expert study on Financial instruments for the SET-Plan (including authors from financial organisations, such as the European Investment Bank, The European Private Equity and Venture Capital Association, Insurance Europe, the World Bank, and the Climate Change Capital) concluded that financial instruments, loans and guarantees are potentially available. A range of potential support mechanisms are outlined in the report.

InnovFin Energy Demonstration Projects (EDP) facility

In June 2015, the EC and the European Investment Bank launched the InnovFin Energy Demo Projects (EDP) Facility, which enables the EIB to finance innovative first-of-a-kind demonstration projects in the field of renewable energy and hydrogen/fuel cells. The EIB provides loans between EUR 7.5m and EUR 75m.

InnovFin – EU Finance for Innovators is a joint initiative by the EIB Group and the European Commission under Horizon 2020, the EU framework for research and innovation ("R&I") 2014-2020. InnovFin builds on the success of the Risk-Sharing Finance Facility developed under the seventh EU framework for research and technological development (FP7), which for the period 2007-2013 financed 114 R&I projects of EUR 11.3bn and provided loan guarantees for another EUR 1.4bn.

The new facility will support cutting-edge energy technology projects that may otherwise not be bankable during their pre-commercial stage, covering the higher risk faced during the construction and initial operating stages. Specifically, InnovFin Energy Demo Projects will provide loans to first-of-a-kind commercial-scale industrial demonstration projects in the fields of renewable energy and hydrogen and fuel cells, helping to bridge the gap from demonstration to commercialisation and contributing to the broader objectives of the Energy Union and the Strategic Energy Technology (SET) Plan.

The need for a supportive and stable regulatory framework after 2020

Even with support available, a number of NER300 projects on advanced biofuels have been withdrawn, citing uncertainty about long-term biofuels policy as a deciding factor. For example, investors have been unnerved by the recent changes to rules on state aid for biofuels and the non-inclusion of biofuels targets in the policy framework for climate and energy in the period from 2020 to 2030, and the ongong political debates over proposals to amend the Renewable Energy Directives and Fuel Quality Directives.

Hence the current dilemma is:

- advanced biofuels technologies are available at industrial scale;
- finance is potentially available to construct the facilities demonstrating integration of these technologies and commercial operation of value chains (from feedstock supply to end product) on a single site;
- but, crucially, there is no certainty of consistent long-term policies in support of biofuels markets up to 2030 and beyond, offering clear opportunities to profit from this high-risk technology investment in future

This means it is more attractive for investors to look at other technology areas or other parts of the world.

From the perspective of industry and investors, the solution is for EU Institutions to set long-term targets for renewable transport fuels in Europe and increase coordination of policy areas to achieve those targets. If not, Europe may not only end up dependent on imported energy, but even more dependent on importing sustainable energy technologies.

Institutional investment in renewable energy including bioenergy and biofuels

The media has recently highlighted a number of prominent institutional investment funds that are moving away from fossil fuels and/or looking to make investments in renewable energy, including advanced bioenergy:

In September 2014, the BBC in the UK reported that "The Rockefeller Brothers Fund is joining a coalition of philanthropists pledging to rid themselves of more than $50bn (£31bn) in fossil fuel assets. Some 650 individuals and 180 institutions have joined the coalition." [Source: BBC website].

Valerie Rockefeller Wayne, a great-great-granddaughter of 'Rockefeller and a trustee of the fund, is quoted by the Washington Post as saying "There is a moral imperative to preserve a healthy planet."

Google has pledged to invest in green energy, and the Google Ventures Portfolio includes the Cool Planet project to produce. Cool Planet (with investors including BP, Google Ventures, ConocoPhillips and GE), is using a thermo-mechanical fractionation system (pyrolyzer) to convert wood waste and energy crops into hydrocarbon chains (gases). These are converted via catalysts to high-octane, renewable gasoline blendstocks (known as "Reformate"), which can be used to enhance the energy content of gasoline, diesel, and jet fuel.

In September 2014, the Guardian newspaper, UK, highlighted an increasing trend for pension funds to invest in 'Clean Tech' companies. See also OECD report from August 2012 The Role of Instiutional Investors in Financing Clean Energy.

An Ernst and Young studies shows that investors are not being driven by purely moral and philanthropic principles but by the better long-term returns offered by sustainable technologies and renewable energy sources [*Source:* Pension and insurance fund attitudes toward investment in renewable energy infrastructure, November 2013].

the lagest investments have been in wind and solar energy. However, there is also bioenergy investment by pension funds. For example the PensionDanmak investment of £160m in a new biomass power plant, Brigg Renewable Energy Plant, which is to be built in Lincolnshire, in the east of England.

Regulatory Framework

Biofuels Policy and Legislation

A number of directives cover biofuels use in the EU including the **Renewable Energy Directive 2009/28/EC,** the **Fuel Quality Directive** and the **Biofuels Directive 2003**. Relevant communications and links to further information on biofuels legislation are included below.

Recent EC legislation, policies and communciations relating to biofuels

Joint input to SET Plan governance discussion from four ETPs and EUREC

On 18 March 2015 the European Commission presented to the SET Plan Steering Group the first draft of its proposals for reforming the governance of the SET Plan. In meetings with European Technology Platforms (ETPs) in renewable energy in the weeks that followed, EUREC offered to draft a joint reaction to the EC's proposals, and they accepted the proposal.

The emerging joint EUREC-ETP consensus was discussed with the European Commission on 8 June in a meeting between the EC and representatives from EUREC and the ETPs. Five main messages (see below) were sent two days later, with a full-length paper being sent to the EC and national delegates to the SET Plan Steering Group on 31 August. The final paper was signed by the ETPs EU PV TP, RHC-Platform, EBTP and ETP-Smart Grids, as well as EUREC. [*Souce: EUREC website October 2015*].

Revision to the Fuel Quality Directive and Renewable Energy Directive

On 28 April 2015, the European Parliament voted to approve new legislation, the "iLUC Directive", which limits the way Member States can meet the target of 10% for renewables in transport fuels by 2020, bringing to an end many months of debate. There will be a cap of 7% on the contribution of biofuels produced from 'food' crops, and a greater emphasis on the production of advanced biofuels from waste feedstocks. Member States must then include the law in national legislation by 2017, and show how they are going to meet sub-targets for advanced biofuels.

Key elements of the draft EU Directive

The contribution of biofuels produced from 'food' crops (to the 10 % renewables in transport target) is capped at 7%

The other 3% will come from a variety of multiple counted alternatives:

- Biofuels from Used Cooking Oil and Animal Fats (double counted)
- Renewable electricity in rail (counted 2.5 times)
- Renewable electricity in electric vehicles (counted 5 times)
- Advanced biofuels (double counted and with an indicative 0.5% sub-target)

The agreement also includes the reporting and publishing of data on ILUC-related emissions on both national and European level.

Member States have to transpose the directive into national legislation by mid-2017, and establish the level of their national indicative sub-targets for advanced biofuels within 18 months (end 2016 - beginning 2017).

EBTP Response to the ILUC Directive

The European Biofuels Technology Platform (EBTP) appreciates that the on-going debate about the biofuels legislation through the RED and FQD review is settled for now; this debate has caused many uncertainties and blocked many investment decisions for the past three years. However EBTP would like to comment on key elements of the final legislation:

1. The **non-binding and double counted advanced biofuels target of 0.5%** is not ambitious enough to foster the deployment of advanced biofuels. Member States have options to go below 0.5% and experience in the EU demonstrates that indicative targets are usually not achieved. A European wide and binding sub target is the most effective way to support innovative pathways. Innovative pathways are based on technologies with a high implementation potential and high well-to-wheel energy efficiency, but also high upfront development and demonstration costs, since they are not yet widely commercially available. By securing market demand, investments can be made in deployment.
2. The EBTP is in favour of the decision to maintain dedicated energy crops or the so-called “grassy energy crops with a low starch content” among the advanced biofuels feedstocks list. Dedicated energy crops provide best land-use efficiency, can be grown also on marginal or degraded land and are able to create additional income for farmers.

The cap of 7% on the contribution of biofuels from food crops is a political compromise that affects the **healthy sustainable conventional biofuels** industry in Europe. The vision for advanced biofuels industrialisation is related to the existing conventional biofuels industry where technical, operational and financial synergies exist with advanced innovative pathways. Capping all conventional biofuels without distinction is not providing the sector with reassurances that policy-makers can define objective and evidence-based biofuels policy in the future. However, the recognition of the concept of low ILUC risk conventional biofuels is a positive signal. The final ILUC directive is a first step towards a stable and consistent framework for biofuels in Europe. However it is urgent to define a new biofuel policy post 2020. A coherent European approach on the development and implementation of legislation, policies, projects and programmes in the field of alternative transport fuels, contributing towards an energy-efficient, decarbonised transport sector is needed in order to address the key challenges faced by the transport sector in Europe in terms of GHG emissions and energy dependency. Sustainable biofuel technologies have a key role to play in addressing these challenges.

