processes

Editorial

Green Chemistry: From Wastes to Value-Added Products

Alazne Gutiérrez [1,*] and Roberto Palos [2]

1 Department of Chemical Engineering, University of the Basque Country UPV/EHU, 48080 Bilbao, Spain
2 Department of Chemical and Environmental Engineering, University of the Basque Country UPV/EHU, Plaza Ingeniero Torres Quevedo 1, 48013 Bilbao, Spain; roberto.palos@ehu.eus
* Correspondence: alazne.gutierrez@ehu.eus

The concept of "From wastes to value-added products" sums up the essence of the circular economy and its transformative potential. Rather than viewing waste as a problem, this philosophy urges us to see it as an opportunity for new product creation and value generation. Through waste management strategies, such as recycling, reuse and recovery, we can divert materials from landfills and avoid their incineration for energy production (with the associated environmental problems), and convert them into products with greater economic and environmental value. This implies a fundamental change in our mindset and in the way we conceive the life cycle of materials. It is no longer just about extracting, manufacturing, using and discarding, but about designing products from the ground up with the idea of recovery and reuse in mind. By applying advanced chemical and technological principles, we can transform waste into renewable materials, bioplastics, bioenergy, and biofuels and other high-value products, closing material cycles and reducing our dependence on natural resources. This approach not only offers economic benefits, but also contributes to preserving the environment, reducing our carbon footprint and promoting a more sustainable and resilient society. By adopting the vision of "From wastes to value-added products", we are building a future in which the circular economy and sustainability are fundamental pillars of our development. This new circular economy paradigm is key to maintaining a healthy lifestyle, reducing pressure on natural resources, reducing pollution and greenhouse gas emissions, and creating new economic opportunities while preserving the environment for future generations. In this Special Issue, we will look at different valorization routes for different materials, which, although they have been considered waste until today, within the new paradigm of the circular economy, may become by-products with a high potential to produce valuable products.

Biomass residues are organic materials obtained after agricultural, forestry or industrial processes, including the food industry (skins, shells, etc.) and also organic matter from municipal solid waste (food waste, sewage sludge, etc.). Among the various potential uses of these wastes is the production of biofuels (bioethanol or biodiesel) and biogas, which can reduce the impact of CO_2 emissions from the energy sector, as the CO_2 fixed during biomass growth has a neutral impact on the carbon balance. The use of these wastes can reduce dependence on fossil fuels and contribute to waste management by reducing landfilling and reducing greenhouse gas emissions due to their decomposition.

The conversion of lignocellulosic biomass into alcohols involves an important first pretreatment step, where the lignin that binds to cellulose and hemicelluloses is broken down, reducing the crystalline structure of the cellulose and increasing the available surface area that facilitates enzymatic reactions with the cellulose and hemicelluloses, and subsequent hydrolysis and fermentation to obtain biofuels such as ethanol or biodiesel. The usual pretreatment with dilute sulfuric acid works well by solubilizing the hemicellulose and depolymerizing the lignin, but as sulfuric acid is very corrosive, specialized equipment is required and the spent liquor requires further treatment before safe disposal, adding costs to the overall process. Ansanay et al. [1] (paper 3 of the Special Issue) have found a more efficient and environmentally friendly alternative, employing "sulfonic solid

check for updates

Citation: Gutiérrez, A.; Palos, R. Green Chemistry: From Wastes to Value-Added Products. *Processes* **2023**, *11*, 2131. https://doi.org/10.3390/pr11072131

Received: 19 June 2023
Revised: 28 June 2023
Accepted: 6 July 2023
Published: 17 July 2023

acid-impregnated carbon catalysts", which are easy to synthesize and can be reused several times with minimal loss of activity, for pretreating switchgrass for subsequent hydrolysis into glucose. These catalysts have been found to be effective at lower temperatures than conventional liquid sulfuric acid, in addition to maintaining their activity during consecutive cycles.

