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Editorial: Lignocellulose valorization: Fractionation, conversion and applications

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Editorial on the Research Topic
Lignocellulose valorization: Fractionation, conversion and applications

Introduction

Lignocellulosic biomass is the most abundant form of renewable feedstock on the Earth (Zhang et al., 2017). Chemicals, energies, and materials derived from lignocellulosic biomass are renewable and sustainable, and have the potential to replace fossil feedstocks (Shen et al., 2022). Biorefinery, a process to fractionate lignocellulose into the three major components, is considered the most pivotal step for bioenergy, biomaterials and biochemicals (Shen and Sun, 2021). However, due to the complex hierarchy and chemical structures, only limited lignocellulose is valorized into value-added products, and most of them are burnt or just discarded. Therefore, there is a need to investigate the heterogeneous structure of lignocellulose, improve its efficient fractionation into cellulose, hemicelluloses and lignin, and develop the technology that can convert the lignocellulose into high-value chemical products and high-performance functional materials in a sustainable and promising configuration (Ragauskas et al., 2006; Vermerris and Abril, 2015). In short, the ultimate goal of biomass utilization is that the production of biofuels and biomaterials in industrial applications must be cost-, and performance-competitive with petroleum-derived equivalents.

The topic "*Lignocellulose Valorization: Fractionation, Conversion and Applications*" covers the new applications of existing techniques and principles in interpreting the heterogeneous structure of lignocellulose, novel and high-efficiency biomass fractionation methods for improving lignin and cellulose quality, new catalytic biomass/lignin valorization technologies. In addition, the developed lignin and carbohydrates-based materials can be applied as electrode and advanced materials. Here we sincerely appreciate the 87 authors for their nice work on this topic. Following are the highlights drawn from their contributions to this research topic.

New application of existing techniques and principles in interpreting the heterogeneous structure of lignocellulose

To enhance the yield of fermentable sugars from enzymatic hydrolysis of cellulose, the understanding of the cellulose supramolecular structure as well as the ability to modify it appropriately are essential. Agarwal proposed a novel Raman characterization method, which can further define aggregated/supramolecular structure of cellulose (Agarwal). In addition to crystallinity, several pieces of structure-related information can be obtained that overall provided a more comprehensive description of the cellulose aggregated state. Additionally, the information by Raman spectroscopy is more resolved because it comes from spectral features that represents both the aggregated and the molecular states of cellulose. To reveal the relationship between transport phenomena and deacetylation kinetics in alkaline pretreatment process, a first-principled, experimentally validated mesoscale modeling framework was developed by *Thornburg et al.* to capture and predict the fundamental reaction-diffusion phenomena that govern effective yields and productivities of corn stover deacetylation by sodium hydroxide (Thornburg et al.). Using this approach, they have demonstrated that the chemistry and physics of corn stover deacetylation compete on the similar time and length scales, with corn stover particles as short as 2.3 mm in length predicted to be entirely mass transfer-limited for acetate extraction processes.

Novel and high-efficiency biomass fractionation methods for improving lignin and cellulose quality

Tricin is a monomer of grass lignin with unique biological properties, which is beneficial to human health with the potential for various applications. The abundant grass lignin could be an alternative source for tricin if an effective separation method is available. *Xie et al.* prepared different lignin preparations, such as alkali lignin (AL), mild acidolysis lignin (MAL), cellulase enzymatic lignin (CEL), γ-valerolactone lignin (GVL), and organosolv lignin (OL) etc., to investigate the effect of different fractionation methods on the tricin content of the wheat straw lignin (Xie et al.). The tricin signal of different lignin fractions can be clearly identified by 2D heteronuclear singular quantum correlation (HSQC) spectra. It was found that γ-valerolactone lignin showed the highest tricin level among these lignin samples as the tricin content of GVL was accounted to be 8.6% by integrals.

The efficient preparation method of nanocellulose is the basis for its subsequent conversion and utilization. In this study, the production of CNC (cellulose nanocrystal) from *Pennisetum hydridum* fiber using ultrasound-assisted sulfuric acid hydrolysis was performed by *Yu and coauthors*. (Yu et al.) The highest yield of CNC was 43.6%. The fiber length of CNC was determined to be within 500 nm and the diameter was within 10 nm. This research showed that *Pennisetum hydridum* could be used as a raw material to prepare CNC, and provided a new way for the valorization of *Pennisetum hydridum* fertilized by municipal sewage sludge (MSS).