Process to reach the compromise agreement

In October 2012, the EC published a proposal to minimise the climate impact of biofuels, by amending the current legislation on biofuels through the Renewable Energy and the Fuel Quality Directives. In particular, the proposals suggest:

- To increase the minimum greenhouse gas saving threshold for new installations to 60% in order to improve the efficiency of biofuel production processes as well as discouraging further investments in installations with low greenhouse gas performance.
- To include indirect land use change (ILUC) factors in the reporting by fuel suppliers and Member States of greenhouse gas savings of biofuels and bioliquids;
- To limit the amount of food crop-based biofuels and bioliquids that can be counted towards the EU's 10% target for renewable energy in the transport sector by 2020, to the current consumption level, 5% up to 2020, while keeping the overall renewable energy and carbon intensity reduction targets;
- To provide market incentives for biofuels with no or low indirect land use change emissions, and in particular the 2nd and 3rd generation biofuels produced from feedstock that do not create an additional demand for land, including algae, straw, and various types of waste, as they will contribute more towards the 10% renewable energy in transport target of the Renewable Energy Directive.

EBTP comments on the RED / FQD Review - a consensus of comments made by members of EBTP Working Group 4 Policy and Sustainability as well as members of the EBTP Steering Committee.

On 12 December 2013 the European Council failed to reach an agreement on a compromise proposal put forward by the Lithuanian Presidency, based on a 7% cap on conventional biofuels. This meant no decision was possible before the European Parliamentary elections in May 2014, and is now unlikely to be made before the end of 2014.

On 11 September 2013 a narrow majority of MEPs voted that "first generation" biofuels should not exceed 6% of the final energy consumption in transport by 2020, as opposed to the current 10% target in existing legislation, while advanced biofuels should represent at least 2.5% of energy consumption in transport by 2020. The MEP vote also endorsed double-counting of biofuels produced from UCO or animal wastes and a minimum 7.5% limit of ethanol in gasoline. Finally, they decided to include an iLUC factor in the Fuel Quality Directive methodology as of 2020. Rapporteur, Ms Lepage, was two votes short of receiving a mandate to negotiate with member states, who then failed to reach a common position of their own in December 2013 (as described above).

Since December 2013, the Council's preparatory bodies continued to work further on the proposal, with a view to facilitating political agreement, which was reached in June 2014 (as outlined above).

The ongoing uncertainty in European biofuels policy from 2012-2014 deterred investment in the industry, making it harder for demonstration and flagship plants to secure the funding needed for commissioning. This potentially puts on hold the creation of 1000s of new jobs in the European Bioeconomy. The barriers to investment in advanced biofuels are highlighted in a report by Agra CEAS Consulting, published in December 2013, EU Biofuels Investment Development: Impact of an Uncertain Policy Environment

On 9 December 2014, the Transport, Telecommunications and Energy Council adopted without debate its first-reading position on the "draft Directive on indirect Land-Use Change", which amends the Fuel Quality Directive and Renewable Energy Directive. The European Parliament initially adopted its first reading position on 11 September 2013. In December 2013, the Energy Council examined a presidency compromise text of this draft directive. However, there were still some outstanding issues. Therefore, the Council's preparatory bodies continued to work further on the proposal, with a view to facilitating political agreement, which was reached in June 2014.

See: Proposal for a Directive of the European Parliament and of the Council amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources (first reading) - Political agreement

See also: Correction to the above document (this affects a single sentence).

References and Further Reading

EBTP Position on Rappoteur Amendment to the RED/FQD Proposal

ePure Press Release

European Biodiesel Board Press Release

iLUC Prevention Study - Copernicus Institute of Sustainable Development

NASA Earth Observatory Tropical Deforestation Update

Renewable ethanol: driving jobs, growth and innovation throughout Europe: State of the Industry Report 2014

Using Recent Land Use Changes to Validate Land Use Change Models

Baseline time accounting: Considering global land use dynamics when estimating the climate impact of indirect land use change caused by biofuels.

Land Use Change Greenhouse Gas Emissions of European Biofuel Policies Utilizing the Global Trade Analysis Project (GTAP) Model

A change for the worse: The campaign to re-dredge 'Indirect Land Use Change'

Greenhouse gas impact of marginal fossil fuel use

Directive on deployment of alternative fuels infrastructure

On 29 September 2014, New EU rules were adopted to ensure the build-up of alternative refuelling points across Europe with common standards for their design and use, including a common plug for recharging electric vehicles. Member States must set and make public their targets and present their national policy frameworks by end-2016. See Directive on the deployment of alternative fuels infrastructure 2014/94/EU (also known as the CPT Directive).

Based on the consultation of stakeholders and national experts, as well as the expertise reflected in the Communication from the Commission of 24 January 2013 entitled 'Clean Power for Transport : A European alternative fuels strategy', electricity, hydrogen, biofuels, natural gas, and liquefied petroleum gas (LPG) were identified as currently the principal alternative fuels with a potential for long-term oil substitution, also in light of their possible simultaneous and combined use by means of, for instance, dual-fuel technology systems.

New rules on state aid for biofuels 2014-2020 (April 2014)

In April 2014, the EC introduced new guidelines on state aid for environmental protection and energy, including renewable energy and biofuels.

Press release summarising main points: **Commission adopts new rules on public support for environmental protection and energy**

Full guidelines: Guidelines on State aid for environmental protection and energy 2014-2020

Commission Vice President in charge of competition policy, Joaquín Almunia, said, "The new guidelines provide a framework for designing more efficient public support measures that reflect market conditions, in a gradual and pragmatic way. Europe should meet its ambitious energy and climate targets at the least possible cost for taxpayers and without undue distortions of competition in the Single Market."

In relation to biofuels, the guidelines state:

(112) In view of the overcapacity in the food-based biofue l market, the Commission will consider that investment aid in new and existing capacity for food-based biofuel is not justified. However, investment aid to convert food-based biofuel plants into advanced biofuel plants is allowed to cover the costs of such conversion. Other than in this particular case, investment aid to biofuels can only be granted in favour of advanced biofuels.

(113) Whilst investment aid to support food-based biofuel will cease with the entry into force of these Guidelines, operating aid to food-based biofuels can only be granted until 2020. Therefore such aid can only be granted to plants that started operation before 31 December 2013 until the plant is fully depreciated but in any event no later than 2020.

(114) In addition, the Commission will consider that the aid does not increase the level of environmental protection and can therefore not be found compatible with the internal market if the aid is granted for biofuels which are subject to a supply or blending obligation, unless a Member State can demonstrate that the aid is limited to sustainable biofuels that are too expensive to come on the market with a supply or blending obligation only.

'sustainable biofuel' means a biofuel fulfilling the sustainability criteria set out in Article 17 of Directive (EC) 2009/28 of the European Parliament and the Council on the promotion of the use of energy from renewable sources and any amendment thereof.

EC Communication on Climate And Energy Policy Framework 2020-2030 (Jan 2014)

On 23 January 2014 the EC published a communication: A policy framework for climate and energy in the period from 2020 to 2030 This is summarised in an accompanying EC press release

Of particular relevance to biofuels was Q&A 12:

"The future of EU transport development should be based on alternative, sustainable fuels as an integrated part of a more holistic approach to the transport sector. The Commission has therefore not proposed new targets for the transport sector after 2020 (current targets: 10% renewable energy for the transport sector. The share of renewables in transport rose to 4.7% in 2010 from 1.2% in 2005). Based on the lessons of the existing target and on the assessment of how to minimise indirect land-use change emissions, it is clear that first generation biofuels have a limited role in decarbonising the transport sector. A range of alternative renewable fuels and a mix of targeted policy measures building on the Transport White Paper are thus needed to address the challenges of the transport sector in a 2030 perspective and beyond."

EC communication on Energy Technologies and Innovation (May 2013)

On 2 May 2013 the EC published a Communication on Energy Technologies and Innovation COM(2013) 253 final. The plan - updating the existing SET-Plan - aims to bridge the gap between research and market deployment and provide a boost for a wider range of energy technologies, including the cutting of energy consumption, and innovation in energy storage, radioactive waste management and alternative fuels, as well as renewable cooling and concentrated solar thermal power for industrial heating. A strengthened SET Plan steering group has been developing a roadmap for energy innovation. The new plan will be financed through the EU's Horizon 2020 research programme and other sources such as the European Investment Bank and the Connecting Europe Facility. Funding would also come from the member states and the private sector.

