© APR 2025 | IRE Journals | Volume 8 Issue 10 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV8I10-1723032

Biomass-Derived Platform Chemicals as Renewable Feedstocks for the Synthesis of High-Value Organic Molecules and Sustainable Functional Materials

DR. K. S. LAMANI
Associate professor, Department of chemistry, C.S. Bembalagi, S.M.R.Palaredha science and G.L.Rathi commerce college Ramdurg

Abstract- The increased focus on sustainably produced chemicals has fostered significant interest in using biomass-derived renewable sources as substitute carbon resources to traditional petroleum-based resources due to their inherent resource depletion issues, green gas emissions, environmental pollution, and dependency on non-renewable carbons; consequently, the conversion of bio renewable resources into useful platform chemicals (like lignocellulosic biomass, agro-residues, vegetable oil, and organic wastes streams) has become an important research arena known as biomass valorization chemistry, intended for producing platform molecules that can be transformed into functional polymers, high-value organic chemicals, or advanced materials (Corma et al., 2007; Ragauskas et al., 2006); valuable biomass-derived platform molecules include carbohydrate derivatives like 5-hydroxymethylfurfural (HMF), furfural, levulinic acid, and lactic acid that possess reactive functional groups applicable for synthesis of monomers, pharmaceuticals, fuels, solvents, specialty chemicals. Lipid-derived compounds such as fatty acid and glycerol derivatives could bring new approaches for producing biopolymers, bio-based chemicals, surfactants etc. Lignin-derived derivatives including vanillin, functional polymers, and various phenolic monomers are renewable aromatic resource for building functional polymers, and valuable materials; However, the research and development in biomass utilization have encountered various challenges including the low efficiency of using biomass resources, complex structural characteristics, low conversion efficiency, catalyst deactivation, lack of selectivity and the difficulties in product separation. Further, the limitation of laboratory-level research to achieve sustainable industrial production has emerged in terms of cost-effectiveness (Sheldon, 2017); this work presents a conceptual integrated route involving biomass pretreatment, catalytic conversion and biorefinery methods, utilization of green solvent, coupled catalytic upgrade and polymer and advanced material production in order to transform renewable feedstocks to highly value chemicals; various kinds of catalysis such as homogeneous, heterogeneous catalysis, biocatalysis and advanced computational-designed catalyst are investigated to control pathways, enhance the reaction selectivities, reduce the energy consumption and carbon utilization efficiency; Bio renewable platform molecules derived from biomass exhibit prominent application prospects in sustainable organic synthesis and novel biogenic functional material developments such as degradable polymers, biopolymer, organic materials in electronic industry, advanced composite material for packing materials, energy storage and biomass conversion based medical engineering; Integrated study of biorefinery, greener catalysts and materials design is beneficial for renewable carbon utilization, sustainable chemical production and development of a bio-economy to turn waste bio resource into valuable products under decreasing environmental impacts.

Keywords: Biomass valorization, Renewable feedstocks, Platform chemicals, 5-Hydroxymethylfurfural, Green chemistry

I. INTRODUCTION AND BACKGROUND RELATED TO THE STUDY

Growing global concerns over sustainability in chemical manufacturing have accelerated the shift from fossil-based manufacturing toward a renewable carbon chemistry economy. This has been fueled by the long-term unsustainability of petroleum-derived feedstocks (availability, GWP of manufacturing and usage, and environmental impacts) prompting an urgent need for alternative renewable carbon sources for chemicals, materials and products manufacturing. Biomass has been identified as a feasible renewable feedstock as it is an abundant source of oxygenated organic structures that can be easily modified (chemically and biologically) into versatile platform chemicals and then converted into high value organic molecules, polymers and products within an integrated biorefinery concept (Ragauskas et al. 2006; Corma et al. 2007). The basic concept for bio-valorization is schematically illustrated below: Biomass platform chemicals-high value products, indicating that it is a complex biological material which is fractionated, converted and upgraded into useful chemical intermediates to be applied in pharmaceutical, agrochemicals, polymers, solvents, fuels, and advanced material industries; cellulose, as a significant constituent of plant biomass, has been identified as one of the most abundant polysaccharide. It is a linear chain made up of -(14)- linked glucose unit and it is a carbohydrate storage component in plants with its repeating molecule (CHO)n unit. Cellulose can be readily converted to high-demand value-added compounds (e.g., furan derivatives such as 5-hydroxymethyl furfural HMF) via hydrolysis to glucose followed by catalytic dehydratration to form molecules such as; but cellulosic sugars are a preferred starting material source for biodegradable products and renewable chemical intermediates (van Putten et al. 2013); hemicelluloses are the amorphous polysaccharide portion of plant cell walls. Similar to cellulose it is a carbohydrate polymer composed mainly of D-xylose units but it also contains mannose, arabinose, galactose, and other sugar components in a less organized structure than cellulose. Hemicellulose can also be decomposed via acid dehydration to yield other sugar-based platform molecules and furfural, such as the other type of furan derivative. They are utilized to synthesize resins and can be also applied as solvents and fine chemicals; lignins represent major recalcitrant aromatic biopolymers and an important constituent of plant biomass, being primarily responsible for the structure of vascular tissues in plants and they represent potential as an alternative renewable aromatic resource to obtain aromatic monomers, molecules such as substituted phenols and vanillin derived chemicals which have potential to create new aromatic monomers and molecules useful to develop new bio-based polymers, paints, adhesives and advanced functional materials although it is structurally resistant to various reactions which makes it a challenge to valorize efficiently (Zakzeski et al. 2010); the lipidic part includes different types of biomass as vegetable oils and other triglyceride based lipids, fatty acids, fatty acid esters and glycerol derivatives, which can be transformed by various chemical and catalytic reactions to fatty acid derivatives, surfactants, lubricants, and molecules suitable as building blocks in the formation of monomers used for polymer syntheses; hence, the co-utilization of carbohydrate, lignin and lipid resources in integrated biorefinery processes offer great potential for constructing a closed-loop carbon economy producing a multitude of valuable products, improving overall material efficiency, generating less waste, as well as facilitating the transition to the renewable chemical manufacturing sector; however to realize these goals, further research and development into the design of selective catalysts, clean and efficient technologies, green solvents, energy-efficient processes, and highly integrated biorefinery approaches are indispensable.

