Screening of Value-Added Market Opportunities for Lignin

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Introduction

In a 2nd generation biorefinery, the cellulose and hemicellulose portions of biomass are converted into fuels via one of two pathways (see Figure 1). However, the third predominant component of plant matter, lignin, is left largely untouched. In most cases, lignin can be extracted from the process as an isolated product. Unfortunately, this is largely regarded as low-value waste stream, which is best epitomized by the well-known saying "you can make anything out of lignin, except money."

Despite this commonly held notion, high-value applications for lignin do exist. If properly implemented, these possibilities can turn a low-value waste stream into profitable co-products. This would bolster the economics of current biorefineries, and can help expedite the commercialization of emerging 2nd generation biorefineries.

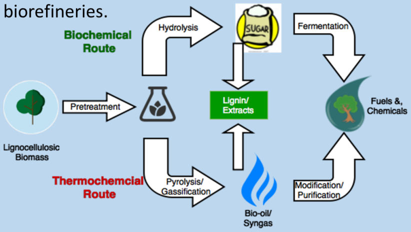
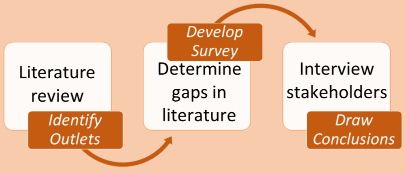


Figure 1. Schematic Representation of a 2nd Generation Biorefinery

Objectives

- Investigate market challenges and opportunities for lignin value-added products.
- Apply these findings to the operation of a 2nd generation biorefinery.
- Develop a recommendation for which value-added opportunities to pursue.

Methodology



Literature Findings

Outlets for lignin were researched and identified over the course of the literature review. The results were summarized below in Table 1.

Table 1. Selected Lignin Applications from Literature

Application	Description	Current Status
Direct Combustion	Low Value: ~ $0.04/ lb fuel value[1].	Commercialized. Represents over 98% of current lignin consumption (i.e. all non-commercialized lignin)[2].
Gasification	Controlled burning of lignin in absence of oxygen, vaporizing inputs to produce a CO & H_2 rich gas mixture ("syngas").	Near-term upscale status. Process improvements must be made to decrease tar byproduct. No instances of commercialization.
Pyrolysis	Controlled burning of lignin in absence of oxygen to produce syngas, bio-oil, and bio-char products.	Near-term upscale status. Process improvements include optimizing bio-oil yield & reducing temperature range of process. Pilot-scale tests exist using whole woody biomass.
Hydroliquidification	Depoylmerization of lignin, followed by conversion into hydrocarbon fuels.	Medium-term upscale status. Improving catalysis and underlying economics must be evaluated.
Activated Carbon (AC) *	Carbonization & activation of lignin to produce a porous, carbon-rich char capable of sequestering pollutants.	Medium-term upscale status. Commercial-grade AC from lignin has been demonstrated. Lack of economic & market analyses on said processes.
Carbon Fiber (CF)	Spinning of lignin into fibers, followed by stabilization and carbonization of these fibers to yield a durable polymer.	Medium-term upscale status. Lignin-derived CF is cheap to produce, but lacks mechanical properties of oil-derived counterparts.
Phenol-Formaldehyde (PF) Resins	Displacement of phenol by lignin in the synthesis of PF resins, commonly used as a binder in wood products.	Short to medium potential for upscale. Extensive literature exists demonstrating 30% phenol displacement without mechanical degradation.
Epoxy Resins *	Blending of either modified or unmodified lignin with epoxy resins.	Medium-term upscale status. Epoxy resins have been blended with multiple types of lignin, however this process has not been commercialized.
Thermoplastics *	Blending of lignin with traditional thermoplastic material to increase biodegradability and decrease manufacturing costs.	Medium to long potential for upscale. A variety of lignin-based thermoplastics have been synthesized, however, this research is still preliminary.
Concrete Admixtures	Blending of lignin in concrete to improve strength and decrease water consumption.	Commercialized. Accounts for 38% of all commercialized lignin[3].
Animal Feed	Use of lignin in animal feed to improve nutritional value of product.	Commercialized.
Dust Control	Applying lignin onto road as a dust suppressant.	Commercialized. In 1991, 5-10% of all dust control applicants were lignin-derived[4].
BTX Chemicals	Depolymerize lignin into aromatic monomers, then further convert into BTX.	Long-term upscale status. Still in R&D phase; improvements in yield and specificity needed.
Vanillin	Selectively depolymerizing lignin structure to convert to vanillin, an aromatic molecule.	Commercialized, although not common today due to environmental concerns.

*Emphasis of NARA R&D efforts:

Activated Carbon

Epoxy Resins

Thermoplastics

Interview Findings

Note: Interview findings are preliminary, and based off n=3 interviews in an ongoing pilot test.

- Currently, 2nd generation biorefineries could not be feasible without finding a value-added output for lignin. (n=3)
- 2 main drivers identified behind valorizing lignin: economic and environmental. The former is self-evident. However, the environmental driver has not been previously reported in literature. Is this also the views of the industry, or just the environmentally-minded NARA alliance? (n=3)
- Sulfonated lignin has mature & commercialized outlets; sulfur-free lignin does not yet. (n=2)
- Factors for evaluating which outlets to pursue include: size and value of market, maturity of conversion, and level of environmental mitigation. (n=1)

Conclusion

Implementing value-added outlets for lignin will be imperative in commercializing 2nd generation biorefineries. This economic reality is a huge driver behind developing these applications, but environmental mitigation is another important aspect. Selecting which value-added applications to pursue is a criteria of size and value of market, maturity of conversion, and level of environmental mitigation. For these reasons, NARA has placed emphasis on developing activated carbon, epoxy resins, and thermoplastic outlets.

Future Works

- Finish literature review to present a complete picture of lignin markets.
- Expand interview population to yield new insight.

References

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Images: http://www.cocarb.com/wp-content/uploads/2013/12/activated-carbon-by-cocarb-460x300.jpg; http://s3files.core77.com/blog/images/2 014/09/0PHOTO3_abouttomix.jpg; http://ecycler.com/wp-content/uploads/2010/12/styrofoam.jpg.

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