New catalytic biomass/lignin valorization technologies

The degradation of lignin is critical in the conversion of lignocellulose into second-generation biofuels which could facilitate the lignin valorization approaches. Effective ligninolytic *Bacillus sp.* strains were isolated from forest soils by Yang and coauthors (Yang et al.). Subsequently, they investigated the degradation capability of alkali lignin by the strains. Results showed that TR-03 displayed optimal 26.72% alkali lignin (2 g/L) degradation at 7 days and a 71.23% Azure-B (0.01%) decolorization at 36 h by cultivation at 37°C. These results also proved that *Bacillus sp.* strains were important microorganism in the depolymerization of lignin, and further study should focus on the degrading mechanism of lignin by *Bacillus sp*.

It is a promising strategy to break the interlinkages and remove oxygen by selective catalytic cracking of the C–O bond to further transform the main components of biomass into small molecular products. In a mini-review, *Jian et al.* discuss the significance of selectivity control of C–O bond cleavage with well-tailored catalytic systems/strategies for furnishing biofuels and value-added chemicals with high efficiency from lignocellulosic biomass (Jian et al.). The current challenges and future opportunities of converting lignocellulose biomass into high-value chemicals are also summarized and analyzed.

Catalytic hydrodeoxygenation (HDO) is one of the most important topics for upgrading and refining bio-oil or lignin degradation products. *Tong et al.* prepared the Nb_2O_5-supported bimetallic catalysts with the impregnation method applied for the *in-situ* hydrogenation of guaiacol (Tong et al.). Guaiacol can be effectively transformed into cyclohexanol over different bimetallic catalysts, using alcohol as a hydrogen donor.

The mercerization of fiber is an important method for the high-value utilization of cellulose. *Cao et al.* have investigated the mercerization of bagasse fiber by freeze–thaw-assisted alkali treatment (FT/AT) (Cao et al.). The effects of freezing temperature, freezing time, alkali concentration, and thawing temperature on cellulose and hemicellulose removal were studied. The effective alkali concentration (5.0%) in causing complete transformation of cellulose I to cellulose II was decreased by 66.67% compared with traditional alkaline mercerization (15.0%). It provides theoretical support for promoting the high-value utilization of lignocellulosic biomass.

The development of pretreatment processes to identify potential woody biomass feedstock for sustainable biorefinery and energy applications is highly needed. *Choudhary et al.* demonstrated and compared the feasibility of the IL pretreatment process for two woody biomasses, namely Maple and Aspen, using two distinct ILs, i.e., 1-ethyl-3-methylimidazolium acetate ([C2mim][OAc]) and cholinium lysinate ([Ch][Lys]) as the solvent (Choudhary et al.). Results showed that the two ionic liquids showed different pretreatment effects in terms of fractionation efficiency, enzymatic saccharification, cellulose transformation and lignin depolymerization.

Application of carbohydrates, lignin-based materials and other components in related fields

Valorization of side streams offers novel types of raw materials to complement or replace synthetic and food-based alternatives in materials and biological medicine science, increasing profitability and decreasing the environmental impacts. *Asikanius et al.* present how LCCs, derived from pulp mill effluent, can be turned into valuable biopolymers for industrial polymer film applications (Asikanius et al.).

The flexible and transparent film heaters (FTFHs) with the advantages of mechanical flexibility, portability, and excellent electrothermal performance, are key to the next generation portable, wearable heaters and thermal protection systems. In Cui et al.' work, the transparent regenerated cellulose fibers made from completely dissolving in NMMO solution followed by a regeneration process are presented to disperse and support carbon nanotubes (CNTs) by a vacuum-dewatering process (Liu et al., 2022). The FTFHs made with earth-abundant, cost-effective, and recyclable materials, have excellent potential in the areas of green flexible and transparent film heaters.

Establishing the processing-structure-property-performance relationships (PSPP) through an efficient activation method for preparing activated carbons from different lignin precursors with enhanced electrochemical properties is very important for industrial-scale manufacturing of activated carbons (ACs). In *Yu et al.'* work, the extracted lignins from two kinds of biomass were converted to carbon precursors for synthesizing porous activated carbon electrodes for high-energy-density supercapacitors (Yu et al.). This research detailed the impact of lignin composition on the derived porous structures and electrochemical properties of activated carbons. The inexpensive lignin-based porous electrodes synthesized in this work can be used for various electrochemical devices for improved performance, decreased cost, and enhanced durability.