See also: Technology Assessment SWD(2013) 158 final and JRC Scientific and Policy Reports R & D Investment in the Technologies of the European Strategic Energy Technology Plan

Other EC and European Parliament policy activity on biofuels

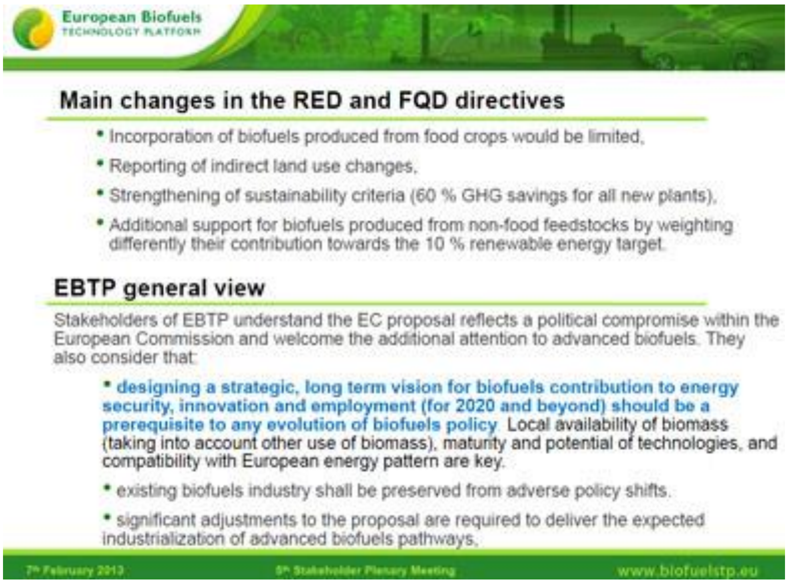
On 16 October 2013 the European Parliament Intergroup on 'Climate Change, Biodiversity and Sustainable Development' held a workshop entitled 'The future of Biofuels as alternative fuel for the transport sector'. A summary report and presentations are now available.

On 24th January 2013 the EC published COM(2013) 17 Clean Power for Transport: A European Alternative Fuels Strategy, which encompasses biofuels as well as LNG, SNG, electricity and hydrogen. See also the Press Release Europe Launches Clean Fuel Strategy. The strategy document advocates support for sustainable advanced biofuels produced from lignocellulosic feedstocks and wastes, as well as algae and microorganisms. It recommends no further public support for first generation biofuels produced from food crops after 2020.

EBTP comments on the RED / FQD Review - a consensus of comments made by members of EBTP Working Group 4 Policy and Sustainability as well as members of the EBTP Steering Committee.

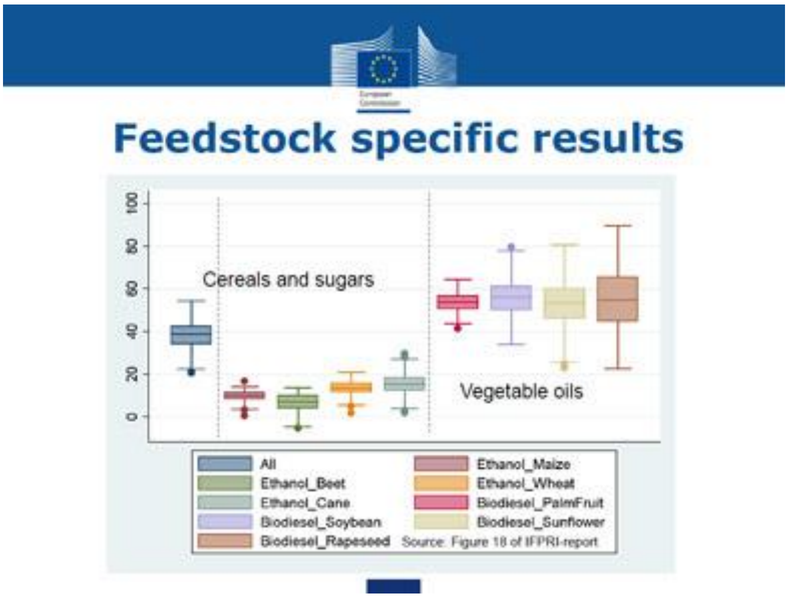
Presentations from the 5th Stakeholder Plenary Meeting of EBTP in February 2013

EBTP general views on the RED and FQD review
Marc Gillmann, Chair EBTP WG4 - Policy and Sustainability; Total Supply and Marketing, Stratégie biocarburants et développement agricole



Existing policy framework and proposal to review RED and FQD to take ILUC of biofuels into account

Øyvind Vessia, Policy Officer, Unit C1 Renewables and CCS Policy, DG ENER, European Commission



Links to EC Policies, intiatives and official information relating to biofuels

Biofuels are covered by a number of existing EU policies and initiatives on bioenergy, sustainable transport and the wider bioeconomy, for example: the SET Plan; the European Industrial Bioenergy Initiative; **Energy 2020 A strategy for competitive, sustainable and secure energy**; and the **Strategy for a Sustainable European Bioeconomy**.

Further links are included below:

Background Information and EU Policy >>

Europa pages on Bioenergy and Biofuels >>

Directives and Communications >>

Older legislation >>

Background information and EU Policy

Relevant EU policy documents and links include:

SET plan

Communication on Energy Technologies and Innovation SWD(2013) 157 final / SWD(2013) 158 final (May 2013)

JRC support to the SET Plan

Energy 2020 A strategy for competitive, sustainable and secure energy

Strategy for a Sustainable European Bioeconomy

A resource-efficient Europe – Flagship initiative of the Europe 2020 Strategy

Strategic Energy Technologies Information System (SETIS)

See also MEMO/09/437 – Questions and answers

Renewable Energy Road Map

EU Strategy for Biofuels (2006)

Clean Vehicles Directive

Emission performance standards for new cars

Climate Change: 2050 - the future begins today

Europa pages on bioenergy and biofuels

Bioenergy

Bioenergy: Sustainability Criteria

Bioenergy Installations / Permits

National Biomass Action Plans

Bioenergy Demonstration Projects

Biofuels and other renewable energy sources in the transport sector

Member States Reports on biofuels and renewable energy in transport

Biofuels standards

Biofuels sustainability criteria

Biofuels demonstration projects

Directives and Communications

Further information on European Legislation is available through EUR-Lex the portal to European Union law. EUR-Lex provides direct free access to European Union law. The system makes it possible to consult the Official Journal of the European Union and it includes inter alia the treaties, legislation, case-law and legislative proposals. It offers extensive search facilities.

EC communications and directives on biofuels and bioenergy

- Proposal for a Directive of the European Parliament and of the Council amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources (first reading) - Political agreement

See also: Correction to the above document (this affects a single sentence).

- Communication from the Commission on the practical implementation of the EU biofuels and bioliquids sustainability scheme and on counting rules for biofuels
- Communication from the Commission on voluntary schemes and default values in the EU biofuels and bioliquids sustainability scheme
- COMMISSION DECISION of 10 June 2010 on guidelines for the calculation of land carbon stocks for the purpose of Annex V to Directive 2009/28/EC
- 'Anti-dumping' measures

- **Biofuels Directive 2003**
- **Renewable Energy Directive 2009/28/EC**
- **Fuel Quality Directive**
- **Emission performance standards for new passenger cars**

Member States action plans and reporting on biofuels and bioenergy

The Europa "Renewable Energy" page includes the **National Renewable Energy Action Plans** for all member states as well as important reports and communications on sustainable cultivation and use of biomass, bioenergy and biofuels, as follows:

- The National Renewable Energy Action Plans and related reporting, documentation and information (including specific sections on Biofuels and Bioenergy)

'Anti-dumping' duties

As of 27 November 2013 the EU will impose definitive anti-dumping duties on imports of biodiesel from **Argentina** and **Indonesia**. The antidumping measures consist of an additional duty of on average 24.6% for Argentina and 18.9% for Indonesia. The measures are based on a decision taken this week by the Council, following a 15-month investigation carried out by the European Commission. It revealed that Argentine and Indonesian biodiesel producers were dumping their products on the EU market. The dumped exports had a significant negative effect on the financial and operational performance of European producers.

COMMISSION REGULATION (EC) No 193/2009 imposing a provisional anti-dumping duty on imports of biodiesel originating in the **United States of America**

- EC procedure started 13 June 2008 on initiative of European Biodiesel Board
- Background: subsidies for B99 in the US
- Anti-dumping and countervailing duties approved on 11 Mar 2009 and published 12 Mar 2009 (EC 193 and 194/2009), differentiated by producer
- Anti dumping duty 23.6-208.2 €/t
- Countervailing duty 211.2-237.0 €/t

'Original' Renewable Energy Directive 2009/28/EC

Renewable Energy Directive

- Approval by European Parliament on 17 Dec 2008
- By 2020, 20 % share of RES in final energy consumption, 20 % increase in energy efficiency
- 10 % target for RES in transport in each Member State
- National Renewable Energy Action Plans required by June 2010
- Burden sharing for RES targets except transport
- Harmonised approach with Fuel Quality Directive
- No biofuels from carbon rich or biodiverse land

- EC has to report on compliance with environmental and social sustainability criteria of major biofuel exporting countries
- Minimum GHG reduction for biofuels 35 % and 50 % from 2017 on; 60 % for new installations from 2017 on. For plants operating in Jan 2008 GHG requirement will start in Apr 2013
- Bonus of 29 g CO_2/MJ for biofuels from degraded/contaminated land
- EC proposal for incorporating indirect land use changes by the end of 2010; special clauses for plants built before 2013
- Biofuels from waste, residues, non food cellulosic material, and lignocellulosic material will count twice for RES transport target
- Mass balance approach for certification of sustainability
- EC will negotiate bilateral and multilateral agreements
- Establishment of a committee for sustainability of biofuels

DIRECTIVE 2009/30/EC - amendment to Directive 98/70/EC on environmental quality standards for fuel (Fuel Quality Directive)

The amendement to the Fuel Quality Directive aims at:

