RESEARCH NEWS

Wood-based circular economy

Biohydrogen from Wood Waste

Up to now, wood waste has had to be disposed of at great expense and, at best, has been used to generate energy in incineration plants. Fraunhofer researchers are now using this valuable resource to produce biohydrogen in the Black Forest region of Germany. In the joint project H_2Wood — BlackForest, fermentation processes using hydrogen-producing bacteria and microalgae have been specially developed for the biotechnological production of this green energy carrier. A pilot plant for the production of biohydrogen is to be commissioned as early as 2025. A study published as part of the project also examines the potentials, barriers and measures for regenerative hydrogen production from waste wood and old wood in the Black Forest region.

The Black Forest region is home to a large number of wood processing companies, including many furniture manufacturers. Large quantities of wood waste are produced during furniture processing, pallet disposal and building demolition. Until now, this waste has been disposed of in incineration plants. Since old wood often contains wood preservatives that have long been banned due to their harmful effects on human health, the waste gas from the incineration process also has to be cleaned at great expense. This motivated the Fraunhofer researchers to look for alternative uses for the regional wood waste. The idea was that waste wood and old wood could be used to produce regenerative hydrogen, and that biohydrogen could be produced from the waste using biotechnological processes — perfectly in line with a wood-based circular economy. The trick is that the researchers use sugar from the wood to produce hydrogen using bacteria. The resulting CO_2 is then used to grow microalgae that can also produce hydrogen. In addition to the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB and the Fraunhofer Institute for Manufacturing Engineering and Automation IPA, the University of Stuttgart, with its Institute of Industrial Manufacturing and Management IFF, and Campus Schwarzwald are also involved in the implementation of the H_2Wood — BlackForest project, which was initiated in 2021. The German Federal Ministry of Education and Research (BMBF) is funding the project with 12 million euros.

The production process of biohydrogen starts with the pre-processing of old and waste wood. First, the wood waste, such as pallets or old garden fences, is pulped and broken down into its basic components. To do this, the researchers boil the wood under pressure at up to 200 °C in a mixture of ethanol and water. Lignin as well as adhesives,

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solvents and paints from the wood waste dissolve in the ethanol, separating the chemical contaminants from the wood fibers. In the next step, the wood fiber fraction that remains after boiling, the cellulose, and part of the hemicellulose are broken down into individual sugar molecules (glucose and xylose), which serve as food or substrate for the hydrogen-producing microorganisms. "Separating wood into its fractions is a process that requires experience. This is where we draw on the many years of expertise that we have gained in the construction of our lignocellulose biorefinery in Leuna," says Dr. Ursula Schliessmann, Deputy Institute Director at Fraunhofer IGB in Stuttgart, which is responsible for the project coordination and technology development. To convert the produced sugar into hydrogen, the researchers at Fraunhofer IGB have established two interlinked fermentation processes using hydrogen-producing bacteria and microalgae.

Carbon-based by-products produced in addition to hydrogen

Pre-processing produces by-products such as lignin, and the biotechnological conversion of the wood releases hydrogen and CO_2. The latter is then converted into by-products such as starch and carotenoids during microalgae production. Dr. Schliessmann explains the cascade process: "When the wood is fractionated, the wood fibers are freed from lignin, which, in addition to cellulose and hemicellulose, makes up twenty to thirty percent of the wood cell wall substance. As one of the by-products, this lignin has many uses — for example, in composite materials. One example of its use is in car panels." Whereas the long sugar chain molecules of the cellulose are used to produce glucose, which is added to the fermenter with bacteria and serves as a carbon source for bacterial growth. The bacteria then produce hydrogen and CO_2. The researchers separate the CO_2 from the gas mixture and transfer it to the algae reactor, a photobioreactor. The microalgae are able to use CO_2 as a carbon source and multiply. Unlike bacteria, they do not require sugar. "The metabolic products of the bacteria, i.e., the apparent waste stream of CO_2, are food for the microalgae and therefore do not enter the exhaust as a harmful greenhouse gas. The microalgae use this to synthesize carotenoids or pigments under the influence of light as further by-products that can be used by various industrial sectors." In a second step, the microalgae are transferred to a specially designed reactor where they release hydrogen via direct photolysis.

