European Biofuels Technology Platform – Support for Advanced Biofuels Stakeholders

Overview on general information for each of the 9 topics

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EXECUTIVE SUMMARY

This deliverable displays the general 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.

Many different definitions exist for the term advanced biofuels, and the EIBI definition reads as follows:

> Advanced Biofuels are those (1) produced from lignocellulosic feedstocks (i.e. agricultural and forestry residues, e.g. wheat straw/corn stover/bagasse, wood based biomass), non-food crops (i.e. grasses, miscanthus, algae), or industrial waste and residue streams, (2) having low CO2 emission or high GHG reduction, and (3) reaching zero or low ILUC impact

Biofuels can be produced from a range of biomass resources including either dedicated crops such as sugar crops, starch crops, oil crops, lignocellulosic crops, algae and aquatic biomass, or residues such as oil-based residues, lignocellulosic residues, organic residues and others, and waste gases.

These feedstocks can be converted applying biochemical, thermochemical or oleochemical conversion technologies, all of which are briefly described in this document. The resulting fuels mostly feed into road transport, but may also be used in rail, aviation or shipping.

The biofuels market is a political market, and is in Europe mainly driven by the Renewable Energy Directive (RED) and the Fuel Quality Directive. Sustainability criteria have to be fulfilled in order for a fuel to account towards the target volume of 10% renewables in the transport sector by 2020. There is a cap of 7% on the contribution of biofuels produced from 'food' crops, and biofuels from waste, residues, non food cellulosic material, and lignocellulosic material are double counted. Fuel standards are in place that allow for the use of biodiesel and bioethanol as blending components in diesel and gasoline fuels.

While R&D on advanced biofuels technologies is progressing, it proves difficult to find the funds required to build demonstration and flagship facilities.

The interested reader will find more detailed information in deliverable D2.5.

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

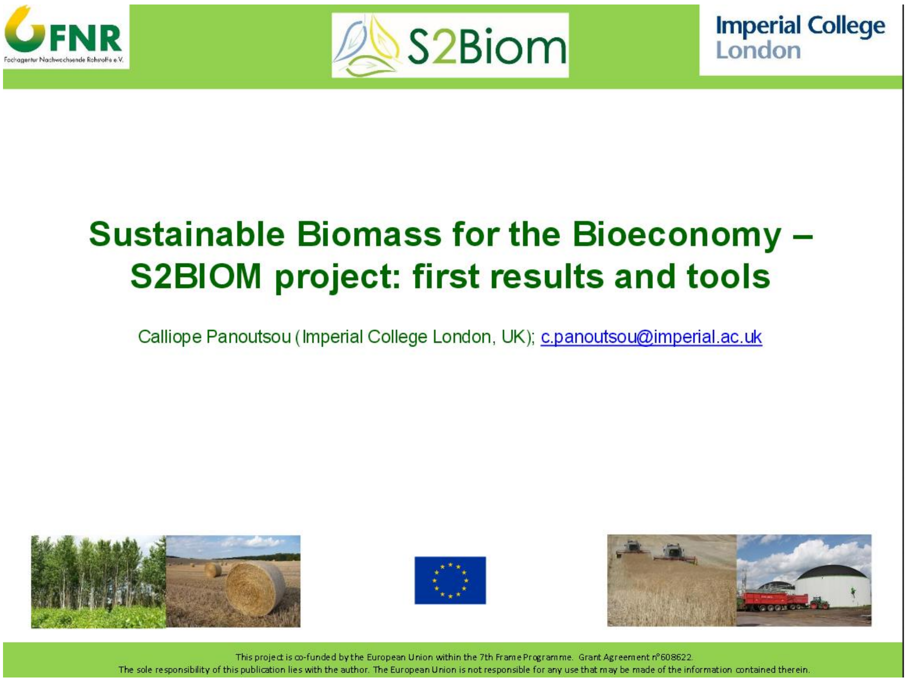
Introduction

This deliverable displays the general 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

EBTP SPM7 Presentation on Sustainable and resource efficient biomass

Presentation on Sustainable and resource efficient biomass by Calliope Panoutsou, Imperial College London, based on the panel discussion held at EBTP7, June 2016



Sustainable feedstocks for biofuels production

Biomass is the oldest source of fuel energy. However, using biomass for the production of transport fuels is a relatively new application with a significant increase during the last 10 to 15 years. Biofuels can substitute fossil derived transport fuels, with the advantage of providing carbon from a renewable source.

In broad terms, the various types of biomass feedstocks potentially available for biofuels production can be categorized as follows :

Dedicated Crops	Wastes and Residues
Sugar Crops	Oil-based Residues
Starch Crops	Lignocellulosic Residues
Oil Crops	Organic Residues and others
Lignocellulosic Crops	Waste gases
Algae and Aquatic Biomass	

On the basis of the feedstock used in production, biofuels may be referred to as:

Conventional (first-generation) biofuels are produced from food crops (sugar, starch, oil), such as palm, rapeseed, soy, beets and cereals (corn, wheat, etc).

Advanced (second-generation and third-generation) biofuels - as defined by the European Commission - are produced from feedstock that "do not compete directly with food and feed crops, such as wastes and agricultural residues (i.e. wheat straw, municipal waste), non-food crops (i.e. miscanthus and short rotation coppice) and algae." At the moment only about 2 % of biofuel production are covered by advanced biofuels [Bacovsky et al. 2012].

Following global concerns about the impacts of using food crops for production of biofuels, the EC has introduced measures to encourage a more diverse range of feedstocks to be used in future. Measures include restricting state aid for conventional biofuels, a proposed cap of 7% (of transport energy use) on biofuels from "food crops", and double counting of biofuels produced from certain wastes and residues. Hence, the future expansion of biofuels (for road freight, air transport, shipping, and other uses) will require the commercial deployment of innovative conversion technologies that may be more complex and costly than conventional production methods.

This page contains general information and links on a range of sustainable feedstocks that could be used for producing advanced biofuels. These include:

- **Energy crops grown on marginal land** - that do not compete directly with food crops for land or cause indirect Land Use Change
- **Wastes and residues** - agricultural, forestry, food, MSW, and other organic wastes and residues
- **Novel feedstocks** - such as aquatic plants, macroalage (seaweed), microalgae and other microbial biomass

The term advanced biofuels typically refers to biofuels produced from lignocellulosic (LC) biomass (i.e. any non-food 'woody' parts of plants that humans cannot digest). This covers a range of plant molecules/biomass containing cellulose and hemicelluose with varying amounts of lignin, chain length, and degrees of polymerization. Some cellulosic materials are relatively easy to breakdown into substrates that can be used to create fuel molecules. For example, citrus peel may be converted to plant sugars. For more complex cellulosic materials containing greater amounts of lignin (e.g. hardwood) the production route to liquid biofuels requires pretreatment and may be more challenging and costly.

An EEA report published in July 2013 EU bioenergy potential from a resource efficiency perspective provides a recent overview on the use of biomass feedstocks in Europe, and discusses some of the issues surrounding expansion of energy crop production.

Globally, 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.

The links at the end of this page provide more detailed information on the various types of sustainable feedstocks for production of advanced biofuels.

List of sustainable feedstocks

A wide range of sustainable feedstocks are potentially available for the production of advanced biofuels:

Agricultural residues *(see "double counted" feedstocks below)*

Forest biomass *(see "double counted" feedstocks below)*

Energy crops

“Energy crops” may be defined as crops specifically bred and cultivated:

- To produce biomass with specific traits to serve as an energy vector to release energy either by direct combustion or by conversion to other vectors such as biogas or liquid biofuels, or;
- To be used in biorefinery concepts (to produce Fibre, Biochemicals, etc) and are;
- Typically grown on marginal land not suitable for production of food crops.

Other biowaste streams *(see "double counted" feedstocks below)*

Algae/Aquaculture

- algae cultivated in raceway ponds or bioreactors
- seaweeds
- pondweeds grown in freshwater
- cyanobacteria and other microorganisms

Feedstocks "counted double" under the proposed revision to the Renewable Energy Directive

See Fuel quality directive and renewable energy directive (P8_TA-PROV(2015)0100 Fuel quality directive and renewable energy directive II; European Parliament legislative resolution of 28 April 2015 on the Council position at first reading with a view to the adoption of 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 (10710/2/2014 – C8-0004/2015 – 2012/0288(COD)))

See also: Correction to the above document (this affects a single sentence).

In the Annex to the above proposal, the following feedstocks are considered to be non-food feedstocks (suitable for conversion to "advanced biofuels") and hence are counted double towards the 10% 2020 target for renewable fuels in transport under the RED.

Part A. Feedstocks and fuels whose contribution towards the target(s) referred to in Article 3(4) shall be considered to be twice their energy content:

(a) Algae if cultivated on land in ponds or photobioreactors

(b) Biomass fraction of mixed municipal waste, but not separated household waste subject to recycling targets under Article 11(2)(a) of Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives.

(c) Bio-waste as defined in Article 3(4) of Directive 2008/98/EC from private households subject to separate collection as defined in Article 3(11) of that Directive.

(d) Biomass fraction of industrial waste not fit for use in the food or feed chain, including material from retail and wholesale and the agro- food and fish and aquaculture industry, and excluding feedstocks listed in Part B of this Annex.

(e) Straw.

(f) Animal manure and sewage sludge.

(g) Palm oil mill effluent and empty palm fruit bunches.

(h) Tall oil pitch.

(i) Crude glycerine.

(j) Bagasse.

(k) Grape marcs and wine lees.

(l)Nut shells.

(m) Husks.

(n) Cobs cleaned of kernels of corn.

(o) Biomass fraction of wastes and residues from forestry and forest-based industries, i.e. b ark, branches, pre-commercial thinnings, leaves, needles, tree tops, saw dust, cutter shavings, black liquor, brown liquor, fibre sludge, lignin and tall oil.

(p) Other non-food cellulosic material as defined in point r) of the second subparagraph of Article 2.

(q) Other ligno- cellulosic material as defined in point s) of the second subparagraph of Article 2 except saw logs and veneer logs.

(r) Renewable liquid and gaseous fuels of non-biological origin.

(s) Carbon capture and utilization for transport purposes, if the energy source is renewable in accordance with Article 2(a).

(t) Bacteria, if the energy source is renewable in accordance with Article 2(a).

Part B. Feedstocks whose contribution towards the target referred to in the first subparagraph of Article 3(4) shall be considered to be twice their energy content

(a) Used cooking oil.

(b) Animal fats classified as category I and II in accordance with Regulation (EC) No 1069/2009 laying down health rules as regards animal by-products and derived products not intended for human consumption and repealing Regulation (EC) No 1774/2002 (Animal by-products Regulation).

