ANCRE

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BIOFUELS AND BIOGAS

1. State of the art and current development

Gen-2 (second generation) **thermochemical** biofuels can be divided into 3 technologies:

Technology 1: Autothermical BtL[1] Process – Gen-2 Biofuels (biodiesel or biojet)
This technology involves biomass gasification that converts carbonaceous materials into carbon monoxide, hydrogen and carbon dioxide. This is achieved by reacting the material at high temperatures (over 1000 °C) without combustion, with a controlled amount of oxygen and/or steam. The resulting gas mixture is called syngas (from synthesis gas or synthetic gas)... Once purified, this mix is used to produce biofuel via the Fischer-Tropsch synthesis. This process generates synthetic fuel.
Energy yield for BtL is only of 37% as the technology is limited by physical constraints —endothermic reactions, poor CO/H_2 ratio, etc. Typically only w25% of the biomass carbon is converted into fuel carbon.

Technology 2: Allothermic BtL[1] Process – Gen-2 Biofuels (biodiesel or biojet)
Allothermic BtL involves using an external source of energy to proceed to biomass gasification. This increases mass yield.

Technology 3: Methanation – Gen-2 BioSNG
Methanation begins with the same gasification process. The resulting CO and H_2 then form 'syngas' via the catalytic methanation process. The process has a high overall energy efficiency —a conversion rate of biomass to biomethane of 55% to 60%. Syngas can be directly used or may be converted into diesel, ethanol or other fuel molecules —e.g. via Methanol-to-Gasoline technology[2].

Gasification aims at producing biodiesel or bioSNG[3], but can also produce other products such as methanol.

Biological biofuels can be divided into 3 technologies:

Technology 4: Fermentation - Gen-2 Bioethanol (organic)
Gen-2 ethanol is produced by fermenting sugars present in lignocellulosic biomass. 'Classical' processes involve four steps: i) pretreatment which includes conditioning followed by a physical-chemical treatment aiming at breaking up the structure of the lignocellulosic matrix, ii) hydrolysis of cellulose and hemicelluloses into monomeric sugars, iii) fermentation of monomeric sugars to ethanol, usually by using yeasts, and iv) separation of ethanol from the fermentation broth, usually by distillation. An alternative is to convert the sugars obtained into other products such as butanol using specific microorganisms.

Technology 5: Heterotrophy
Heterotrophic production is defined here as the biological production of non-alcohol biofuels from organic carbon substrates such as glucose. In such processes, microorganisms can be yeasts, bacteria or microalgae, cultivated in stirred-tank bioreactors. When using algae in heterotrophy, growth is independent of light energy, which allows for much simpler scale-up possibilities since smaller reactor surface to volume ratio may be used. These systems provide a high degree of growth control and also lower harvesting costs due to the higher cell densities achieved." (Brennan&Owende, 2009[4]). Heterotrophy also includes biotechnology pathways which involve extracting sugars from plants or plant waste (lignocellulose) and fermenting them by

[1] BtL: Biomass to Liquid
[2] Sources: Oil and Gas Science Technology, *Second and Third Generation Biofuels: Towards Sustainability and Competitiveness* (2013); European Biofuels Technology Platform official website
[3] NG: Synthetic Natural Gas
[4] Source: Owende P., Brennan L. (2009), "Biofuels from microalgae—A review of technologies for production, processing, and extractions of biofuels and co-products, in Renewable and Sustainable Energy Reviews.

adding microorganisms to obtain molecules of interest for fuels and chemicals —e.g. the Amyris project (which involves screening and engineering microorganisms for the production of farnesene, a key molecule obtained through hydrogenation) or the production of lipids by the yeast *Yarrowia*.

Technology 6: Anaerobic digestion - Biomethane

Anaerobic digestion involves creating biogas from organic wastes such as sewage, manure, food wastes, landfill, etc. Biogas is a mixture of biomethane CH_4 (65-70%) and CO_2 (30-35%) and small amounts of other gases. Biogas may also be produced from lignocellulosic feedstock such as straw, following pre-treatment with steam and enzymes. After further purification, biogas becomes biomethane with the same quality as natural gas, which can be used in vehicles or injected into the natural gas network[5].

