

# LIGNOCELLULOSIC BIOMASS: AN ECONOMICAL AND SUSTAINABLE NATURAL BIOENERGY SOURCE

## Abstract

Lignocellulosic biomass; significantly vital, inexpensive and widely existing feedstock, comprising of agro waste/ agro residues, forestry and solid wastes for fuel production and value-added material formation. Lignocellulosic biomass assists in decreased requirement of fossil fuels thus reducing environmental pollution. Economically, lignocellulosic biomass can be formed rapidly and at low cost. Lignocellulosic biomass is a promising alternative to fossil fuels to meet the raw material needs of industrial production and contribute to the transition from linear to industrial cycles to meet international labour standards. In this book chapter, we have discussed structural complexity of lignocellulosic biomass and different biomass conversion methods. along with merits and demerits of pretreatment methods.

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## I. INTRODUCTION

Lignocellulosic biomass (LCB) is the utmost economical and renewable natural feedstock throughout the world. As a result, the interest has been enhanced in chemicals development derived from lignocellulosic biomass. A number of techniques have been established to produce different basic chemicals for example alcohols from sugars, organic acids, oligo and polysaccharides using different biorefining technologies. The generation of renewable energy obtained from LCB as a substitute for fossil fuel is eventually essential for the persistence of the human race. LCB is generally divided into three categories of waste: biomass, primary biomass and energy crops. Generally, primary biomass includes trees, shrubs, and grasses, waste biomass comprises of agro residues, aggregates, and bagasse. Energy crops are used as the primary raw substrate for second-generation biofuel production as they proposed high biomass efficiency. These LCB can also be employed for the generation of different value-added chemicals/products (Rahman et al. 2020). The LCB applications are expanded in several industries like biofuel production (Afolalu et al., 2021), paper industry (Limaye et al., 2017) and other pharmaceutical sectors (Bala et al., 2023). The LCB deliver nearly 38% and 17% of the direct fuel supply and electricity worldwide by 2050, respectively (Ong et al., 2021).

Bioenergy has attracted substantial attention as a source of sustainable energy to substitute depleting fossil fuels and support tackle rising fuel prices. In calculation to basic survival desires of food, water, and oxygen, living organisms requires supplemental sources of energy to sustain itself (Nanda et al., 2015). Although fossil fuels (oil, gasoline, coal, and natural gas) have enhanced industrialization globally over the past years, their unfavourable experiences cannot be denied. The use of fossil fuel directly led to increases in greenhouse gases; specifically, carbon dioxide. The use of oil spills enhanced smog in urban areas along with air and water pollution. Global warming, acid rain, different climatic variations and adverse weather circumstances are some indirect effects of fossil fuels. Greenhouse gas (GHG) emissions, especially CO<sub>2</sub>, are in direct relation with the fossil fuels utilization (Ehrenberg, 2012). Contempt to the growing charges, the petition for fossil fuels is growing each day.

Bioenergy is seen as an auspicious reserve due to its ecological and economic benefits are being more apparent because of the improvement in technical expertise. As a result of this widespread consciousness in the bioenergy field, it is contemplated as one of the workable growth agenda to achieve the Millennium Development Goals for 2015, particularly in the area of combating worldwide hunger and poverty, implemented in 2000 by the United Nations General Assembly (Nanda et al., 2015). Most importantly, the introduction and generation of such type fuels should have negligible effects on food web, aquatic resources, terrestrial use pattern, environment and ecosystem (Chung, 2013). Residual waste/biomass is the utmost promising sources of energy that supports the requirement of a rising economy. It is therefore necessary to enlarge the advancement in technologies that would empower the transformation of residual biomass into bioenergy with regard to thermodynamical effectiveness and environmental influences. In recent years, significant research on bioenergy has been focused on pretreatment, characterization, thermochemical and biochemical conversion of biomass, as well as biofuel refining.

In this book chapter, characteristics and structure of lignocellulosic biomass are primarily introduced. Afterward, the conversion or hydrolysis, which is one of the vital processes used to produce different kind of bio-energies, is introduced. This chapter presents an effort to evaluate the LCB sustainability regarding the production of next-generation biofuels.