- further tightening environmental quality standards for a number of fuel parameters,
- enabling more widespread use of ethanol in petrol and
- introducing a mechanism for reporting and reduction of the life cycle greenhouse gas emissions from fuel
- Reduction in life cycle GHG emissions from energy supplied. Binding target of 6% as first step while leaving open the possibility for increasing the future level of ambition to 10%.
- To that effect, in a 2012 review, the Commission will need to assess a further increase of the ambition level of 2% from other technological advances, such as the supply of electricity for use in transport. A further 2% is envisaged to be achieved by the use of CDM credits for flaring reductions not linked to EU oil consumption.
- Incorporation of sustainability criteria for biofuels used to meet GHG reduction requirement. Creation of specific Committee jointly with the RED to coordinate the energy and environment aspects in future development of biofuel sustainability criteria.
- Reduction of sulphur content of inland waterway fuel in one step to 10ppm by 1 January 2011.
- Phasing in of 10% Ethanol (E10) petrol: To avoid potential damage to old cars, continued marketing of petrol containing maximum 5% ethanol guaranteed until 2013, with the possibility of an extension to that date if needed.
- Derogations for petrol vapour pressure for cold summer conditions and blending in of ethanol are subject to Commission approval following an assessment of the socio-economic and environmental impacts, in particular on air quality.
- Increase of allowed biodiesel content in diesel to 7% (B7) by volume, with an option for more than 7% with consumer info.

Emission performance standards for new passenger cars

- 130 g/120 g CO_2/km limit for new cars in 2012 (10 g by additional measures)

- Limit of 95 g CO_2/km in 2020
- Step by step approach; bonus for eco innovations
- 5 % bonus for E85 cars until Dec 2015 if sustainable E85 is available at least at 30 % of all filling stations of the Member State where the car is registered

Archive Legislation

Some previous legislative and related documents are listed below. The entries are divided into the following sections:

Fuels

Vehicles

Markets

Fuels

COM(2007) 18 . Proposal, of 31 January 2007, for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive 98/70/EC as regards the specification of petrol, diesel and gas-oil and the introduction of a mechanism to monitor and reduce greenhouse gas emissions from the use of road transport fuels and amending Council Directive 1999/32/EC, as regards the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EEC download (PDF 88Kb)

Opinion of the European Economic and Social Committee on The development and promotion of alternative fuels for road transport in the European Union OJ C 195, 18.8.2006

COM 2003/30/EC ("Biofuels Directive") of the European Parliament and of the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport Official Journal L 123, 17/05/2003 P. 0042 - 0046

COM/2001/0547 final Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions on alternative fuels for road transportation and on a set of measures to promote the use of biofuels

COM(2001) 547 final: Communication of the European Commission of 07/11/2001 on an Action Plan and two Proposals for Directives to foster the use of Alternative Fuels for Transport, starting with the regulatory and fiscal promotion of biofuels

Directive 98/70/EC of the European Parliament and of the Council of 13 October 1998 relating to the quality of petrol and diesel fuels and amending Council Directive 93/12/EEC OJ L 350, 28.12.1998, p. 58–68

Commission Directive 87/441/EEC of 29 July 1987 on crude-oil savings through the use of substitute fuel components in petrol OJ L 238, 21.8.1987, p. 40–41

Vehicles

Opinion of the Committee of the Regions on the Proposal for a Directive of the European Parliament and of the Council on the promotion of clean road transport vehicles OJ C 229, 22.9.2006, p. 18–21

Directive 98/69/EC of the European Parliament and of the Council of 13 October 1998 relating to measures to be taken against air pollution by emissions from motor vehicles and amending Council Directive 70/220/EEC, OJ L 350, 28.12.1998, p. 1–57

Markets

Council Directive 2003/96/EC of 27 October 2003 restructuring the Community framework for the taxation of energy products and electricity (Text with EEA relevance) OJ L 283, 31.10.2003, p. 51–70

2003/238/EC: Commission Decision of 15 May 2002 on the aid scheme implemented by France applying a differentiated rate of excise duty to biofuels (notified under document number C(2002) 1866) Official Journal L 094 , 10/04/2003 P. 0001 - 0042

2002/550/EC: Council Decision of 27 June 2002 authorising the United Kingdom to apply a differentiated rate of excise duty to fuels containing biodiesel in accordance with Article 8(4) of Directive 92/81/EEC OJ L 180, 10.7.2002, p. 20–21

Commission Regulation (EC) No 2546/95 of 30 October 1995 amending Commission Regulation (EC) No 3199/93 on the mutual recognition of procedures for the complete denaturing of alcohol for the purposes of exemption from excise duty OJ L 260, 31.10.1995, p. 45–46

Standards for the production, storage and transportation of biofuels

Overview

Biofuels Standards in the EU

The production, storage, transportation and use of various biofuels is governed by a range of international standards.

The European Commission works closely with CEN for the development and continuous improvement of standards for biofuel use in automotive engines via various tools such as mandates, studies and contracts. The work is carried out by CEN Technical Committee 19 which consists of experts from the automotive industry, the fuel industry, biofuels producers as well as various stakeholders.

Relevant standards include:
EN590 (biodiesel)
EN14214 (FAME)
EN228, EN15736 (bioethanol)

View the CEN business plan for TC19: Gaseous and Liquid Fuels, Lubricants and Related Products of Petroleum, Synthetic and Biological Origin

CEN/TC 19/WG 41 is currently developing standards for fast pyrolysis oils in response to EC mandate M/525 (2013). Three standards will be developed for replacement of heavy fuel oil, light fuel oil and for use of bio-oils in stationary combusiton engines. Later, two further technical specifications may also be introduced for use of fast pyrolysis oils as gasfication feedstocks and for mineral oil refinery co-processing, as and when required.

Standards organisations for biofuels

ASTM (search on biodiesel, biofuel, bioethanol, etc.)

CEN (select TC19 and "go")

ISO TC SC/28 7

SAE

Recent ASTM biofuels standards / specifications

ASTM Aviation Fuel Subcommittee

ASTM D7566-11, Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons

In June 2014, Renewable Synthesized Iso-Paraffinic (SIP) fuel (renewable farnesane hydrocarbon) was included in ASTM International standard D7566.

In December 2014, ASTM D7875, was approved: 'Standard Test Method for Determination of Butanol and Acetone Content of Butanol for Blending with Gasoline by Gas Chromatography'. The standard is primarily designed to ensure the purity of isobutanol manufactured for use as a fuel.

In October 2013, ASTM D7862 was announced for blends of butanol with gasoline at 1 - 12.5 % vol in automotive spark ignition engines. The specification covers three butanol isomers: 1-butanol, 2-butanol, and 2-methyl-1-propanol. The specification specifically excludes 2-methyl-2-propanol (that is, tert-butyl alcohol).

REACH Regulation

EU REACH Regulation (Regulation (EC) 1907/2006) entered into force on June 1st, 2007 and deals with the **R**egistration, **E**valuation, **A**uthorisation and Restriction of **CH**emicals. The overall objective of the REACH Regulation is to ensure high levels of human health and environmental protection through the registration of chemical substances circulated in the EU and identification of their intrinsic properties.

Biofuels compatibility / testing

There are several commercial laboratories that test and inspect biofuels in various ways. Examples include Intertek and SGS.

The effects of E20 on Plastic Automative Fuel System Components (Minnesota Center for Automotive Researech)

CEN/TC 383 Sustainably produced biomass for energy applications (EN 16214)

A new standard (EN 16214), has been developed by CEN/TC 383 on Sustainably produced biomass for energy applications. The standard, in four parts (Terminology; Conformity assessment; Biodiversity & environmental aspects; and Calculation methods) was made available in the autumn of 2012.

CEN Technical Committee (TC) 383 was created in 2008 in order to work on European Standards (EN 16214) dealing with sustainability principles, criteria and indicators including their verification and auditing schemes for biomass for energy applications. This includes green house gas emission and fossil fuel balances, biodiversity, environmental, economic and social aspects and indirect effects within each of the aspects.

The Renewable Energy Directive (2009/28) sets the framework for the work of TC 383. Sustainability criteria related to the quality of petrol and diesel fuels were also requested in the Fuel Quality Directive (98/70/EC). In May 2009, the European Commission (EC) requested CEN/TC 383 through a letter to initiate work on standards. CEN is finalising a European Standard in 4 parts which is going to be available in autumn 2012. The EC has indicated its willingness to acknowledge them at this stage as a way of supporting compliance of biofuels and bioliquids with the Renewable Energy Directive.

The European Standard EN 16214 has been developed by CEN/TC 383 as the following:

- EN 16214-1:2012 Sustainably produced biomass for energy applications - Principles, criteria, indicators and verifiers for biofuels and bioliquids - Part 1: Terminology
- CEN/TS 16214-2:2014 Sustainably produced biomass for energy applications - Principles, criteria, indicators and verifiers for biofuels and bioliquids - Part 2: Conformity assessment including chain of custody and mass balance
- EN 16214-3:2012 Sustainably produced biomass for energy applications - Principles, criteria, indicators and verifiers for biofuels and bioliquids - Part 3: Biodiversity and environmental aspects related to nature protection purposes

EN 16214-4:2013 Sustainably produced biomass for energy applications - Principles, criteria, indicators and verifiers for biofuels and bioliquids - Part 4: Calculation methods of the greenhouse gas emission balance using a life cycle analysis.