Gen-1 biofuels are produced from resources that are potentially competing with food crops and feed uses. There are 3 main conversion technologies, each leading to different products:

Technology 7: Fatty Acid Methyl Ester (FAME) Gen-1 Biodiesel

FAMEs result from the transesterification process, which converts fatty acids —generally from vegetable oils— into esters blended with Diesel oil in limited proportion —around 10% volume in common engines, between 30 and 100% volume in adapted engines. This product is largely used in countries with high dieselization fleet, mainly in Europe.

Technology 8: Hydrotreated Vegetable Oil (sometimes called Gen-1bis biodiesel or biojet)

HVO process involves a hydrotreatement of fatty acids to produce a synthetic biodiesel or biojet with a high incorporation rate potential. The main industrial capacities are in Asia and in Europe but development is currently limited due to competition on biomass resources and to less competitive production costs.

Technology 9: Gen-1 Bioethanol

Gen-1 bioethanol is the most consumed biofuel (worldwide), in blend with gasoline. Gen-1 ethanol is produced by fermenting sugars from sugar crops —such as sugarcane or sugarbeet— and from starch crops —such as wheat and corn. The main industrial production capacities are located in the U.S.A. and in Brazil.

Due to the high temperature conditions, the thermochemical processes (technologies 1 to 3) accept various primary resources that could be suitable for local technical and economic potentials. However this favorable criterion can be counterweighted by the size of the unit, which needs to be bigger when several primary resources are used. For instance the biomass used in the BtL process is made up of forest and plant wastes, straw and other lignocellulosic materials sourced from different locations. The BtL process aims at full flexibility through the innovative concept of co-processing, which means not only developing a process chain that works with a wide variety of biomass feedstock, but also with liquid and solid fossil fuel feedstock. The target can be to propose a process chain capable to handle both pure biomass and pure fossil feedstock. This idea is highly favorable to be in the position to build large-size plants, which seem to be the only profitable plants for now.

The deployment pathway of bio-processes chain in general and thermo-chemical processes in particular is based on finding a balance between international technologies and (local) biomass resources. Moreover the way fuel market is structured (for Diesel or gasoline) also impacts the intensity of the effort made on technologies —Europe and France in particular are looking for a substitute to diesel.)

[5] Sources: European Biofuels Technology Platform official website; Engie official website < *http://www.gdfsuez.com/en/businesses/gas/gas-energies/biogas/what-is-biomethane>*

2. Maturity level and technological perspectives

Maturity of elementary technologies associated with biofuels and biogas

Methodological information:

The maturity level is the TRL, reduced to 5 levels with market deployment enclosed in the higher TRL classes; maturity level scaling: 0 = none; 1 = fundamental research; 2 = R&D; 3 = demonstrator; 4 = low deployment; 5 = large deployment.

	2015	2020	2030	2040	2050
Autothermic BtL (Gen-2 biodiesel)	2	3	4	4-5	5
Allothermic BtL (Gen-2 biodiesel)	2	3	4	4	4
Methanation (bioSNG)	2	3	4	4	5
Fermentation (Gen-2 bioethanol)	4	4-5	5	5	5
Heterotrophy (Amyris project)	2	3	3	4	4
Anaerobic digestion	4-5	4-5	4-5	4-5	4-5
Fatty Acid Methyl Ester (Gen-1 biodiesel)	5	5	5	5	5
Hydrotreated Vegetable Oil (Gen-1bis biodiesel/biojet)	4-5	4-5	5	5	5
Fermentation (Gen-1 bioethanol)	5	5	5	5	5

This table takes into account the **most advanced technologies** (or the best available technologies). Therefore only one allothermic BtL process is considered as it stands out as the most mature of allothermic BtL technologies. This table shows that most technologies are not mature yet. However in many countries anaerobic digestion still involves small facilities. Germany is a prime example as it is developing many facilities —some of which will be based on microalgae. Resource availability issues have a very strong impact on the development of technologies. As a consequence, even if bioethanol seems to mature rapidly —compared to biodiesel—, this technology might not be competitive enough compared to Gen-1 bioethanol. The development of most of Gen-2 technologies will not only depend on technological advancement: resource price and availability will also condition how these technologies will develop. Last but not least, allothermic BtL technologies are electricity-consuming, the country's electric mix will determine the technology's carbon emissions. This technology can also be considered as an electricity storage solution.