## II. LIGNOCELLULOSIC BIOMASS STRUCTURE AND CHARACTERISTICS

Lignocellulosic biomass comprises numerous agricultural waste and residues like as hardwood and softwood, pulp and paper industry waste, and energy crops. The chemical characteristics and features of the lignocellulosic materials build them a suitable substrate of extensive biotechnological usefulness (Nagar et al., 2022). The structure of LCB is multifaceted, with unmanageable and diversified properties, and inherent holocellulose is resilient to enzymatic hydrolysis. The main components of these materials are cellulose 30–50%, hemicellulose 20–40%, and lignin 15–25% (Otieno & Ahring, 2012; Santibanez et al., 2021). The remaining portion of lignocellulosic biomass contains different proteins, ash and oils (Leng et al., 2010).

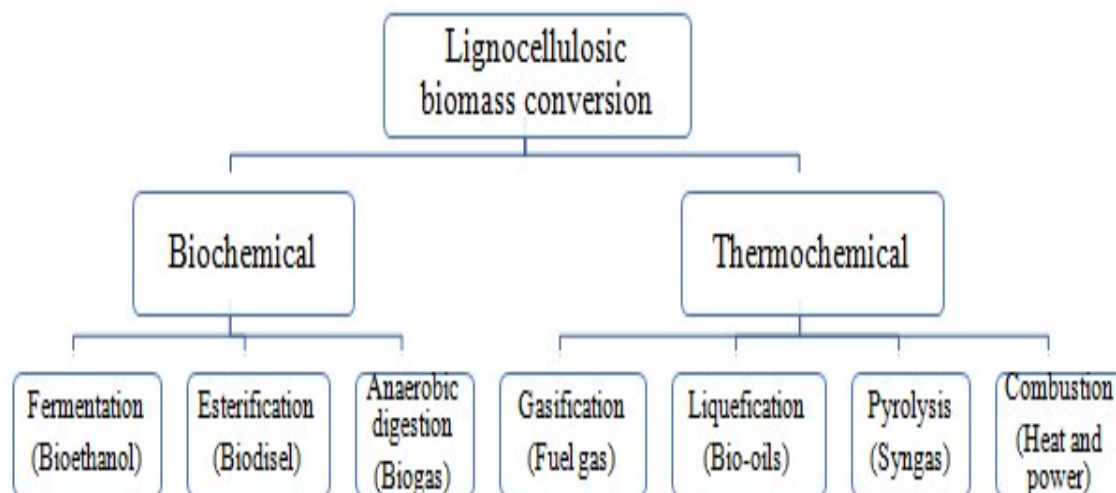
These three core constituents (cellulose, hemicellulose and lignin) are unequally dispersed in the cell wall and offer skeletal framework to plants (Ong et al., 2021; Bhagia et al., 2022). The assembly among cellulose and hemicelluloses or lignin arises primarily through hydrogen bonding, although the joining of hemicelluloses and lignin happens through both hydrogen as well as covalent bonds (Liu et al., 2015; Galkin & Samec, 2016; Provost et al., 2022). From the structural view, cellulose also known as a glucan polymer consisting of d -glucopyranose units joined through  $\beta$ -(1–4)-glycosidic linkages (Mansora et al., 2019). The hemicelluloses possess a low degree of polymerization in comparison to cellulose. It mainly encompasses sugars for example d-glucopyranose, d-xylopyranose, d-galactopyranose, l-arabinofuranose, d-mannopyranose, and d-galactopyranosyluronic acid etc. In addition, lignin has its particular properties such as a three-dimensional, extremely branched and amorphous phenolic polymer (Ong et al., 2021). Lignin is produced by an irregular process of biosynthesis composed of three elementary phenylpropanoid monomers; p-hydroxyphenyl, syringyl and guaiacyl units (Katahira et al., 2018).

