# Overview on biofuel technologies: feedstocks and processes development

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## 1. Introduction: renewable energy and bioenergy current scenario

Bioenergy has hystorically been a major component of the whole renewable energy generation volume in the world. The today so-called "traditional biomass" has been the main source of energy for cooking and domestic heating, this fact not always corresponding to sustainable and environmentally sound use of this resource. After the '70s oil crisis, and expecially in the most recent years in relation to the increase of the CO2 and GHGs in the atmosphere, the interest in renewable energy technologies and bioenergy has rapidly increased.

Renewable energy in power generation grew by 15.5 % in 2010 and accounted for 1.3 % of global primary energy consumption. Growth remains concentrated in the leading consuming centers: Europe and Eurasia, Asia Pacific, and North America. Renewable forms of energy account for 3.3 % of global power generation, with the highest share in Europe and Eurasia (5.8 %).

In Europe, EU's primary renewable energy consumption rised by 5 % between 2008 and 2009, achieving 9.4 % of EU's gross inland energy consumption in 2009 [[2]].

Within this scenario, bioenergy represent the major actor, covering approximately 66 % of renewable primary energy consumption in 2009. As regards instead electricity generation, the EU leading technology is hydropower (55.8 %), followed by wind energy (22.4 %) and then biomass (18.3 %).

The 2009 European Directive on the promotion of renewable energies (RED) gave a strong impulse to the whole sector of renewable energy, but biomass was probably the most treated issue in this important EC Directive. Origin, traceability, sustainability where among the most significant issues addressed, and the impact on technology development was extremely relevant. In addition, given the wide deployment of liquid fuels (expecially vegetable oils) for energy generation, the European Commission introduced a clear distinction between liquid biofuels (for trasnports) and bioliquids (for stationary energy generation).

We will now focus on transport biofuels, as this is the sector where the most intensive R&D&D activity is being carried out and that is likely to generate also the greatest technological fallout on the entire bioenergy sector (thus, also on stationary energy generation).

## 2. 1st and 2nd generation biofuels: towards advanced biofuels

The biofuel scenario has evolved very rapidly in the most recent years, and several demonstration plants are under development and commercialisation. Liquid biofuels can be distinguished among first and second ones, according to the definitions given with IEA-Bioenergy Task 39 (Commercialising First and Second Generation Biofuels) [[3]]:

- first Generation Biofuels. These biofuels, largely available on the market, are produced from sugar/starch or oil/fat feedstocks. A possible interaction between food and fuel therefore could occur for this feedstock. Examples are pure vegetable oil, biodiesel, bioethanol from sugar cane or sugar beet. The industrial technologies behind this processes are fully mature, efficient and commercial: R&D is mainly related today to environmental aspects/balances improvement;

- second Generation Biofuels. The feedstocks used for the 2nd gen biofuel chain are above all the lignocellulsic one, even if other unconventional feedstocks are also considered (e.g. algae: sometimes fuels from algae are called third generation biofuels). Lignocellulosic biomass is either thermally and biochemically destructured into cellulose-hemicellulose-lignin components, or thermochemically converted into syngas (mainly composed by CO and H2). 2nd gen biofuels show very good quality characteristics, and this "premium" quality can be better controlled and maintained than in the case - for instance - of biodiesel. Among these innovative fuels we can list Biomass-To-Liquid Fuels (BTL), such as DME, Fischer-Tropsch fuels, pyrolysis oil, etc, or lignocellulosic ethanol.

The main production processes for 2nd gen biofuels are listed in the following figure, while in Table 1 the main products are given.

The main industrial processes in this field are monitored by IEA [[3]].