Potential development of technologies related to biofuels and biogas

Methodological information:

Potential development is measured as the percentage of the technology's contribution to environmental protection. This means evaluating, in terms of carbon emissions and of carbon emissions reduction, to what extent this new technology can contribute to limiting temperature increase to 2°C above pre-industrial level according to the time horizon considered in this study. Potential development scaling: 0 = not significant; 1 = significant (i.e. more than 1% of global emissions reduction) in some countries; 2 = significant on the global scale; 3 = very significant on the global scale (i.e. up to 3% of global emissions reduction); 4 = major technology vs. climate change (i.e. more than 3% of global emissions reduction).

	2020	2030	2040	2050
Potential development Gen-2 & biogas	0	0	1	2
Potential development Gen-1	1	1	1	1

Gen-1 technologies are mature technologies and are well developed in every continent. They already have a significant contribution regarding the current incorporation rate near 5% Lower Heating Value at global scale, but their expansion will remain limited due to constraints on resource availabilities.
Most of Gen-2 technologies will only start developing after 2040 and 2050 (see previous table on maturity levels). This is why it will be long before Gen-2 biofuels have a significant impact on CO_2 emissions reduction.

3. Technological, economic and social bottlenecks

Methodological information:

The following table ranks the bottlenecks according to their impact on the development of the technology. A bottleneck ranking at 6 on the scale will hinder or stall the deployment of the technology compared with bottlenecks ranking at 1; conversely, a bottleneck ranking at 1 will hinder the deployment of the technology much less than bottlenecks ranking at 6. Note that the ranking is relative, meaning that a bottleneck ranking at 6 is not necessarily hard to remove; conversely, a bottleneck ranking at 1 is not necessarily easy to remove. Technologies rank according to: research, finance, regulations, resources & environment, security and acceptability. The table also contains keywords associated with each bottleneck.

It must be stressed that the ranking of such different factors must be considered with caution; as an expert's judgement, not a quantitative assessment.

Technology		Research & technological bottlenecks	Economy and financial bottlenecks (investment, risks)	Regulation & institutional environment	Resources & environmental impacts (including scarcity of raw materials, water, land, climate)	Safety & security (impacts on health, people and security assets)	Socio-technical feasibility
Autothermic BtL	Rank	3	6	4	5	2	1
	Key-words		High investment costs	EU regulation	Scales of plants not adapted to local biomass resources		
Allothermic BtL	Rank	3	6	4	5	2	1
	Key-words		Very high investment costs	EU regulation	Scales of plants not adapted to local biomass resources		
SNG methanation	Rank	2	5	6	3	4	1
	Key-words		High investment costs	EU regulation	Scales of plants adapted to local biomass resources	CO management	
Gen-2 Bioethanol	Rank	3	5	6	4	2	1
	Key-words						
Heterotrophy (Amyris project)	Rank	5	6	4	3	2	1
	Key-words						
Biomethane	Rank	2	3	4	6	1	5
	Key-words	Purification					
FAME (Gen-1 biodiesel)	Rank	1	4	5	6	2	3
	Key-words		Risk with high price volatility	EU regulation	Various impacts according to resource availability and potential land use		
HVO (Gen-1bis biodiesel/biojet)	Rank	1	4	5	6	2	3
	Key-words		Risk with high price volatility	EU regulation	Various impacts according to resource availability and potential land use		
Fermentation (Gen-1 bioethanol)	Rank	1	4	5	6	2	3
	Key-words		Risk with high price volatility	EU regulation	Potential land use change impacts		

A focus on some bottlenecks

Safety and security - Specific and heavy facilities are required to manage carbon monoxide emissions.