Current biomass feedstock production

Elbersen et al. (2012) estimate that there are approximately 5.5 million hectares of agricultural land on which bioenergy cropping takes place. This amounts to 3.2 % of the total cropping area (and around 1 % of the utilised agricultural area) in the EU-27. Practically all of this land is used for biofuel cropping, mostly oil crops (82 % of the land used for biomass production), which are processed into biodiesel.

The rest is used for the production of ethanol crops (11 %), biogas (7 %), and perennials which go mostly into electricity and heat generation (1 %). The table below shows the cultivated area of the most important energy crops in Europe [Source: Bacovsky after Elbersen et al (2012)].

Bioenergy Cropping Area in Europe (2006-2008)

Crop	Area (hectares)
Rape	3,258,571
Sunflower	1,105,038
Wheat	398,852
Maize	386,160
Barley	210,479
Sugar Beet	53,000
Miscanthus	38,300
Willow	28,500
Reed Canary Grass	19,480
Poplar	6,518
Hemp	600
Other arables (e.g. sorghum)	104

Archive presentations on feedstocks

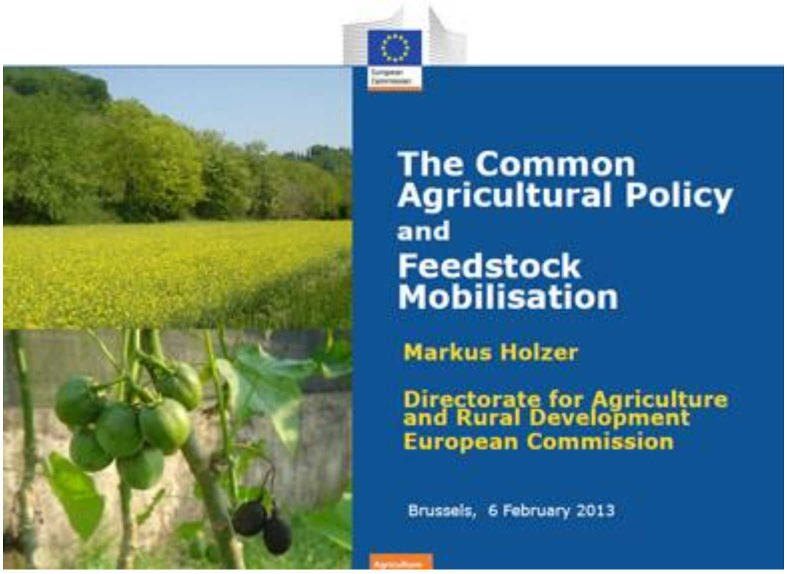
EBTP SPM6 Presentation on biomass mobilisation and sustainability

Presentation on biomass mobilisation and sustainability by Calliope Panoutsou, Imperial College London, based on the panel discussion held at EBTP SPM6, October 2014.

Feedstock presentations From EBTP SPM5 February 2013

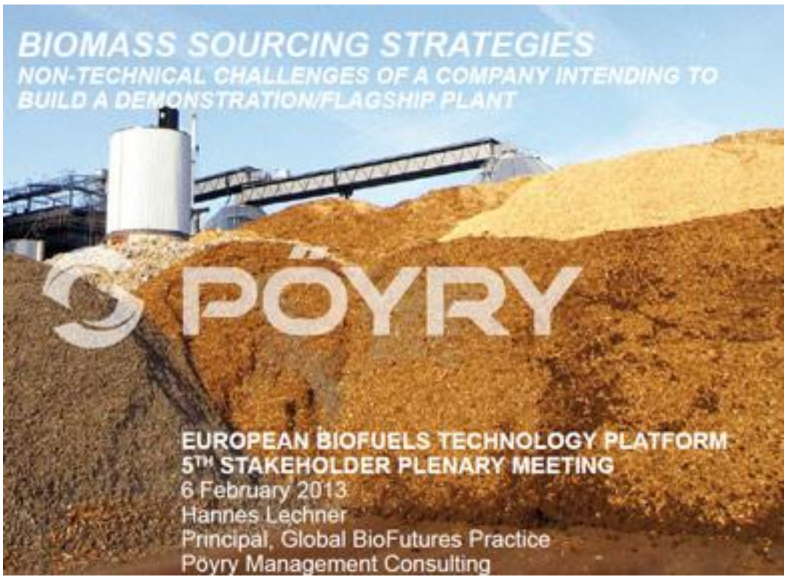
[Agricultural policies to ensure feedstock mobilisation]

Markus Holzer, Head of Unit, Bioenergy, Forest and Climatic Change, European Commission, DG AGRI



Non-technical challenges for a company intending to build a demonstration/flagship plant - biomass sourcing strategy

Hannes Lechner, Principal - Global Bioenergy Practice, Pöyry Management Consulting (UK) Ltd



Biomass Supply Challenges: How to meet biomass demand by 2020? was a half-day workshop held at the Beurs-World Trade Centre, Rotterdam on 15 March 2012. The workshop was jointly organised by Working Group 1 of the European Biofuels Technology Platform and the Renewable Heating and Cooling European Technology Platform, in co-operation with World Biofuels Markets 2012. Demand for sustainable biomass is forecast to increase greatly over the next decade for biofuels producers (road, air and marine), biorefineries, utilities and bioenergy producers. This workshop brought together speakers from various sectors across Europe to discuss the challenge of providing reliable volumes of biomass at competitive cost, while meeting sustainability criteria. View workshop Presentations.

The pathway to low-input, high-efficiency feedstocks - sustainability, land availability, economics, and policy issues. Presentation by Calliope Panoutsou at EBTP SPM4 on 15-09-11

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.

EU projects and studies on biomass supply and demand, availability assessments and mapping of biomass

Various EU projects (among others) have addressed the availability, mapping and valorisation of biomass resources across Europe:

S2Biom Project - Delivery of sustainable supply of non-food biomass to support a “resource-efficient” Bioeconomy in Europe. Its main aim is to support the sustainable delivery of non-food biomass feedstock at local, regional and pan European level through developing strategies, and roadmaps that will be informed by a “computerized and easy to use” toolset (and respective databases) with updated harmonized datasets at local, regional, national and pan European level for EU28, Western Balkans, Moldova, Turkey and Ukraine.

See also the Forestry page for further studies, projects and the EC's sustainable forestry strategy

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 resource 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.

AquaTerrE - Integrated European Network for biomass and waste reutilisation for Bioproducts aimed to promote the cooperation between research centres, business and other stakeholders in Europe devoted to the research, development and application of biomass and biofuel production and valorisation. The main goal of AquaTerrE was to make an inventory of existing biomass feedstocks in Europe and quantify the potential and identify of the best ones. In addition, to study the best possibilities for implementing different biomass sources in different environments to improve their utilisation. Pursuing this target, literature and data survey and current research review will be carried out. AquaTerrE will also mapo European biomass feedstocks using different tools, such as Geographical Information Systems (GIS).

BEE - Biomass Energy Europe (FP7 - 213417) aimed to harmonise biomass resource assessments, focusing on the availability of biomass for energy in Europe and its neighbouring regions. This harmonisation will improve the consistency, accuracy and reliability of biomass assessments, which can serve the planning of a transition to renewable energy in the European Union.

The **BIOCLUS** project was focused on the sustainable use of biomass resources and aims at boosting regional competitiveness and growth in five European cluster regions: Central Finland, Navarre (Spain), Western Macedonia (Greece), Slovakia and Wielkopolska (Poland). This is achieved by:

- Promoting scientific, strategic and business competence at cluster and consortium level
- Developing collaboration capabilities in the clusters and consortium level
- Improving innovation to business environment by mutual learning and by mentoring.

The BIOCLUS project was funded by FP7 and is coordinated by JAMK, University of Applied Sciences, Jyväskylä, Finland.

Biomass Futures (IEE) The Biomass Futures Project assessed the role that biomass can play in meeting EU energy policy targets. It will develop tailored information packages for stakeholders, as well as inform and support policy makers at both the European and national levels. The project will define the key factors likely to influence biomass supply, demand and uptake over the next twenty years (meeting the RED targets). Among other factors, partners will examine the EU heat, electricity-CHP and transport markets; supply and demand dynamics; the effects of indirect land use change, water use and social aspects on future biomass supply, etc.

CEUBIOM - Classification of European Biomass Potential for Using Terrestrial and Earth Observations (FP7 - 213634) aims to develop a common methodology for gathering information on biomass potential using terrestrial and earth observations. This objective will be achieved by the implementation of a systematic assessment work plan and will result in the establishment of a harmonised approach and an e-training tool for dissemination. The e-training environment will be an important tool for reaching the much needed European harmonisation, whereas a Stakeholder Platform will facilitate access to reliable and common datasets on biomass potential and as such it will offer a more efficient use of the available European biomass feedstock.

Earlier studies on biomass resource potential in Europe

Previously, several studies have been conducted at European and global level in order to assess the potentials of different biomass resources for production of bifouels. The respective results present a wide variety of estimates based on various assumptions and hypotheses. Conservative results on total biomass potential come from the EEA study: *How much bioenergy can Europe produce without harming the environment?* It estimates a total bioenergy potential from agriculture, forestry and waste of almost 300 MtOE in 2030. Of this 142 MTOE will come from agriculture only which is obtained from 19 million hectares of agricultural land. This is equivalent to 12 % of the utilised agricultural area in 2030.

The potential study of VIEWLS (2004) comes with a much higher estimate of 35-44 million hectares of land available for biomass production only in EU-10. VIEWLS does however not take environmental considerations as a stating point. Shift gear to Biofuels - Results and Recomendations from the VIEWLS Project

In 2007, REFUEL and IIASA Land Use Change and Agriculture Programme produced the report: Assessment of biomass potentials for biofuel feedstock production in Europe.

The JRC Action on Sustainability of Bioenergy has looked at availability and sustainability of bioenergy feedstocks in Europe and other countries (e.g. the tropics). The JEC Biofuels Programme (JRC, EUCAR, CONCAWE) also covered availability of biofuels feedstocks. Further activities on availability and sustainability of biofuels are covered by the JRC Biofuels Thematic Programme.

The BeCoTeps project addressed availability and sustainability of biomass for a range of non-food uses, through a series of workshops and associated activities.

Archive examples of EU Supported Research, Development and Demonstration activities and Related Studies

ENFA European Non-Food Agriculture (FP6 – 006581) This project will establish a dynamic agricultural and forest sector model for the integrated economic and environmental assessment of non-food alternatives in European agriculture and forestry. This tool will be used to analyze market and environmental impacts from the adoption of non-food strategies. Market impacts include supply potentials for agricultural non-food product lines under alternative policy and technology scenarios, supply, price, and trade effects for traditional agricultural and forestry products, and measures of rural community change such as changes in farm welfare, labor demand, and land values.