Biotechnological process with a high hydrogen yield

The project partners expect a high yield: Initially, around 0.2 kilograms of glucose can be produced from one kilogram of old wood. "We can then produce 50 liters of H_2 with this using anaerobic microorganisms," says Dr. Schliessmann. During fermentation with anaerobic bacteria, CO_2 is produced in equal portions, i.e., 50 percent. Once the hydrogen has been separated from the gas mixture, approx. two kilograms of CO_2 in the photobioreactor can produce one kilogram of microalgae biomass. This biomass has a starch content of up to 50 percent. It also contains the pigment lutein. The by-product algae biomass could, for example, be used for plastic components with the help of bacteria.

The modularly expandable pilot plant with three bioreactors is currently under construction. The biorefinery is scheduled to go into operation in Campus Schwarzwald at the beginning of 2025. In the future, it will be possible to combine different process steps in a modular way — an ideal prerequisite for testing new technologies.

Hydrogen road map for the Black Forest region

In this project, Fraunhofer IPA, together with the Institute of Industrial Manufacturing and Management IFF, is conducting a study to determine how the local demand for green hydrogen in the industrial, transport, household and building sectors can be met, and what quantities of waste wood and old wood are available for its production. As a result of this hydrogen road map, recommendations have been made for the development of the hydrogen economy in the Black Forest region. The proposed measures include the promotion of research and development, the expansion of the regional hydrogen infrastructure and the strengthening of energy systems integration in order to establish hydrogen as an integral part of the energy transition. "The study shows that the Black Forest region has a significant potential to produce hydrogen from local resources, but this potential can only be fully exploited by further developing the technologies and expanding the infrastructure," says Vladimir Jelschow, a research scientist at Fraunhofer IPA and one of the authors of the hydrogen road map.

Fig. 1 Currently, old wood treated with wood preservative has to be incinerated in authorized large power plants. In H_2Wood, this wood is used to produce hydrogen, carotenoids and starch.

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Fig. 2 **From left: Untreated old wood, wood in pulping solution, cellulose fibers (after boiling and washing), sugar solution from cellulose fibers, anaerobic hydrogen producers (bacteria), microalgae**

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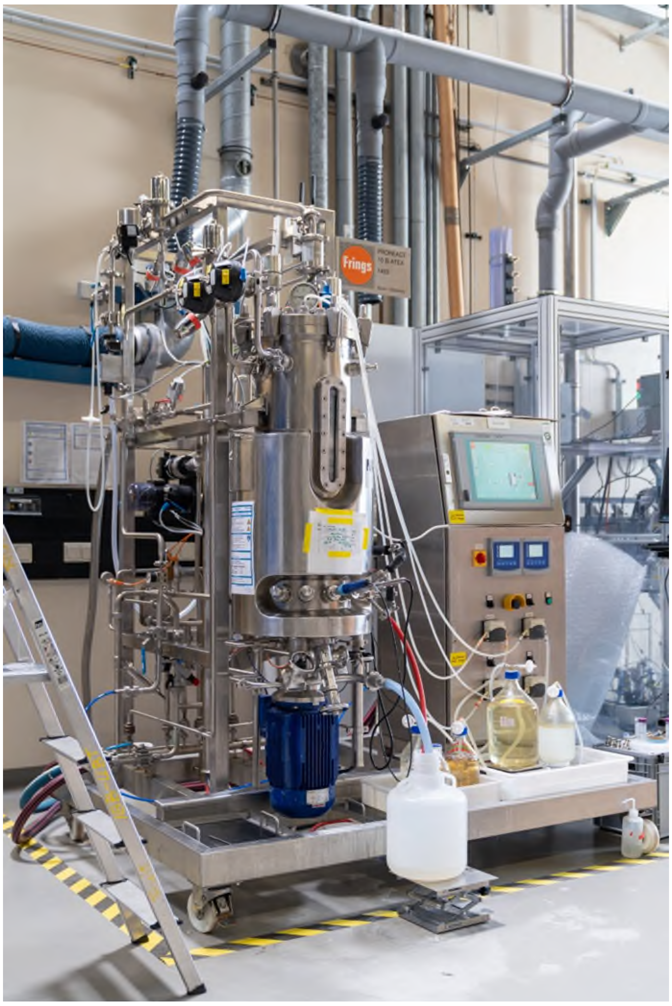

Fig. 3 The bacteria grow with the sugars produced from the wood and produce hydrogen and CO_2 as a result.

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