Additional Links on national and international biofuels standards and regulations

Biofuel Systems Ltd table of Biodiesel Standards for Europe, Germany and USA

Biofuels certification and verification systems in Europe

Introduction

As biofuels gain market share and international trading of biomass, raw materials and biofuels expands, the need to ensure socio-economic sustainability along the whole supply chain becomes more pressing. This includes aspects such as land use, agricultural practices, competition with food, energy efficiency and GHG emissions, life cycle analysis (LCA), etc.

Sustainability of a given biofuel needs to be guaranteed in a transparent way. This is only possible if appropriate policy measures influencing and steering the overall supply chain are adopted. A strategy to achieve sustainability includes the need for certification systems (i.e. proof of compliance with sustainability criteris) and systems for verifying the origin of sustainable biofuels.

EC certification of sustainable biofuels

On 10 June 2010, the EC announced its scheme for certifying sustainable biofuels, part of a set of guidelines explaining how the Renewable Energy Directive, coming into effect in December 2010, should be implemented.

- Communication from the Commission on the practical implementation of the EU biofuels and bioliquids sustainability scheme and on counting rules for biofuels
- Communication from the Commission on voluntary schemes and default values in the EU biofuels and bioliquids sustainability scheme

- COMMISSION DECISION of 10 June 2010 on guidelines for the calculation of land carbon stocks for the purpose of Annex V to Directive 2009/28/EC

The following schemes that "demonstrate compliance with the sustainability criteria for biofuels" were recognised as at April 2014:

1. ISCC (International Sustainability and Carbon Certification)

- Decision
- Scheme

2. Bonsucro EU

- Decision
- Scheme

3. RTRS EU RED (Round Table on Responsible Soy EU RED)

- Decision
- Scheme

4. RSB EU RED (Roundtable of Sustainable Biofuels EU RED)

- Decision
- Scheme

5. 2BSvs (Biomass Biofuels voluntary scheme)

- Decision
- Scheme

6. RBSA(Abengoa RED Bioenergy Sustainability Assurance)

- Decision
- Scheme

7. Greenergy (Greenergy Brazilian Bioethanol verification programme)

- Decision
- Scheme

8. Ensus voluntary scheme under RED for Ensus bioethanol production

- Decision
- Scheme

9. Red Tractor (Red Tractor Farm Assurance Combinable Crops & Sugar Beet Scheme)

- Decision
- Scheme

10. SQC (Scottish Quality Farm Assured Combinable Crops (SQC) scheme)

- Decision
- Scheme

11. Red Cert

- Decision
- Scheme

12. NTA 8080

- Decision
- Scheme

13. RSPO RED (Roundtable on Sustainable Palm Oil RED)

- Decision
- Scheme

14. Biograce GHG calculation tool

- Decision
- Scheme

15. HVO Renewable Diesel Scheme for Verification of Compliance with the RED sustainability criteria for biofuels

- Decision
- Scheme

16. Gafta Trade Assurance Scheme

- Decision
- Scheme

17. KZR INIG System

- Decision
- Scheme

18. Trade Assurance Scheme for Combinable Crops

- Decision
- Scheme

19. Universal Feed Assurance Scheme

- Decision
- Scheme

EC Projects on Biofuels Certification

Global-Bio-Pact Project

Global-Bio-Pact, co-funded under FP7, aimed to develop and harmonize global sustainability certification systems for biomass production, conversion systems and trade in order to prevent negative socio-economic impacts. The project concluded in 2013.

Systems for verifying the origin of sustainable biofuels

Register of Biofuels Origination (RBO) Consortium

The aim of the Register of Biofuels Origination (RBO) Consortium is to provide a 'simple and solid' international system to act as a reference tool for EU Member States authorities and EC Commission to verify the genuine origin of biofuels substances to be considered as advanced biofuels and claimed for extra incentives and/or for double counting, without interfering with the national definitions and listings of these products (different definitions and lists are set in each EU Member State).

RBO suggets that an imbalance between incentives and verification tools increases the probability of incorrect trading practices. This is facilitated by two current realities: firstly, final biofuel products often have the same chemical composition, regardless of whether they originate from waste, traditional crops or other sources; secondly, the absence of a common European scheme for registering physical biofuels under a single system generates the possibility for semi-fraudulent untrustworthy multiple claims of the same physical biofuels substances under two or more national schemes. [Source: RBO Consortium Launch Meeting communication, January 2013].

The NABISY - Sustainable biomass system in Germany

The German NABISY sustainable biomass system illustrates how a "proof of sustainability" database can be implemented to 'track' trade in (and movements of) sustainable biomass/biofuels produced by EU Member States as well as biofuels imported through EU ports and subsequently traded within the EU.

In Germany, pursuant to the provisions laid down in the Biomass-electricity sustainability ordinance (BioST-NachV) and the Biofuel sustainability ordinance (Biokraft-NachV), in the field of biofuels proofs of sustainability or partial proofs of sustainability must be submitted to the customs office in order to be counted against the biofuel quota. The same applies to the claiming of tax relief according to the Energy Tax Act (Energiesteuergesetz (EnergieStG). In the field of bioelectricity, operators of an installation are only entitled to claim remuneration pursuant to the Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz (EEG)) from the network operator, if they submit proofs of sustainability or partial proofs of sustainability.

NABISY facilitates the application of "mass balancing" principles. This ensures that the quantity of sustainable biomass extracted from a mixture [of biomass from various sources] does not exceed the amount of sustainable biomass that has previously been added to the mixture. The type, quantity and other important attributes of sustainable biomass are regulary documented in the mass balance system.

For a more detailed explanation please refer to: Information Leaflet: Sustainable Biomass Production

Neste Oil's sustainability verification system

Neste Oil's sustainability verification system was approved by the European Commission in January 2014, who confirmed that it complies with the standards set for reliability, transparency, and independent third-party auditing. Verifications made under the system are always carried out by an impartial, external expert. Existing certificates recognized by the Commission can be used as part of the verification process. The new verification system covers all diesel fuel produced from renewable feedstocks, in accordance with the EU's Renewable Energy Directive.

Trace your Claim (TYC) Database

The Trace your Claim database was developed to ensure that biomass, waste and residue based material which complies with the specific requirements of the Renewable Energy Directive and the Fuel Quality Directive is eligible for 'double counting'. The database covers the entire supply chain from the point of waste or residue origination via further processing and conversion towards trade and final use by quota obligated parties. Interfaces will be provided to other public databases as well as databases operated by national authorities (e.g. Nabisy) and up- and download functions in order to ease data handling.

The Trace your Claim database can guarantee the origin, product code and the exact quantities of 'double counting' material marketed between any of the registered user such as collectors, biodiesel plants and traders. For this purpose users can upload important documents such as waste transfer notes, delivery notes and any other document required for proving compliance with relevant national ordinances. Especially users which from January 1, 2013 will have to comply with the very strict new German legislation (BimschV) will be enabled to document identity preservation [Source:Trace your Claim website].

Certification of sustainable biomass in the EU (for heat and power)

The Sustainable Biomass Partnership SBP Framework of standards and processes enables producers of woody biomass to demonstrate that they source their raw material responsibly and that it complies with the regulatory, including sustainability, requirements applicable to European power generators burning woody biomass to produce energy.

Under the SBP Framework the Biomass Producer, typically a pellet mill, is certified by a SBP-approved Certification Body. To become SBP-approved, a Certification Body must first provide evidence that it meets the SBP requirements regarding its existing accreditations and it must also demonstrate that it has sufficient resources and competence to manage the certification programme.

Sustainability assessment

Environmental Impacts of Biofuels

Cultivation of crops or foresty for food or non-food uses can have a range of environmental impacts both positive (e.g. soil stabilisation, phytoremediation) and negative (e.g. possible reduction in biodiversity, water and fertilizer issues).

Some intensive modern farming methods may have a range of negative effects on the environment, such as soil erosion, water shortage, pollution from pesticides and problems with over use of fertilizers (including eutrophication). Eutrophication, the decrease in the biodiversity of an ecosystem as the result of release of chemical nutrients (typically compounds containing nitrogen or phosphorous), is only one threat to biodiversity, which may also be impacted by the replacement of a natural ecosystem by monocultures, whether annual fields of rapeseed, sugarbeet or cereals, or large areas of coppice, energy crops or short rotation forest.

A number of projects are re-assessing the availability and environmental impact of biofuel feedstocks, while the focus of biofuels R&D&D in Europe is on second generation technologies that use waste oils and fats, MSW, agricultural residues, forest biomass or energy crops, which can be grown on marginal land, with lower requirements for fertiliser and other inputs. Work also continues to increase the efficiency and sustainability of first-generation biofuel production (see the plant biochnology, process innovation, biodiesel and bioethanol pages). For example, Triticale has been tested as an alternative to wheat as a bioethanol feedstock. Trials in the UK in 2011 showed it offered greater yields at the same or lower levels of nitrogen inputs.