EPOBIO - Realising the economic potential of sustainable resources - bioproducts from non-food crops (FP6 – 022681) This project is carrying out an integrated analysis of the European agricultural industrial and market potential requires in terms of technical and non-technical barriers facing non-food applications so that further RTD effort can be is focused on those areas with a high possibility of success. It reviews scientific and technical challenges in the context of societal expectations and economic, environmental legislative and regulatory parameters. It will result in recommendations of key activities (Flagship Programmes) that are most likely to result in development of products/ applications that can be developed from agriculture and forestry and provide tangible societal benefit by 2020. One of the first Flagship Reports includes an analysis of plant cell wall utilisation.

BIOCARD - Global Process To Improve Cynara cardunculus Exploitation for Energy Applications. (FP6 - 19829) The proposal aimed at demonstrating technical and economical feasibility of a global process for cardoon (Cynara cardunculus L.) exploitation for energy applications. This energy crop is appropriated for Mediterranean Area, where high problems about water insufficient exist. A combined process to produce a low-cost liquid biofuel from seeds and energy from lignocellulosic biomass is proposed. Different technologies for biomass energy conversion will be researched and compared in order to increase competitiveness and improve the costs. New heterogeneous catalysis for liquid biofuel production will be tested.

CROPGEN - Renewable energy from crops and agrowastes (FP6 - 502824) The overall objective of this project is to produce from biomass a sustainable fuel source that can be integrated into the existing energy infrastructure in the medium term, and in the longer term will also provide a safe and economical means of supplying the needs of a developing hydrogen fuel economy. The concept is based on the use of anaerobic digestion (AD) as a means of producing methane from biomass, including energy crops and agricultural residues. The technology of biochemical methane generation is well established: the breakthrough to a cost-effective and competitive energy supply will come from engineering and technical improvements to increase conversion efficiencies, and from reductions in the cost of biomass. The research will determine how the technology can best be applied to provide a versatile, low-cost, carbon-neutral biofuel in an environmentally sound and sustainable agricultural framework.

European Energy Crops Processing and Utilisation in Europe (FAIR-CT95-0512) The objective of this concerted action was to to improve the access to existing information on the production, processing and utilisation of energy crops as well as to enhance the integration of research, development and implementation activities on energy crops.

SWEETFUEL - Sweet sorghum: an alternative energy crop (FP7 - 227422) 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. Fuel-food crops can thereby help reconciling energy and food security issues. This project will breed for improved cultivars and hybrids of sorghum for temperate, tropical semi-arid and tropical acid-soil environments by pyramiding in various combinations, depending on region and ideotype, tolerance to cold, drought and acid (Al-toxic) soils; and high production of stalk sugars, easily digestible biomass and grain. SweetFuel aims also to identify and recommend the best cultural and harvest practices to make the system more sustainable and to provide for integrated technology and impact assessments including economics, dissemination and coordination. Research involves structured participation of stake holders, including policy makers. Project outcomes will be new germplasm, sustainable practices and commodity chain concepts adapted to each target region. (Source: EPSO)

SORGHUM: Environmental studies on sweet and fibre sorghum sustainable crops for biomass and energy (FAIR-CT96-1913) The general objective of this project was to study the environmental impacts of sweet and fibre sorghum within real cropping systems with particular reference to nitrogen balance. The aim was to provide information that was lacking in order to introduce these crops in crop rotations and establish the environmental impact under field conditions on existing cropping systems.

Sweet Sorghum, A Sustainable Crop for Energy Production in Europe (AIR1-CT92-0041) This project aimed to optimize the production of this crop in various pedoclimatic situations from north to south Europe using previous data and reliable references in order to propose a model for agro-industry systems (technical, economic and environmental) in different European scenarios as well as solve or reduce the limitations of this crop identified in previous studies.

US projects to develop supply chains for sustainable biofuel feedstocks

In December 2014, the U.S. Department of Energy announced funding of two projects on bioenergy feedstock logistics. The State University of New York, College of Environmental Science and Forestry, Syracuse, will carry out a $3.5m project to lower the cost of SRC, and improve harvesting and processes, to deliver feedstocks better tailored to the needs of biorefineries. The University of Tennessee, Knoxville, will carry out a $3.5m study on optimised blending of biomass feedstocks within the delivery radius of a biorefinery. The project will develop a processing facility to provide more consistent feedstock.

The USDA NIFA is coordinating 6 regional development projects to develop feedstocks for advanced biofuels, including energy grasses, sorghum, energy cane, oil crops and cellulosic biomass. The University of Washington is leading the Advanced Hardwood Biofuels Northwest project, as well as the Northwest Advanced Renewables Alliance: which is encouraging the conversion of forestry residues to aviation fuels. The Southeast Partnership for Integrated Biomass Supply Systems led by the University of Tennessee is using switchgrass and woody biomass to produce butanol and aviation fuel. Biofuels Center of North Carolina recently awarded $684,000 for six projects to accelerate the renewable fuels industry in western North Carolina [Source: Biomass Magazine April 2013].

Energy crop premium (abolished in 2009)

In September 2006 the European Commission proposed to extend the energy crop premium introduced by the 2003 Common Agricultural Policy reform to the eight Member States which currently did not benefit from it. In a further push to encourage the production of feedstocks for renewable energy production, the Commission also proposed allowing the Member States to grant national aid of up to 50 percent of the costs of establishing multi-annual crops on areas on which an application for the energy crop aid has been made. In the interests of simplifying the management of the CAP, the Commission also proposed to allow eight Member States which joined the EU in 2004 to continue operating the Single Area Payment Scheme for a further two years until 2010. The countries affected were Czech Republic, Estonia, Cyprus, Latvia, Lithuania, Hungary, Poland, and Slovakia. However, in 2009 it was announced that the energy crop premium would be abolished, along with mandatory set aside.

Links and references

Fuel quality directive and renewable energy directive (P8_TA-PROV(2015)0100 Fuel quality directive and renewable energy directive II; European Parliament legislative resolution of 28 April 2015 on the Council position at first reading with a view to the adoption of 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 (10710/2/2014 – C8-0004/2015 – 2012/0288(COD))).

OECD-FAO Agricultural Outlook 2014-2023 (Chapter 3: Biofuels) *OECD (2014)*

Setting up international biobased commodity trade chains *Netherlands Enterprise Agency* (2014)

Sustainable Biomass Production and Use - Lessons Learned from the Netherlands Programe on Sustainable Biomass (NPSB) 2009-2013 *Netherlands Enterprise Agency* (2014)

Space for Energy Crops - Assessing the potential contribution to Europe's energy future *Produced by IEEP for European Environmental Bureau, Birdlife International and Transport & Environment* (2014)

Prospects for Agricultural Markets and Income in the EU 2013-2023 *EC Agriculture and Rural Development* (2014)

EU bioenergy potential from a resource efficiency perspective *EEA* (2013)

Mobilising Cereal Straw in the EU to Feed Advanced Biofuel Production *Institute for European Environmental Policy IEEP (Report produced for Novozymes, 2012)*

Smart Use of Residues - Exploring the factors affecting the sustainable extraction rate of agricultural residues for advanced biofuels *WWF-World Wide Fund For Nature (with support from Novozymes and EU, 2012)*

Atlas of EU biomass potentials Deliverable 3.3: Spatially detailed and quantified overview of EU biomass potential taking into account the main criteria determining biomass availability from different sources Elbersen et al. (2012)

Bioenergy – a Sustainable and Reliable Energy Source – Main Report IEA Bioenergy: ExCo: 2009:06

Wasted – Europe's Untapped Resource. An Assessment of Advanced Biofuels from Wastes & Residues. Malins et al. (2014)

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Sustainable Production of Second-generation Biofuels. IEA Information Paper Eisentraut, A.(2010)

New and better switchgrass varieties for biofuels

FUELS AND CONVERSION

Advanced Biofuels in Europe

Contents

This page offers general information on advanced biofuels in Europe, with links to more detailed information on the EBTP website and other information sources.

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What are Advanced biofuels?

The EIBI definition

Advanced Biofuels are those (1) produced from lignocellulosic feedstocks (i.e. agricultural and forestry residues, e.g. wheat straw/corn stover/bagasse, wood based biomass), non-food crops (i.e. grasses, miscanthus, algae), or industrial waste and residue streams, (2) having low CO_2 emission or high GHG reduction, and (3) reaching zero or low ILUC impact

Definitions of advanced biofuels - different approaches

A wide range of terms are used to refer to biofuels: first generation, second generation, third generation, 1G, 2G, 3G, next generation, sustainable, renewable, advanced, etc.. These classifications are variously based on:

- type of feedstock;
- conversion technology used;
- properties of the fuel molecules produced;

all or any of which may be considered as advanced or next generation by different organisations.

These different approaches to classification arise partly because a great diversity of biofuels feedstocks and processes are currently being developed to meet sustainability and fuel quality standards, as well as the needs of road, aviation and marine end users. In additon. biofuels may be marketed as good, renewable, sustainable or next generation, partly for promotional purposes. So achieving a widely accepted definition of advanced and/or sustainable biofuels is a challenge.

Often the term is applied to biofuels produced from lignocellulosic (LC) or cellulosic biomass. This covers a range of plant molecules / materials containing cellulose, with varying amounts of lignin, chain length, and degrees of polymerization. This essentially means some cellulosic materials are relatively easy to breakdown into substrates (e.g. plant sugars) that can be used to create fuel molecules. For more complex ("more woody") cellulosic materials the production route to liquid biofuels may be more difficult and costly.

Taking this into account, the term advanced biofuels is typically used in a general way to describe:

a. Biofuels produced by *advanced processes from non-food feedstocks (e.g. wastes, agricultural & forestry residues, energy crops, algae). The end product may be equivalent to fuels produced by first generation technology (e.g. ethanol or FAME), or may be a different type of advanced biofuel (such as, BioDME or biokerosene). Generally, these "next generation" biofuels are considered more sustainable as the feedstock and processes used offer greater levels of GHG reduction and do not compete with food crops for land use.

b. The term "advanced biofuels" is also applied to biofuels with advanced properties, such as HVO, biopetroleum, biojet fuel, biobutanol, etc.. These end products may be more compatible with existing fuel infrastructures or offer other technical benefits. However, biofuels with improved properties may be made from a range of feedstocks (for example, oil crops or plant sugars). Ultimately, the aim is to produce biofuels with advanced properties from sustainable feedstocks that are not considered to compete adversely with food production systems, or lead to loss of stored carbon through deforestation.

This is covered in detail in the sustainability section of the EBTP website.