## III. METHODS OF BIOMASS CONVERSION

In general, the two utmost common procedures used for conversion of biomass include biological/biochemical and thermochemical conversion (Figure 1). In the biochemical conversion method, enzymes are positioned to destruct and decompose biomass constituents to produce the desirable products. Whereas during thermochemical conversion, increased temperature and pressure are used to break down biomass in the existence of chemical catalysts for the production of fine and course materials, fuels and different valuable products. Although, there is another type of conversion, identified as hybrid transformation, and it associated both thermochemical as well as biochemical methods (Inyang et al., 2022).

Each pathway of biomass conversion has numerous of its own advantages and limitations; the suitable conversion pathway is identified by various factors which includes types of feedstocks, technology accessibility, the necessity for particular enzymes and

vigorous microbes for conversion, and energy supplies. The different types of conversion process are described here with their definitions.



**Figure 1:** Lignocellulosic biomass transformation methods

## 1. Biochemical conversions of LCB

- **Fermentation:** Fermentation is the process of converting the sugar particles into simpler components so as to form substances that can be utilized in formation of chemical energy or the method during which sugars get converted into a new product using chemical reactions supported by microorganisms. All the microorganisms employed in fermentation require the essential building blocks for their synthesis: carbon source, nitrogen source, salts, and different cofactors. Lignocellulosic biomass is extensively used in the field of xylanase production due to its low price and easy availability. Thus, xylanase secretion ability of *Bacillus pumilus* in submerged fermentation was tested using wheat bran as a substrate and a good xylanase titre was achieved (Tanwar et al., 2022). Another example of LCB conversion via fermentation is the generation of bioethanol as a second-generation biofuel (Malik et al., 2022).
- **Esterification:** The chemical reaction of an alcohol and an acid to form an ester is known as esterification. It is an industrially important process applied for pharmaceuticals, flavourings, and biodiesel production. An example of biodiesel production using oleic acid catalysed by the biomass-derived sulfonated polycyclic aromatic carbon catalysts (Yadav et al., 2023).
- **Anaerobic digestion:** It is the process of organic matter (animal manure, wastewater biosolids, and food wastes) breakdown through microorganisms or one can say that the sequence of reactions through which microorganisms deteriorate biodegradable substances in the anaerobic conditions. Thermophilic anaerobic digestion process has been implemented globally mainly because of its sterile method, besides increased yield of biogas and decreased hydraulic retention period. Considering the high

metabolic proportion, thermophiles are widely investigated as an effective inoculum for LCB deprivation and upgraded biomethane formation (Singh et al., 2023).

## 2. Thermochemical conversions of LCB

- **Gasification:** Gasification is a process which utilizes heat, pressure, and steam to transform biomass or carbonaceous materials directly into a gas. The supercritical water gasification (SCWG) of waste biomass for hydrogen generation was reported earlier (Wang et al., 2023).
- **Liquefaction:** Liquefaction is a thermochemical conversion of the carbonaceous matters of biomass into liquid products in the existence of a solvent at relatively decreased temperature (Li et al., 2022). The conversion of LCB to bio-oils is generally termed as direct liquefaction. In a previous study, spent catalyst ( $V_2O_5-WO_3/TiO_2$ ) was potentially employed as the catalyst in hydrothermal liquefaction for the production of bio-oil (Qian et al., 2022).
- **Pyrolysis:** It is a thermochemical process of biomass decomposition taking place in absence or limited supply of oxygen. Syngas or the synthesis gas is a valuable flammable mixture of hydrogen and carbon monoxide gases with smaller quantities of methane, carbon dioxide and hydrocarbons (Awe et al., 2017). The use of thermochemical process pyrolysis was greatly employed previously (Ghodke et al., 2023; Sridevi et al., 2023).
- **Combustion:** Biomass combustion is the most common process of consecutive heterogeneous and homogeneous reactions for converting the solid biomass fuels to energy (Mizakova et al., 2021). The co-combustion behaviours of lignocellulosic biomass with coal, coal and hemicellulose/cellulose/lignin and their synergistic effects were investigated (Wang et al., 2022).

