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Industrial Initiatives Towards Lignocellulosic Biofuel Deployment: an Assessment in US and EU

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During recent years, in the United States (US) and European Union (EU) a large number of industrial initiatives on so-called “lignocellulosic advanced biofuels” have taken off. The second generation biofuels are today on the ambitious path from lab or pilot scale to demonstration scale in order to facilitate commercial production. In fact, lignocellulosic biomasses are among the most promising feedstocks to develop sustainable biofuels, either from residual (e.g. agricultural wastes like corn stover, wheat staw) or dedicated energy crops (eg.,perennial grasses, short rotation woody biomass). Different types of processing technologies have been investigated and are being demonstrated in pilot scale, namely, biochemical, thermochemical or hybrid: in the hybrid configuration, a combination of thermochemical and biochemical approaches are considered and integrated in a single plant.
Various industrial plants have been designed and built in both the EU and US during the last few years: these state-of-art conversion systems represent the first cases of large scale industrial biorefineries. In the present work, a review of the most relevant ongoing initiatives in EU and US was carried out: the common element of all these projects is represented by the use of lignocellulosic biomass as input material. More than 80 industrial projects in the EU and US have been identified, classified and elaborated, according to location, process type, feedstock, plant scale (feedstock in, product out), type of products, technologies and investment cost (Balan et al, 2013). Processes aiming at gasoline-substituting biofuels versus diesel-like biofuels were separately considered in the analysis, e.g. ethanol or biocrude from advanced thermochemical conversion, as well as the opportunities in terms of new biorefinery pathways. Projections on production costs were considered and discussed. The need for appropriate policy framework is also discussed, examining the most relevant differences between the US and the EU regulatory conditions.
So far, biochemical based industrial initiatives seems to be leading the scenario, with the large commercial plants being constructed using these technologies. Nevertheless, a renewed effort has been recently allocated by various industries to implement thermochemical-based biofuel production projects. Some of these plants are expected to come into full commercial operation in2014.

1. Introduction

During the recent years a great attention has been devoted to the development of lignocellulosic fuels, a type of advanced biofuels. Industry has been deeply involved in this process, and a number of initiatives developed towards large scale demonstration plants, with the support of public Institutions and in collaboration with different research enterprises. The main motivations towards so called second generation biofuels can be summarized as follows:

- Higher yield per ha, lower cost per Ton of feedstock
- No land competition with food (not Hydrotreated Vegetable Oil-HVO, unless Used Cooking Oil-UCO is used or cultivation on marginal land) if areas not economically suitable for food crop production or wastes are used

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- Production plants: higher capital expenditure (CAPEX), but lower operating expenses (OPEX) than first generation biofuels
- Advanced biofuels could become competitive with fossil fuels without support from the government
- They are often high quality / premium fuels in terms of physical-chemical characteristics (this is the case of biodiesel versus HVO/FT-Diesel, for instance). Thus, they could become also 'Drop in' fuels (fuels that can be blended at any certain percentage with fossil fuel. They thus can break the blending walls, and be fully compatible with infrastructure and logistic as well.
- In addition to producing biofuels for road transport, aviation biofuels are also considered.

Producing cost competitive advanced lignocellulosic fuels also have the benefit of CO_2 reduction. Among different biofuels that could be produced from lignocellulosic biomass, ethanol is one of the leading contenders. The present work addresses the EU and US industrial initiatives in this area, as well as provides some hints on the current and future policy framework that will help to commercialize this technology in the near future.

2. Policy framework on lignocellulosic biofuels

There are a large number of possible options for producing Advanced Biofuel that have been investigated in the recent years at different universities and research laboratories. However, only few of these promising options are scaled up in the industrial demonstration point. The definition of "Advanced Biofuels" is however not trivial, as it can quite significantly differ depending on policy priorities, which relates to different policy goals. For instance, considering EU, US and Brazil, one will see various definitions that do not actually and fully match each other.