Biofuels produced from non-food crops or residues (e.g. oil crops grown on marginal land or Used Cooking Oils or animal fats) via first generation technology may also be referred to as next generation or sustainable, or sometimes grouped with advanced biofuels, even if no advanced processing technology is used.

A definition of Generations of Biofuels based on carbon resource

To overcome the anomalies discussed above, a more scientific definition of the various generation biofuels (1G, 2G, 3G) can be described based on the carbon source from which the biofuel is derived as, as follows:

1st Generation - the source of carbon for the biofuel is sugar, lipid or starch directly extracted from a plant. The crop is actually or potentially considered to be in competition with food.

2nd Generation - the biofuel carbon is derived from cellulose, hemicellulose, lignin or pectin. For example this may include agricultural, foresty wastes or residues, or purpose-grown non-food feedstocks (e.g. Short Rotation Coppice, Energy Grasses).

3rd Generation - the biofuel carbon is derived from aquatic autotrophic organism (e.g. algae). Light, carbon dioxide and nutrients are used to produce the feedstock "extending" the carbon resouce available for biofuel production. This means, however, that a heterotrophic organism (using sugar or cellulose to produce biofuels) would not be considered as 3G.

This does not necessarily imply that 2G is always more sustainable that 1G and 3G is always more sustainable than 2G or 1G, as other factors relating to land use, competition with food crops, and the efficiency of the production process, total energy balance, etc need to be taken into account across each specific value chain.

What is the current production of Advanced Biofuels?

In its report "Status of Advanced Biofuels Demonstration Facilities in 2012", IEA Bioenergy Task 39 lists 71 advanced biofuels production facilities worldwide, with a cumulative production capacity of 2,530,000 tons per year in 2012. Of all technologies for the production of advanced biofuels, hydrotreatment of vegetable oils has developed most rapidly and has contributed 2,190,000 tons per year to the worldwide biofuels production (representing ~2,4 % of the total worldwide biofuels production).

Information on European projects is available in the R&D&D Mapping section of the EBTP website. Worldwide mapping is done by IEA Bioenergy Task 39 in its online database on advanced biofuels production facilities.

In 2011, the Advanced Biofuels Tracking Database listed 130 advanced biofuels production facilities, with a combined annual production capacity of ~700 million gallons in 2011, the largest part of which is HVO (572 million gallons in 2011).

What are the benefits of advanced biofuels?

Advanced bioenergy, including advanced biofuels, has the potential to create thousands of new jobs, stimulate rural development and generate wealth within the growing European bioeconomy. They contribute significantly to energy security in the transport sector, reduce GHG emissions and provide a long-term sustainable alternative to fossil fuels in Europe.

What types of Advanced biofuels are there?

The following describes in general terms some of the main types of advanced biofuels being developed in Europe and globally.

Cellulosic ethanol can be produced by hydrolysis and fermentation of lignocellulosic agricultural wastes such as straw or corn stover or from energy grasses or other energy crops. The end product is the same as conventional bioethanol, which is typically blended with gasoline.

Biomass to Liquid (BtL) is generally produced via gasification (heating in partial presence of oxygen to produce carbon monoxide and hydrogen). Feedstocks include woody residues or wastes or energy crops. Gasification is followed by conditioning and then fuel synthesis via Fischer Tropsch or the "methanol-to-gasoline" process. BtL is used in diesel engines. It has also been approved as an aviation fuel.

High temperature plasma gasification can be used to convert a wider range of feedstocks to syngas, which can then be cleaned and converted into fuels.

Hydrotreated Vegetable Oils (HVO) / Hydroprocessed Esters and Fatty Acids (HEFA) do not have the detrimental effects of ester-type biodiesel fuels, such as increased NOx emission, deposit formation, storage stability problems, more rapid aging of engine oil or poor cold properties. HVOs are straight-chain paraffinic hydrocarbons that are free of aromatics, oxygen and sulfur and have high cetane numbers. They are also approved for use as aviation fuels. The aim is to produce HVOs from sustainable feedstocks.

BioDME (dimethylether) can be produced via catalytic dehydration of methanol or directly from syngas. Above -25°C or below 5 bar DME is a gas. Hence its use as a transport fuel can be considered similar to that of LPG.

BioSynthetic Natural Gas (BioSNG) is produced via an initial gasification step followed by gas conditioning, SNG synthesis and gas upgrading. BioSNG can be used in a similar way to biomethane (biogas) generated via anaerobic digestion (a biological process). Syngas may also be converted to liquid fuels.

Bio-oil/Bio-crude is produced by pyrolysis, processes that use rapid heating or super-heated water to convert organic matter to oil. Flash pyrolysis involves rapid heating (1-2 seconds) of fine material up to 500°C. Thermochemical Conversion uses superheated water to convert organic matter to bio-oil. This may be followed by anhydrous cracking/distillation. The combined process is known as Thermal depolymerization (TDP). Bio-oil can be used as a heating fuel or can be further converted to advanced biofuels.

Torrefaction (heating at 200-300 °C in the absence of oxygen, at atmospheric pressure) converts biomass to "bio-coal", which can be more easily used for power generation than untreated biomass.

Biobutanol is an alcohol that can be used as a transport fuel. Each molecule contains four carbon atoms rather than two as in ethanol. It is more compatible with existing fuel infrastructures and engines than ethanol. Novel fermentation techniques are being developed to convert sugars into butanol using modified yeast strains.

Algal biofuels may be produced from macro algae (seaweeds) and microalgae via a range of technologies. A number of projects and pilot plants are now identifying the best types of algae to use and the best production technologies. Algal biofuels have attracted great interest as they do not compete with food crops for land use, but the technology is not yet as mature as that for some other advanced biofuels.

Hydrocarbons via chemical catalysis of plant sugars Chemical catalysis or modified mircorganisms offer great potential for converting sugars into specific fuel molecules including biopetroleum, bio jet fuel and other drop-in fuels, which have very similar properties to their fossil fuel counterparts.

Drop-in biofuels via biotechnology Synthetic biology, modified metabolism and other techniques are being developed to convert plant sugars to a range of fuels that have similar properties to fossil gasoline or diesel.

Biohydrogen Hydrogen can potentially be produced from biomass via various routes and can be used as a vehicle fuel. Biohydrogen is not currently being produced at significant volumes, but could be an important fuel in the future.

What feedstocks are used for advanced biofuels in Europe? What volumes are available?

In general, advanced biofuels are produced from cellulosic and lignocellulosic materials, such as agricultural and forestry residues or wastes, or energy crops. The aim is to develop energy crops that result in the production of more fuel per unit of land used and require less chemical and energy input for production and harvesting. This results in a higher yield in terms of net GJ energy produced per hectare land used. Preferably, energy crops are grown on marginal land that does not compete directly with (or displace) land used for food crops.

Many availability assessments have been carried out covering a range of biomass feedstocks in Europe. This work is ongoing, but it is clear that to meet the competing demands from different sectors, the efficiency of biomass supply chains in Europe needs to be maximised. A wider range of biomass feedstocks need to be made available through improved logistics. At the same time, feedstock costs need to remain competitive, and sustainabiltiy criteria need to be met.

To make best use of biomass resources in Europe, a co-ordinated approach is required to match the most appropriate feedstocks to the most beneficial end use in the most favourable location.

Are the feedstocks for advanced biofuels sustainable?

An energy balance can be calculated for each advanced biofuel taking into account the type of feedstock, the energy used in fuel production and in transporting the end product. Generally this shows that advanced biofuels offer a great reduction in Greenhouse Gas (GHG) than conventional biofuels. However, there remains competition for land and feedstock between liquid biofuels and the rapidly expanding use for heat and power generation through combustion.

The sustainability of biofuels is covered by the Biofuels Certification Scheme, while projects such as BioGrace and Global-Bio-Pact aim to harmonise the way sustainability of bioenergy and biofuels is calculated and certified. However, the same rules need to be applied to all use of biomass for food and other products. There is limited value in creating sustainable biofuels if unregulated and unsustainable biomass production is allowed for other uses.

At the moment there is a vigorous debate about indirect Land Use Change (iLUC), which is covered in greater detail on the sustainability page of the EBTP website.

What types of transport can advanced biofuels be used for? Are advanced biofuels compatible with existing engines and infrastructures?

R&D&D activities in the EU, US and China and Brazil are demonstrating the potential of a wide range of advanced biofuels for use in road, marine (shipping), and air transport. See the individual pages for further details.

What is the being done to support commercialisation of advanced biofuels technology in Europe?

A wide range of FP7 projects made a significant contribution to the development of advanced biofuels technology in Europe. Links and details are included on research funding page of the EBTP website. This R&D&D is being continued under the "**Horizon 2020 - the Framework Programme for Research and Innovation**"

The European Industrial Bioenergy Initiative (one of the industrial initiatives under the SET-Plan) aims to have the first commercial plants in operation by 2020 with a focus on advanced biofuels, which could meet 4% of EU transport energy needs, while strengthening EU technology leadership.

The EIBI covers industrial bioenergy projects of European relevance, with the potential of large scale deployment along seven value chains (covering both biochemical and thermochemical technologies, as outlined above). There are two main types of unit:

- **Demonstration Units**, which prove the performance of an innovative advanced bioenergy technology and pave the way for
- **Flagship Plants**, the first commercial-scale unit

EIBI demonstration units or flagship plants should encompass:

- a reliable long-term source of feedstock (at a competitive price)
- a high-performance conversion process
- and a marketable end-product

Units or plants may adopt a biorefinery approach, but advanced bioenergy or biofuels must be the main output.

The required investment for EIBI is estimated at 9 billion Euros for 2010-2020. In the current economic environment securing investment for any innovative technology is not easy. But there are still possibilities. Significant FP7 financing has helped establish some of the advanced bioenergy technologies. Close-to-market bioenergy and advanced biofuels projects are also included within NER300. Other forms of funding, such as the Emissions Trading Scheme, EIB loans, EU Structural funds also offer potential. By sharing risk between industry, governments and among the Member States, advanced biofuels can be commercialised more quickly.

Regulatory support is also required to enable the commercialisation of innovative advanced bioenergy technologies. The EBTP is working with the EC on this, as well as on the identifying the most promising mix of feedstock, technology and end-product.

Pretreatment of biomass to facilitate conversion to bioenergy or biofuels

Overview

Before energy crops or organic wastes can be converted to biofuels, typically some form of pretreatment is required, by physical (mechanical), chemical, thermochemical or biochemical methods.

Mechanical processing

Generally, the first step is to mechanically process the feedstock (for example wood waste, straw, etc) to reduce size by shredding and grinding. Size reduction by mechanical processing (milling, grinding, extrusion, irradiation, etc):

- faciltates handling
- increases surface area
- decreases crystallanity
- reduces degree of polymerization
- improves the efficiency of enymatic or acid hydrolysis, and processes such as pyrolysis and torrefaction (outlined below).

