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Editorial

Upstream Bioprocesses to Biomass-Based Platform Chemicals and Derivatives

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Over the past few decades, the need for new, more accessible and renewable raw materials has become evident. The biomass or matter contained and created by living beings through their metabolisms is created annually in quantities of more than 180 billion tons, an amount far greater than the 8 billion tons of fossil resources mobilized each year [1]. Most of this biomass is lignocellulosic (more than 80%) and is not directly edible for humans, which avoids tensions in the food market. Combining the plentiful availability of biomass and the knowledge and, in part, the technology gained during the last 150 years in crude refining and transformation, biorefineries are thought as complex, multifeedstock, multiprocess, integrated facilities, transforming diverse biomasses in a wide range of products via diverse platform chemicals: bio-oils, biochars, biogas, sugars, fatty acids, proteins and more [2].

Originally, biorefineries have been inspired by processes in the food and pulp and paper industries [3,4]. The use of food resources is typical in the so-called first-generation biorefineries, initially meant to produce huge amounts of bioethanol by yeast fermentation of sucrose derived from corn via enzymatic hydrolysis (in the USA) or from sugar factories in Brazil transforming enormous quantities of sugarcane—which is the bioethanol mixed with gasoline in various amounts, up to 85% v/v [5]. In parallel, most biodiesel is obtained from food-grade oil that is rich in triglycerides extracted from oil palm nuts, soya beans, rapeseed, sunflower seeds, etc. [6]. The extraction operations are typical in the food industry, and only the transesterification of triglycerides with low-molecular-weight alcohols can be envisaged as a different type of process; even the hydrogenation of triglycerides to HVO—a biomass-based substitute of diesel—is based on oil hydrogenations common in margarine manufacturing. Therefore, as biofuels are increasingly being blended with gasoline and diesel (up to 85% in gasoline; up to 20% in diesel) and most bioethanol is still produced via the aforementioned first-generation biorefining, a notable stress in the food sector has emerged. HVO is emerging as a supplement for diesel, together with biodiesel from transesterification; however, to reiterate, most oil transformed is from an edible source [7].

The second- and third-generation biorefineries emerge as a solution to the stress posed by first-generation biorefinery processes and expand the biorefinery solution by including the majority of biomass created annually at a global scale [8]. The huge cultivation of macro- and microalgae needed for third-generation biorefineries is still in its infancy, though rapidly progressing. In contrast, lignocellulosic biomass is widely available and can originate from the agriculture, forestry and food sectors, either directly or as residues. Lignocellulose transformation can be performed by combining physical, chemical, biocatalytic and microbial processes via a thermochemical approach [9], a fractionation strategy (as shown in Figure 1) [10] or combining them. However, the high oxygen content of this feedstock, the even higher resistance to physical and chemical change and the chemical diversity of lignocellulosic biomass pose notable technical and scientific challenges.