Besides the applications of carbohydrates and lignin in numerous fields, the application of plant extracts in biological medicine can also increase the additional value of lignocellulosic biomass. The branches of *Ulmus davidiana var. japonica* (ULDA) have traditionally been used in Korea and other Asian countries. ULDA extracts are complex substances consisting of many components; a few of them have pharmaceutical applications in various diseases, such as inflammation and other chronic problems, and as antimicrobial agents. In this study, *Yun and coauthors* have investigated the effects of supercritical fluid-fractionated ULDA, including initial fractions of polyphenols, hydrophobic substances, and flavonoids, on innate immunity modulation and recovery of intestinal function in an *in vitro* model (Yun et al.). These results suggest that U. davidiana and catechin-glycoside may be useful for improving immune system function.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and the final version for publication.

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Conflict of interest

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References

Liu, D., Cui, J., Li, Y., Xu, K., Li, Y., Shen, H., et al. (2022). The flexible and transparent film heaters based on regenerated cellulose and carbon nanotubes. *Front. Energy Res.* 10, 879257. doi:10.3389/fenrg.2022.879257

Ragauskas, A. J., Williams, C. K., Davison, B. H., Britovsek, G., Cairney, J., Eckert, C. A., et al. (2006). The path forward for biofuels and biomaterials. *Science* 311, 484–489. doi:10.1126/science.1114736

Shen, X., and Sun, R. (2021). Recent advances in lignocellulose prior-fractionation for biomaterials, biochemicals, and bioenergy. *Carbohydr. Polym.* 261, 117884. doi:10.1016/j.carbpol.2021.117884

Shen, X., Zhang, C., Han, B., and Wang, F. (2022). Catalytic self-transfer hydrogenolysis of lignin with endogenous hydrogen: Road to the carbon-neutral future. *Chem. Soc. Rev.* 51, 1608–1628. doi:10.1039/D1CS00908G

Thornburg, N., Ness, R., Crowley, M., Bu, L., Pecha, M., Usseglio-Viretta, F., et al. (2022). Mass transport limitations and kinetic consequences of corn stover deacetylation. *Front. Energy Res.* 10, 841169. doi:10.3389/fenrg.2022.841169

Tong, L., Cai, B., Zhang, R., Feng, J., and Pan, H. (2021). *In situ* hydrodeoxygenation of lignin-derived phenols with synergistic effect between the bimetal and Nb2O5 support. *Front. Energy Res.* 9, 746109. doi:10.3389/fenrg.2021.746109

Vermerris, W., and Abril, A. (2015). Enhancing cellulose utilization for fuels and chemicals by genetic modification of plant cell wall architecture. *Curr. Opin. Biotechnol.* 32, 104–112. doi:10.1016/j.copbio.2014.11.024

Xie, M., Chen, Z., Xia, Y., Lin, M., Li, J., Zhang, L., et al. (20222021). Influence of the lignin extraction methods on the content of tricin in grass lignins. *Front. Energy Res.* 9, 756285. doi:10.3389/fenrg.2021.756285

Yang, J., Zhao, J., Xu, H., Zhang, N., Xie, J. C., and Wei, M. (2021). Isolation and characterization of Bacillus sp. Capable of degradating alkali lignin. *Front. Energy Res.* 9, 807286. doi:10.3389/fenrg.2021.807286

Yu, L., Seabright, K., Bajaj, I., Keffer, D. J., Alonso, D. M., Hsieh, C. T., et al. (2022). Performance and economic analysis of organosolv softwood and herbaceous lignins to activated carbons as electrode materials in supercapacitors. *Front. Energy Res.* 10, 849949. doi:10.3389/fenrg.2022.849949

Yu, X., Jiang, Y., Wu, Q., Wei, Z., Lin, X., Chen, Y., et al. (2021). Preparation and characterization of cellulose nanocrystal extraction from Pennisetum hydridum fertilized by municipal sewage sludge via sulfuric acid hydrolysis. *Front. Energy Res.* 9, 774783. doi:10.3389/fenrg.2021.774783

Yun, J. H., Kim, H. O., Jeong, J. H., Min, Y., Park, K. H., Si, C. L., et al. (2022). Ulmus davidiana var. japonica extracts suppress lipopolysaccharide-induced apoptosis through intracellular calcium modulation in U937 macrophages. *Front. Energy Res.* 10, 820330. doi:10.3389/fenrg.2022.820330

Zhang, Z., Song, J., and Han, B. (2017). Catalytic transformation of lignocellulose into chemicals and fuel products in ionic liquids. *Chem. Rev.* 117, 6834–6880. doi:10.1021/acs.chemrev.6b00457