II. HISTORICAL DEVELOPMENT OF BIOMASS CONVERSION CHEMISTRY

Historically, the research and development of biomass conversion chemistry has evolved from using biomass directly for various human applications to advanced sustainable chemical production, reflecting humanity's progressively creative approaches to convert renewable biological resource into tangible benefits; Biomass was originally consumed only directly as energy carriers, animal feeds, construction materials, aliments, and primary fermentation products, without sufficient knowledge on the opportunity as renewable molecules resources: But with an ever deepening knowledge of chemistry and industrial biotechnology, more and more chemical structure compounds existed in biomass have been discovered as the complementary carbon reservoir resources on production of fuels, chemicals and functional materials as that shown by cellulose, hemicellulose, lignin and lipids (Ragauskas et al., 2006); And subsequently, the modern concept biorefinery is emerged as a significant breakthroughs by providing an integrative process on conversion as the parallel with petroleum refinery, separating and processing the different fractions present in biomass into different valuable platform chemicals, polymers, fuels and even specialty products, leading to a maximization of value and to the shift for renewable carbon resource consumption (Cherubini, 2010); Green chemistry also drives this development, especially for catalyst innovation, focusing on waste reduction, use of renewable resources, energy efficient processing, the usage of renewable feedstocks (anastas and warner,

1998) and the need for better atom economy on conversion; Catalan biomass valorization becomes then the focus subject based on the research and development on various catalysts including heterogeneous catalytic systems, homogeneous ones, enzymatic ones, as well as hybrid systems for precise conversion on dehydration, hydrogenation, oxidation, hydrolysis and polymerization of molecules derived from biomass including 5-hydroxymethyl furfural, furfural, levulinic acid and aromatic lignin molecules; Meanwhile, renewably polymers from biomass-derived chemicals start emerging by synthesizing polylactic acid, polyhydroxyalkanoates, furan polymers with similar properties as that of petroleum-based plastics and to explore new material from renewable resources, the application thereof broadened from single products to advanced materials, as described by Gandini (2011); In recent, circular economy approaches promote to achieve the utilization for renewable carbon resources on an indefinite life through turning biomass waste into value through bio-catalyst for resource cycling, improvement of carbon efficiency and integration of biorefinery systems; In brief, biomass conversion chemistry has been transformed from the primitive methods of biomass usage to a multidisciplinary research topic integrated with catalysis, bio-technology, chemistry and material science to find future renewable chemical industries based on the valorization of biomass.