Energy densification

Pretreatment helps to improve the energy density of the biomass, allowing it to be more efficiently transported from the point of production (field, forest or bioindustrial facility) to the point of use. See Biomass Densification for Energy Production, Fact Sheet produced by Ministry of Agriculture, Food and Rural Affairs, Ontario, Canada, June 2011.

Biomass may be compressed into pellets, cubes or pucks (similar in size and shape to the eponymous ice hockey pucks), or treated with heat and pressure (e.g. pyrolysis, torrefaction) to create 'bio-coal' or 'bio-oil' as outlined in more detail below.

Pelletisation

Compressing fractionated biomass to form fuel pellets improves handling and creates a product that has similar flow properties to plant grains. Pellets can be more easily delivered to homes, businesses and power plants and, due to their consitent size and shape, can be automatically fed into advanced pellet boilers in a controlled and callibrated way. Wood pellet production has more than doubled between 2006 and 2010 to over 14 million tons [Source: IEA Task 4].

Fractionation

Biomass fractionation (most commonly by steam explosion) converts lignocellulosic feedstocks into three discrete fractions of lignin, cellulose and hemicelluloses. The yield and purity of the three fractions is a key advantage in downstream applications [Source: NNFCC, UK]. This allows the fractions to be more efficiently processed within a bioefinery (where a number of different products are produced on the same site in a cascading process that maximises the value of the biomass feedstock e.g. production of heat and power, fuel additives, ethanol, biochemicals, etc).

Steam explosion

"Steam Explosion (SE) is the most commonly used pretreatment of biomass and uses both physical and chemical methods to break the structure of the lignocellulosic material through an hydrothermal treatment. The biomass is treated with high pressure steam at high temperature for a short time, then it is rapidly depressurized and the fibrils structure is destroyed by this explosive decompression. This defibration and the remarkable autohydrolysis significantly improve the substrate digestibility and bioconversion as well as its reactivity toward other catalytic reactions. The successive sudden decompression reduces temperature, quenching the process."

Steam explosion also produces some toxic compounds which must be removed before fermentation. Dilute acids may be used in combination with steam explosion.

[Source: Anna Maria Raspolli Galletti, Claudia Antonetti, University of Pisa, Department of Chemistry and Industrial Chemistry, from presentation at EUROBIOREF Summer School on Biomass pre-treatment: separation of cellulose, hemicellulose and treatment: separation of cellulose, hemicellulose and lignin. Existing technologies and perspectives, September 2011].

Similar processes to steam explosion include:

Ammonia Fibre Explosion AFEX - Biomass is treated with liquid ammonia at high temperature and pressure. When the pressure is released the ammonia vapizes and can be recovered. For example, see Michigan State University AFEX technology.

Super-critical Carbon dioxide explosion - See Pretreatment of Lignocellulosic Biomass Using Supercritical Carbon Dioxide as a Green Solvent, Tingyue Gu, 2013

Alkaline hydrolysis

Alkaline hydrolysis inolves treatment of biomass with an high concentration of alkaline at a lower temperature for a longer time period. *See* Hydrolysis of Lignocellulosic Biomass: Current Status of Processes and Technologies and Future Perspectives, Alessandra Verardi *et al*, ENEA, Italy. This paper also compares the pros and cons of various per-treatment methods.

Liquid hot water (LHW)

LHW (also known as aqueous fractionation, aquasolv or hydrothermolysis) involves immersion of biomass in water at 180-230° C) at high pressure. This releases acid compounds in the biomass that break it down via 'autohydrolysis'.

Use of Ionic liquids (ILs)

ILs are compounds composed solely of ions with immeasurable combinations of anions and cations. They possess widely
tuneable properties, such as hydrophobicity, polarity and solvent power. Various ILs have been investigated for pre-treatment of biomass as discussed in the paper Ionic liquids as a tool for lignocellulosic biomass fractionation, Andre M da Costa Lopes et al, 2013.

In August 2014, researchers (Aaron Socha et al) at US Do Joint BioEnergy Institute published a paper on "Efficient biomass pretreatment using ionic liquids derived from lignin and hemicellulose" in Proceedings of National Academy of Sciences PNAS. The aim of the research is to replace conventional ionic solvents with a renewable product - tertiary amine-based ionic liquids synthesised from aromatic aldehydes in lignin and hemicellulose.

Plantrose process (supercritical hydrolysis)

Renmatix Inc., has developed the patented 'Plantrose process', which uses supercritical hydrolysis to produce high volume cellulosic sugars at low cost. Renmatix investors include BASF, Kleiner Perkins Caufield & Byersa and Total. Renamtix has acquired the Mascoma manufacturing facility in Rome, New York. The new feedstock processing facility (FPF) opened officially on 20 April 2015.

Low Temperature Steep Delignification (LTSD)

LTSD, developed by Bio-Process Innovation Inc, uses low inputs of non-toxic chemicals, oxygen and base, at mild reaction conditions to break down lignocellulosic feedstocks. In February 2015, the company announced the start-up of a one ton pilot plant in Indiana, following ten years of process optimisation. The technology is now commercially available for use in biorefineries.

Co-solvent Enhanced Lignocellulosic Fractionation CELF

CELF uses renewable, water-miscible tetrahydrofuran (THF) with dilute sulfuric acid to fractionate cellulosic biomass and achieve high yields of sugars for fermentation or furfural, 5-hydroxymethylfurfural, and levulinic acid for catalytic conversion into fuels and chemicals. The technology developed by the University of California, has been licensed by CogniTek. A new company "MG Fuels" is being set up to commercialize the technology.

Organosolv process

Oragnosolv was originally developed as an alternative to the KRAFT process for pulping, and uses organic solvents (such as ethanol, methanol, butanol, acetic acid, etc) to solubilise lignin and hemicellulose. It is now being developed for biorefinery systems and cellulosic ethanol production.

American, Science and Technology AST has developed a patented Organosolv process (at pilot scale, using sulphuric acid, butanol and other organic solvents) to convert lignocellulosic biomass into sugars, pure lignin, pulp and added value biochemicals. The fractionation process is operated at 140-180 C under autogenous to 50-60 psi added pressure (200-280 psi at the peak temperature). The hydrolysis process works at 40-60 C and 4-5 psi. The fractionation process yields 40-55% cellulose, 20-30% lignin, and 20-25% hemicelluloses. This process is very efficient in producing more than 95% yield to sugars. Lignin is also more than 95%.

Lignol Energy Corporation, similarly, used an ethanol-based organosolv process to yield high-quality lignin. As per the transaction announced on March 9, 2015, Lignol Energy Corporation was acquired by Fibria Celulose SA.

Similar technologies with vaious solvents have been developed e.g. Organocell (methanol), Compagnie Industrielle de la Materière Végétale CIMV (acetic acid/formic acid) and Chempolis (formic acid).

Ozonolysis

Pretreatment of biomass with ozone prior to enzyme hydrolysis has been investigated, for example as outlined in the paper Association of wet disk milling and ozonolysis as pretreatment for enzymatic saccharification of sugarcane bagasse and straw, Rodrigo da Rocha Olivieri de Barrosa et al, Bioresource Tecnology, May 2013.

Pyrolysis

Pyrolysis is the chemical decomposition of organic matter by heating. Flash pyrolysis involves rapid heating (1-2 seconds) of fine material up to 500°C. Thermochemical conversion uses superheated water to convert organic matter to bio-oil. This may be followed by anhydrous cracking/distillation. The combined process is known as Thermal depolymerization (TDP).

Please see the page on 'biocrude' for further information about recent demonstrations of pyrolysis technology to convert lignocellulosic biomass to intermediate liquids (bio-oil) for further upgrading to advanced biofuels for transport, or for use as heating fuels or refinery feedstocks.

Torrefaction

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'.

Please see the torrefaction page for further informaiton about recent research and demonstrations in Europe and the United States.

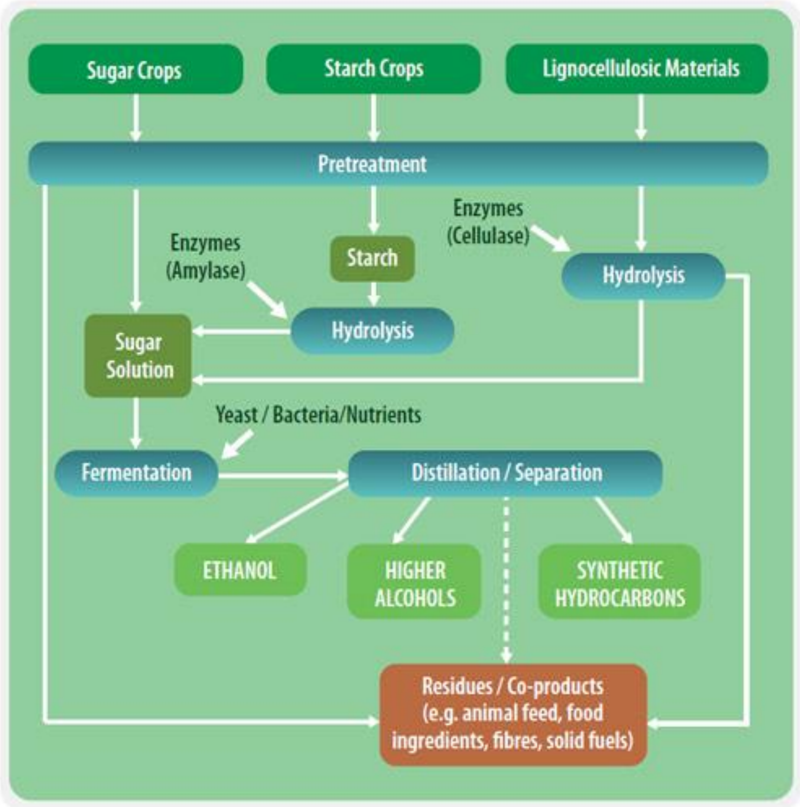
Biochemical value chains for production of biofuels

Introduction

The most common biochemical conversion used for biofuel production is yeast-fermentation to ethanol. First generation ethanol is derived from sugar or starch produced by food crops (e.g. wheat, corn, sugar beet, sugar cane, etc). Second generation ethanol or 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 into simple sugars prior to distillation. Cellulosic ethanol is chemically identical to first generation bioethanol (i.e. CH_3CH_2OH). See ethanol fact sheet and conventional ethanol page.

Other types of biochemical conversion include:

- Microbial fermentation via acetic acid,
- Microbial fermentation via farnesene
- Yeast fermentation to butanol
- Microbial fermentation of gases



Biochemical value chains
View at larger size >>

Cellulosic ethanol

See the cellulosic ethanol page for details of commercial demonstrations and reseach in areas such as valorization of C5 sugars and lignin.