As regards the biochemical route, the most relevant activities in the field of lignocelllulosic ethanol today are led by Mossi & Ghisolfi/Chemtex (I), Dong Inbicon (DK), Abengoa (ES), SEKAB (SE), in EU, while in USA and Canada Abengoa, BBI, Frontier, KL Energy, Verenium (and other, Iogen, where planned) [IEA-T40]. The largest EU demo plant currently in operation is the Danish Kalundborg lignocellulosic ethanol pant by Dong/Inbicon, processing approximately 30.000 t of straw per year (~4 t/h) into 4300 t/y of ethanol, and the Spanish one by Abengoa, of similar capacity. M&G/Chemtex in Italy is building the largest world lignocellulosic plant in Crescentino (Vercelli, Piedmont Region) based on the proprietary innovative PROESA technology (a new research center fully devoted to this technology has been estabished and operted since 2008): approximately 180.000 will be converted into 40.000 t/y of ethanol (and 12 MWe will be generated from lignin). The plant construction should be completed by mid 2012. M&G/Chemtex, Dong/Inbicon and Abengoa plants were all supported by the European Commission through the EU FP7 programme.

With respect to the thermochemical pathway, the following demo activities can be mentioned: Chemrec (SE), Choren (D), ed NSE (FI), in EU, while in Canada Enerkem in Canada and Range Fuels in USA are also important ongoing demonstration actions. Most of these systems aim at producing Fischer-Tropsch (FT) fuels, DME (Di-MetylEther), bio-methanol or bio-ethanol. In this field, also the SNG (Synthetic Natural Gas) route represent a very important target. The product is biomass-derived natural gas, which is very close to the biomethane that can be obtained from anaerobic digestion followed by cleaning and CH4 separation.

Finally, some demonstration projects (e.g. INEO BIO) are also under completion in the field of syngas fermentation. This route, initially explored in the '80s in USA by Gaddy, is a very original mix among the thermochemical and the biochemical route, as gasification is used to produce a biomass-derived gas that is then ferment to alcohols.

Other high quality biofuels can be produced through other process routes, as vegetable oil hudrogenation (Neste Oy NEXtBTL, PETROBRAS H-BIO, ENI Green Diesel). However, until today these systems still rely on traditional feedstocks as vegetable oils and animal fats. This approach is currently the closest to the production of aviation (i.e. kerosene) biofuels.

Very important routes worth to be mentioned are instead those based on the production of diesel-like fuels from sugars, either "traditional" or lignocellulosic sugars.

Finally, the term "advanced" biofuels is more and more used, being this referred to almost pure hydrocarbon biofuels. This is the case, for instance, of the aviation biofuels mentioned above.

## 3. Green chemicals

The development of second generation technologies also offers great opportunities in the green chemicals field. It has to be remarked that 4 % of each oil barrel is converted into chemicals, and that the market value of these products is at least (in average) one order of magnitude above that of fuels. The fractionation of biomass into C5, C6 and lignin compounds, or the conversion to syngas, can allow the development of process routes to produce Olephines, (Polyethylene, Polypropylene), Solvents, Polymers, Paintings, Resins, Adhesives. Thus, a real large scale Green Chemical Industry could be developed from biomass in the next years.

## 4. Feedstocks

The scenario which has been described in the previous chapter will need large amount of low-cost biomass to be operated. Various considerations can be drawn about that.

Main advantages of these lignocellulosic (or unconventional) feedstocks can be summarised as follows:

- high availability, either as residues (e.g. straw) or as dedicated crop;
- possibility to cultivate lignocellulosic crops on marginal land;
- most of these draught-resistant dedicated crops also requires low amount of fertilizers;
- the unit cost for these dedicated or residual crops is significantly lower than traditional crops for 1st gen biofuels (excluding sugar cane);
- these biomasses do not compete with food crops, unless cultivated in primary agricultural land (the food-fuel conflict is on the land use side, not on the crop side);
- the sustainabiity and environmental balance for these bioenergy chain is very positive and significantly higher that common first generatoin chains (excluding sugar cane).