III. RESEARCH PROBLEM

The sustainable chemistry and use of renewable resources, though advancing significantly, still presents significant hurdles in the industrial application and of chemical manufacturing at present due to its dependency on fossil derived feedstocks, inadequacy of current biomass conversion technologies and economic implementation as petroleum-based chemical industries rely on finite resources not easily replenished that consequently release a massive greenhouse gas load, carbon dense process and pollute the environment during extraction, processing and production phases (Ragauskas et al., 2006); in comparison to a petrochemical based system which employs highly optimized infrastructure and predictable feedstock composition, continued application of the conventional processes raises concerns of the sustainability over long term and consequently the need for renewable carbon alternatives which can support our industrial chemical production in the near future. Renewable carbon-based resources, while plentiful and offering wide possibilities, present several complications arising from heterogeneous and highly functionalized nature of bio-based materials which means components such as cellulose, hemicellulose, lignin and lipid need to be effectively separated and chemically converted in to viable industrial feedstocks and often results in conflicting reaction paths and thus non-uniformity in conversion and selectivity and low molecular transformation selectivity (Corma et al., 2007). Besides that catalyst deactivation results from such processes can due to various factor such as presence of impure compounds in the feed, excessive adsorption of oxygenated compounds onto the catalyst, deposition of carbon, structural changes of catalyst and etc, leading to the erosion of catalytic activity and increased process cost and many of the bio-mass converting technologies have high requirement of energy for their application due to processes need high pressure, high temperature or high effort in separation procedures; a problem with further extent appears when product purification in biorefineries needs more complex and economic processes for separated separation due to high similarity in functional group of chemical constituents, thus it can be stated that industrial scale application of bio-based production of organic molecules faces other further barrier such as challenges in reactor designs, process integration of multiple components to achieve better overall efficiency, economic competitiveness against well-established petrochemical technology, uncertainty of the feedstock composition, due to the variations depending on plant species, geographical origin, species culturing and season; therefore the solution to these problems lies in developing highly active catalysts systems, efficient fractionation techniques, computationally guided optimal design for a reaction, integrated process technology of bio-based biorefineries.

IV. LITERATURE REVIEW

Sustainable chemical production utilizes these biomass-derived platform chemicals, like 5-hydroxymethylfurfural (HMF), 2,5-furandicarboxylic acid (FDCA), furfural, levulinic acid, and lactic acid, as versatile and essential renewable building blocks in combined biorefinery/catalytic approaches to form other sustainable materials, as well as fuels, pharmaceuticals, and polymers. One of the most researched renewable and sustainable platform molecules derived from carbohydrates, 5-hydroxymethylfurfural (HMF) consists of a multifunctional furan ring with hydroxymethyl and aldehyde groups, which impart versatility to a range of chemical transformations. HMF is manufactured through acid catalyzed dehydration of hexoses such as glucose and fructose, where the water molecules are removed from the molecule structure creating a renewable intermediate. The acid catalyzed oxidation of HMF provides a renewable alternative to petroleum-derived terephthalic acid and an important source material, such as polyethylene furanoate (PEF), for the creation of new bio-based polyesters with suitable physical and barrier properties in packaging (van Putten et al. 2013) applications. Other HMF transformation chemistries in the presence of the appropriate catalysts are hydrogenation, oxidation, etherification and addition of other functionalities that produce chemical intermediates or products for fuels or specialty materials and solvents. Another prominent biomass derived platform chemical is furfural that originates from the dehydration of xylose and other C5 sugars in lignocellulosic biomass through the utilization of mineral acid catalysis yielding a versatile building block for solvent and resin production, fuel additives, and specialty chemicals (Mamman et al. 2008). Since lignocellulosic biomass and agriculture residues contain a lot of carbohydrate in the form of both hemicellulose (with C5 sugars) and cellulose (with C6 sugars) furfural is one of the most significant platform molecules on the renewable chemical market today. Hydrolysis and degradation of sugar derived intermediates including HMF leads to levulinic acid, a important platform molecule with dual functionalization due to ketone and carboxylic acid groups for transformation into pharmaceutical precursors, biofuels or solvents, and polymers, and uses are still emerging for its various selectively catalytic derivatizations into pharmaceuticals and polymer precursors such as -valerolactone (Rackemann & Doherty 2011). Similar to levulinic acid and furfural, lactic acid is strategically significant bio-based platform molecules that are derived from renew able carbohydrate fermentation and a key monomer for the production of polylactic acid (PLA), biodegradable and compostable packaging materials that are studied extensively. Consequently, there are considerable possibilities for using biomass derived platform chemicals like HMF, furfural, levulinic acid and lactic acid as a renewable carbon source for the creation of high value chemical intermediates and products, however further research is required to develop selective catalytic transformations and efficient separation processes necessary for establishing a commercially viable biomass-based chemical industry.

