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Editorial

Algal Biomass: From Bioproducts to Biofuels

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Microalgae covers an extremely diverse type of unicellular microorganisms that use light and efficiently fix CO_2 through the process of photosynthesis. They represent an enormous potential not only for producing bio-energy but also as a source of new bio-based materials [1].

The use of microalgae to produce cosmetics and nutraceuticals is a growing industry with many new upcoming products (for example, specific microalgae extracts used as food supplements [2] and active molecules for the cosmetic industry [3]). In the meantime, research to make biofuels from microalgae viable are making significative improvements in terms of productivity, cost and environmental impacts [4]. However, their cost is still far above what would be needed to be economically feasible due to the current oil cost [5]. There is still a need for further research and development for the microalgae industry to make the step from the high-value to the commodity products.

This Special Issue, entitled "Algal Biomass: From Bioproducts to Biofuels" had the objective to promote various research actions from strain selection to through techno-economic analyses culture optimization. It consists of 7 articles in which 5 are research papers and 2 are reviews.

Besides biodiesel and bio-jetfuel, hydrogen is another energy carrier that can be produce by microalgae. Hydrogen has been the focus in the early years of the Aquatic Species Program (ASP) from 1978 to 1982, before the ASP turned to microalgae biodiesel. Research on hydrogen production by microalgae has continued since to overcome the main challenge to produce hydrogen in a steady and continuous manner. Together with the increasing interest to hydrogen as an energy carrier, breakthroughs have been recently made that pave the way to microalgae hydrogen production. One of them is to design synthetic algal-bacteria consortium to stimulate symbiosis effects and produce hydrogen continuously and steadily. Hupp et al. managed to design a *Chlorella-Bacillus* consortium that is producing significantly more hydrogen using starch than the *Chlorella* alone [6]. The next step of this research would be to replace starch with a carbon source of negative cost coming from waste.

Selecting the most appropriate microalgae is one of the major step to the path to sustainable microalgae biofuel production. To that purpose, lipid productivity is a crucial requirement, but other parameters are also important such as robustness (growth capability in the various environmental conditions of industrial culture) and also an adequate biomass composition. Ideally, the lipid profile should mainly be composed of fatty acids suitable for biofuel applications and the biomass should contain very few heteroatoms and ash that are detrimental to the resulting biofuel characteristics. Ramírez-Romero et al. selected a microalgae strain that fulfil these requirements [7]. Under balanced nutrient limitation, *Chlorella vulgaris* NIES 227 could produce up to 54% of total lipids mainly constituted of MonoUnsaturated Fatty Acids (MUFA), ideal for biodiesel applications. Moreover, the produced biomass was low in N, O, S and ash, reducing its potential to produce NOx and SOx during the combustion of the biofuel. In a second paper, Chambonnière et al. proved that *Chlorella vulgaris* NIES 227 was also capable of producing lipid at the pilot-scale in various conditions [8]. The authors also managed to correlate the photosynthetic capacity

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of the microalgae to fix carbon to the cell internal-protein content. This relation could help to develop productivity models, with the aim of optimizing lipid productivity at the industrial scale.

Nannochloropsis and *Chlorella* are two genera well known for producing high level of lipid. However, they are also very robust strains with cell membrane and wall difficult to break, an important pretreatment step for lipid extraction. In their techno-economic study, Valdovinos-García et al. estimated the impact of various cell disruption technologies to the energy consumption and biofuel production cost [9]. The authors showed that the cost and energy consumption of cell disruption could be as high as USD 41/kg and 8.9 kWh/kg respectively for bead milling. With an energy content below 6 kWh/kg and targeted production cost below USD 1/kg, the cell disruption technology should therefore be carefully chosen. Large improvements on cell disruption are still needed for the lipid extraction pathway to produce sustainable biofuel.

The storage of microalgae would certainly be a major challenge for future biorefineries. Indeed, the feedstock would need to endure minimal changes in its composition not to affect the process efficiency. Oginni et al. showed that wet anaerobic storage could be a good option for preserving the biomass quality of *Nannochloropsis gaditana* [10]. They inoculated the biomass with lactic acid bacteria that convert algal sugars into organic acid preventing other microbial activities. This new technique could be of great help to optimize the logistics of microalgae biofuel production.

The path to sustainability for microalgae biofuel production will certainly include bioremediation [11]. The use of waste streams (either industrial fumes containing CO_2 or wastewaters containing nutrients) can indeed reduce the environmental impact of microalgae biofuel (benefit from carbon credit for CO_2, reduce the high environmental cost of nutrients, reduce the water footprint) and decrease its production cost. In a review, de Carvalho et al. investigated the potential of agro-industrial wastewaters for the microalgae industry [12]. The authors discussed the enormous variety of waste streams of this industry (e.g., digestate, sugarcane vinasse, palm oil mill effluent, dairy processing wastewater, . . .) together with their potential use by microalgae and the associated challenges (e.g., their high concentration in organic pollutants and resulting turbidity). They also proposed some perspectives for the development for coupling microalgae production with agro-industry waste recycling.

Anaerobic digestion is a promising technology for microalgae as it can efficiently convert its biomass into methane. It can successfully be applied to the residues obtained after lipid extraction, improving the energy balance of the whole process [13]. However, a preatreatment step is needed to break the microalgae cells and make their content available to anaerobic bacteria. The second review article of this Special Issue provides insights into the efficiency and energy balance of different pretreatment methods [14]. These two parameters are essential for the industrial implementation of microalgae anaerobic digestion. The authors suggested that improvements should be done on various aspects such as less-energy-intensive technologies, combination of pretreatment methods or process integration.

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