IEA 2009 World Energy Outlook [[6]] estimates (Reference Scenario) that the biofuel demand at 2030 could reach 167 bill.liters gasoline equivalent, equivalent to 4 % of the forecast demand at that time.

Various other scenarios ranges from 9.3 % (450 Scenario) to 2.2 % (ETP Baseline Scenario), to 26 % (Blu Map Scenario). This last scenario by IEA would allow to achieve the target of 50 % GHG emission reduction: it would consist in a biofuel production of 880 bill.liters gasoline equivalent.

It is finally important to remark that - according to IEA 450 Scenario - the use of 10 % only of available agricultural residues would be sufficient to cover 45-63 % of the biofuel demand at 2030 (approximately 349 bill.liters), while the use of 25 % of residues could generate 385-554 bill.liters of biofuels, well above the target foreseen by 2030. This, thanks to second generation technologies, without using dedicated crops, that could instead be cultivated on low quality marginal land.

Dedicated crops are in fact expected to play a significant role in the future. Among the most interesting options, polyannual crops distinguish among the other in terms of production and sustainability. These crops require a limited fertiliser input during the 15-20 years of cultivation, contribute to biodiversity and to soil protection, and their roots reduce the risks of soil erosion (a serious risk for large areas of Europe).

As an example, Arundo donax (Giant Reed), originated from the Indian sub-continent but largely diffused in the Mediterranean and East Asean areas, represent a major crops for these biofuel chains. Assuming Arundo is used for lignocellulosic ethanol production (as foreseen in the ossi & Ghisolfi / Chemtex project), GHG emission saving should be around 70 %. Another crop of great interest is Miscanthus.

## 5. Conclusions

The potential offered by second generation biofuels is considerable: according to IEA 450 Scenario, the use of only 10 % of residues could be sufficient to satisfy approximately 50% of biofuel demand at 2030. Most likely the major development in the field will occur in OECD Countries and Emerging Economies, as Brasil, India, China.

This system will promote rural development, and new agricultural systems will be developed around bioenergy, without competing with the food chain: however, sustainability of bioenergy systems will have to controlled and traced, so to improve constantly both the environmental performances and the socio-economic impacts.

Rural energy generation through innovative sustainable technologies, low input high yield crops, use of residues, new generation biofuels, biorefining and green chemicals will be the keyword for a bioenergy revolution in the coming years.

## References


[1] **BP Statistical Review** of World Energy. June 2011. Available at bp.com/statisticalreview

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[3] **Bacovsky D., Dallos M., Woergetter M.** Status of 2nd Generation Biofuels Demonstration Facilities in June 2010 - A report to IEA Bioenergy Task 39. Report T39-P1b 27 July 2010.

[4] **Bradley D., Cuypers D., Pelkmans L.** 2nd Generation Biofuels and Trade - An exploratory study. IEA Task 40, Dec 14, 2009

[5] **Jungmeier G.** Classification and Assessment of Biorefinery Concepts in IEA Bioenergy Task 42 “Biorefineries”, ICPS Conference, Leipzig, 2010

[6] **Eisentraut A.** Sustainable production of second generation biofuels. Potential and perspectives in major economies and developing countries. OECD/IEA, Paris, February 2010

**Figure 1** - Renewable energy consumption (million tonnes oil equivalent) and share (%), excluding hydro, by Region. *Source: [[1]]*