In **February 2013** a report was produced by Winrock, IEEP and Ecofys on behalf of EC on **Mandatory requirements in relation to air, soil, or water protection: analysis of need and feasibility**. The report forms part of the wider 'Study on the operation of the system for the biofuels and bioliquids sustainability scheme'.

Energy crops and phytoremediation

Cultivation of energy crops can be used for **phytoremediation of contaminated or poor soils**, while offering the potential of future feedstock production. For example, see Multi-tasking plants for phytoremediation and bioenergy [Source: CABI 2013]. Globally, there is vast potential to grow energy crops on 'contaminated' land and poor soils, which are unsuitable for food crops. Current research is focused on trials of energy crop strains that could offer reasonable production potential. The low nutrient levels and inconsistent soils of marginal land tend to result in lower yields, especially in initial years. However, many plant species have evolved to grow in poorer soils, and may improve soil condition and future yields if cultivation is properly managed to maximise soil carbon and nutrient cycling. See also Second Harvest: Bioenergy from Cover Crop Biomass [Kemp Consulting and NRDC, 2011].

In August 2013, the U.S. EPA announced an update of its RE-Powering Mapping and Screening Tool, which has now identified 66,000 locations where contaminated land, landfill and mine sites could be used for cultivation of energy feedstocks.

Water resources and bioenergy production

"The avilability of freshwater resources is an increasingly important in many parts of the world. A growing population and changing dietary trends mean a steeply rising water demand. Under the impact of climate change the population at risk of water stress could increase substantially by the end of the century. In this context, water demand for bioenergy production might place an additional burden on water availability worldwide and induce increased competition over water resources in an increasing number of regions. However, bioenergy demand also leads to new opportunities to develop strategies to adapt to climate change in agriculture: a number of crops that are suitable for bioenergy production are drought tolerant and relatively water efficient and by adopting such crops farmers may better cope with a change in precipitation patterns and increased rates of evapotranspiration1 (ET) due to higher temperature." [Source: Water demand for global bioenergy production: trends, risks and opportunities; Göran Berndes, WBGU].

In November 2009 the Water Supply and Sanitation Technology Platform WssTP launched a consultation on the review of the WssTP Strategic Research Agenda, (727 Kb PDF), which covers among other topics the use of water by agriculture and industry.

Archive Reports on environmental impact of biofuels

Sustainability Standards for Bioenergy (1.5 Mb PDF) – Uwe R. Fritsche, Katja Hünecke, Andreas Hermann, Falk Schulze and Kirsten Wiegmann with contributions from Michel Adolphe, Öko-Institut e.V., Darmstadt. Published by WWF Germany, Frankfurt am Main, November 2006.

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Land availability for biofuels

The amount of biomass required to replace a significant proportion of the fossil fuel used in transport runs into millions of tonnes. Hence, a crucial question is that of biomass yield. Higher yields obviously enable a similar amount of biofuel to be replaced using less land. However, land use efficiency may also be improved by selecting an overall production chain that can use a high yielding biomass crop.

For instance most oils seed crops only produce a few tonnes per hectare per annum, sugar and starch crops may generate 5 to 10 tonnes, while significantly greater yields come from woody plants – or from conventional crops such as cereals if the straw can be used. Greater utilisation of such materials depends on the development of second generation biofuels.

Even when these higher yielding methods come to market, land availability still sets limits to what may be produced. Suggestions have been made for the movement of biomass or biomass derived fuels from the more productive regions to the more industrialised countries.

See also Indirect Land Use Change ILUC

Projects such as the Landscape Biomass Project Iowa State University look at how to balance needs for food, feed, fuel and energy, by integrating advanced biofuels technologies and novel energy crops.

Land use projects in Europe

The Volante Project (Vision of Land Use Transition in Europe) will provide an interdisciplinary scientific basis to inform land use and natural resource management policies and decision-making. It will achieve this by advancing knowledge in land system science and using this knowledge to develop a Roadmap for future land rsource management in Europe and will design new methodologies and integrated models to analyse human environment interactions, feedbacks in land use systems, hotspots of land use transitions and identify critical thresholds in land system dynamics. The Roadmap will bring together this science-base with key players in research, policy, business and NGOs, and will be a significant European Science Policy Briefing for the years to come in the promotion of multifunctional and sustainable pathways of land system change.

Value of preserving biodiversity through mechanims such as REDD Plus

In many potentially productive areas, preserving biodiversity may offer greater environmental and economic benefit than clearing forest to produce energy crops. Hence mechanisms need to be put into place to recognise the value of biodiversity These include the use of payments for ecosystem services, such as Reducing Emissions from Deforestation and Degradation (REDD) and REDD-plus (which places a greater value on biodiversity rather than just the quantity of carbon held in the forest system).

An ILUC paper has also been produced. In the context of the discussion around indirect land use change for biofuels, the European Biofuels Technology Platform holds the view that there is an opportunity for the EU to signal its support to policies that further enhance the deployment of advanced biofuels.

Views on ILUC (74 Kb)

Food versus Fuel

The global population continues to grow, in places at an alarming rate, and will need to be fed and will expect to live an improved life style, consuming more energy. This raises questions of 'Food versus Fuel'; how much land and other resources are available, how should they be used and what are the priorities?

In the long term, crop yields are increasing year-on-year. However, lower than expected yields in any given year tend to increase global grain prices, as occurred in 2012 partly due to bad weather and drought affecting the Russian and US harvests, repsectively. The effects of yield variations may be exacerbated by speculation in agricultural commodities. In turn, this may contribute to short-term spikes in food prices for consumers.

The role of biofuels in global food price dynamics has been the subject of considerable discussion and media attention since 2007. In the summer of 2012, the UN Food and Agriculture Organisation called for a renewed debate on biofuels.

In 2012, the Chairman of Nestle, Peter Brabeck-Letmathe, blamed biofuels for the increase in food prices, stating, "If no food was used for fuel, the prices would come down again - that is very clear." However, a number of reports contradict this assertion.

Paul Conway, Chairman of Cargill, said, "The bigger picture globally is increased urbanisation, which leads to more food being consumed...there has also been an explosion in biofuel use and the financialisation of the agricultural markets." [Source: BBC Business News, Interview 2012].

Reports relevant to the food vs. fuels debate

In September 2013 a studied carried out by ECOFYS on behalf of ePure showed that ethanol is not causing major increases in food prices. The study Biofuels and food security: Risks and opportunities suggests that the impact of biofuel production on food prices is actually less than 1%.

The ECOFYS report conflicted with a short report by the EC Joint Research Centre (based on AGLINK-COSIMO model) Impacts of the EU biofuel policy on agricultural markets and land use. This suggests that if no biofuel policy was in place from 2013 in the EU, close to 6 million hectares (0.7% of world total) less cereals, oilseeds, sugar crops and palm oil would be harvested in the world in 2020 in comparison to the baseline scenario. However, the JEC report suggests a greater impact of biofuel policy on prices.

When considering the potential impact of first generation biofuels on food prices, a diversity of factors also need to be taken into account, such as oil prices, fertiliser costs, rising demand for meat in emerging economies, demands on land for bioenergy (heat and power) and other bioproducts (e.g. plant oils for non-food use), rising global populations, the effects of climate change on agricultural productivity, local market conditions, and other factors that impact on price and availability of food in the short and long term.

In January 2013, The Institution of Mechnical Engineers in the UK published a report Global Food: Waste Not, Want Not, which points out: "We produce about four billion metric tonnes of food per annum. Yet due to poor practices in harvesting, storage and transportation, as well as market and consumer wastage, it is estimated that 30–50% (or 1.2–2 billion tonnes) of all food produced never reaches a human stomach. Furthermore, this figure does not reflect the fact that large amounts of land, energy, fertilisers and water have also been lost in the production of foodstuffs which simply end up as waste. This level of wastage is a tragedy that cannot continue if we are to succeed in the challenge of sustainably meeting our future food demands."

The issue is further covered in the following publications, some of which are piublished by organisations that campaign against increased use of biofuels:

Biofuels for Transport Fact Sheet A summary published in 2013 by WBA, suggesting that there is sufficient land available for production of more food and feed as well as more biofuel and bioenergy feedstocks

(BIO) Fuelling Injustice (1.6 Mb PDF) A report published in 2012 by EuropAfrica. The report suggests that 66% of the land grabs in Africa are intended for biofuel production, some 18.8 million hectares.

Determinants for the Level and Volatility of Agricultural Commodity Prices on International Markets - Are Biofuels Responsible for Price Volatility and Food Insecurity? (2.6 Mb PDF) A report published in 2012 by Union for the Promotion of Oilseeds and Protein Plants (UFOP) and the Association of the German Biofuel Indistry (VDB)

Price Volatility in Food and Agricultural Markets (900kb PDF) A report coordinated by FAO and OECD in response ot request from G20, with input from FAO, IFAD, IMF, OECD, UNCTAD,WFP, the World Bank, the WTO, IFPRI and the UN HLTF.

Meals per Gallon (1.0 Mb PDF) Published by Action Aid, January 2010. A report supporting a wider campaign against the expansion of biofuels, particularly first generation.