Financial - BtL is a very capital-consuming technology: indeed, prices for BtL factories amount to about one current billion euros.

Resource – Resource limitation and food/feed competition are the main bottlenecks for Gen-1 technologies. Furthermore regarding lignocellulosic resources, because of availability issues, the size of BtL factories is not always linked to the resource location and can be developed in harbors with large imports. This can hinder the development of the technology (public support is often based on local development).

Regulation – Regulation is also a crucial bottleneck for Gen-1 technologies and particularly in Europe where a maximum incorporation rate is established in the 2020 EU Energy & Climate Package targets. The regulation dimension is not only linked with the development of (large) industrial facilities, but also with the biomass procurement issues including land use, competition with food, biodiversity, water consumption… This bottleneck can be found in standards incorporating the sustainability dimension of those productions. For instance, the EU[6] has defined a set of sustainability criteria to ensure that the use of biofuels (used in transport) and bioliquids (used for electricity and heating) is done in a way that guarantees real carbon savings and protects biodiversity. Only products that comply with the criteria can receive government support or count towards national renewable energy targets. Moreover, for bioethanol, due to the more direct relationship with the agriculture sector due to the used biomass, the regulation is less harmonized in Europe and can impact the deployment of the associated technology.

4. Potential radical and incremental innovations

Methodological information:

The following table lists the nature of innovations needed to overcome the bottlenecks mentioned earlier. There are two types of innovations: I stands for 'incremental innovation' (i.e. improving existing products and processes) and R stands for 'radical innovation' (i.e. developing new products and processes).

Technology		Research & technological innovations	Economy and financial bottlenecks (investment, risks)	Regulation & institutional environment	Resources & environmental impacts (including scarcity of raw materials, water, land, climate)	Safety & security (impacts on health, people and security assets)	Socio-technical feasibility
Autothermic BtL	I or R	R	R	R	R	I	I
	Key-words	Smaller size	High investment costs	EU			
Allothermic BtL	I or R	R	R	R	R	I	I
	Key-words	Smaller size, plasma (nuclear energy)	High investment costs	EU			
SNG methanation	I or R	R	R	R	I	I	I
	Key-words	Size		EU			
Gen-2 Bioethanol	I or R	I	R	R	R	I	I
	Key-words			EU			
Heterotrophy (Amyris project)	I or R	R	R	R	I	I	I
	Key-words			EU			
Biomethane	I or R	I	I	I	I	I	I
	Key-words			EU			
FAME (Gen-1 biodiesel)	I or R	I	I	I	I	I	I
	Key-words				Resource substitution with waste biomass		
HVO (Gen-1bis biodiesel/biojet)	I or R	I	I	I	I	I	I
	Key-words				Resource substitution with waste biomass		
Fermentation (Gen-1 bioethanol)	I or R	I	I	I	I	I	I
	Key-words				Resource substitution with waste biomass		

[6] https://ec.europa.eu/energy/en/topics/renewable-energy/biofuels/sustainability-criteria

The radical innovations are found for the tryptic already mentioned - “financial/resource/regulation”:

- Investment needs are very high (mainly for BtL and BtL allothermic processes). These types of biofuel need adapted regulation and biomass supply has to be organized (EU-level needed for European countries).
- There is a huge financial risk concerning resources. Resource price is a significant factor as it conditions the technology’s development, cost, etc.
- Gen-1 technologies can also be produced from waste type biomass like waste cooking oil, animal grease, industrial byproduct (stillage), etc. which can overcome EU policy limitation. However, these resources availability remains limited.

The fourth radical innovation is on R&D, mainly:

- Small plants need to be more profitable, which will be possible if a technological radical innovation occurs.
- Concerning BtL processes, new gasification reactors need to be very flexible as the nature of biomass and wastes is usually highly versatile.
- The production of high added value byproducts, in particular for the heterotrophy technology, should be improved for chemistry or pharmaceutical industries.