Decarbonization Wedges Exercise

December 2015 – www.allianceenergie.fr

3G BIOFUELS (MICROALGAE)

1. State of the art and current development

3G biofuels are based on the exploitation of microalgae (photosynthetic microorganisms). Three steps are required.

- The first step is strain selection. There are different ways of selecting algae strains for industrial-scale culture: research laboratories are currently considering biodiversity screening, metabolic optimization and synthetic biology;
- Microalgae are then placed in large culture systems exposed to solar radiation to consume CO_2 either from air or from neighboring CO_2-emitting plants;
- The last step is post-processing, which can be done in several ways. The most common method is the extractive method which involves extracting wet biomass in different steps: harvest, biomass concentration, cell destruction together with the extraction of lipid molecules which is the base and the purpose of algae energetic valorization. Algae refineries are based on valorizing molecules of interest. Hydrothermal liquefaction is another post-processing method, which involves the conversion of concentrated biomass into bio-crude using a pressurized reactor —100 bars, 250°C. Traditional oil industry techniques are then used to refine the bio-crude.

Considering the three processes —strain selection, culture and post-processing— as a whole is crucial to the development of microalgae technology as a source of energy.

2. Maturity level and technological perspectives

Maturity of 3G biofuel (microalgae)

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
Maturity level	2-3	2-3	3	4	5

The three processes —strain selection, culture and post-processing— have different maturity levels, and they are even less mature if the microalgae technology is implemented on an industrial-scale. In theory the same post-processing method is used for algal lipid transformation into biofuels as for plant lipid transformation into biofuels, but concretely the algal lipid transformation technique is much more complicated.

The two post-processing methods mentioned above —extractive method and hydrothermal liquefaction— currently rank at 2 on the maturity scale (R&D) with pre-industrial pilots that do not allow the coupling of each step of the culture process and of post-processing —including harvest, biomass treatment and conversion.

All other technologies which produce biofuel from microalgae rank at 1 (fundamental research) on the maturity scale. This includes the excretion of energetic molecules —lipids, alkanes, alcohols— directly from the algae's culture medium, which is interesting: indeed as some processing are not required, significant energetic and economic savings are achieved.

Several American companies use quite large facilities —compared to microalgae facilities elsewhere in the world, notably in France— but their technology is not mature. Bio-crude production at a relatively low price through pre-industrial pilots can be expected by 2025. Therefore demonstrators displaying a quite mature technology level (large deployment) should not be expected before 2030.

Potential development of 3G biofuel

<u>Methodological information:</u>

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	0	0	0	0-1

Microalgae technology will not be part of the energy mix until 2030, and the slow deployment of this technology will not lead to any significant decarbonization until 2050.

3. Technological, economic and social bottlenecks

<u>Methodological information:</u>

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
Photosynthetic micro-organisms	Rank	6	5	1	4	2	3
	Key-words	Mutagenesis, GMO, Synthetic biology Large scale production systems Positive energy production processes Down Stream Processing	Research investments		Culture medium recycling and water treatment Optimization of biofuels production vs. co-products valorization. Land footprint	Problem of GMO spreading	Problem of GMO spreading

Regulation and perception about GMOs are different in the EU, in the U.S.A and in Asia. Indigenous species have few impacts on the environment. However GMO species raise the issue of GMO spreading and of including a genetic switch which would prevent the genetically modified strain from surviving into the wild.

There is also a possible issue of conflict over available land, notably concerning land footprint on onshore land, and near CO_2 industrial sources.

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**
Photosynthetic micro-organisms	I or R	I/R		R	I/R		
	Key-words	More efficient processes and better algae strains		Protection of intellectual property rights	Promotion of circular economy		

Concerning research, incremental innovation is possible by adapting existing technologies to wet algal biomass. Developing specific harvest, cell destruction and molecule extraction techniques through energy optimization of the whole process, as well as achieving molecules salting-out through strain selection with no cell destruction pertain to radical innovation.

Technology-wise, incremental innovation is possible through raceway-based facilities for microalgae technology. Furthermore, developing a rapid —i.e. lasting a few seconds— and energetically efficient hydrothermal liquefaction method would increase biomass efficiency and energy as well as reduce environmental impact.

Radical innovation is possible through industrial-scale culture methods through cost and energy optimization as well as the idea of achieving "ideal strains" through synthetic biology.