In the production of biodiesel, glycerol is obtained, with a large production volume and low market value. Following the philosophy of the circular economy, a valorization route for this by-product should be proposed. One of the possible recovery routes is the one discussed in paper 2 of this Special Issue by Roncaglia et al. [2], where glycerol is transformed into acetals, which are added to gasoline to increase its octane number or to diesel to reduce particulate emissions. For the process to be cost-effective, and therefore scalable, it is necessary to use simple and robust chemistry. In this paper the potential of simple acids supported on silica is studied for the glycerol acetalization reaction, demonstrating that plain bisulfate on silica (SSANa 3.0 mmol/g) an inexpensive and simple to prepare catalyst, produces, under mild process conditions, high conversion and selectivity of the reaction to solketal, provided that a suitable anhydration technique is used. One of the major advantages of this catalyst over sulphuric acid adsorbed on silica is that the introduction of the sodium salt reduces the acidity of the catalyst, leading to fewer corrosion problems and better recyclability (easily separated from the reaction mixture).

Food waste, on the other hand, has potential as a raw material for composting and also for energy production. The biological decomposition of organic substances in an anaerobic environment (anaerobic digestion) produces a biologically stabilized material called digestate (mainly used as fertilizer) and biogas (mainly methane). The stability of the process is logically key, but finding a parameter that is easy to measure and indicative of it, so that we can act as soon as an imbalance is detected in the fermenter, is not easy. Platosova et al. [3] (Issue paper 1) verify the possibility of early detection of process instability by monitoring dissolved hydrogen concentration using an amperometric microsensor, although this parameter cannot be used to assess overload, which is difficult to detect quickly and with easily measurable parameters, as indicated in this paper.

Wastewater, which until recently was treated as waste, is also a source of organic substances latent in energy and nutrients. Microbial fuel cells (MFCs) are bioelectrochemical devices that use microorganisms to degrade organic pollutants and, at the same time, generate electricity, which is an innovative and promising approach in the field of resource management and sustainability. In paper 7 of this Special Issue [4], an extensive review of the status of MFCs has been carried out, focusing on recent advances in the areas of removal and/or recovery of valuable nutrients, such as nitrogen and phosphorus, and organic compounds (COD) with simultaneous generation of bioenergy. MFC research is constantly evolving, with the aim of improving efficiency, exploring new applications and overcoming the technical and economic challenges associated with these technologies, as MFCs are expected to play an important role in the transition to a more sustainable future and in the search for innovative energy and environmental solutions. Thus, paper 8 of this Special Issue [5] studied the influence that the arrangement of MFCs has on the power density obtained, concluding that power can be increased by connecting MFCs in series.

While it is true that, given the environmental problems and global warming that we are currently experiencing, initiatives have been promoted to mitigate pollution and the harmful effects of the use of fossil fuels, these, in turn, generate new challenges for the management of the new wastes formed. In the case of the energy sector, where there is a shift towards the installation of solar panels (mainly crystalline silicon solar cells), there is growing concern about the management of photovoltaic cell waste. If action is not taken now, discarded panels will become an unavoidable waste problem, as the lead they contain is a toxic metal that can cause damage to the environment if deposited unchecked. In addition, these cells are composed of valuable materials such as silicon, copper and lead. In paper 5 of this Special Issue, Chen et al. [6] delt with the process of separation and recovery of silicon and raw metals (Ag, Cu, Pb and Sn), recovering 99.5% of the copper wire. The purities of the final recovered products are 99.7% for CuO, 99.47% for PbO, 99.68% for SnO_2 and 98.85% for Ag, respectively.

To face plastic pollution, which is a global problem that is already becoming a crisis, the use of bioplastics is being promoted. These materials are derived from renewable sources (plant biomass or microorganisms), and, unlike conventional plastics, which are produced from non-renewable resources such as petroleum, bioplastics are considered more sustainable and environmentally friendly. However, it is important to bear in mind that their biodegradability varies according to the type of bioplastic and the environmental conditions in which they are found. In the specific case of polylactic acid (PLA), which has mechanical properties comparable to those of polystyrene (PS), it undergoes long biodegradation times in the environment, and, to ensure that it does not add to the current pollution problem, it should be chemically recycled. In paper 6 of the Special Issue [7], the chemical recycling of PLA using methanol or ethanol to generate the value-added products methyl lactate and ethyl lactate, respectively, is presented, which, according to the results obtained by the authors, could be carried out on a large scale.