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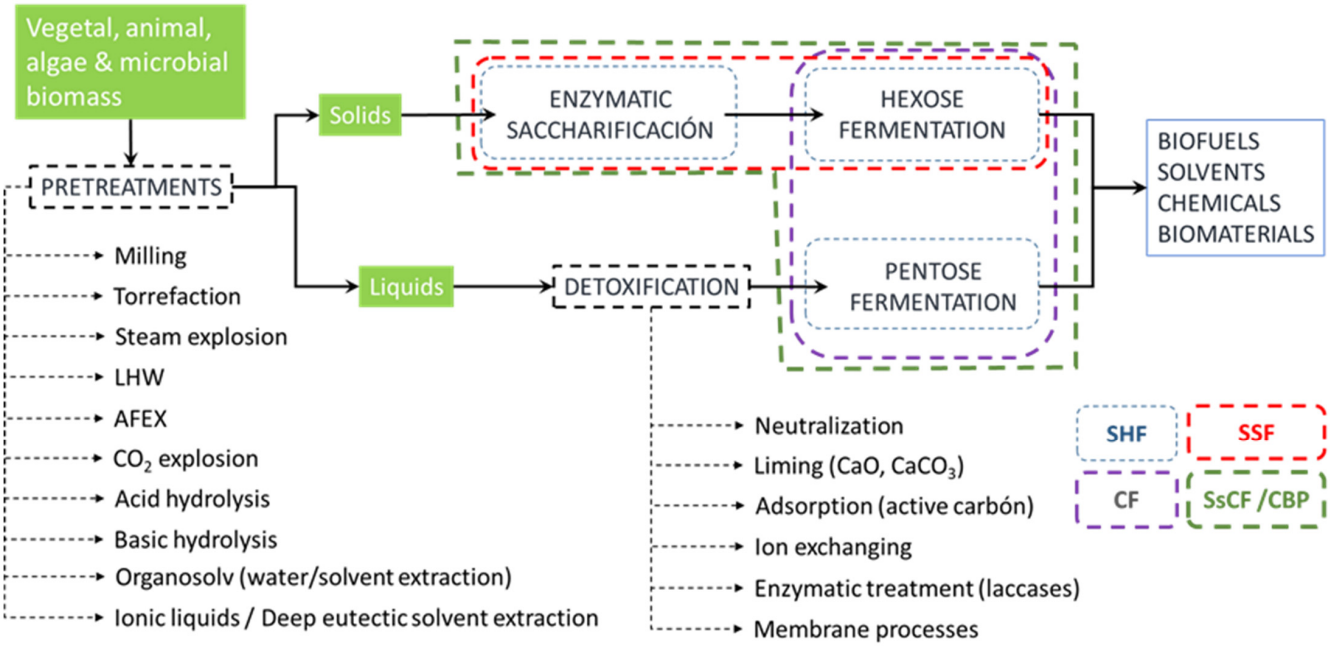

Figure 1. The general fractionation biological biorefinery scheme: From biomass to chemicals and materials via bioprocessing with enzymes and microorganisms. Pretreatments are needed to render the most recalcitrant biomasses amenable for bioprocessing, together, sometimes, with detoxification processes to remove acids, aldehydes, lipopolysaccharides and phenols (including diverse lignin types and lignin oligosaccharides). Enzymatic and microbial bioprocessing can be applied in-series (SHF: separated hydrolysis and fermentation) or together (SSF: simultaneous saccharification and fermentation). Some microorganisms are capable of using pentoses from hemicelluloses and pectin and hexoses from all polysaccharides at the same time (CF: co-fermentation) and can be combined with enzyme cocktails working at the same bioreactor in a one-pot strategy to obtain the targeted compounds (SsCF: simultaneous saccharification and co-fermentation). The ultimate approach is to create genetically engineered microorganisms that can synthetize enzymes, which are able to degrade the biomass to low-molecular-weight compounds that can be transported within the cell and metabolize to products of interest (CB: consolidated bioprocessing).

In this Special Issue, several of the key processes in the upstream section of biorefineries, devoted to the creation of platform chemicals and industrial intermediates, key ingredients or reagents for the final market products, are tackled. It is a collection of notable contributions showcasing diverse key aspects of the first processes of a biorefinery: the upstream section.

Contribution 1 focused on the statistical optimization of steam explosion [11] as a pretreatment that renders a lignocellulose biomass suitable for the next transformation here studied: the production of bioethanol at high-solid load after the enzymatic transformation of the pretreated biomass into a glucose-rich hydrolysate. To this end, the authors employed both horizontal and vertical fermenters which had suitable propellers for operation, with large solid concentrations. In contribution 8, the authors applied an empirical modeling of the response surface, severity factor and multi-response desirability function methodology to explore the feasibility of soybean hull, a major lignocellulosic residue, as a source of bioethanol. To this end, a thermochemical pretreatment based on H_2SO_4 was optimized and supported the SHF process to bioethanol with *Saccharomyces cerevisiae* as the biocatalyst in good mass yields.

Pretreatments open the door to economically feasible productions of bioethanol, lactic acid, succinic acid, fumaric acid, microbial alginate—a most promising exopolysaccharide—and bioplastics, all of which are potential substitutes, at least partially, of petrochemical-based polymers [12–14], to name but a few of the large diversity of potential biorefinery platform chemicals and material ingredients. The importance of bioethanol as co-fuel has

been commented before; even if it is not a perfect substitute for gasoline, its power as a polar solvent is of utmost importance in the extraction of bioactive, antimicrobial, antioxidant mixtures out of several lignocellulose biomasses. Lactic, succinic and fumaric acids act as acidulants and flavors in the food and feed industry, but they are also considered promising biomonomers to synthetize biobased polyesters and polyamides.

