Reductive Lignin Depolymerization: A carbon efficient pathway towards Biomaterials and Green Chemicals

Balaji Sridharan[a], Paul Jusner[a], Brent Daelemans[a], Marc Comí Bonachí[a], Elias Feghali[a,b], Kelly Servaes[a], Karolien Vanbroekhoven[a]

[a]Flemish Institute for Technological Research (VITO), Unit Separation and Conversion Technology, Boeretang 200, 2400, Mol, Belgium
[b]Chemical Engineering Program, Notre Dame University-Louaize, Zouk Mosbeh 1211, Lebanon

Lignin-first biorefineries highlight the potential of lignin's aromatic-rich structure for producing high-value green chemicals. A key step in lignin valorization is depolymerization, which converts the complex biopolymer into monomers, dimers, and oligomers, with product functionality governed by catalyst and process conditions. While reductive depolymerization has advanced significantly, it has largely been demonstrated at small (mg–g) semi-continuous scales using wood feedstocks [1–3]. Integrating this technology with existing biorefineries (e.g., kraft, hydrolysis, and organosolv) is therefore critical.

Here, we demonstrate long-term continuous reductive depolymerization of lignins from commercial biorefineries at lab scale and its successful scale-up to two fully operational LignoValue pilot units at VITO (Belgium). Lab-scale experiments were performed in a continuously operated packed-bed reactor containing 15–30 g of Pd/Al_2O_3 or Ru/Al_2O_3. The effects of temperature (200–250 °C), lignin concentration (5 - 40 wt.% in methanol), feed rate (25–100 mL h^{-1}), and catalyst selection were systematically studied. The resulting depolymerized lignin oil (DLO) was characterized by GC-MS/FID, NMR (^{13}C, ^{31}P, 2D HSQC), GPC, and CHN analysis. **Furthermore, process intensification through solvent optimization and equipment redesign enabled near-quantitative carbon utilization while significantly reducing projected production costs.**

Continuous depolymerization of hydrolysis and organosolv lignins was sustained for over 100 h time-on-stream at 235 °C using Pd/Al_2O_3 and methanol, resulting in a pronounced reduction in molecular weight and carbon efficiencies exceeding 90%, with minimal coke or gas formation [4]. Importantly, the resulting DLO was directly applied at near-pilot scale in the synthesis of renewable structural materials, including polyurethane foams, coatings, and epoxy resins performed either inhouse at VITO or in collaboration with industrial partners over several European and regional projects. These demonstrations highlight the potential of lignin-derived streams as practical, sustainable alternatives to fossil-based feedstocks. Overall, this study establishes a scalable and industry-relevant route for integrating lignin valorization and renewable material production within existing biorefinery infrastructures.

References:

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