## IV. PRETREATMENT OF LIGNOCELLULOSIC BIOMASS

The main focus of the pretreatment protocols is to disassemble the multifaceted structure of biomass to make each biopolymer easily utilized for the fuels, chemicals and power production. Pretreatment is also taken as the central main unit procedure which impacts the efficacy of biomass processing techniques (Guragain and Vadlani, 2021). Several pretreatment approaches are existing such as physical, chemical, physico-chemical, and biological pretreatments. The pre-treatment set up determine the potency of the process; higher the yield produced better the process (Otieno and Ahring, 2012). Different merits and demerits of the pretreatment procedures are described in table 1. Some of the pretreatment methods are listed below:

- Physical methods: microwave and extrusion pretreatment.
- Chemical methods: acid pretreatment and alkali pretreatment
- Biological methods: use of microorganisms
- Physico-chemical methods: steam explosion and ammonia fiber explosion

**Table 1: Different Pretreatment methods and their Advantages and Limitations**

Pretreatment method	Advantages	Limitations
Physical	<ul style="list-style-type: none"> <li>➤ No inhibitory compounds formation</li> <li>➤ Easy process monitoring</li> <li>➤ Continuous and controlled process</li> <li>➤ Combined with other pretreatment methods</li> <li>➤ No need of biomass washing</li> </ul>	<ul style="list-style-type: none"> <li>➤ Lack of data analysis</li> <li>➤ Energy consuming process</li> <li>➤ May lead to burning of material</li> </ul>
Chemical	<ul style="list-style-type: none"> <li>➤ Can be designed for separate hemicellulose and cellulose hydrolysate</li> <li>➤ Effective delignification (alkali treatment)</li> <li>➤ Cost saving for xylanase enzyme</li> </ul>	<ul style="list-style-type: none"> <li>➤ Production of unintended product</li> <li>➤ Environmental concerns due to high use of chemicals</li> </ul>
Physico-chemical	<ul style="list-style-type: none"> <li>➤ Relatively low dilution of released materials</li> <li>➤ High particle biomass can be used</li> <li>➤ High selectivity for delignification (AFEX)</li> <li>➤ No use of additional chemicals (LHW)</li> <li>➤ Minimal generation of inhibitory components</li> </ul>	<ul style="list-style-type: none"> <li>➤ Cost of solvent recovery</li> <li>➤ Environmental concerns</li> </ul>
Biological	<ul style="list-style-type: none"> <li>➤ No inhibitory compounds are produced</li> <li>➤ Environment friendly</li> </ul>	<ul style="list-style-type: none"> <li>➤ Strict control over the process is required</li> </ul>

\*AFEX: Ammonia fiber explosion pretreatment, LHW: Liquid hot water treatment

## V. CONCLUSION

The lignocellulosic biomass contributes to economic value as the bioenergy production is without an increase of the agricultural areas. The expansion of effective and economically feasible pretreatment method is essential for a sustainable bioenergy production. Though, the development of a sole pretreatment process for all categories of input raw materials is nearly impossible because of the considerable differences in the composition and multifaceted biomass framework. Each pretreatment procedure is accompanying with its own advantages and disadvantages, which in turn relay on the constitution and structure of the biomass. Consequently, the amalgamation of two or more pretreatment procedures with systematic energy incorporation would be an extra effective selection to establish a sustainable lignocellulosic industry.

## REFERENCES

- [1] Afolalu, S. A., Yusuf, O. O., Abioye, A. A., Emetere, M. E., Ongbali, S. O., & Samuel, O. D. (2021). Biofuel; A sustainable renewable source of energy-a review. In IOP Conference Series: *Earth and Environmental Science*, 665(1): 012040.