The definition of 'Advanced Biofuels' should consider two different key components, namely, the feedstock and the technology. The combination of these two elements should be used to define what is truly advanced. This approach would exclude the Hydro-treated Vegetable Oils from the list of Advanced Biofuels, as the oily feedstock is often considered as a low-sustainable feedstock's, unless used cooking oil (UCO) or residual waste oils like technical corn oil (TCO) are used in the process. Other potential oil feedstock which could be sustainable, include, inedible oil such as Camelina, that are produced in marginal lands with low amount of fertilizer and irrigation inputs, or other sustainability-certified oil or sugar crops (Macedo et al, 2008; Shonnard et al, 2010; Ackom et al, 2010).

Another recent approach to define 'Advanced Biofuel' characteristics, by examining the land Use (Direct and Indirect) impacts, and adopting this element to evaluate the sustainability of any biofuel. Thus a new criteria is added (or, maybe, on top) to reduce GHG emissions. That is, 'no land' is used for producing biofuels. In other words, biofuels should be produced only using agricultural wastes as feedstock and not using energy crops that require additional land (even if they are grown on marginal land) for cultivation. This was the recent approach proposed by the EU Parliament (EU Parliament, 2013), in response to the EU Commission proposal amending the Renewable Energy Directive 28/2009 (European Commission, 2009; European Commission, 2012), that aimed at stimulating biofuels.

Formerly, the EU Commission, in its proposal for revision of the EU Directive (European Commissin, 2012), was also recognizing the importance of stimulating the combination of lignocellulosic materials (or other unconventional feedstock, as algae, for instance) with highly innovative technologies. The Commission's proposal was also including lignocellulosic energy crops, and further promoting - through different levels of multiple counting - the use of agricultural wastes.

The European Council is developing its own position in these days, which will probably differ from the Parliament's ad Council's positions. The main topics on which basic differences are present between the European Parliament, the European Council draft position and the Commission's proposal can be summarized as follows:

- Cap to first generation biofuels (particularly, to what extent the cap should be applied?)
- Waste vs Energy crops (i.e. whether energy crops should be allowed or not for advanced biofuels production?)
- Advanced biofuels mandates to be included (or not) in the targets
- How to account advanced biofuels double/multiple counting?
- cascade use of wastes

The European policy to this matter is yet to be clearly defined. This is creating some barrier to commercialize Advanced Biofuels technologies in EU. This could potentially help biofuels being produced outside EU territory (eg., North and South America, and Asia) and sold in EU.

The United States is a net importer of petroleum products. Among the several renewable energy options available, biomass is the only renewable source that is capable of producing petroleum-compatible products. In recent years, government has sponsored numerous research studies and demonstration projects, for developing abundantly available biomass resources in the US for biofuels applications. The major focus is on non-food resources or so-called second generation biofuels. Non-food based cellulosic biomass from different resources such as energy crops (switchgrass, miscanthus), agricultural, and forest residues have been investigated for the production of various biofuels. The US Energy Independence and Security Act (EISA) of 2007 mandates 36 billion gallons per year (BGY) of biofuels production by 2022 from biomass feedstock, from which about 16 BGY is expected to be produced from lignocellulosic biomass. In order to meet this requirement, a number of biochemical and thermochemical methods were developed and tested to produce renewable fuels from lignocellulosic biomass

3. Lignocellulosic Biofuels: processes and products

The next figure 1 describes most of the possible routes for biomass conversion to biofuels.