Pretreatment of lignocellulosic feedstock

In contrast to the traditional bioethanol production from sugar and starch, production based on lignocellulosic material requires additional processing steps. The reason is that the cellulose (source of C6 sugars such as glucose) as well as hemicellulose (mainly source of C5 sugars such as xylose) is not accessible to the traditional bioethanol producing micro-organisms.

Within the first step, the size is reduced through milling or chopping. This straightforward step is performed by various types of mills in order to increase the accessibility of the processed material for the pretreatment step.
The main purpose of the pretreatment is to increase the reactivity of the cellulose and hemicellulose material to the subsequent hydrolysis steps, to decrease the crystallinity of the cellulose and to increase the porosity of the material. Only after breaking this shell the sugar containing materials become accessible for hydrolysis.
A general classification of the pretreatment methods into three groups may be undertaken: chemical, physical und biological pretreatment methods.

Well known chemical pretreatments run on concentrated and diluted acids (H_2SO_4 generally); diluted acids allow reducing corrosion problems and environmental issues but give lower yields. Still under research are methods using ammonia, lye, organosolv and ionic liquids. In terms of physical pretreatment, steam explosion has been frequently applied and delivers high yields; ammonia fibre explosion requires less energy input but raises environmental issues; methods under development are liquid hot water and CO2- explosion which promise less side-products or low environmental impact respectively. Not well known and not much used are biological processes based on conversion by fungi and bacteria.

See the pretreatment page for further information and links.

Hydrolysis

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

Cellulose is chemically very stable and extremely insoluble. Although acid hydrolysis of the celluloses is possible and has been applied previously, the current state-of-art method is enzymatic hydrolysis by a cellulase enzyme complex produced for example by the fungus Trichoderma reesei. The complex is composed by three proteinic units: endocellulase breaks the crystalline structure to generate shorter chain fragments; exocellulase works on (14) glucosidic bonds of linear cellulose to release cellobiose (it is composed by two sugar units); cellobiase (or β-glucosidase) finally works on cellobiose and splits off glucose to make the material suitable for fermentation.

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

Yeast fermentation to ethanol and upgrading

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

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

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

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

- **Evaporation of ethanol from beer**: in this step the first evaporation of ethanol is performed in order to obtain ‘crude’ ethanol with concentration ~45%V/V.
- **Rectification**: in rectification the ethanol concentration is increased to ~96%V/V
- **Dehydration**: by dehydration the remaining azeotropic water is removed in order to obtain the fuel bioethanol with concentration 98.7%m/m and water content below 0.3% m/m1.

Types of process integration

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

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

The SSCF - Simultaneous Saccharification and Co-Current Fermentation set-up is currently the best developed lignocellulose processing method where hydrolysis and C5 and C6 fermentation can be performed in a common step.

The CBP - Consolidated BioProcessing (previously also called DMC - Direct Microbial Conversion), though, envisages a unique step between pretreatment and distillation, unifying cellulase production, C5 and C6 hydrolysis and C5 and C6 fermentation. From today's point of view, the establishment of CBP would mark a significant step forward, in terms of efficiency and simplicity of the process, yet it requires further research and development.

Microbial Fermentation via Acetic Acid

Microbial fermentation of sugars can – in contrast to the more commonly used yeast fermentation to ethanol – also use an acetogenic pathway to produce acetic acid without CO_2 as a by-product. This increases the carbon utilization of the process. The acetic acid is converted to an ester which can then be reacted with hydrogen to make ethanol.
The hydrogen required to convert the ester to ethanol can be produced through gasification of the lignin residue. This requires fractionation of the feedstock into a sugar stream and a lignin residue at the beginning of the process. This process is applied by ZeaChem.

Microbial Fermentation via Farnesene

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

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

See the biofuels biotechnology page for related research.

Yeast Fermentation to Butanol

Due to an excess of ethanol in the US and Brazil (the 'blend wall') there is significant interest in the production of butanol for use as a biofuel. Yeast can be engineered to produce butanol instead of ethanol. Butanol may serve as an alternative fuel, as 85% Butanol/gasoline blends can be used in unmodified petrol engines. Several companies are developing butanol-production technologies including: Gevo, Butamax™ Advanced Biofuels, Abengoa, Green Biologics, Cobalt Technologies, Tetravitae Bioscience and METabolic EXplorer.

See the butanol page for details of the latest R&D&D developments and fuel standards for butanol.

Microbial Fermentation of Gases

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

Use of Lignin

Cellulose and hemicellulose are most conveniently used for energy production with a conversion rate of up to 100%. Lignin represents a residue in the sugar fermentation system for ethanol production, as microorganisms can metabolize only sugars (which form cellulose and hemi-cellulose) but not aromatic alcohols (which are the main component of lignin).

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

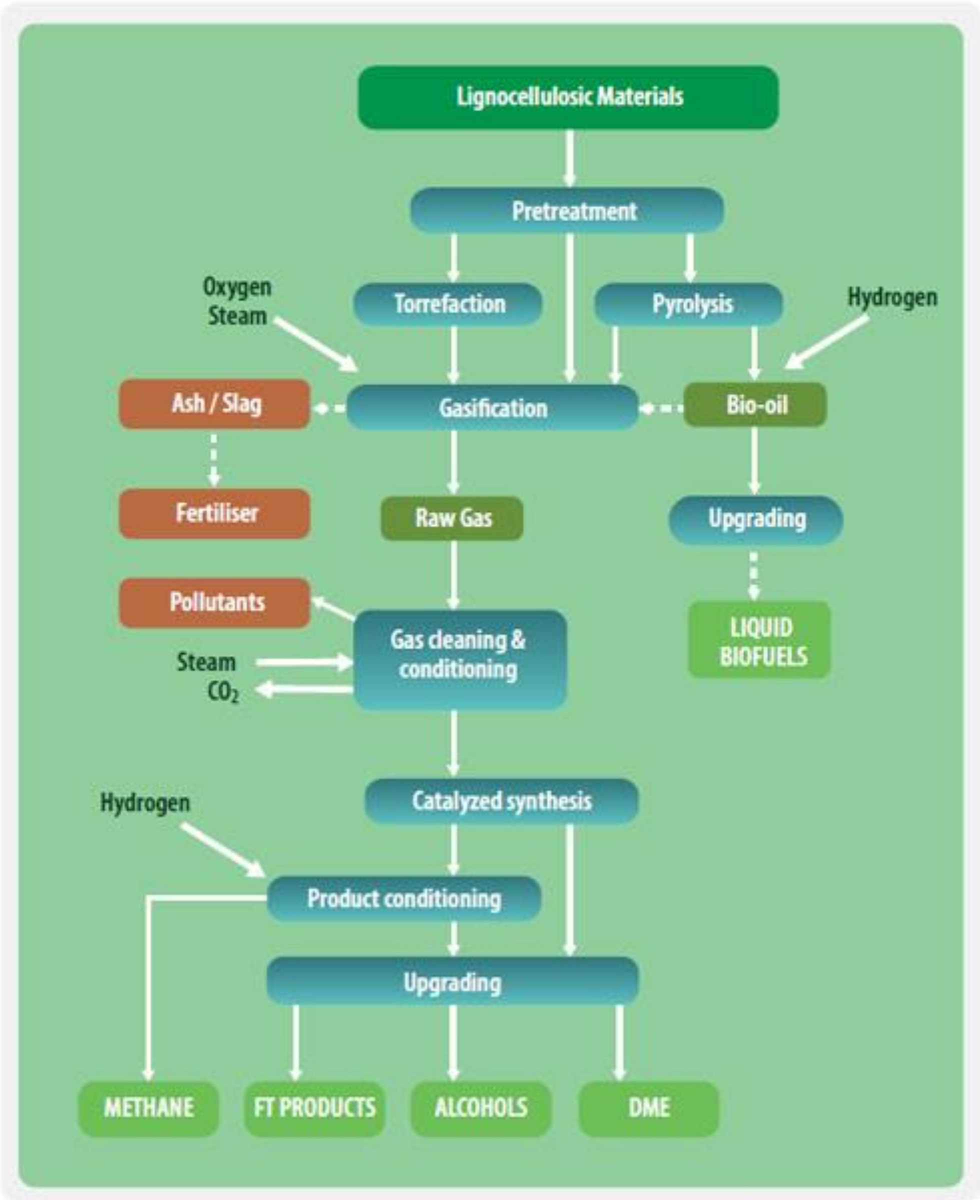
See further links and information on valorization of lignin on the cellulosic ethanol page.

Thermochemical value chains for production of biofuels

Introduction

The thermochemical process includes gasification, pyrolysis and torrefaction.

- Gasification of solid biomass at temperatures above 700°C with limited oxygen produces synthesis gas, which can be upgraded to transport fuels.
- Flash pyrolysis involves rapid heating (1-2 seconds) of fine material up to 500°C. It is used to convert organic matter to bio crude oil. This may be followed by anhydrous cracking/distillation. The combined process is known as Thermal depolymerization (TDP).
- Torrefaction is a thermochemical process typically at 200-350 °C in the absence of oxygen, at atmospheric 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'.



Thermochemical value chains
View at larger size >>

Torrefaction

For further information on commercial development of torrefaction technology, please see the torrefaction page.

The gasification pathway

Within this production scheme the biomass is first thermally fragmented to synthesis gas consisting of rather simple molecules such as: hydrogen, carbon monoxide, carbon dioxide, water, methane, etc. These gaseous material are then chemically re-synthesized to biofuels. Various catalytic process can be performed:

- The Fischer-Tropsch process for production of diesel from biomass
- Methanation to obtain bio-SNG as a substitute for natural gas
- Synthesis into mixed alcohols
- Production of BioDME
- Mobil process - a two-stage catalytic process for production of hydrocarbons via methanol

See the BtL page for further details

Syngas Production and Cleaning

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

The gasification processes may be distinguished according to the gasification agent used and the type of heat supply. Typical gasification agents are: oxygen, water, and air (carbon dioxide and hydrogen are also possible). Two types of processes are distinguished based on how heat is supplied.

- In autothermic processes the heat is provided through partial combustion of the processed material in the gasification stage.
- In allothermic processes, the heat is provided externally via heat exchangers or heat transferring medium. In these processes the heat may come from combustion of the processed material (i.e., combustion and gasification are physically separated) or from external sources.

The choice of the gasification agent is based on the desired composition of the product gas. The combustible part is mainly composed of hydrogen (H_2), carbon monoxide (CO), methane (CH_4) and short chain hydrocarbons, moreover inert gases. A higher process temperature or using steam as a gasification agent leads to increased H_2 content. High pressure, on the other hand, decreases the H_2 and CO content. A change of H_2/CO ratio can be achieved by varying steam/O_2 ratio. Moreover, when using air as a gasification agent, nitrogen is present. If the product gas is to be used for fuel synthesis, the use of air as a gasification agent is not favourable (due to the resulting high N_2 content in the product gas).

