NREL Overcomes Obstacles in Lignin Valorization

Highlights in Science

Using a "funneling" pathway inherent in nature, NREL researchers show that lignin can be converted into renewable fuels, chemicals, and materials.

It has long been known how to convert biomass-derived carbohydrates, such as glucose, into fuels and chemicals such as ethanol. However, plants also contain a significant amount of lignin, comprising up to 30% of their cell walls. Lignin is a heterogeneous aromatic polymer that plants use for strength, for defense against pathogens, and to transport water in their tissues. In biofuel production, lignin is typically considered a hindrance to cost effectively obtaining carbohydrates, and residual lignin is burned for process heat because it is difficult to depolymerize and upgrade into fuels or chemicals. Because of its heterogeneity, nearly all processes that break down lignin produce a mixture of aromatic molecules that are then difficult to upgrade separately into valuable chemicals.

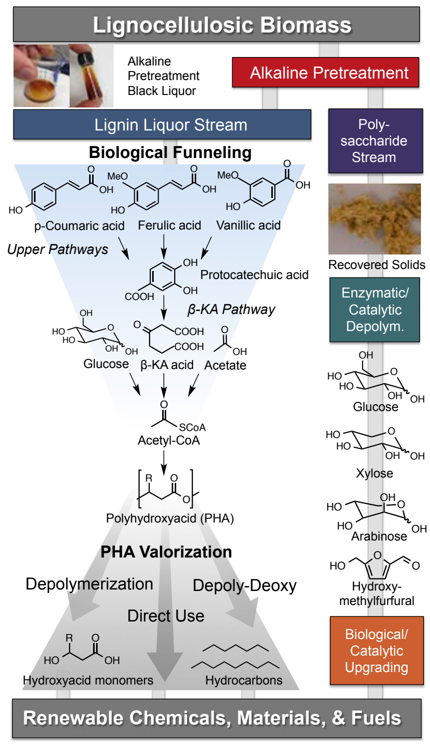

Illustration of how alkaline pretreatment was used to produce a lignin-enriched stream, which was then subjected to biological funneling to produce mcl-PHAs, which can serve directly as a bioplastic, be depolymerized to chemicals, or catalytically converted to fuels. Image by Derek R. Vardon, NREL

In nature, however, some microorganisms have developed the means to overcome the heterogeneity of lignin via "funneling" pathways, in which microbes uptake the resulting aromatic molecules and use them as a carbon and energy source. Researchers from the National Renewable Energy Laboratory (NREL) have demonstrated that the use of these aromatic catabolic pathways may facilitate new routes to overcome the lignin utilization barrier that, in turn, may enable a broader slate of molecules derived from lignocellulosic biomass. In particular, NREL researchers have used biological funneling combined with downstream chemical catalysis to demonstrate the production of natural bioplastics (polyhydroxyalkanoates), hydroxy acids, and fuel-range alkanes from lignin-derived streams. By coupling metabolic engineering of the biological funneling pathways to chemical catalysis, this approach can also be used in the production of lignin-derived adipic acid, which is a precursor to nylon and currently the most abundantly produced dicarboxylic acid from petroleum.

Going forward, this approach can be applied to many different types of biomass feedstocks and combined with a variety of strategies for breaking down lignin, engineering the biological pathways to produce different intermediates, and catalytically upgrading the biologically derived product to develop a wider range of valuable molecules derived from lignin.

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References: Linger, J.G., et al. (2014). "Lignin valorization through integrated biological funneling and chemical catalysis." *PNAS* (111:33); pp. 12013-12018. *http://dx.doi.org/10.1073/pnas.1410657111*

Vardon, D.R., et al. (2015). "Adipic acid production from lignin." *Energy Env. Sci. http://dx.doi.org/10.1039/C4EE03230F*

Key Research Results

Achievement

This study demonstrates how the utilization of natural aromatic catabolic pathways enables a direct means to lignin valorization.

Key Result

Using this "biological funneling" approach, carbon from lignin can be directed to the tricarboxylic acid cycle. Researchers recently produced bioplastics, chemical precursors, and fuel-range alkanes by coupling biological funneling and chemical catalysis. Alternatively, metabolic engineering of the biological funnel, again coupled to chemical catalysis, allows the ability to produce adipic acid, a precursor to nylon and other materials.

Potential Impact

Lignin valorization is essential for the economic viability of third-generation biorefineries and is the single biggest contributor to meeting a $3/gasoline gallon equivalent. This new research provides even more opportunities for the successful conversion of lignin into a variety of renewable fuels, chemicals, and materials for a sustainable energy economy.

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

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