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Editorial

Topical Advisory Panel Members' Collection Series: Biomass Catalytic Conversion

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The transition toward a sustainable, low-carbon economy has placed biomass valorization and green fuel production at the forefront of catalytic research. Indeed, due to the current energy scenario (with geopolitics playing a significant role [1,2]) and existing environmental problems, this transition is becoming increasingly relevant, with interest growing among local and international organizations. Indeed, the United Nations (UN) and its Sustainable Development Goals (SDGs) are the cornerstone for this energy transition, promoting responsible consumption and clean energy policies, among other activities [3]. In this sense, different wastes can be valorized, like sewage sludge [4] or lignocellulosic biomass in agro-industrial residue [5,6], among others. However, green technologies present different challenges for their implementation on an industrial scale, mainly requiring efficiency improvement, along with other factors. This is why the development of green catalysts, whose performance should be outstanding, is important, as these new products should have a low environmental impact during their production, performance, and final management after use. The reason for this research effort is simple, as these new processes should be a feasible replacement (from an economic and environmental point of view) for the fossil fuel industry.

Considering the above, this Collection Series deals with current research devoted to innovative alternatives for the sustainable catalytic conversion of biomass into valuable products, with a special focus on the valorization of different kinds of waste. Thus, the 24 works included in this collection are mainly focused on the development of efficient, selective, and environmentally benign catalytic systems for converting renewable feedstocks into value-added chemicals and fuels. Although the subjects covered by these works are heterogeneous (dealing with different issues, from biodiesel production to the synthesis of several chemicals), some common and interesting ideas or findings can be inferred, as observed in Figure 1.

As observed in this figure, the following points can be inferred:

- There is a special focus on feedstocks, especially those derived from waste, including lignocellulosic biomass, glycerol, vegetable oils and fatty acids, plastic waste and co-pyrolysis residues, and biomass-derived platform molecules. These feedstocks are mainly used for conversion into biofuels (like ethanol, biodiesel or green diesel, among others) and value-added chemicals (such as acetol, xylitol, acrolein or organic acids). This fact highlights the strong commitment to the circular economy in this Special Issue.
- The use of innovative heterogeneous catalysts, in general, is based on transition metals like Ni (for hydrogenation, deoxygenation and reforming), Cu (for glycerol conversion and hydrogenolysis), Co (for hydrodeoxygenation and Fischer-Tropsch synthesis), Fe and Ru (for redox reactions and hydrogenation), or Ag (for NO_2 reduction and surface

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activation). These active phases are normally supported on different materials, some of them advanced ones, like activated carbon, biochar, clay minerals (like attapulgite or vermiculite), metal oxides (for instance, ZrO_2, CeO_2, Al_2O_3 or TiO_2), zeolites, or mesoporous silica. To improve the characteristics and performance of these catalysts, support modification (through doping, surface functionalization or the use of nanostructures) is normally required to enhance metal dispersion, acid–base properties, and redox behavior.