V. BIOMASS CONVERSION TECHNOLOGIES

Biomass conversion technologies are core process steps which achieve renewable and complex biomass resources convert into products like platform chemical, fuels, organic materials and functionalized materials. The main procedures in biomass conversion include chemical processes, catalytic processes and biological processes. Hydrolysis is an initial conversion process, which deconstructs polysaccharides such as cellulose and hemicellulose to fermentable sugars like glucose, xylose through breaking the glycosidic bonds with the utilization of enzymes, acid or catalysts, making carbohydrate intermediates to be readily chemically upgrading. The dehydration reaction occurs after the hydrolysis step, which could be an important conversion pathway converting sugar molecules into oxygenated furan compounds. Removal of water from hexose and pentose sugars produces valuable platform chemicals such as HMF from glucose or fructose (van Putten et al. 2013), and furfural from sugarcane xylose containing hemicellulose fraction (van Putten et al. 2013). The furan compound intermediates can act as useful precursor of polymers, solvents, fuels and specialty chemicals. The oxidation reaction also is an important biomass transformation strategy; specific oxidations of hydroxyls groups within biomass could result to aldehydes, ketones and carboxylic acids, having higher chemical activity enabling for the production of vanillin derivatives, furan di-carboxylic acids etc. Which are useful intermediate products. Hydrogenation, on the other hand, can convert a carbonyl compound-containing biomass into alcohol,

© APR 2025 | IRE Journals | Volume 8 Issue 10 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV8I10-1723032

utilizing addition of hydrogen for obtaining sugar alcohols, polyols, fuels and other relevant molecules through careful design of catalyst in order to avoid side reactions. The biological pathway, fermentation, produces organic acids and alcohol from sugar molecule of biomass-derived intermediates; it occurs in relatively mild conditions compared with the other processes. Lactic acid production for the synthesis of PLA, ethanol production for fuel and the production of various acids in a large-scale level have been achieved and well-established application. However, there exist great challenges such as heterogeneity, stability, selectivity, inhibitor formation, and energy utilization to the efficient utilization of biomass. The coupled reactor designs are required and integrated biorefinery that combine PRE TREATMENT, catalysis, enzymatic reaction and Separation are extensively developed. Hence, combining hydrolysis, dehydration, oxidation, hydrogenation and fermentation can produce various valuable products from biomass.

VI. RESEARCH METHODOLOGY

The presented conceptual research methodology for the production of biomass-derived platform chemicals and the transformation into valuable organic chemicals and sustainable functional materials is described as an integrated platform, starting from renewable biomass feedstock, and followed by pretreatment and fractionation, platform chemical production, catalytic upgrading, molecular synthesis, characterization and application evaluation, in each step focusing on optimal carbon utilization, enhancing product selectivity and promoting sustainable production of chemicals. Initially, renewable biomass resources such as lignocellulose residue, agricultural waste, cellulose rich sources, lignin rich biomass or lipid-derived sources will be identified, chosen and utilized in the research, on the basis of a number of factors including available sources of biomass, its composition, its renewability and possibility to convert into desired chemical intermediates (Ragauskas et al., 2006). Biomass pretreatment and fractionation refer to the steps of utilization or addition of physical, chemical, or biological (or combined) approach, for breaking up the solid plant biomass complex, increase accessibility of the cellulose and hemicellulose fractions, as well as to enable access to other desired chemical entities such as fermentable carbohydrates, aromatics and lipid compounds. Platform chemical production refers to the highly selective transformation from the biomass-derived intermediates, into a defined target building block, such as, e.g., 5-hydroxymethyl furfural, fural, levulinic acid, lactic acid, phenols or compounds similar to them, utilizing enzymatic catalysis, or, fermentation approaches, or catalytic ones. As a main and central step in this research method, catalytic upgrading will investigate the conversion into valuable products under the assistance of homogeneous catalyst, heterogeneous catalyst, biological catalyst or newest computably designed catalysis, with reactions that can take advantage of oxidative, reductive, hydrogenation, dehydration, coupling and polymerization behavior, so as to enhance efficiency and to reduce pollution (Corma et al., 2007). The generated value-added intermediates are further applied to synthesize a multitude of organic chemicals, bio-based polymers, monomers for functional materials with applications from pharma, packaging, energetic storage to medical applications or electronic device. Structural and chemical characterization of the biomass derivatives shall be realized through instrumental techniques as Fourier-transform infrared spectroscopy (FTIR), nuclear magnetic resonance spectroscopy (NMR), mass spectrometry, X-ray diffraction (XRD), scanning electron microscopy (SEM) and thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC), in order to determine its structural composition, its components, the morphologies and crystals and its performance. Furthermore, application evaluation for each derived product is performed on its chemical function, mechanical, thermal behavior, bio-degradability, environmental suitability etc., at the same time green chemistry metrics and life-cycle analysis will assess its sustainability, the utilization efficiency of the resources, as well as its potential application scope and value, so as to realize the whole conception research about the sustainable production of valuable chemical products and sustainable functional materials.