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

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

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

An optimal H_2/CO ratio of 1.5 – 3.0 is obtained by the Water-gas-shift (WGS) reaction: $CO + H_2O \leftrightarrow CO_2 + H_2$.
The gas reforming reaction converts short-chain organic molecules to CO and H_2 (for an example: $CH_4 + H_2O \leftrightarrow CO + 3\ H_2$).

CO_2 removal can be performed by physical (absorption to water or other solvents) or chemical (absorption to chemical compounds) methods. Other absorption methods are based on pressure or temperature variations.

Fischer-Tropsch Liquids

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

- High Temperature Fischer-Tropsch (HTFT) synthesis (300 – 350°C and 20 – 40 bar), poduces basic petrochemical materials and gas.
- Low Temperature Fischer-Tropsch (LTFT) technology (200 – 220°C and less 20 bar) provides outputs for diesel production.

The raw product, though, cannot be directly used as fuel, it needs to be upgraded via distillation to split it into fractions; via hydration and isomerization of the C5 – C6 fraction and reforming of the C7 – C10 fraction in order to increase the octane number for petrol use; and via cracking by application of hydrogen under high pressure in order to convert long-chain fractions into petrol and diesel fraction.

Synthetic Natural Gas

The upgrading to SNG (synthetic natural gas) requires methanation of the product gas, desulfuration, drying and $CO_2$2 removal. In the methanation step (catalyzed by nickel oxide at 20-30 bar pressure conditions) carbon monoxide reacts with hydrogen forming methane and water:

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

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

Mixed Alcohols

Starting from a suitably upgraded product gas, it is possible to synthesize alcohols as main products via catalytic conversion. The higher alcohol synthesis (HAS) follows the reaction:

$3CO + 3H_2 \leftrightarrow C_3H_5OH + CO2$;

using a number of catalysts (alkali-doped, methanol, modified FT-catalysts).

As HAS is a highly exothermic process, the optimization of heat removal is of particular interest. The product upgrading of the obtained alcohol mixture consists typically of de-gassing, drying and separation into three streams: methanol, ethanol and higher alcohols.

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.

BioDME production

Dimethyl ether (typically abbreviated as DME), also known as methoxymethane, wood ether, dimethyl oxide or methyl ether, is the simplest ether. It is a colourless, slightly narcotic, non-toxic, highly flammable gas at ambient conditions, but can be handled as a liquid when lightly pressurized. The properties of DME are similar to those of Liquefied Petroleum Gas (LPG).

Syngas is converted into DME via a two-step synthesis, first to methanol in the presence of catalyst (usually copper-based), and then by subsequent methanol dehydration in the presence of a different catalyst (for example, silica-alumina) into DME.

The following reactions occur:

$2H_2 + CO \Leftrightarrow CH_3OH$

$2CH_3OH \Leftrightarrow CH_3OCH_3 + H_2O$

$CO + H_2O \Leftrightarrow CO_2 + H_2$

Alternatively, DME can be produced through direct synthesis using a dual-catalyst system which permits both methanol synthesis and dehydration in the same process unit, with no intermediate methanol separation, a procedure that, by eliminating the intermediate methanol synthesis stage, the licensors claim promises efficiency advantages and cost benefits. Both the one-step and two-step processes are commercially available. DME can also be converted itself into olefins and synthetic hydrocarbons.

See the BioDME page for further information.

The pyrolysis pathway

Pyrolysis uses rapid heating or super-heated water to convert organic matter to oil. Flash pyrolysis involves rapid heating (1-2 seconds) of fine material up to 500°C. Thermochemical conversion uses superheated water to convert organic matter to bio-oil. This may be followed by anhydrous cracking/distillation. The combined process is known as Thermal depolymerization (TDP). Bio-oil can be used as a heating fuel or can be further converted to advanced biofuels.

The HTU Process

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).

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."

Tall oil (produced via the Kraft process)

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.

See the Bio-oil page for further information on commercial development of pyrolysis technologies.

Oleochemical value chains for production of biofuels

Various pathways can be used to convert fats and oils (oil crops and waste oils) to liquid transport fuels:

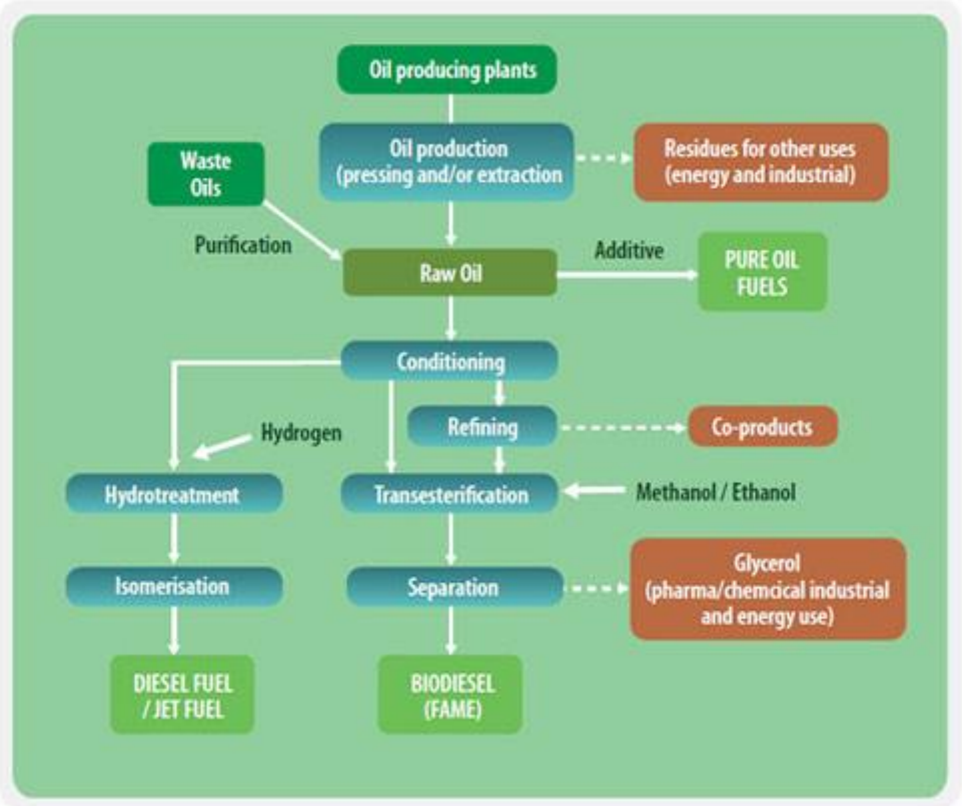
Transesterification of Oils

Hydrotreatment of Oils

Catalytic Decarboxylation

Methanol Production

Algal oils



Oleochemical value chains
View at larger size >>

Transesterification of Oils

The transesterification of vegetable oils, animal fats or waste cooking oils is the process behind conventional biodiesel. In the transesterification process a glyceride reacts with an alcohol in the presence of a catalyst, forming a mixture of fatty acids esters and an alcohol. Using triglycerides results in the production of glycerol.

Transesterification is a reversible reaction and is carried out by mixing the reactants. A strong base or a strong acid can be used as a catalyst. At the industrial scale, sodium or potassium methanolate is mostly used.

The end products of the transesterification process are raw biodiesel and raw glycerol. After a cleaning step biodiesel (FAME) is produced. The purified glycerol can be used in the food and cosmetic industries, as well as in the oleochemical industry. The glycerol can also be used as a substrate for anaerobic digestion.

See the biodiesel page for updates on biodiesel RTD and process innovation.

Hydrotreatment of Oils

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

See the HEFA/HVO page for further details

Catalytic Decarboxylation

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

Methanol Production

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

See the methanol page for further information

Algal oils

Please see the algae biofuels page for updated information on production of advanced biofuels from algal oils.

END USE

Overview

Transport represents a fundamental sector of our economy and society, it secures personal mobility and supports economic growth. In final energy consumption the EU transport sector holds a share of 33 % in 2011, which corresponds to 364 Mtoe (see figure 1). In comparison: the worldwide share of transport in the final energy consumption was 18 % (2,221 Mtoe) in 2009 (IEA-AMF 2012). This emphasizes that transport is an essential energy topic for the European Member States, in goods and people transport, both individual and mass.

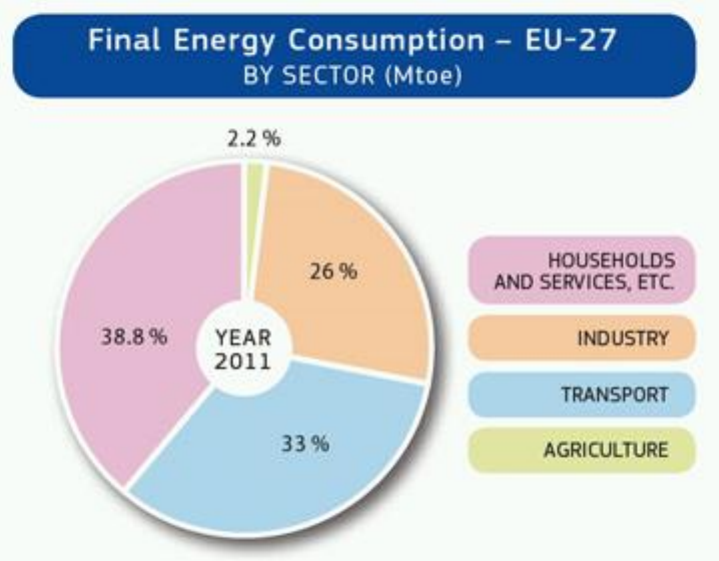


Figure 1: Final Energy Consumption – EU-27 by sector (Mtoe) (EC 2013, EU transport in figures)

Total energy consumption of transport in Europe

In Europe total energy consumption of transport accounts for 364 Mtoe in 2011, with the different transport modes - road (81.7 %), air (13.9 %), rail (2.0 %) and water (1.6 %) (EC 2013). For the years 1990 and 2010 the energy consumption of transport by mode in the EU is given in figure 2 (Odyssee-Mure 2013).