- [2] Awe, O. W., Zhao, Y., Nzihou, A., Minh, D. P., & Lyczko, N. (2017). A review of biogas utilisation, purification and upgrading technologies. *Waste and Biomass Valorization*, 8, 267-283.
- [3] Bala, S., Garg, D., Sridhar, K., Inbaraj, B. S., Singh, R., Kamma, S., ... & Sharma, M. (2023). Transformation of agro-waste into value-added bioproducts and bioactive compounds: Micro/nano formulations and application in the agri-food-pharma sector. *Bioengineering*, 10(2): 152.
- [4] Bhagia, S., Đurkovič, J., Lagaña, R., Kardosova, M., Kacik, F., Cernescu, A., ... & Ragauskas, A. J. (2022). Nanoscale FTIR and mechanical mapping of plant cell walls for understanding biomass deconstruction. *ACS sustainable chemistry & engineering*, 10(9), 3016-3026.
- [5] Chung, J. N. (2013). Grand challenges in bioenergy and biofuel research: engineering and technology development, environmental impact, and sustainability. *Frontiers in Energy Research*, 1, 4.
- [6] Ehrenberg, R. (2012). The facts behind the frack: Scientists weigh in on the hydraulic fracturing debate. *Science News*, 182(5), 20-25.
- [7] Galkin, M. V., & Samec, J. S. (2016). Lignin valorization through catalytic lignocellulose fractionation: a fundamental platform for the future biorefinery. *ChemSusChem*, 9(13), 1544-1558.
- [8] Ghodke, P. K., Sharma, A. K., Jayaseelan, A., & Gopinath, K. P. (2023). Hydrogen-rich syngas production from the lignocellulosic biomass by catalytic gasification: A state of art review on advance technologies, economic challenges, and future prospectus. *Fuel*, 342, 127800.
- [9] Guragain, Y. N., & Vadlani, P. V. (2021). Renewable biomass utilization: A way forward to establish sustainable chemical and processing industries. *Clean Technologies*, 3(1), 243-259.
- [10] Inyang, V., Laseinde, O. T., & Kanakana, G. M. (2022). Techniques and applications of lignocellulose biomass sources as transport fuels and other bioproducts. *International Journal of Low-Carbon Technologies*, 17, 900-909.
- [11] Katahira, R., Elder, T. J., & Beckham, G. T. Chapter 1. A Brief Introduction to Lignin Structure, 2018.
- [12] Leng, L., Zhang, W., Peng, H., Li, H., Jiang, S., & Huang, H. (2020). Nitrogen in bio-oil produced from hydrothermal liquefaction of biomass: A review. *Chemical Engineering Journal*, 401, 126030.
- [13] Li, Q., Yuan, X., Hu, X., Meers, E., Ong, H. C., Chen, W. H., ... & Ok, Y. S. (2022). Co-liquefaction of mixed biomass feedstocks for bio-oil production: a critical review. *Renewable and Sustainable Energy Reviews*, 154, 111814.
- [14] Limaye, L., Patil, R., Ranadive, P., & Kamath, G. (2017). Application of potent actinomycete strains for biodegradation of domestic agro-waste by composting and treatment of pulp-paper mill effluent. *Advances in Microbiology*, 7(1): 94-108.
- [15] Liu, M., Yang, J., Liu, Z., He, W., Liu, Q., Li, Y., & Yang, Y. (2015). Cleavage of covalent bonds in the pyrolysis of lignin, cellulose, and hemicellulose. *Energy & Fuels*, 29(9), 5773-5780.
- [16] Malik, K., Sharma, P., Yang, Y., Zhang, P., Zhang, L., Xing, X., ... & Li, X. (2022). Lignocellulosic biomass for bioethanol: Insight into the advanced pretreatment and fermentation approaches. *Industrial Crops and Products*, 188, 115569.
- [17] Mansora, A. M., Lima, J. S., Anib, F. N., Hashima, H., & Hoa, W. S. (2019). Characteristics of cellulose, hemicellulose and lignin of MD2 pineapple biomass. *Chem. Eng.*, 72(1), 79-84.
- [18] Mižáková, J., Piteř, J., Hořovský, A., Pavlenko, I., Ochowiak, M., & Khovanskyi, S. (2021). Biomass combustion control in small and medium-scale boilers based on low cost sensing the trend of carbon monoxide emissions. *Processes*, 9(11), 2030.
- [19] Nagar, S., Kumari, K., Goyal, S., Sonu, Kharor, N. (2022). Different Type of Paper Pulping and Process of Green Bleaching. *Chemical Science Review and Letters*, 11(24): 410-416.
- [20] Nanda, S., Azargohar, R., Dalai, A. K., & Kozinski, J. A. (2015). An assessment on the sustainability of lignocellulosic biomass for biorefining. *Renewable and Sustainable Energy Reviews*, 50, 925-941.
- [21] Ong, H. C., Yu, K. L., Chen, W. H., Pillejera, M. K., Bi, X., Tran, K. Q., ... & Petrisans, M. (2021). Variation of lignocellulosic biomass structure from torrefaction: A critical review. *Renewable and Sustainable Energy Reviews*, 152, 111698.
- [22] Otieno, D. O., & Ahring, B. K. (2012). The potential for oligosaccharide production from the hemicellulose fraction of biomasses through pretreatment processes: xylooligosaccharides (XOS), arabinooligosaccharides (AOS), and mannoooligosaccharides (MOS). *Carbohydrate Research*, 360: 84-92.
- [23] Provost, V., Dumarcay, S., Ziegler-Devin, I., Boltoeva, M., Trébouet, D., & Villain-Gambier, M. (2022). Deep eutectic solvent pretreatment of biomass: Influence of hydrogen bond donor and temperature on lignin extraction with high  $\beta$ -O-4 content. *Bioresource technology*, 349, 126837.
- [24] Qian, L., Zhao, B., Wang, H., Bao, G., Hu, Y., Xu, C. C., & Long, H. (2022). Valorization of the spent catalyst from flue gas denitrogenation by improving bio-oil production from hydrothermal liquefaction of pinewood sawdust. *Fuel*, 312, 122804.