Sustainability Standards for Bioenergy (1.5 Mb PDF) – Uwe R. Fritsche, Katja Hünecke, Andreas Hermann, Falk Schulze and Kirsten Wiegmann with contributions from Michel Adolphe, Öko-Institut e.V., Darmstadt. Published by WWF Germany, Frankfurt am Main, November 2006.

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Livestock Production vs. Energy Crops

Globally, there is an increasing demand for land for livestock production (grazing and animal feed production), driven partly by rising middle class incomes in rapidly expanding economies. Not all land used for meat production is essential for human nutrition, with much consumption being a lifestyle choice. Production of plant protein is less energy intensive. Some land currently used for livestock could potentially be used for energy crops, without a negative impact on human health or any increase in GHG emissions. Some reports suggest that conversion of land from meat production to bioenergy feedstocks could offer environmental and health benefits, for example Zero Carbon Britain.

In September 2013, the FAO report Tackling Climate Change through Livestock estimated that 7.1 gigatonnes of carbon dioxide equivalent (CO2-eq) per annum was produced by the livestock industry representing 14.5 % of all human-induced emissions (other studies put the figue as high as 18 %, more than the total emissions from all forms of transport).. Beef and dairy production account for the majority of emissions, respectively contributing 41 and 19 % of the sector's emissions. While pig meat and poultry meat and eggs contribute respectively 9% and 8% to the sector's emissions. Sources of emissions include: feed production and processing (45% of the total – with 9 percent attributable to the expansion of pasture and feed crops into forests), enteric fermentation from ruminants (39%), and manure decomposition (10%). The remainder is attributable to the processing and transportation of animal products.

Indirect Land Use Change (iLUC)

Overview

What is iLUC?

It has been suggested that growing energy crops on agricultural land may displace existing food-crop production, causing land use change in another location. This Indirect Land Use Change (iLUC) might occur in a neighbouring area or even in another country hundreds of miles away, where an area of high biodiversity (and high levels of "stored carbon") might be cleared to make more land available for growing food crops.

In the US, this concept was the subject of a paper by Timothy Searchinger et al Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change published in Science in February 2008 [Vol. 319 no. 5867 pp. 1238-1240]. It has been suggested that increased use of rape seed oil for biodiesel production in Europe could reduce the amount available for the food industry, leading in turn to increased demands for imports of palm oil (potentially increasing deforestation in producer countries).

Since 2008, there has been much debate about the assumptions made and methods used to establish the impact of Indirect Land Use Change. However, there is a concensus that land use change is very complex and affected by a wide range of factors, not only biofuels. Some recent studies have cast doubts on the validity of iLUC models.

In September 2012, a paper by Jesper Hedal Kløverpris and Steffen Mueller published in the International Journal of Life Cycle Assessment suggested that the current methodology for iLUC calculations may considerably overestimate the climate impact of biofuels and a more sophisticated approach is required. *See* Baseline time accounting: Considering global land use dynamics when estimating the climate impact of indirect land use change caused by biofuels.

See also *iLUC Prevention Study - Copernicus Institute of Sustainable Development* (February 2015).

In November 2014, a paper published by B. A. Babcock and Z. Iqbal, Centre for Agiculture and Rural Development, Iowa State University, US Using Recent Land Use Changes to Validate Land Use Change Models looked at real world data on land change in recent years. The study concluded that "…the primary land use change response of the world's farmers in the last 10 years has been to use available land resources more efficiently rather than to expand the amount of land brought into production."

This study also found that a number of key crop-producing countries and regions, including the European Union, Canada, United States, Russia, China, India, and Ukraine, had "negligible or negative" cropland expansion during the past decade, and thus "should be presumed to not have converted pasture or forest to crops in response to biofuel-induced higher prices."

International Standards for iLUC

In April 2015, The Roundtable on Sustainable Biomaterials launched a draft standard:

RSB Low iLUC Risk Biomass Criteria and Compliance Indicators

Evolution of the iLUC Debate and EU Biofuels Policy

See the Biofuels Legislation page for updates to the EU proposals to amend the RED/FQD to reflect public and political concerns over iLUC.

iLUC factors in the EC proposal (October 2012) to minimise the climate impact of biofuels

The proposal to minimise the climate impact of biofuels, published by the EC in October 2012, suggested the inclusion of indirect land use change (iLUC) factors in reporting by fuel suppliers and Member States of greenhouse gas savings of biofuels and bioliquids. Annex V of this document includes estimated indirect land-use change emissions from biofuels (gCO2eq/MJ) as follows:

- Cereals and other starch rich crops, 12
- Sugars, 13
- Oil crops, 55

Other feedstocks (e.g. residues and wastes) were considered to have a value of 0. iLUC values were not applied for feedstocks where direct land use change emissions have already been calculated.

The proposals allow for iLUC factors to be added, deaggregated or amended to allow for new feedstocks, such as energy crops, or more detailed scientific data.

European Parliament Committee on Environment, Public Health and Food Safety: Workshop on Sustainable Biofuels: addressing indirect land use change (iLUC) (February 2013)

View presentations by organisations represented at the workshop including European Biodiesel Board, ePure, COPA-COGECA, Transport & Environment, Oxfam, Roundtable on sustainable Biofuels, JRC, International Council on Clean Transportation, International Food Policy Research Institute, OECD, Air Resources Board, California, and Imperial College London

European Parliament Workshop on Biofuels and Indirect Land Use Change (January 2012)

In anticipation of the release of the European Commission's impact assessment on 'indirect land use change (iLUC) related to biofuels and bioliquids on greenhouse gas emissions and addressing ways to minimize it', the Coordinators of the ENVI Committee organised a workshop on this issue (view workshop proceedings - including presentations, discussion & conclusions). The workshop in January 2012 consisted of different presentations and an exchange of views with Members and established experts in the area of biofuels and iLUC.

EBTP Concensus Paper on iLUC

In October 2011 an iLUC paper was produced by the former WG5 of the EBTP (now WG4 Policy and Sustainability). In the context of the discussion around indirect land use change for biofuels, the European Biofuels Technology Platform holds the view that there is an opportunity for the EU to signal its support to policies that further enhance the deployment of advanced biofuels.

EBTP Views on iLUC (74 Kb)

Issues surrounding the complexity of iLUC modelling

See the EBTP Reports Database for recent papers and reports on iLUC research and policy implementation

In September 2013, EBB released a study carried out by Air Improvement Resource, (S&T)2 Consultants, and the University of Illinois. The study Land Use Change Greenhouse Gas Emissions of European Biofuel Policies Utilizing the Global Trade Analysis Project (GTAP) Model showed that iLUC effects calculated by the GTAP model were far lower than those calculated by IFPRI. This is largely due to differing assumptions about the conversion of forestry land and yields of new crop land.

The models that underpin proposed EC iLUC policy have also been criticised in a short report A change for the worse: The campaign to re-dredge 'Indirect Land Use Change' published in July 2013 by World Growth - Palm Oil Green Development Campaign.

The inherent complexity of iLUC modelling was illustrated by the ePure paper "Indirect land use change impacts of biofuels", which addressed issues with several models being used.

While in May 2011, the report Indirect Effects of Biofuels Production produced for GBEP suggested that the Low Indirect Impact Biofuels approach (Ecofys et al) may offer pragmatic solutions by mitigating biofuels production effects at the local level.

In March 2011, IEEP published a report Anticipated Indirect Land Use Change Associated with Expanded Use of Biofuels and Bioliquids in the EU – An Analysis of the National Renewable Energy Action Plans. This report attempts to quantify iLUC impacts, and was prepared for ActionAid, BirdLife International, ClientEarth, European Environmental Bureau, FERN, Friends of the Earth Europe, Greenpeace, Transport & Environment and Wetlands International.

In February 2011, a report to the European Parliament by Oeko Institute suggested that "current scientific knowledge allows deriving a valid quantitative approximation for GHG emissions from iLUC effects which can be differentiated for various biofuels." This raised the possibility of iLUC factors being applied when calculating the "GHG reduction value" of biofuels from various crops or feedstocks (e.g. oil crops, wheat, sugar, wastes, etc). Dutch policy makers suggested using a generic iLUC factor until further crop-specific research was carried out.

On the other side of the debate, a study *Indirect land use change for biofuels: Testing predictions and improving analytical methodologies* published in May 2011 in *Biomass and Bioenergy* [Volume 35, Issue 7, July 2011, Pages 3235-3240] suggests historical data shows no impirical correlation between increases in biofuels production and land use changes for soy and corn production in US trading partners.

A pragmatic report by Greenergy 'Measuring Indirect Land Use Change from Biofuels' updated in March 2011, discusses how BioCarbon Tracker, a web platform (based on satellite imagery) can be used to show where carbon reserves are located, and which are most at risk from agricultural expansion.

