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Editorial

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A Perspective on Lignin Refining, Functionalization, and Utilization

Lignin is the second most abundant natural polymer in the world, yet its utilization (other than for fuel) makes up only a tiny fraction of the billions of pounds processed from harvested wood and other lignocellulosic crops. There is no doubt that our society is placing a renewed emphasis on the possibility of using lignin streams as a replacement for aromatic components of petrochemical origin. A cursory examination of the literature over the past 5 years shows tremendous activity in this area, with many reviews appearing, addressing various aspects of lignin chemistry and utilization. Despite this interest, however, obstacles remain toward making this valuable resource a feedstock and reality for many of our industry's processes. These obstacles are technical, economic, and cultural.

Lignin streams impose significant technical challenges to becoming and/or replacing most petrochemical-based feedstocks due to its inherent variability, heterogeneity, color, and reactivity. Numerous process variations including seasonal feedstock variability, H-factor, and related delignification alterations, which are all currently based in producing cellulosic materials, create an inherently complex mixture of unpredictable specifications. This reality necessitates that any lignin streams that are envisaged to become feedstocks for further utilization need to first be refined to a set of products with consistent specifications. This is analogous to crude oil utilization, where refining operations take an otherwise intractable mixture, that is only good as a fuel, and refine it to a multitude of chemicals, which are the foundation of the chemical industry. In this respect, lignin refining or fractionation efforts are pivotal and need to become part of our thinking prior to any of the proposed lignin utilization avenues can be industrially viable. The lignin community needs to become acutely aware of the need to offer the user sector a product of consistent specifications on a daily basis. Technically sound and economically feasible advances in lignin refining are thus essential. The economic challenges that lignin products face are related to competition from petrochemical sources. As long as the price of oil remains low these constraints can only become more acute.

In addition, the current low price of lignin offers relatively low financial margins for producing lignin feedstocks with consistent specifications. Consequently, it becomes apparent that our community needs to apply a large degree of innovation so as to create useful value-added products based on lignin. This is necessitated by the enumerated technical, financial, and cultural contraints.

It is without a doubt that the pulp and paper industry and possibly emerging biorefineries will be the prime candidates to offer lignin streams to society for further utilization. In both cases, however, the current objective of these industries is not to make lignin for further utilization but to make paper, bioethanol, or other products. In this respect, lignin has always been a secondary product and treated as such. This situation presents challenges in convincing the user sector to include lignin in their feedstock.

Although all of the above considerations may offer a picture of a rather intractable problem, the potential of lignin as a feedstock is enormous due to its aromatic, phenolic, reactive character and its abundance. As evidenced by the contents of this *ACS Sustainable Chemistry & Engineering* Special Issue {http://pubs.acs.org/toc/ascecg/4/10}, the degree of innovation our community has been displaying is high. Significant advances are apparent and demonstrate that, indeed, technical lignins can be economically and reproducibly fractionated to discrete and uniform "cuts". Lignin can be made to offer high value nanocapsules and polymer melts as well as precursors for carbon fibers. These are only but a few of the tangible and demonstrable potential applications for this valuable resource, with more such approaches rapidly emerging.

Obviously, the issue of lignin utilization rests in the hands of researchers, lignin producers, and users. Researchers need to become acutely aware of the difference between Innovation and Invention. In other words, researchers need to gain the confidence and work closely with lignin producers and the user sector to ensure the transition from idea to application becomes seamless.

An entrepreneurial spirit should be adopted around lignin production. An open dialogue between lignin producers and innovators could catalyze thinking at identifying target applications and markets. Cross-business attitudes, front end market research to identify market economics, market dominance considerations, and potential regulatory barriers or opportunities should all be part of the dialogue. Lignin producers and innovators need to be able to converse and convincingly connect with the chemical and allied industries, demonstrating that they can provide a reliable feedstock. This can only occur if the lignin producers and innovators show a serious commitment to such an endeavor that will require a major cultural shift by no longer treating lignin as a secondary byproduct but treat it with the respect accorded to a valuable chemical feedstock.

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