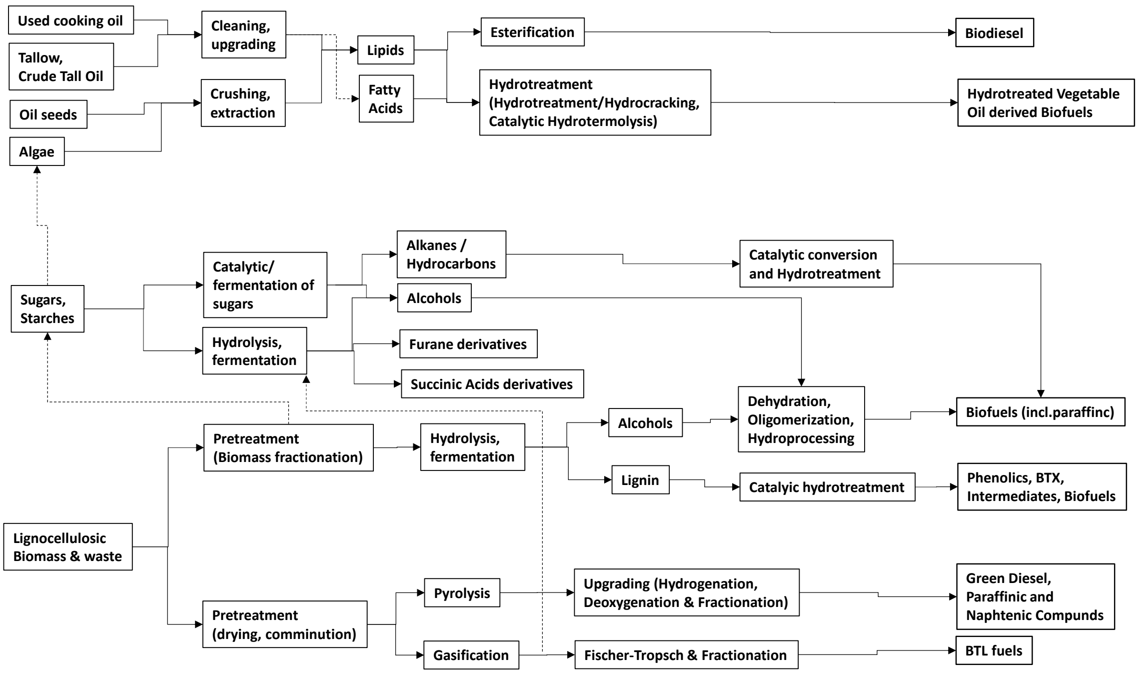

Figure 1 – Possible routes to produce biofuels using different bio based feedstock.

Lipids, sugars and starch are the three dominant bio-based feedstocks that will be used for producing biofuels using biochemical or chemical route. While, synthesis gas will be used for most of the catalytic conversion pathways. Non-conventional feedstock such as lignocellulosic biomass, industrial wastes or algae could also be used for making biofuels. The two main routes are: the biochemical and the thermochemical route. The other possible route of producing biofuel is by using the “hybrid” route, where syngas (that are produced from non-conventional feed stocks) is fermented to different products.

The two most commercially developed biofuels include biodiesel and bioethanol. These oxygenated biofuels are used mostly for road transportation, blended at various percentages with fossil fuel (petrol and diesel) according to different country and regions of the world, local climatic conditions, etc. Table 1 gives an overview of ethanol (and ETBE) blends in different regions of the world.

However, a growing attention is given today to ‘drop-in biofuels’. This term is used to indicate (Karatzos et al, 2013) liquid hydrocarbons that are oxygen free and functionally equivalent to petroleum transportation fuel that can be directly blended with petroleum products fuel. Drop-in biofuels are therefore fully compatible with existing transportation fuel infrastructure and engines. This drop in biofuel is promoted by transportation engine manufacturers and industries, since no new technology is needed for the distribution and logistics of supply chain. In the future, the same biofuels could be used in the aviation sector that currently uses pure paraffinic fuels for running their engines.

Several of the production chains that are listed in Figure 1 end up with drop-in biofuels A common characteristic of this group is represented by the implementation of hydro-treatment/hydro-cracking processes, to remove the oxygen from the raw biofuel and produce the required bio-hydrocarbon products. The critical factor thus become the hydrogen demand, and the amount needed to achieve the required H/C ratio (thus to climb the so called "H/C staircase") (Karatzos et al, 2013).