VII. CHARACTERIZATION METHODS

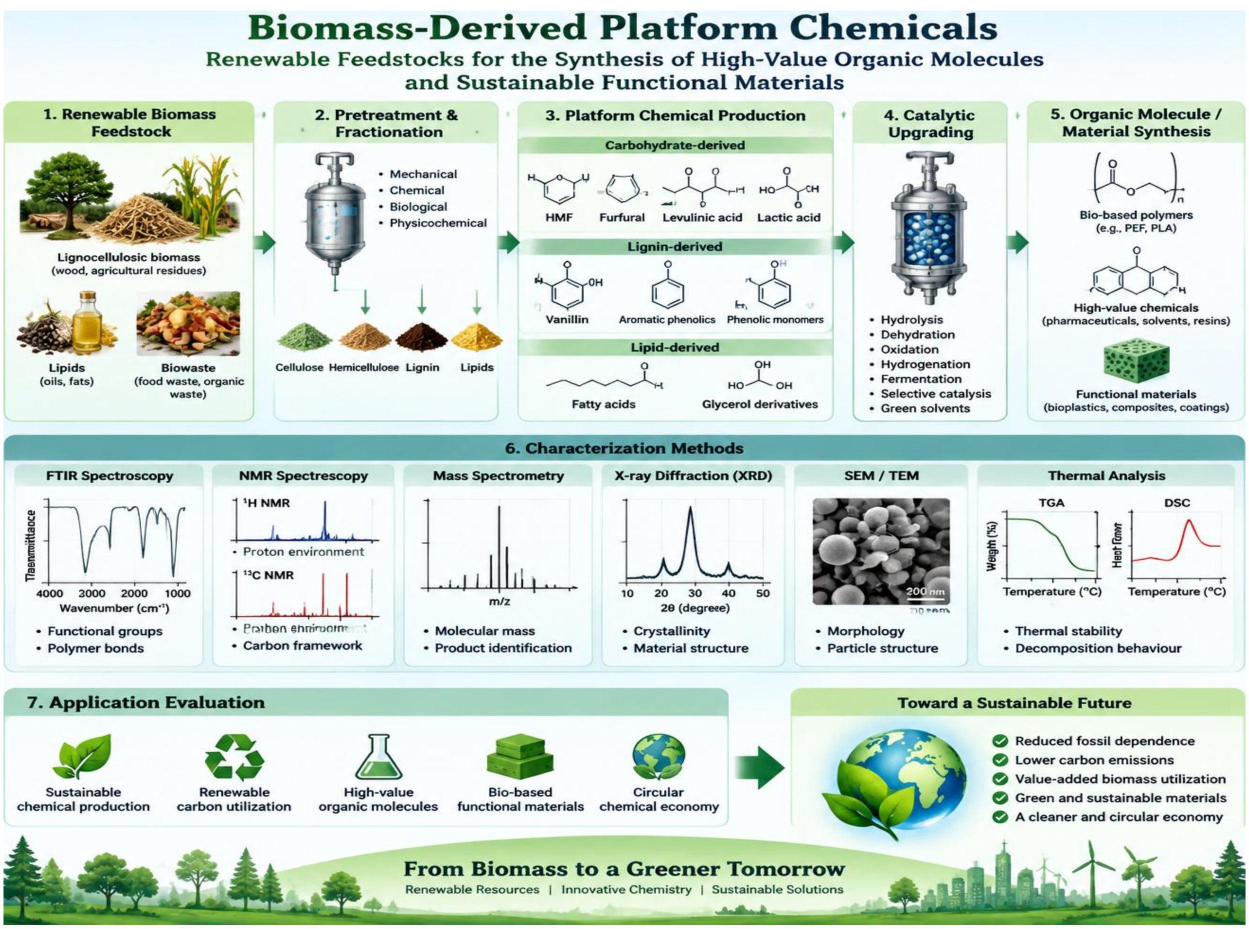
Biomass-derived platform chemicals, high value organic molecules and the development of functional sustainable materials require integrated characterization methodology that will use spectroscopic (e.g. FTIR, NMR, Mass-Spectroscopy), structural (XRD), morphological (e.g. SEM, TEM) and thermal (e.g. TGA, DSC) analysis to the full extent, in order to define the chemical identity and structural arrangement of molecular architecture (material structure) and evaluate the functional performance (material function). FTIR spectra, as essential element in the study, may provide functional group information and confirm the various chemical transformations occurred based on their corresponding vibrational frequencies, such as hydroxyl-, carbonyl-, ether- , aromatic-, ester and polymer backbone groups, which would provide good evidences for the successful biomass-derived intermediates transformation to the desired organic molecules or polymeric material (Pavia et al., 2008); NMR offers deep insight at molecular level (proton- (H NMR) and Carbon-(C NMR)) through analysis of chemical environment surrounding both atoms. H NMR can provide information of chemical shift (identification of protons within specific electronic environments and in relation to other atoms) , coupling (interconnectedness of atoms) and spin decoupling which ultimately allow the identification of their position in molecule and substituent positions; C NMR allows the characterization of the carbon framework (total number and chemical nature of carbon atoms and bonds between them) , carbon-hetero atom bond interactions, and change in different state of carbon atoms during catalytic upgrading process or polymerization. Mass-Spectroscopy could add additional crucial information to all above techniques in determination of Molecular mass, molecular formulae, fragmentation patterns, product identification etc. Leading to an unambiguous determination of biomass-derived platform chemicals and their reaction intermediates and products. X-Ray diffraction analyses the overall structure, symmetry and crystallinity of bio-based polymer materials (or functional materials) for structure property analysis which might correlate the changes in mechanics, thermal or electronic properties. SEM and TEM have the abilities to reveal the micro/nano structural features and organization of the biomass-derived material (organic molecule and polymers) or the bio-catalyst, so as to illustrate the effect of the process to the structures and so on. Using different thermal characterization methods like TGA for studying termal stability, melting points, decomposition processes (e.g., glass transition) for DSC it can be further used to determine the industrial potential. Therefore, the combination of spectroscopic, structural, morphological, and thermal analysis methods provides a powerful approach to characterizing biomass-derived chemicals, intermediates, functional sustainable material or product to assure the validity of the proposed catalytic upgrading route and analyze structure property relationship of resulting molecule (functional material).

