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Opinion

Path Forward to the Viable Production of Lignin Derived Biopolymers

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Opinion

The growing concerns over climate change impacts have been driving the interest in the production of biomass derived polymers (e.g., polylactic acid) with applications in a range of sectors like building materials and packaging. Cellulose, first most abundantly available biopolymer in nature,has been used as a candidate feedstock to produce a range of biomass derived polymers. The high-quality polymer composites and functional polymeric materials can be synthesized using cellulosefibers, nanocellulose, and cellulose derivatives as fillers or matrices in bio composites materials, which is an efficient bio sustainable alternative to produce most petroleum-based polymers. However, the commercial production of cellulose derived biopolymers may face a strong competition from renewable fuel and chemical producers as these producers also use cellulose as a source of carbon to produce renewable fuels and chemicals in biorefineries.[1] Lignin, the second most abundantly available biopolymer in nature, is currently underutilized in biorefineries by using it mostly to produce bioenergy [1]. The use of lignin to make high value-added biopolymers and cellulose/hemicellulose fraction of biomass (like wood chips) to fuels/chemicals can increase the commercial viability of biorefineries and eventually reduce the feedstock competition with the production of biopolymers (Figure 1); [1]. In this opinion, we discuss a path forward to make effective lignin derived biopolymers with various applications.

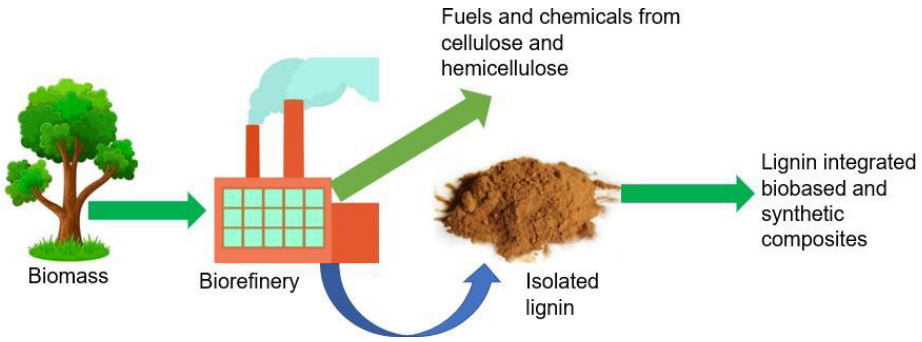

Figure 1: Concept of the future biorefinery.

Lignin biopolymer has been studied as a filler/reinforcement in both biopolymer matrix (polybutylene succinate, poly lactic acid, natural rubber, etc.) and synthetic polymer matrices (low density polyethylene, high density polyethylene, polypropylene, polystyrene, polyethylene terephthalate, etc.) for enhancing various properties of bio and synthetic polymer composites including thermal and mechanical properties [2]. The lignin content up to 80 wt.% was used in the production of lignin reinforced bio and synthetic polymer composites [2]. A more than 10% increase in the tensile properties of polymers has been found when lignin (20 wt.%) is reinforced with polymer composites [3]. However, the correlation between lignin polymer attributes (molecular weight, polydispersity index, chemical structure, etc.) and mechanical properties of lignin reinforced polymer composites has not been understood yet.

The nascent lignin three-dimensional (3D) printing field has been emerged recently by bringing lignin research to the additive manufacturing [4,5]. The 3D printable technologies like fused diffusion modeling, direct ink writing, and Vat photopolymerization have been used to make lignin-based polymer composites. The 3D printable acrylonitrile-butadiene-lignin and lignin-nylon 12 composites were synthesized by integrating lignin into nitrile-butadiene rubber (an analog to the acrylonitrile-butadiene-styrene) and lignin into nylon 12, respectively [4]. It has been shown that incorporation of lignin enhances the stiffness and tensile strength at room temperature and printability of lignin modified nylon composites [4]. Like the mechanical properties, the viscoelastic properties of lignin modified composites are dependent on the structural characteristics of lignin [4]. Detail understanding of the influence of molecular attributes of lignin (molecular weight, chemical structure, etc) on the viscoelastic properties of lignin modified composites is necessary to produce 3D printable lignin derivatives with enhanced properties.

The molecular attributes of lignin greatly vary with feedstock source (e.g., softwood, hardwood, corn stover etc.), type of isolation method (Kraft method, Organosolv, etc.), precipitation methods, and the number of isolation stages. It is critical to understand the influence of isolation method, solvents used in isolation method, combination of solvents used for the lignin isolation followed by precipitation, and operating conditions of isolation method on the molecular attributes of resulting lignin. The analytical techniques like gel permeation chromatography, nuclear magnetic resonance spectroscopy, Fourier-transform infrared spectroscopy, and differential scanning calorimetry are critical for determining the resulting changes in the molecular attributes of lignin because of isolation and precipitation methods.

The studies must be focused on the developing new processes to control the molecular attributes of isolated lignin. Simultaneously, lignin with varying molecular attributes must be integrated into biobased and synthetic polymer composites and study the viscoelastic, mechanical, thermal, and other use specific properties to determine the correlation between lignin molecular attributes and different properties of lignin derived composites. Such correlations enable the development of lignin derived composites with an enhanced viscoelastic, mechanical, thermal, and other use specific properties and eventually accelerates the growth of nascent biobased industry. Finally, the production of lignin desired molecular attributes can also lead to the production of carbon fibers and thermosetting resins [6] for use in Army applications (e.g., high performance light weight transparent armor).

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