Techno-economic analysis and life cycle assessment of a biorefinery utilizing reductive catalytic fractionation

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Project Goals: The Center for Bioenergy Innovation (CBI) vision is *to accelerate domestication of bioenergy-relevant, non-model plants and microbes to enable high-impact innovations at multiple points in the bioenergy supply chain.* CBI addresses strategic barriers to the current bioeconomy in the areas of 1) high-yielding, robust feedstocks, 2) lower capital and processing costs via consolidated bioprocessing (CBP) to specialty biofuels, and 3) methods to create valuable byproducts from the lignin. CBI will identify and utilize key plant genes for growth, composition, and sustainability phenotypes as a means of achieving lower feedstock costs, focusing on poplar and switchgrass. We will convert these feedstocks to biofuels using CBP with cotreatment at high rates, titers and yield in combination with catalytic upgrading into drop-in hydrocarbon fuel blendstocks.

The aromatic polymer, lignin, which comprises a major fraction of carbon in plants, remains a challenge to cost effectively and sustainably convert to valuable products, despite a century of microbial, genomic, and catalytic research. While potential bench-scale routes to convert lignin-derived compounds into both fuels and valuable chemicals exist, industrially viable methods to depolymerize lignin into usable fragments conducive to these valorization routes remains a subject of ongoing research and development. Reductive catalytic fractionation (RCF) is one promising approach to fractionate lignocellulosic biomass and convert lignin into a narrow slate of products amenable to upgrading[1]. To quantitatively guide research towards critical areas for commercialization, cost and sustainability must be considered. To that end, we report a detailed techno-economic analysis (TEA) and life cycle assessment (LCA) of the RCF process, wherein biomass carbohydrates are converted to ethanol and the lignin-rich RCF oil is the lignin-derived product. We first evaluate a process configuration using methanol as a solvent and H_2 as a hydrogen source which predicts a minimum crude RCF oil selling price of $0.51/lb when the coproduct ethanol is sold at $2.50/gallon of gasoline equivalent. When normalized to just the lignin content of the RCF oil, the minimum selling price of the lignin fraction is $0.79/lb. Analysis of additional cases using different solvents and an *in situ* hydrogen donor from hemicellulose-derived compounds revealed that limiting reactor pressure using solvents with lower vapor pressure could greatly reduce capital expenses while still maximizing lignin yields and exhibiting promising economics and environmental impacts. Process configurations that reduce the energy demand for solvent separation also improve both global warming potential (GWP) and cumulative energy demand (CED) through reducing natural gas demand. This study suggests prioritization of research that can reduce capital expenses and environmental impacts by lowering RCF operating pressure, minimizing solvent loading to reduce reactor size and energy required for solvent recovery, implementing condensed-phase separations for solvent recovery, and utilizing the entirety of RCF oil for value-added products.

References/Publications

1. W. Schutyser, T. Renders, S. Van den Bosch, S.-F. Koelewijn, G.T. Beckham, and B.F. Sels. "Chemicals from lignin: an interplay of lignocellulose fractionation, depolymerization, and upgrading." *Chem Society Rev.* (2018), **47:** 852-908.

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