VIII. CHARACTERIZATION METHODS

To comprehensively characterize the biomass-derived platform chemicals, organic value-added compounds and sustainable functional materials, integrated analysis techniques by combinations of spectroscopic, structural, morphological, thermal approaches should be employed to determine chemical identities, molecular architectures, materials structuring, as well as the functional performances. Among all the spectroscopic methods, FTIR analysis (Fourier Transform infrared Spectroscopy) represents an effective technique by which to detect characteristic functional groups and trace chemical transformations, via monitoring infrared absorptions associated with the hydroxyl (-OH), carbonyl (-C=O), ether (-C-O-C), aromatic ring system, ester (R-C(=O)-O-) and polymer chain functional group species, giving substantial evidence for the transformation of biomass-derived intermediaries into desired organic molecules and polymeric compounds (Pavia et al., 2015). NMR (Nuclear Magnetic Resonance) spectroscopy offers molecular level details and provides profound information when characterizing organic molecules; proton (H) NMR can elucidate individual proton species chemical environment, molecular connectivity, arrangement of substituent atoms and functional group; carbon (C) NMR can well characterize the carbon framework and distinguish C-C and C- heteroatom bond, revealing the carbon and skeleton changes occurred during the catalytic modification or polymer polymerization reaction. Mass spectrometry can supplement the spectroscopic investigation, supplying crucial information of molecular mass and formula, fragmentation behaviors

© APR 2025 | IRE Journals | Volume 8 Issue 10 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV8I10-1723032

and identifying the molecular identities, in turn achieving correct molecular identities for the biomass-derived platform chemicals, intermediate products and final organic compounds. XRD (X-ray Diffraction) can present crystallinity, phase species, molecular orientation and the structure organization, important and prerequisite for correlation between material properties and structures as well as performance of biomass-derived polymers and functional materials; SEM (Scanning Electron Microscope) and TEM (Transmission Electron Microscope) are widely applied for surface morphology, particle size distribution internal structure and nanostructure (within the realm of scanning and transmission Electron Microscopy respectively), enabling interpretation on process behaviors or performances of biomass-derived compounds, catalysts and polymer related systems. Thermogravimetric analysis (TGA) and Differential Scanning Calorimetry (DSC) are instrumental methods for obtaining detailed information on thermal stability, decomposition characteristics, glass transition temperature(s), melting behavior and degradation routes, which has become crucial factors to determine its application potentiality in industrial manufacturing, packaging, biomedical and fine material fields. Therefore, the combinatorial methods, comprising FTIR, NMR, Mass, XRD, SEM/TEM and thermogravimetry were considered as a comprehensive chemical characterization strategy that provides an effective way to determine chemical identity, structures, properties and to optimize the development of biomass derived organic molecules and sustainable functional materials.



Above diagram showing Biomass-Derived Platform Chemicals as Renewable Feedstocks

IX. DISCUSSION

Biomass-derived platform chemicals are expected to pave the way for increased sustainability in the chemical manufacturing industry in four primary ways: via improvements in environmental performance; reduction in the use of petrochemical resources as a carbon supply; new possibilities for high value organic molecules; and improved functional materials. The efficiency of a carbon input stream into the chemical process industry should increase if these carbon inputs are sourced from biomass: lignocellulosic biomass, agricultural waste, plants and other biologic source of carbon to replace the petrochemical source of carbon. The transformation of biological materials through chemical synthesis has the effect of replacing petrochemical materials, so that they and the associated GHG emissions associated with producing them are no longer part of our economy.