The circular economy paradigm can also be applied to soils contaminated by metals. Instead of considering contaminated soils as an environmental liability, the circular economy proposes: (i) the valorization of these soils using innovative technologies and processes to recover the metals present in soils and convert them into valuable resources. Recovered metals can be reused in various industries, such as electronics, construction and automobile manufacturing, thus closing the metals cycle and reducing the need to extract new natural resources; (ii) the very practical and low-cost chemical immobilization of metals, using inorganic and organic compounds to reduce the mobilization, bioavailability and toxicity of metals. The circular economy approach, in this case, lies in the use of industrial and agro-food by-products and wastes as valuable immobilizing agents for the remediation of metal-contaminated range soils. This topic is addressed in paper 4 of this Special Issue [8], which is a state-of-the art review.

The papers in this Special Issue demonstrate that the adoption of different technologies for waste valorization, in line with the principles of the circular economy, opens up a world of possibilities for transforming waste into high value-added products. Through innovative approaches such as recycling, biotechnology, biorefinery and microbial fuel cells, we are redefining the way we think about waste, leaving behind the linear paradigm of production and consumption. These technologies not only allow us to reduce our dependence on natural resources and minimize waste generation, but also provide us with the opportunity to generate significant economic and environmental benefits. By integrating these solutions into our industrial and waste management practices, we are paving the way towards a sustainable future, where waste becomes valuable resources, thus driving the circular economy and building a more resilient society that is aware of the importance of using resources efficiently and responsibly.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Ansanay, Y.; Kolar, P.; Sharma-Shivappa, R.; Cheng, J.; Arellano, C. Pretreatment of Switchgrass for Production of Glucose via Sulfonic Acid-Impregnated Activated Carbon. *Processes* **2021**, *9*, 504. [CrossRef]
2. Roncaglia, F.; Forti, L.; D'Anna, S.; Maletti, L. An Expedient Catalytic Process to Obtain Solketal from Biobased Glycerol. *Processes* **2021**, *9*, 141. [CrossRef]
3. Platošová, D.; Rusín, J.; Platoš, J.; Smutná, K.; Buryjan, R. Case Study of Anaerobic Digestion Process Stability Detected by Dissolved Hydrogen Concentration. *Processes* **2021**, *9*, 106. [CrossRef]
4. Paucar, N.E.; Sato, C. Microbial Fuel Cell for Energy Production, Nutrient Removal and Recovery from Wastewater: A Review. *Processes* **2021**, *9*, 1318. [CrossRef]
5. Sato, C.; Paucar, N.E.; Chiu, S.; Mahmud, M.Z.I.M.; Dudgeon, J. Single-Chamber Microbial Fuel Cell with Multiple Plates of Bamboo Charcoal Anode: Performance Evaluation. *Processes* **2021**, *9*, 2194. [CrossRef]
6. Chen, W.S.; Chen, Y.J.; Lee, C.H.; Cheng, Y.J.; Chen, Y.A.; Liu, F.W.; Wang, Y.C.; Chueh, Y.L. Recovery of Valuable Materials from the Waste Crystalline-Silicon Photovoltaic Cell and Ribbon. *Processes* **2021**, *9*, 712. [CrossRef]

7. Lamberti, F.M.; Ingram, A.; Wood, J. Synergistic Dual Catalytic System and Kinetics for the Alcoholysis of Poly(Lactic Acid). *Processes* **2021**, *9*, 921. [CrossRef]
8. Gómez-Sagasti, M.T.; Anza, M.; Hidalgo, J.; Artetxe, U.; Garbisu, C.; Becerril, J.M. Recent Trends in Sustainable Remediation of Pb-Contaminated Shooting Range Soils: Rethinking Waste Management within a Circular Economy. *Processes* **2021**, *9*, 572. [CrossRef]