- The search for green technologies and process intensification. In order to reduce energy and solvent consumption or integrate multiple steps in single and efficient processes, these studies are typically based on different green principles, like microwave-assisted or ultrasound-induced synthesis, hydrodynamic cavitation for pre-treatments, deep eutectic solvents and ionic liquids for better extraction and catalytic performance, etc.
- The improvement of selectivity towards the desired products by assessing different pathways for this purpose. Thus, different steps are included in this Special Issue, like hydrodeoxygenation for the conversion of triglycerides and fatty acids into diesel-range hydrocarbons; the hydrogenolysis and reforming of glycerol and polyols into acetol, propanediol and syngas; esterification and transesterification for biodiesel production; the dehydration and oxidation of biomass-derived alcohols and acids into different chemicals; and the co-pyrolysis and catalytic cracking of biomass and plastics into fuels and aromatic compounds.
- A complete characterization of the catalysts and main products, along with their corresponding feedstocks and intermediate products, has been carried out, including X-ray diffraction analysis (XRD), scanning electron microscopy (SEM), and transmission electron microscopy (TEM) for structural and morphological analysis; Brunauer–Emmett–Teller (BET) surface analysis for surface area and porosity determination; X-ray photoelectron spectroscopy (XPS) and Fourier transform infrared spectroscopy (FTIR) to determine surface chemistry and functional groups; temperature-programmed detection and reduction (TPD and TPR) for acidity basicity and redox behavior, etc. These techniques allowed the correlation between molecular structure and activity (or deactivation pathways like coking, sintering, or leaching), the determination of reaction mechanisms, and the identification of active sites.
- One of the most relevant issues in this field is the optimization of the process to compete with pre-established industries (normally based on petroleum). Thus, the optimization of catalytic performance is essential, and several articles included in this Special Issue incorporate statistical and computational tools for this purpose (response surface methodology, principal component analysis, multiple regression analysis, and kinetic modeling, among others).
- Finally, the main objective of these works is their ultimate environmental and energy application. Thus, the implementation of these technologies in a biorefinery context is feasible in many cases, addressing global sustainability challenges like the production of renewable fuels to replace fossil-derived ones, pollution control (reducing NO_2 and volatile organic compounds emissions and improving wastewater treatments), and carbon neutrality (through CO_2 valorization and biomass carbon recycling). In this sense, life cycle assessment will be a prevailing tool to validate new green technologies, considering as many stages as possible (from cradle to grave).

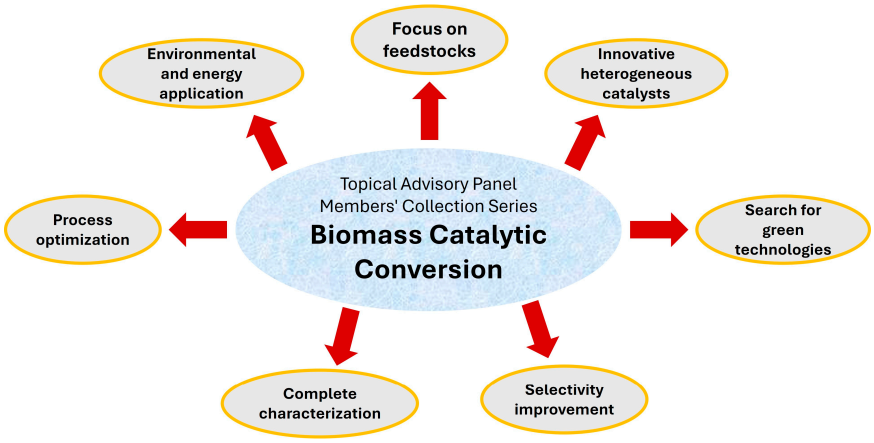

Figure 1. Summary of the present Topical Advisory Panel Members' Collection Series about biomass catalytic conversion.

In conclusion, according to these works, catalytic biomass conversion to obtain different fuels and chemicals is a continuously evolving field, which is mainly characterized by the interdisciplinary integration of different fields like catalysis, materials science, green chemistry, and process engineering. Also, scalability and implementation at the industrial scale represent one of the main goals of these works, including techno-economic analysis and life cycle assessment, proving the practical character of these studies. Thus, the future of this field is highly linked to the UN Sustainable Development Goals, especially concerning clean energy and responsible consumption.

Regarding future prospects, these works point out different promising research lines, like the following:

- The use, optimization, and combination of enzymatic and heterogeneous catalysts for mild reaction conditions and selective conversions.
- The design of catalysts through artificial intelligence, using machine learning to predict optimal composition and structures for better catalytic performance.
- The development of electrocatalysis and photocatalysis for CO_2 reduction or solar-driven biomass conversion, among other applications.
- The implementation of modular biorefineries to integrate multiple catalytic processes into compact and decentralized units.
- Circular economic strategies promoting the valorization of waste through co-processing.

To sum up, in the current energy scenario, where decarbonization is a reality, the role of catalysts is essential to support sustainable chemical production and renewable energy systems. These innovative works (which contribute to a strong foundation for energy transition), in addition to expanding current knowledge within this field, also provide valuable information about the foundations of biomass catalytic conversion (from feedstocks and catalysts to final products), highlighting this collection's value in reinforcing the scientific background in this area.

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