The concept leads to carbon cycling as there is less wasted biomass when it is converted to chemical intermediates than discarded in the trash heap. The approach in concert with biorefinery concepts, green solvents and efficient processes lead to better resource use of biomass as well (Sheldon, 2017). This molecular concept could lead to an improved and increased functionality, as molecular design and functional modification can precisely alter chemistry and polymer architecture so that material (strength, stability, degradability) is perfectly suited to an intended application. Designing the molecular structure of renewable monomers or functional molecules will allow substitution of backbone units, insertion of either bulky aromatic or flexible chain segments, functional group selection for appropriate solubility or hydrophilicity, all tuned for use in durable yet biodegradable polymers, coatings, composites, packages, biologic systems and electronics. Through strategies of functional modification through chemical derivatization, catalytic upgrading, crosslinking, etc., functional molecule performance might be improved to be more durable, conductive, compatible, have higher barrier properties, or be more resistant to environmental degradation. This connection among renewable feedstock source, molecular architecture and processing strategy determines what material property is produced: as such this interconnection is a key part of developing novel materials going forward. The benefits will accrue: more sustainable carbon resource input; better environmental performance; higher material function-all the way toward a circular carbon cycle where by chemical technology, catalysis, and materials science the carbon input from plants is transformed from a waste commodity to high-value products.

X. CONCLUSION

Use of biomass-derived platform chemicals offer a paradigm-shift for sustainable chemical manufacture as they can serve as bio-based alternatives to the traditional fossil resources in the production of chemical feedstocks, and further facilitate the synthesis of valuable and functional materials through the efficient utilization of carbon resources, wherein renewable molecular constituents extracted from different biomass sources (cellulose, hemicellulose, lignin, and lipids) act as flexible intermediates for creating high-value organic species, polymers and high performance materials through appropriate catalyses processes including hydrolysis, dehydration, oxidation, hydrogenation, fermentation, and selective upgrading methods that provide better performance, selectivity, efficiency, and industrial scalability by converting biomass derived platform chemical to useful chemicals. In view of the dwindling petroleum resources the technology has the potential to achieve circular carbon utilization (Corma et al., 2007); integration of concepts such as green chemistry and computational modeling and AI coupled with design of smart materials offers a holistic platform that can be used to achieve superior performance for chemical reactions while the consumption of energy, and generation of wastes are minimal, apart from creating sustainable materials with tunable structural, and functional characteristics through computational modeling and predicting methods, where the behavior of reactants in various catalyst states are clearly elucidated. Based on this premise future work can envision development of sustainable systems involving novel catalysts and reactions that can ultimately produce smart materials, specialty chemicals, pharmaceuticals, and polymers on a sustainable basis, along with enabling closed-carbon utilization. Therefore, advancement in biomass conversion, bio-refinery process, and materials development could pave the way to realizing the circular economy, with fossil independent systems as envisioned.

REFERENCES

[1] Anastas, P. T., & Warner, J. C. (1998). *Green Chemistry: Theory and Practice*. Oxford University Press.

[2] Bozell, J. J., & Petersen, G. R. (2010). Technology development for the production of biobased products from biorefinery carbohydrates—The US Department of Energy's "Top 10" revisited. *Green Chemistry, 12*(4), 539–554. Crossref

[3] Corma, A., Iborra, S., & Velty, A. (2007). Chemical routes for the transformation of biomass into chemicals. *Chemical Reviews, 107*(6), 2411–2502. Crossref

[4] Cherubini, F. (2010). The biorefinery concept: Using biomass instead of oil for producing energy and chemicals. *Energy Conversion and Management, 51*(7), 1412–1421. Crossref

[5] Dusselier, M., Mascal, M., & Sels, B. F. (2013). Top chemical opportunities from carbohydrate biomass: A chemist's view of the biorefinery. *Topics in Current Chemistry, 353*, 1–40.

[6] Gallezot, P. (2012). Conversion of biomass to selected chemical products. *Chemical Society Reviews, 41*, 1538–1558. Crossref

[7] Gandini, A. (2011). The irruption of polymers from renewable resources on the scene of macromolecular science and technology. *Green Chemistry, 13*(5), 1061–1083. Crossref

[8] Hermann, B. G., Blok, K., & Patel, M. K. (2007). Producing bio-based bulk chemicals using industrial biotechnology saves energy and combats climate change. *Environmental Science & Technology, 41*(22), 7915–7921. Crossref

[9] Huang, Y. B., & Fu, Y. (2013). Hydrolysis of cellulose to glucose by solid acid catalysts. *Green Chemistry, 15*, 1095–1111. Crossref