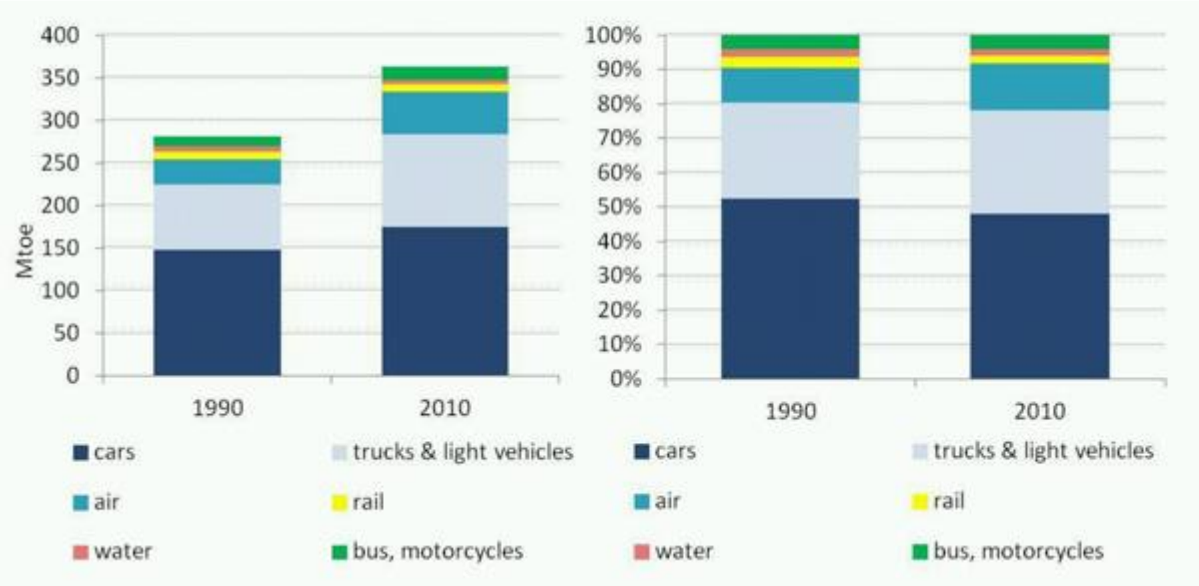


Figure 2: Energy consumption of transport by mode in the EU

Global energy consumption in the transport sector

Global energy consumption in the transport sector accounted for approximately 2,300 Mtoe in 2009, with 77 % of it consumed by road transport, 10 % each by global aviation and by marine transport and 3 % by rail transportation (see figure 3).

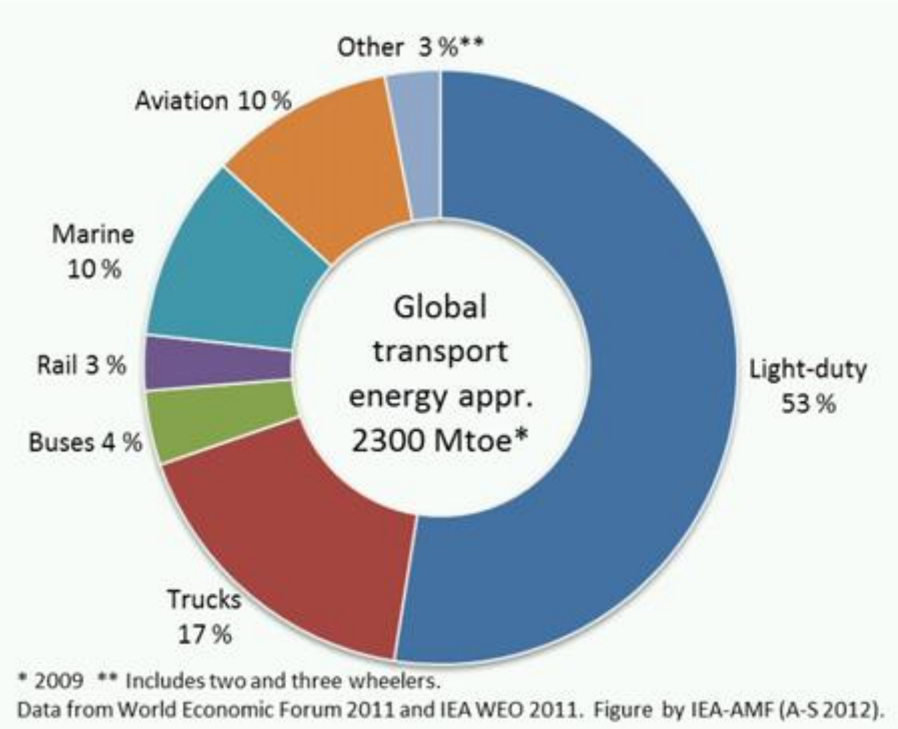


Figure 3: Global view on transport modes 2009 (AMF 2011)

Oil dependency, fuel security and reduction of GHG emsissions in Europe

The EU is strongly dependent on imported crude oil for its energy supply. In 2010, 94 % of the energy consumed for its transport and mobility came from oil products. This contributes to an oil import bill of around €1 billion a day in 2011 (COM (2013) 17). Oil dependency has to be addressed to secure people's ability to travel and to strengthen EU's economy.

A second issue, besides the reduction of oil dependency, is the reduction of world greenhouse gas emissions, with the goal of limiting climate change below 2°C by the end of this century. In the white paper "Roadmap to a single European Transport Area" the European Commission has defined a target for transport of 60 % reduction in 2050 compared to 1990 (COM (2011) 144).

To meet this target the EC defined 10 goals for a competitive and resource efficient transport system subdivided into three main sections:

- Developing and deploying new and sustainable fuels and propulsion systems
- Optimising the performance of multimodal logistic chains, including by making greater use of more energy-efficient modes
- Increasing the efficiency of transport and of infrastructure use with information systems and market-based incentives

The role of biofuels in achieving a competitive and resource efficient transport system

To achieve these goals both, biofuels and electro-mobility will play significant roles, as they together could technically substitute oil in all transport modes. Another important factor is the increase of efficiency of transport modes, regarding all three segments: urban transport, medium and long distance transport.

Liquid biofuels are currently the most important type of alternative fuels, because of their high energy density and the applicability in all transport modes, using existing infrastructure and vehicles. The coverage of transport modes and travel range by the main alternative fuels is depicted in figure 4 (COM (2013) 17). There will be no single fuel solution for the future mobility – a consistent long-term strategy on alternative fuels has to meet the energy needs of the different transport modes.

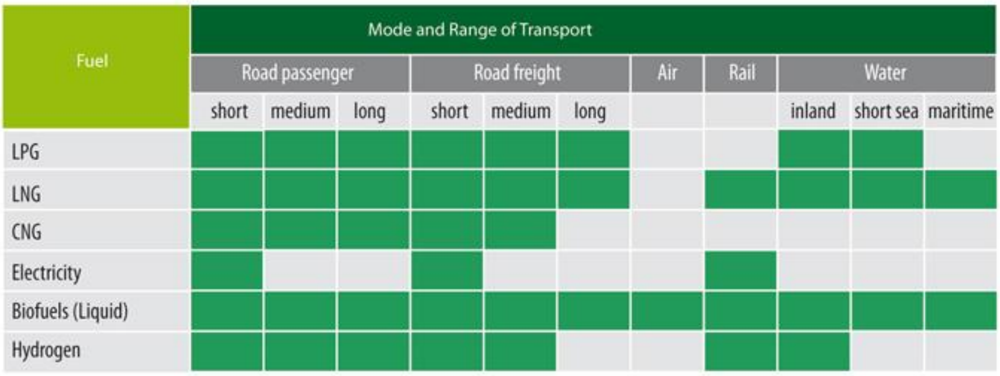


Figure 4: Coverage of transport modes and travel range by the main alternative fuels (COM (2013) 17)

In the ERTRAC Roadmap "Energy Carriers for Powertrains" this table has been extended to the compatibility of different transport modes and energy carriers from a technical prospective for today and in the future. It also gives an overview of research needs for mid and long term for the different combinations of transport modes and energy carriers (see figure 5).

Fuel	Mode of Transport (Passenger and Goods)							
Today / Future ●/●	Car: Urban	Car: Long Distance	LCV 20 Delivery	Truck/Bus: Long Distance	Bus: Urban	Ship	Rail	Plane
Gasoline	●/●	●/●	●/●	/●	/●			
Diesel / Kerosene	●/●	●/●	●/●	●/●	●/●	●/●	●/●	●/●
CNG	●/●	●/●	●/●	●/●	●/●		/●	
LPG	●/●	●/●	●/●					
LNG			/●	●/●	●/●	●/●	/●	/●
Biodiesel (FAME)	●/●	●/●	●/●	●/●	●/●			
XtL	●/●	●/●	●/●	●/●	●/●	●/●	●/●	●/●
Advanced gasoline (cell ethanol, butanol...)	●/●	●/●	●/●	/●	/●		/●	
Advanced diesel/kerosene (BtL, HVO, sugar-to-diesel...)	●/●	●/●	●/●	●/●	●/●	●/●	●/●	●/●
Hydrogen	/●	/●	/●		/●			
Electricty	●/●	/●	/●	/●	/●		●/●	

Figure 5: Transport modes and technical possible energy carriers for today and in future (ERTRAC 2014)

The rising demand of energy for transport in EU member states and worldwide and the reduction of oil dependency can only be met by the comprehensive mix of alternative transport fuels, electro-mobility and increase of energy efficiency. Advanced biofuels have the advantage of a high potential for all transport modes and are the only option for aviation – therefore the development and the progress of advanced biofuels technologies is crucial for rapid market development, which could break the dependence on oil and secure Europe's energy supply, support economic growth and reduce GHG emissions from transport.

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POLICY AND SUSTAINABILITY

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...

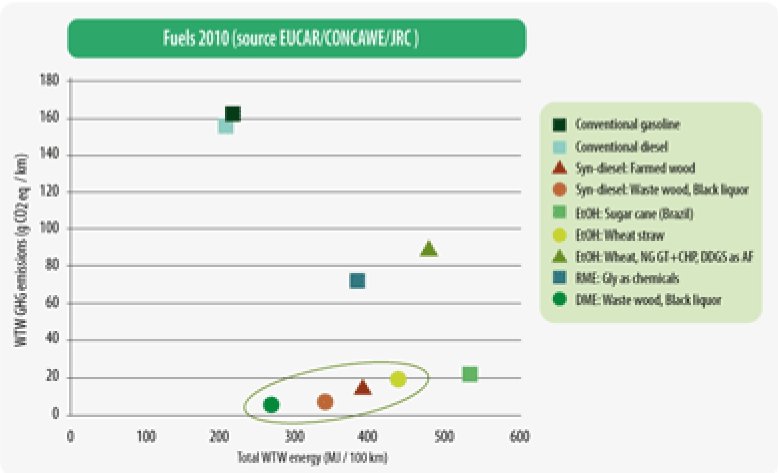
Impact of fertilisers and biofuel policies on the Global Agricultural Supply Chain

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)