"By presenting a "big picture" of land use change, BioCarbon Tracker can provide valuable input to the iLUC debate. BioCarbon Tracker will provide interactive maps of biocarbon stored in vegetation (trees, shrubs, grasses) and soil. It will identify where biocarbon is at risk from agricultural expansion and monitor changes in high risk areas. BioCarbon Tracker will also identify opportunities for increasing biocarbon through improved land management and ecosystem restoration." [Source Greenergy]

In July 2010, The EC launched a public consultation on iLUC and Biofuels. This followed publication of a number of EC studies on this topic:

Study "Global Trade and Environmental Impact Study of the EU Biofuels Mandate" [2 Mn]

Annex 1 [2 Mn]

Annex 2 [223 Kbn]

Study "Impacts of the EU biofuel target on agricultural markets and land use: a comparative modelling assessment" [860 Kb]

Study "The Impact Of Land Use Change On Greenhouse Gas Emissions From Biofuels And Bioliquids" [2 Mb]

Study "Indirect Land Use Change from Increased Biofuels Demand" [2 Mb]

An extensive literature review on iLUC has been carried out by E4Tech as part of a wider iLUC Study, commissioned by the UK Department of Transport. This covers first generation biofuels including: bioethanol from wheat, bioethanol from sugarcane, biodiesel from palm and biodiesel from rapeseed. More recently, E4Tech has published another report: Developing a methodology for GHG emissions from ILUC for different biofuel pathways.

The indirect effect of biofuels has been the subject of a number of influential reports, including the Renewable Fuels Agency Review of the Indirect Effects of Biofuels (a.k.a. The Gallagher Report), which led to a change in biofuels policy in the UK in 2008.

Other relevant reports include Biofuels on the Dutch Market commissioned by BirdLife Europe, Transport & Environment, the European Environmental Bureau and the Dutch NGO Natuur & Milieu. The report, published in February 2013, ranks oil companies in the Netherlands to compare the environmental performance of the biofuels sold by the various fuel suppliers and rank them based on the average greenhouse gas (GHG) emissions (direct and indirect) of their biofuel blends in 2011. The aim is to identify differences in the companies' performance and raise the awareness of Dutch consumers. The data were compiled by the Dutch Emissions Authority (NEa), which publishes a selection of the results. The first report, with data for 2011, was published in 2012. The Netherlands is the second EU country (after the United Kingdom) to make data on biofuels publically available.

Previously, iLUC was also a central theme of the report Biofuels - Handle with Care, jointly published in November 2009 by BirdLife European Division, European Environmental Bureau, FERN, Friends of the Earth Europe, Oxfam International, and Transport and Environment

An IEA Bioenergy Workshop on the Impact of iLUC was held in May 2009 in conjunction with ExCo63, including expert presentations on this issue.

Bio-CCS - Bioenergy with Carbon dioxide Capture and Storage

Overview

The concept of Bioenergy and Carbon Storage (BECS or Bio-CCS) has been suggested as a means of producing carbon negative power (i.e. removing carbon dioxide from the atmopshere via biomass conversion technologies and storage underground). Carbon capture and storage (CCS) technology is currently at a demonstration phase, and research is mainly focused on reducing the costs of capture and storage so that it can be applied to a new generation of large-scale, power stations with lower emissions. However, in the future CCS could potentially be appled to a wide range of energy plants, including those incorporating co-firing or co-gasification of sustainable biomass feedstocks (agricultural and wood wastes and energy crops), or even 100% biomass energy plants, biofuel production facilities or biorefineries.

The release of carbon dioxide into the atmosphere by human activity is caused both by extraction and combustion of fossil fuels and by clearance of forests where large amounts of carbon are stored as biomass. Carbon sequestration through reforestation (long-term storage of carbon in plants and trees), offers potential to remove carbon dioxide from the atmosphere. Reforestation is not only about maximising the amount of carbon stored per unit of land area. For example, to protect biodiversity and preserve habitat, a mix of plant species is desirable, as opposed to monocultures. See Sustainable Forestry Initiative (US) and Sustainable Foresty and the European Union.

European and global activites on Bio-CCS

ZEP/EBTP Bio-CCS JTF

The potential for synergies between advanced CCS and bioenergy/biofuels production technologies is the focus of the Bio-CCS Joint Task Force involving members of both the Zero Emissions Platform and the EBTP. Presentations from the Second International Workshop on Bio-CCS held at Cardiff University in October 2011, are now availble.

Biomass with CO2 Capture and Storage (Bio-CCS) - The way forward for Europe

This report was produced by the Zero Emissions Platform with input from the European Biofuels Technology Platform.

Bio-CCS combines sustainable biomass conversion with CO_2 Capture and Storage (CCS) – e.g. in biofuels and bioenergy production – and is already being deployed at industrial scale in the U.S.*. Use of biofuels and bioenergy is steadily increasing in the European Union (EU) due to targets for renewable energy sources and certain biofuels production routes could provide “low-hanging fruits” for early, low-cost CCS deployment. A recent study indicated that, globally, Bio-CCS could remove 10 billion tonnes of CO_2 from the atmosphere every year by 2050 using available sustainable biomass – equivalent to a third of all current global energy-related emissions. In Europe, Bio-CCS could remove 800 million tonnes of CO_2 from the atmosphere every year by 2050* using available sustainable biomass – equivalent to over 50% of current emissions from the EU power sector. This is in addition to any emissions reductions achieved by replacing fossil fuels with that biomass. Bio-CCS could ultimately result in industry sectors whose overall emissions are below zero, which could then offset emissions in other sectors where reductions are more difficult to attain (*please refer to report for detailed refrences).

Download report (2.5Mb, published 20-06-12)

Assessment Report from the GCEP Workshop on Energy Supply with Negative Carbon Emissions

As part of its assessment towards energy technologies that reduce greenhouse gas (GHG) emissions, The Global Climate and Energy Project (GCEP), held a workshop at Stanford University on June 15, 2012, on the topic of Energy Supply with Negative Carbon Emissions. The workshop addressed 4 main topics: Biomass Energy with Negative Emissions; Carbon Capture, Conversion and Storage; Addressing Other Contributions to Carbon Emissions; and System Modeling. This report summarizes the discussion and highlights research needs that were identified at the workshop by speakers and participants. The unparalleled ability of biological systems to capture and cycle carbon, and the potential to use these systems as part of an energy supply that leads to negative emissions, was brought to the forefront at this workshop, as well as the need for integrated systems of supply, conversion and storage. Reaching net negative carbon emissions on a global scale could also be possible without the use of bioenergy with carbon capture and storage, but the predicted costs of carbon in these energy technology scenarios would be extraordinarily high. Studies aimed at understanding and overcoming the limits to technologies for bioenergy with negative emissions, identification of integrated and optimized systems for negative emissions, and research towards novel carbon storage technologies would represent groundbreaking steps towards technologies that could achieve net negative carbon emissions in our energy supply.

View Assessment Report from the GCEP Workshop on Energy Supply with Negative Carbon Emissions (published June 2012)

Aemetis plans for CO2 production at ethanol plant

In October 2014, Aemetis Inc announced it had entered an agreement with Union Engineering, Denmark to design and construct a facility to capture and produce 300 tons/day of carbon dioxide adjacent to its 55 MMgy ethanol plant in Keyes, California. The liquefied CO_2will be supplied to businesses in central California.

Decatur project for CCS from bioethanol plant, Illinois US

The US DOE has allocated Recovery Act funds to more than 25 projects that capture CO_2 emissions from industrial sources and sequester in underground formations. Three large-scale CCS projects include one in Decatur Illinois, where the **Archer Daniels Midland Company** has captured and sequestered 750,000 tons of CO_2 from an existing ethanol plant in Illinois (by March 2014). The CO_2 is stored ~2km underground in the Mt. Simon Sandstone, a well-characterized saline reservoir located about one mile from the plant. The project team includes Archer Daniels Midland, Schlumberger Carbon Services, and the Illinois State Geological Survey [Source: DoE].

White Rose CCS Project in UK

In December 2013 it was announced that the White Rose CCS project will receive funding from the UK £1 billion CCS Commercialisation Programme. A next generation 426 MW clean coal plant will be built in North Yorkshire will full carbon capture and storage. The facility would have the potential to co-fire biomass. The facility aims to capture capture 2 million metric tons of carbon dioxide per annum and store it beneath the North Sea.

Coal/biomass co-gasification and CCS

Co-gasification of biomass and coal with CSS has been investigated by the US National Energy Technology Laboratory.

Further information relating to Bio-CCS

IEAGHG 2011 Report on Bio-CCS

An overview of global Bio-CCS is provide by the IEAGHG report Potential for Biomass and CO_2 Capture and Storage.

Sustainability issues and large-scale bioenergy

The concept of very large biomass energy power plants (of a size that makes CCS economically viable) has caused some concerns among sustainability organisations, who fear that it could lead to deforestation of diverse habitat to make way for extensive monocultures of energy crops. Such issues are addressed on the sustainability section of this website, and covered by a number of global initiatives on production and certification of sustainable biomass feedstocks.

Carbon sequestration through reforestation

In March 2012 the US EPA published a short report Carbon sequestration through reforestation. The report specifically addresses the potential for reforestation of Abandoned Mine Lands in the United States, but also covers the principles of reforestation as a means of carbon sequestration (i.e. removing carbon dioxide from the atmosphere and storing it long-term within trees and plants).

Background information on CCS technology

IEAGHG

CO_2 Capture Project

ZEP - Zero Emmissions Platform