[10] Isikgor, F. H., & Becer, C. R. (2015). Lignocellulosic biomass: A sustainable platform for the production of bio-based chemicals and polymers. *Polymer Chemistry, 6*, 4497–4559. Crossref

[11] Kamm, B., & Kamm, M. (2004). Principles of biorefineries. *Applied Microbiology and Biotechnology, 64*, 137–145. Crossref

[12] Kumar, R., Mago, G., Balan, V., & Wyman, C. E. (2009). Physical and chemical characterizations of corn stover and poplar solids resulting from leading pretreatment technologies. *Bioresource Technology, 100*(17), 3948–3962. Crossref

[13] Lange, J. P. (2007). Lignocellulose conversion: An introduction to chemistry, process and economics. *Biofuels, Bioproducts and Biorefining, 1*(1), 39–48. Crossref

[14] Luterbacher, J. S., Martin Alonso, D., & Dumesic, J. A. (2014). Targeted chemical upgrading of lignocellulosic biomass to platform molecules. *Green Chemistry, 16*, 4816–4838. Crossref

[15] Mamman, A. S., Lee, J. M., Kim, Y. C., Hwang, I. T., Park, N. J., Hwang, Y. K., Chang, J. S., & Hwang, J. S. (2008). Furfural: Hemicellulose/xylan-derived biochemical. *Biofuels, Bioproducts and Biorefining, 2*(5), 438–454. Crossref

[16] Menon, V., & Rao, M. (2012). Trends in bioconversion of lignocellulose: Biofuels, platform chemicals and biorefinery concept. *Progress in Energy and Combustion Science, 38*(4), 522–550. Crossref

[17] Ragauskas, A. J., Williams, C. K., Davison, B. H., Britovsek, G., Cairney, J., Eckert, C. A., Frederick, W. J., Hallett, J. P., Leak, D. J., Liotta, C. L., Mielenz, J. R., Murphy, R., Templer, R., & Tschaplinski, T. (2006). The path forward for biofuels and biomaterials. *Science, 311*(5760), 484–489. Crossref

[18] Rackemann, D. W., & Doherty, W. O. S. (2011). The conversion of lignocellulosics to levulinic acid. *Biofuels, Bioproducts and Biorefining, 5*(2), 198–214. Crossref

[19] Rosatella, A. A., Simeonov, S. P., Frade, R. F. M., & Afonso, C. A. M. (2011). 5-Hydroxymethylfurfural (HMF) as a building block platform: Biological properties, synthesis and synthetic applications. *Green Chemistry, 13*, 754–793. Crossref

[20] Sheldon, R. A. (2017). The E factor 25 years on: The rise of green chemistry and sustainability. *Green Chemistry, 19*(1), 18–43. Crossref

[21] Serrano-Ruiz, J. C., Luque, R., & Sepúlveda-Escribano, A. (2011). Transformations of biomass-derived platform molecules: From high added-value chemicals to fuels via aqueous-phase processing. *Chemical Society Reviews, 40*, 5266–5281. Crossref

[22] Tuck, C. O., Pérez, E., Horváth, I. T., Sheldon, R. A., & Poliakoff, M. (2012). Valorization of biomass: Deriving more value from waste. *Science, 337*(6095), 695–699. Crossref

[23] van Putten, R. J., van der Waal, J. C., de Jong, E., Rasrendra, C. B., Heeres, H. J., & de Vries, J. G. (2013). Hydroxymethylfurfural, a versatile platform chemical made from renewable resources. *Chemical Reviews, 113*(3), 1499–1597. Crossref

[24] Werpy, T., & Petersen, G. (Eds.). (2004). *Top Value Added Chemicals from Biomass: Volume I—Results of Screening for Potential Candidates from Sugars and Synthesis Gas*. U.S. Department of Energy.

[25] Wyman, C. E. (2007). What is (and is not) vital to advancing cellulosic ethanol. *Trends in Biotechnology, 25*(4), 153–157. Crossref

[26] Yan, N., & Zhao, C. (2012). Catalytic conversion of biomass-derived compounds into chemicals and fuels. *Chemical Society Reviews, 41*, 4125–4145. Crossref

[27] Zakzeski, J., Bruijnincx, P. C. A., Jongerius, A. L., & Weckhuysen, B. M. (2010). The catalytic valorization of lignin for the production of renewable chemicals. *Chemical Reviews, 110*(6), 3552–3599. Crossref

[28] Zhang, Z., & Zhao, Z. K. (2010). Solid acid and base catalysts for the conversion of biomass-derived carbohydrates. *Chemical Society Reviews, 39*, 3520–3534. Crossref

[29] Zhu, J. Y., & Pan, X. J. (2010). Woody biomass pretreatment for cellulosic ethanol production: Technology and energy consumption evaluation. *Bioresource Technology, 101*(13), 4992–5002. Crossref