Table 1 – Ethanol and ethanol-derived fuels use

Neat/Blended biofuel	Description	Use	Countries *(not exhaustive)*
ETBE	< 15% v/v blend in gasoline	All gasoline engines	Spain, Italy, Germany, France
E5	5 % v/v ethanol in gasoline	All gasoline engines	Any Country
E10 (Gasohol)	10 % v/v ethanol in gasoline	All gasoline engines in USA	Sweden, Canada, Brazil, USA *(E15 under discussion)*
E22	22 % v/v ethanol in gasoline	All gasoline engines in Brasil	Brasil
E85	85 % v/v ethanol in gasoline	Flexible Fuel Vehicles	Sweden, Brasil, USA
E95	95 % v/v ethanol in gasoline	Dedicated engines	Sweden, Brasil
E100	100 % hydrous ethanol	Dedicated engines	Sweden, Brasil
Ethanol in Diesel (Diesehol) + additive	< 15 % v/v ethanol in Diesel	Almost standard diesel engine	Various tests in different Countries
ED95 (ex ETAMAX-D)	>92.4 % m/m ethanol + various additives		Various tests in different Countries. Developed in Sweden by SCANIA

4. US and EU Pilot/Demo/Commercial plants

The analysis of US and EU lignocellulosic based biofuel initiatives has identified 80 projects, plus further 6 projects on vegetable oil hydro-treating (including a HVO plant in Singapore) (Balan et al, 2013). Plants are classified as pilot, commercial, demonstration plant, based on the scale and amount of investment. The process technology used in this project are broadly classified in to (i) thermochemical based processes (including the process done using VO hydro-treating), (ii) biochemical processes (typically enzyme and yeasts-based processes) and (iii) hybrid processes (where a combination of Thermochemical and Biochemical routes is present).

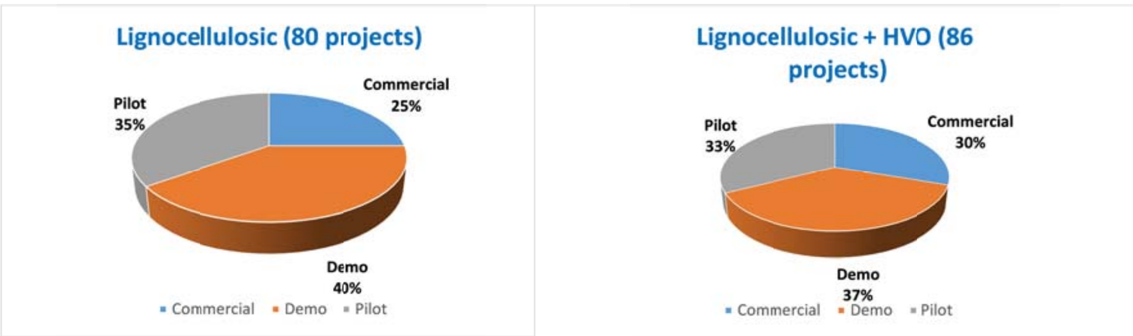

Figure 2 - Advanced biofuels projects identified in the present work

According to developers of these processes, some installations are defined as 'Demonstration' and some other as 'Commercial' (20 out of 80). A common definition of pilot, demonstration and commercial plants has not been reached among technology providers. Sometime companies define their process as "demonstration" plants unit, which can be either of the order of thousand tons or hundred thousand tons. The lack of a common language can create confusion in understanding the real status of the technology.

As a general consideration, various possible criteria could be considered to achieve a most appropriate definition. For instance, a demonstration unit could be considered as the one having an installed capacity of a certain amount between ~1,000 to ~10,000 ton/y. The first unit of that size is however still named “demo”. The commercial plant could start from the scale of ~10,000 to ~100,000 ton/year. In some cases, it will be even higher than 100,000 ton/y.

Another possible definition, more difficult to be applied but probably the most correct one could be, based on the operation of the plant. If a plant is really commercially operated, without any form of support to Research development and demonstration (R&D&D), this would certainly be a full commercial unit. The first plant having this characteristic is often named “Flagship”. Otherwise, if it is commercially operated, but, it received support (either in the form of grant to the investment, or other support as financial guarantees of very low-interest rate loan), then it should still be seen as an industrial demo, as it demonstrate the industrial feasibility of the concept. In other words, the cost of the plant is not yet sustainable without the public support. Clearly, assessing each industrial initiative under this definition can be very complex based on the available information in the public domain. Pilot units have technical risks that was addressed through operation of the pilot plant itself. This is a most agreed definition compared to Demo and Commercial.

