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Replacing oil with wood for the production of chemicals

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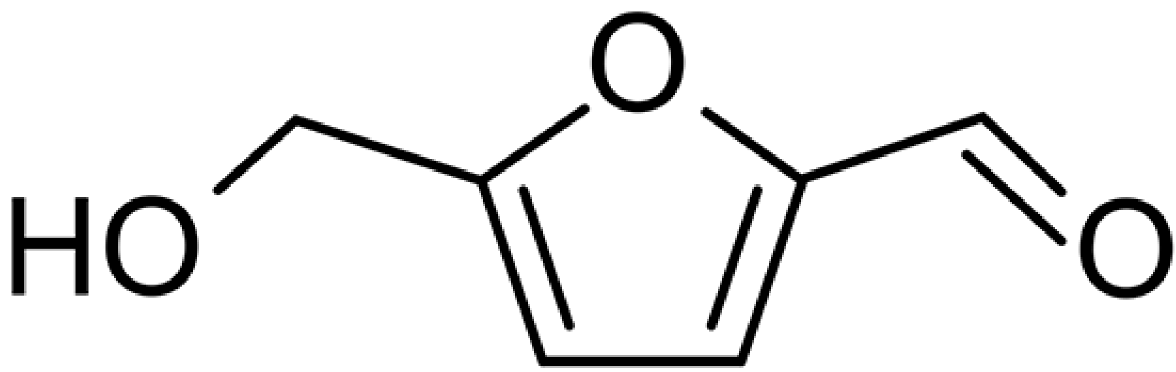

Two research projects of the National Research Programme "Resource Wood" have developed new processes to replace petroleum with wood for the production of important chemicals. These precursors are used in the manufacture of pharmaceuticals, plastics or fertilisers.

Petroleum means fuel, but not only: petrochemicals are a core ingredient of the chemical industry. Without oil, there would be no plastics and few pharmaceuticals or fertilisers. Finding a renewable resource as an alternative to oil will be crucial to face the foreseeable decline in oil extraction.

Two research projects of the National Research Programme "Resource

Wood" (NRP 66) have made significant advances towards replacing oil with biomass derived from plants, in particular from wood. Their goals are complementary, as each one uses one of the two main constituents of wood: cellulose and lignin. These are the two most common organic components on Earth and, importantly, are renewable.

Sviatlana Siankevich of EPFL has designed new catalytic processes to efficiently transform cellulose into hydroxymethylfurfural (HMF), a very important precursor for the production of plastics, fertilisers or biofuels. Inspired by the action of fungi degrading rotting wood, the team of Philippe Corvini at FHNW in Muttenz (BL) has selected enzymes capable of cutting lignin into aromatic compounds useful for making solvents, pesticides, plastics such as polystyrenes as well as active pharmaceutical ingredients.

Chemicals instead of paper

Cellulose is a long chain of carbohydrate (sugar) molecules and accounts for about two-thirds of wood's weight. "It is mainly used for paper production, and the residuals could be better valorised by being transformed into useful chemicals," says Sviatlana Siankevich of EPFL's Institute of Chemical Sciences and Engineering. With colleagues from Queen's University in Canada and the National University of Singapore, the EPFL team led by chemist Paul Dyson synthesised several types of ionic liquids (molten salts) to convert cellulose into HMF, an important molecule for the production of commodity chemicals. In a single step, their reaction reached a 62% yield, a new record.

"Our procedure operates at mild conditions, that is, without very high temperatures or pressure or strong acids", says Siankevich. "We've also been able to reduce the amount of undesired by-products, an important point if the reaction is to be scaled up for industrial processes. Our process can work with wood, but it's often easier to use cellulose extracted from herbaceous plants."

Greener chemistry

At the Fachhochschule Nordwestschweiz (FHNW) in Muttenz, Philippe Corvini and his PhD student Christoph Gasser are developing ways to use lignin, a long molecule which gives trees their rigidity and makes up around 15%-40% of the wood content. "Until now, lignin was not very much valorised, but often simply burned," says Corvini. "But it can be cut into aromatic structures, molecules based on the famous carbon hexagon ubiquitous in organic chemistry. These components represent huge volumes for the chemical industry, and have been so far almost exclusively obtained from petroleum. Lignin is presently the most serious alternative."

Some fungi secrete a combination of enzymes to degrade lignin and chop it into smaller pieces. Corvini's team at FHNW screened the combinations of dozens of such enzymes to select the most efficient. By adding a further catalytic step, they managed to transform 40% of the lignin into very small molecules such as vanillin. The process is of interest to the chemical industry, and collaboration with a lignin producer is already underway. "Most of the lignin today is obtained from wheat or rice straw," says Corvini. "But soft wood such as spruce could prove useful as its lignin is easy to break down."

The FHNW team also developed a way to reuse the enzymes. "We have attached them onto iron nanoparticles coated with silica, explains the researcher. After the reaction, we simply approach with a magnet to attract the particles and recover the enzymes." As these can be reused up to ten times, the energy and resources needed to produce them is significantly reduced and fits well into the concept of "green chemistry".

All of the wood

To be economically viable, wood as a replacement for petrochemicals must be used to the greatest extent possible. "Extracting only one component from wood in small quantity is not enough," says Sviatlana Siankevich. "We need to find complementary processes to use all of it." But more aspects must be considered to assess whether wood can serve as an economically viable substitute for oil. A third project of NRP 66 has recently carried out a sustainability assessment of the production of succinic acid, another important chemical, from wood residues. The study from ETH Zurich and EPFL shows that smart process design can lead to energy savings and environmental benefits, key factors for biorefineries to be competitive.

More information: Sviatlana Siankevich et al. Direct Conversion of Mono- and Polysaccharides into 5-Hydroxymethylfurfural Using Ionic-Liquid Mixtures, *ChemSusChem* (2016). DOI: 10.1002/cssc.201600313

Merten Morales et al. Sustainability assessment of succinic acid production technologies from biomass using metabolic engineering, *Energy Environ. Sci.* (2016). DOI: 10.1039/C6EE00634E

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