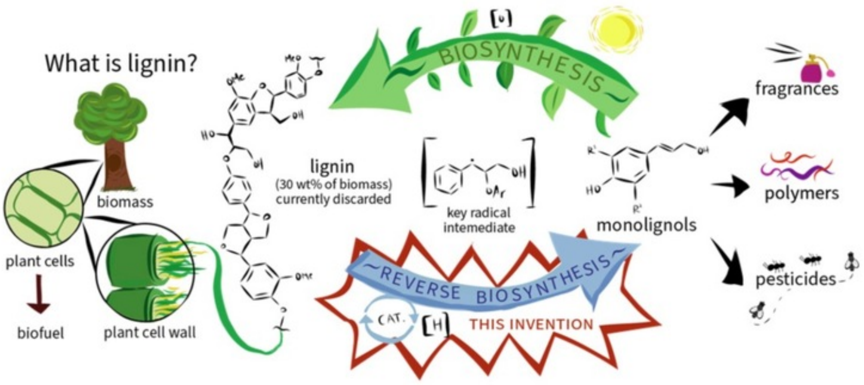
Catalysts to Efficiently Convert Lignin Biomass to Valuable and Sustainable Chemicals

A highly efficient, selective, and sustainable method for converting lignin biomass into valuable, small molecule chemicals.



Cartoon illustrating the biosynthetic cycle of lignin and the industrial applications of monolignols. The reverse biosynthesis pathway uses a titanium catalyst and a reductant, and via a key radical intermediate, results in the highly selective synthesis of monolignols, allowing for easy isolation and purification.

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Technology

NYU researchers in the Diao Lab have developed an efficient, selective and economical synthetic strategy for depolymerizing lignin, a major component of biomass waste, into discrete monomers, such as valuable phenylpropanoids. As described in published proof-of-concept studies (*Chin et al. ACS Catalysis 2022*), this process catalyzed by cost-effective titanium catalyst mimics a microscopic reverse biosynthesis pathway and results in the degradation of a copper-pretreated lignin into valuable monolignols (such as, eugenol and elemicin derivatives) suitable for the fragrance and pharmaceutical industries. (See schematic on next page.) These low-molecular-weight products can be easily isolated and purified using straightforward protocols, such as distillation, offering an economic way to current methods. Specifically, the reverse biosynthesis pathway entails the formation of a key radical intermediate (analogous to that formed in the biosynthetic pathway of lignin) that through an o-atom abstraction reductively triggers β-scission of the adjacent C-O bond to generate monolignols. Monolignols are valuable products that can be readily isolated and purified due to high selectivity. They serve as a starting material for synthetic compounds. The high value of monolignols justifies the use of stoichiometric reductants making this process cost-effective, as evidenced by an 81% overall cost reduction in the production of elemicin. This pioneering strategy opens up opportunities for lignin depolymerization, paving the way for an economical and sustainable production process for valuable phenylpropanoids.

Background

Lignin, an amorphous polymer rich in aromatic motifs and C-O ether bonds, is a main constituent of lignocellulosic biomass, an abundant and renewable resource from plants. The lignin component, which accounts for 15-30% of lignocellulose biomass by weight and 40% by energy, is currently not utilized to its full potential. Despite the promising prospects of using lignocellulosic biomass as a renewable raw material for chemicals (e.g., flavoring agents, pesticides, and pharmaceutical precursors), current methods for converting lignin into valuable small molecules suffer from key limitations. For example, depolymerization via common methodology using reductive catalytic fractionation results in the loss of useful chemical functionalities in the products created; while other existing methods, require harsh conditions, proceed through high reactively intermediates, and/or yield a mixture of products that are difficult to purify and isolate. Currently, there is no commercial method available for upcycling lignin, resulting in the majority of it being disposed of in landfills.

Applications

End products are applicable across industries: Monolignols are highly valuable small molecules that can be products or precursors in fragrances, flavorings, pesticides, polymers, or pharmaceuticals (e.g., local antiseptics and anesthetics).

Advantages

- Efficient and selective: The method yields only allyl-substituted aromatic compounds from lignin
- Sustainable: Utilizes lignin, a renewable biomass material that is largely wasted
- Mild reaction conditions: Conducted at room temperature, the process is environmentally friendly and less energy-intensive compared to existing methods
- High yield: The method produces a high-weight percentage of desired products from lignin

Development Status

There are on-going efforts to develop an electrocatalytic method applying titanium as a catalyst for larger-scale reactions to replace chemical reductants (as used in this iteration of the technology) with electrochemistry.

Intellectual Property

NYU has filed a U.S non-provisional patent application covering the general method for converting a biopolymer from biomass into small molecules.

References

1. Mason Chin, Sang Mi Suh, Zhen Fang, Eric L. Hegg, and Tianning Diao , https://pubs.acs.org/doi/10.1021/acscatal.2c00133
2. Sang Mi Suh, Subramanian Jambu, Mason T. Chin, and Tianning Diao , https://pubs.acs.org/doi/10.1021/acs.orglett.3c01416