Lactic acid production is the target of contribution 3, where the authors start from steam-exploded sugarcane bagasse that is hydrolyzed through a mixture of Cellic CTec3 and Cellic HTec3 enzymatic cocktails and further transformed into the acid by *Bacillus coagulans* DSM 2314 with high yields and productivities. Furthermore, the importance of inhibitor elimination and its relation to pretreatment conditions was evidenced. The authors in contribution 5 explore the possibility of using a lignocellulose-rich source, cow manure, as feedstock for lactic acid production, showing that the proper application of a SHF strategy resulted in promising results for lactic acid production with *Bacillus coagulans* DSM 2314 regarding yield, productivity and titer. Contribution 2 highlights the importance of novel and cost-effective membranes for microbial fuel cells able to treat animal slurry, thus reducing the polluting potential of these concentrated wastewater streams, while producing electricity and struvite, a fertilizer rich in nitrogen, magnesium and phosphate.

The development of efficient operations and biocatalysts and of empirical, simple kinetic models aid their future implementation at an industrial scale. In this sense, authors of contributions 4 and 11 explore diverse operation types for the production of succinic acid from glucose and from xylose using *Actinobacillus succinogenes* DSM 22257, proposing and fitting non-segregated unstructured empirical kinetic models suitable for data retrieved in a wide variety of conditions, including nitrogen stress.

Fumaric acid is another dicarboxylic acid and a top biorefinery platform of interest in the food and the chemical industries. Its production via biotechnological strategies using *Rhizopus arrhizus* NRRL 1526, glucose as the carbon source and batch and fed-batch processing as operational approaches is the subject of contribution 6. Here, the authors show how, under adequate conditions and, as a consequence, morphology, the fungus is able to produce up to 195 g/L of the target biomonomers, reaching industrial-relevant concentrations of the acid within 16 days under closely controlled pH by $CaCO_3$ addition.

Moreover, the need to more efficiently create enzymes and microorganisms, from agricultural and food waste (such as lactose in whey), as well as efficient biocatalysts to transform biomass is presented. In this regard, the obtention of thermostable enzymes, which are key for cellulose saccharification, with a natural higher stability at higher process temperatures shows the need for novel saccharification processes under more efficient conditions [15]. This issue is addressed in contribution 7, where a thermostable endoglucanase (MtEG5-1) from *Myceliophthora thermophila* is overexpressed in *Pichia pastoris* GS115 and is fully characterized. The authors observe that the enzyme expressed in this new host had an even higher thermostability than when expressed in others.

Likewise, the use of food residues to obtain these critical enzymes alleviates the production costs, one of the main economical hindrances in the implementation of second-generation biorefineries [16]. In contribution 9, *Trichoderma guizhouense* NJAU4742 is shown to produce high levels of cellulase under lactose, but not with other carbon sources such as glucose, galactose and sucrose. Additionally, the combination of lactose and wheat straw resulted in higher activities of the targeted enzymes. Moreover, the authors performed a detailed study to show that TgRas family genes are critical to the growth of fungi, whereby this family's proteins play key effects on cell wall integrity, growth site selection, polarity establishment and maintenance. In fact, this work sheds more light on the evidence that TgRas family genes play an indispensable role in fungal survival and lactose metabolism.

Furthermore, in this Special Issue, the production of bioplastics and biomonomers from food wastes is also presented. The authors of the review presented in contribution 12 dwell on the use of sugar beet pulp—a plentiful waste carbon source—for the production of two key precursors of bioplastics: lactic acid and polyhydroxyalkanoates (PHAs). Microbial exopolysaccharides can also be used as ingredients for biomaterials, in addition to notable

applications in the food and fine chemistry sectors. In this regard, in contribution 10, the authors set the conditions for the continuous production of alginate from *Azotobacter vinelandii* under diazotrophic and nondiazotrophic conditions. The results of this work show the feasibility of enhancing alginate production (yields and specific productivity rates) and quality (molecular weight) under nitrogen-fixing conditions.

If carbon sources in bioprocesses present an important raw material cost, complex nitrogen sources such as peptone, tryptone or yeast extract is an even higher economical expenditure [17]. The proper consideration of all operational costs (OPEX) should be carefully performed to ensure the economic feasibility of industrial-scale lignocellulose-based biorefineries.

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