- [25] Rahman, M. S., H. Mondal, M. I., Yeasmin, M. S., Sayeed, M. A., Hossain, M. A., & Ahmed, M. B. (2020). Conversion of lignocellulosic corn agro-waste into cellulose derivative and its potential application as pharmaceutical excipient. *Processes*, 8(6): 711.
- [26] Santibáñez, L., Henríquez, C., Corro-Tejeda, R., Bernal, S., Armijo, B., & Salazar, O. (2021). Xylooligosaccharides from lignocellulosic biomass: A comprehensive review. *Carbohydrate Polymers*, 251: 117118.
- [27] Singh, R., Hans, M., Kumar, S., & Yadav, Y. K. (2023). Thermophilic Anaerobic Digestion: An Advancement towards Enhanced Biogas Production from Lignocellulosic Biomass. *Sustainability*, 15(3), 1859.
- [28] Sridevi, V., Surya, D. V., Reddy, B. R., Shah, M., Gautam, R., Kumar, T. H., ... & Basak, T. (2023). Challenges and opportunities in the production of sustainable hydrogen from lignocellulosic biomass using microwave-assisted pyrolysis: A review. *International Journal of Hydrogen Energy*.
- [29] Tanwar, E., Nagar, S., Kumari, K., Mallesh, G., & Goyal, S. (2022). Enrichment of papaya juice using covalently immobilized xylanase from *Bacillus pumilus* SV-85S. *Biomass Conversion and Biorefinery*, 12: 1-17.
- [30] Wang, Qing, Xu Zhang, Da Cui, Jingru Bai, Zhichao Wang, Faxing Xu, and Zhenye Wang. "Advances in supercritical water gasification of lignocellulosic biomass for hydrogen production." *Journal of Analytical and Applied Pyrolysis* 170 (2023): 105934.
- [31] Wang, S., Zou, C., Lou, C., Yang, H., Pu, Y., Luo, J., ... & Li, Z. (2022). Influence of the synergistic effects between coal and hemicellulose/cellulose/lignin on the co-combustion of coal and lignocellulosic biomass. *Fuel*, 311, 122585.
- [32] Yadav, N., Yadav, G., & Ahmaruzzaman, M. (2023). Biomass-derived sulfonated polycyclic aromatic carbon catalysts for biodiesel production by esterification reaction. *Biofuels, Bioproducts and Biorefining*.