Focusing on EU and the US, and excluding HVO, 39 projects were classified in EU and 41 in US. With regards the EU, we found a total of 16 projects were based on thermochemical processing route and 23 projects were based on biochemical processing route. In US, 9 projects were based on thermochemical route, 25 projects were based on biochemical route and 7 projects were based on hybrid route. With respect to final products, assessing the complete list of possible products that manufacturers plan to generate in these biorefinery plants is not provided in the public domain. Very rarely a single item is the output of the plant, more often a range of possible products is typical produces. In the present work, based on statements from the manufacturers developing each projects in EU and US, we are attempting to define a first possible classification to drive the analysis (Table 2). In our scope, the term indicated in the first column could be used to group all types of products listed in the same row.

Table 2 – Proposed classification for products from biorefineries

Keyword	Product family	Keyword	Product family
Adv-D	Advanced Bio-Diesel: Green Diesel (GD), Synthetic Diesel (SD), Renewable Diesel, Btl-Diesel (Btl-D)	**Adv-D_HVO**	Diesel from Hydrotreated Vegetable Oil
Adv-G	Advanced Bio-Gasoline: Green Gasoline (GG), Gasoline(G)	**AvBio_HVO**	Biofuels for aviation from Hydrotreated Vegetable Oil
AvBio	Biofuels for aviation: SPK (Synthetic Paraffinic Kerosene, GJF (Green Jet Fuel), RJF (Renewable Jet Fuel)	**L**	Lignin
BioA-OH	BioAlcohols: BioButanol (BB), BioEthanol (BE), BioMethanol (BM), IsoButanol (IB), Fatty Alcohols (FAl)	**LHCF**	Liquid HydroCarbons Fuels (FT included)
BioG	BioGas	**N**	Naphta
BioM	BioMethane/SNG	**OA**	Organic Acids
C	Char	**Pc**	Protein cream
Chm	Bio-Chemicals: Acetats (A), Bioacrilycs (BAc), BioChemicals (BChm)	**PO**	Pyrolysis Oil
Cs	Cellulosic sugars	**RLF**	Renewable Liquid Fuels
DME	DiMethylEther	**RP**	Renewable Power
EF	Electrofuel	**S**	Steam
F	Fertilizer	**Syngas**	BioSyngas
FO	Fuel Oil	**PB**	Pretreated Biomass
Gyp	Gypsum	**LPG**	Liquid Petroleum Gas
H2	BioHydrogen	**C5M**	C5 Molasses
HC	Hydrocarbons	**Heat**	

Overall, we have identified 49 projects as bioalcohol production process, representing the large majority of all biofuels that are getting commercialized. It is interesting and important to note that 32 projects were targeting more than 10.000 ton/y to m3/y of products, but in reality almost all of these (31) were even addressing more than 20.000 t/y or m3/y of products. Thus, in both cases, real industrial scale initiatives.
By looking at Advanced Biofuels products that are available in the market (including HVO), hydrotreating of vegetable oil is largely produced with a production capacity ~2.19 Mt out of the total of 2.5 Mt produced in the year 2012. The contribution from lignocellulosic ethanol is ~22.7 kTon/y and DME is ~2.4 kTon/y (Chiaramonti et al, 2013). Remarkably, lignocellulosic ethanol that is commercially produced using complex process route is close to successfully getting commercialized. This scenario is made possible with huge financial support given to the public Institutions in Europe (800 M€) and US (1 Bill US$).

6. Conclusions

The field of Advanced Biofuels in EU and US has experienced a dramatic increase in the number of industrial initiatives, supported by public Institutions on both sides of the ocean to a tune of 1.6 billion € in total. The first few plants are achieving commercial maturity, and few plants that use different biochemical pathways and thermochemical pathways are also slowly improved. A significant number of plants are addressing production above 20.000 ton/y or m3/y, thus they can be fully considered as real industrial scale demonstration. With regards to policy framework, this probably still represents the critical issues, particularly in EU, heavily impacting the financing of these large industrial installations. In this respect, decisions taken by policy makers will influence the market deployment of these commercial plants or otherwise hamper their future growth.

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