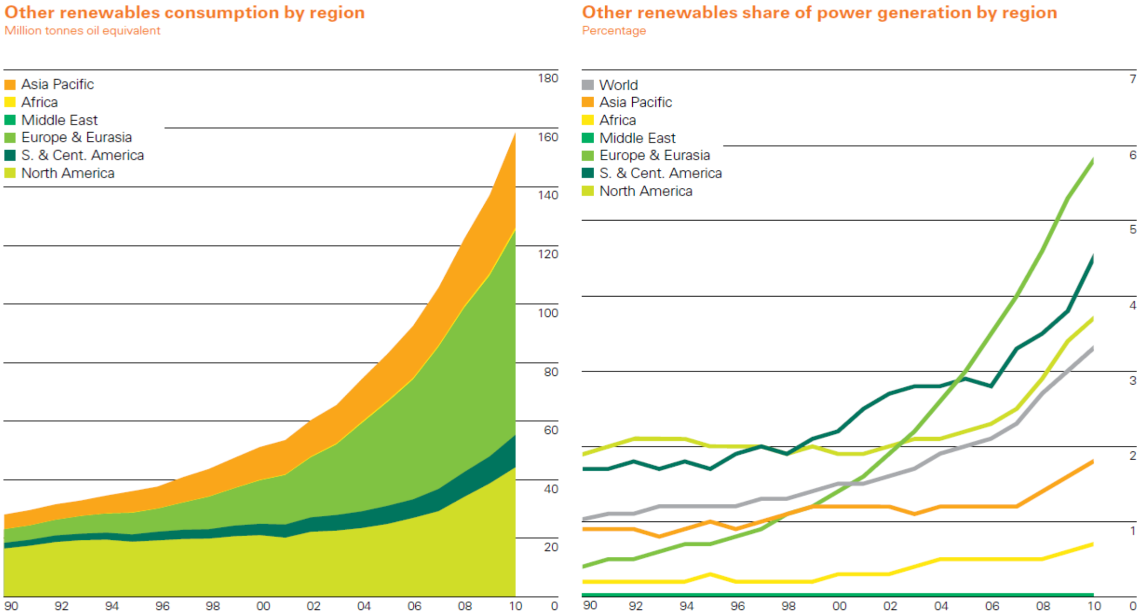


**Figure 2** - Main processes for 2nd generation biofuel production from lignocellulosic biomass. *Source: [[3]]*

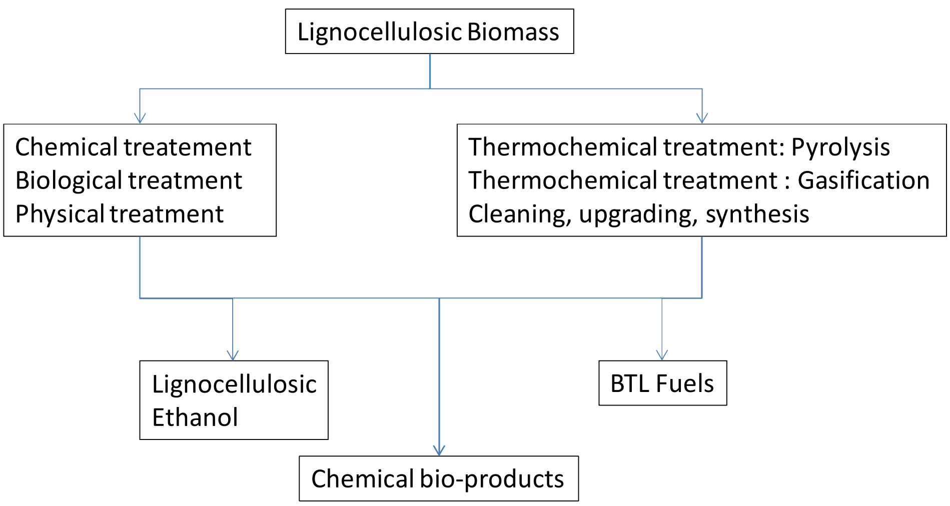

**Figure 3 -** Possible platforms to biorefineries. *Source: [[5]]*

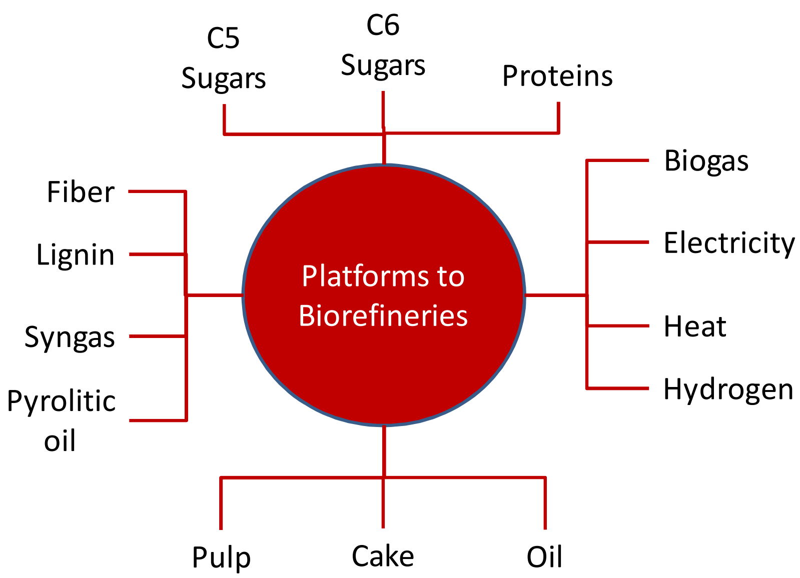


**Figure 4 -** IEA (Blu Map Scenario) estimation of biofuel and land demand at 2050. *Source: [[6]]*

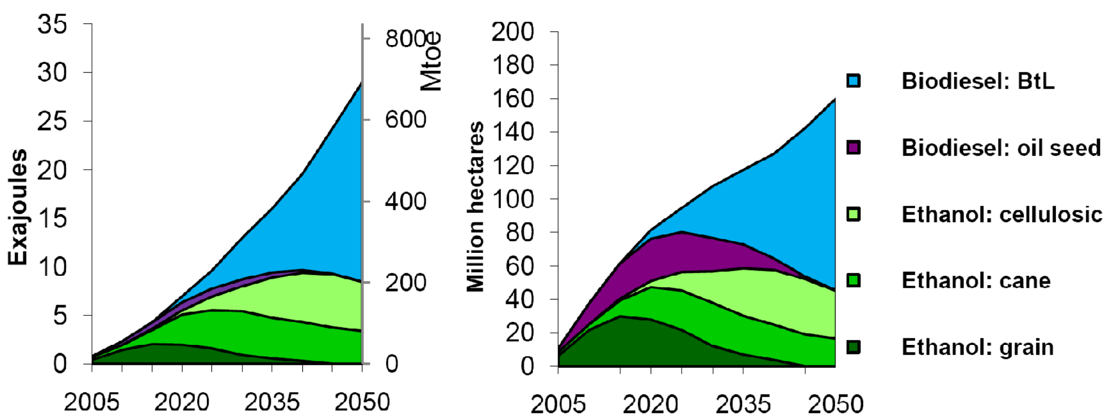

**Table 1** - Main processes and products in 2nd generation biofuels. *Source: [[4]]*

| Biofuel | Type of biofuel | Main production processes |
|---|---|---|
| Ethanol | Ethanol from lignocellulosic biomass | Biochemical: Pretreatement and advanced enzymatic hydrolysis/fermentation<br>Biochemical and thermochemical: syngas fermentation |
| Synthetic biofuels | Fischer-Tropsch Diesel (FT-Diesel)<br>Synthetic Diesel<br>Methanol<br>Di-methyl-ether<br>Higher alcohol (butanol and higher)<br>Ethanol, MTHF, etc | Thermochemical: pyrolysis, gasification, upgrading, synthesis |
| Biodiesel (hybrid 1st e 2nd generation) | Green Pyrolysis diesel<br>H-Bio | Thermochemical: pyrolysis and upgrading<br>Hydrogenation (refining, including vegetable oil) |
| Natural gas | Synthetic Natural Gas | Thermochemical: gasification, synthesis |
| Hydrogen | Biohydrogen | Thermochemical: gasification, synthesis |