RESEARCH NEWS

Microbial polymers for bioplastics

Harnessing Municipal Wastewater as a Resource

Sewage treatment plants do more than just clean wastewater. They are also sources of raw materials. In the KoalAplan project, researchers from the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB are working with partners to recover high-quality products from municipal wastewater. These include ammonium, hydrogen and polyhydroxyalkanoates (PHAs), which can be used to produce bio-based and biodegradable plastics.

Our wastewater carries more than just dirt and excretions. It also contains valuable raw materials, such as nitrogen and organic carbon compounds. Chemical, biological and physical methods can be used to recover hydrogen, ammonium and polyhydroxyalkanoates (PHAs) from it. The recovered ammonium can be used as a nitrogen fertilizer for farming, and PHAs are the raw material for bioplastics. These processes are the subject of inquiry for the researchers working on the KoalAplan project (see below). The project partners' interdisciplinary research work is taking place at the wastewater treatment research facility operated by the University of Stuttgart in Büsnau. Working under real-world conditions, the partners are testing how raw materials can be reclaimed from sewage treatment plants. To this end, a biorefinery has been set up as a pilot plant. It operated for more than six months in 2024.

Getting around biological nitrogen removal

One of the methods established in the project, the primary stream method, involves wastewater treatment following prior solid separation during primary clarification. In a traditional sewage treatment plant, the nitrogen in the wastewater is removed biologically. Microorganisms convert the nitrogen compounds into gaseous nitrogen (green house gases), which escapes unused into the atmosphere. In the KoalAplan project, by contrast, the nitrogen is not lost. Instead, it is recovered as a raw material by physically removing ammonium using a zeolite filter or ion exchange system. After that, the nitrogen is recovered by regenerating the zeolite filter, producing a concentrated ammonium solution that can be used in agriculture as a nitrogen fertilizer.

Recovery of organic carbon from solids found in wastewater

In a traditional municipal sewage treatment plant, a large portion of the solids present in the wastewater is separated through sedimentation during the primary clarification.

Contact
Monika Landgraf | Fraunhofer-Gesellschaft, Munich, Germany | Communications | Phone +49 89 1205-1333 | presse@zv.fraunhofer.de
Claudia Vorbeck | Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB | Communications | Phone +49 711 970-4031 | Nobelstrasse 12 | 70569 Stuttgart, Germany | www.igb.fraunhofer.de | claudia.vorbeck@igb.fraunhofer.de

This "primary sludge" is fermented in a digestion tower, producing methane. In the biorefinery concept, it undergoes dark fermentation instead, with the degradation process being halted at the stage involving production of short-chain organic acids. After two-stage solid separation, a particle-free hydrolysate is produced. This hydrolysate is rich in short-chain organic acids and can be used for a variety of purposes. KoalAplan project explores these pontentials, for eg. microbial electrolysis for production of hydrogen and microbial production of PHAs. "Our job at Fraunhofer IGB was to use fermentation to convert the hydrolysate into PHA, a biodegradable, thermoplastic bacterial biopolymer," explains Pravesh Tamang, senior scientist for PHAs and a researcher at Fraunhofer IGB.

Acidic hydrolysate converted to PHAs

The PHAs are generally produced using microorganisms, which can grow on a wide range of different substrates. The microorganisms use the hydrolysate, which is rich in organic acids such as acetic, propionic and butyric acid, as a source of carbon and energy. "The bacteria need the organic acids to grow and produce the PHAs," Tamang explains. Where is the problem? If these organic acids are present in too high a concentration, they have toxic effects on the microorganisms. This meant that the first step for Tamang and his team was to identify suitable strains of bacteria that can use the acids both for their own growth and to produce PHAs. "Compared to the other bacteria we tested, *Cupriavidus necator* proved to be the more tolerant bacterium in contact with the organic acids," Tamang says.

To prevent the acids from impeding the microorganisms' growth, the researchers also developed a perfusion method with cell retention in the bioreactor. Cell retention takes place using a special filter that ensures that the cells or microorganisms remain in the reactor, enabling high cell density and a longer culture time. Tamang explains the process: "We pass the fermentation broth from the bioreactor through a cross-flow filter and then feed the cells with the PHA granules that are retained in the filter back into the reactor. This cell retention allowed us to feed in variable acid concentrations. The biopolymer is extracted from the bacterial cells at the end of the fermentation."

A sought-after PHA copolymer for a range of applications

The researchers at Fraunhofer IGB were able to use their perfusion method to prevent the bacterial growth from being inhibited. They showed that 97 percent of the carbon from the organic acids was utilized by the microorganisms and converted into biomass and PHAs. "Our PHA product is a specially adjusted poly(3-hydroxybutyrate-co-3-hydroxyvalerate), or PHBV, copolymer. Compared to a homopolymer, it has improved mechanical properties. This is because it contains about ten percent 3-hydroxyvalerate, which reduces crystallinity and makes the material more flexible, easier to shape and more versatile," Tamang explains.

As their next step, Tamang and his team plan to optimize the fermentation process to produce PHBV with an even higher 3-hydroxyvalerate concentration (40 to 70 percent). These specially adjusted PHBV copolymers can then be used by polymer chemists and application experts from industry as samples for testing the biopolymer's material properties and discovering new potential fields of application. The ecofriendly raw material that is produced by this process can be used in a variety of ways — as single-use packaging, mulching film in agriculture, in the pharmaceutical industry, or even for medical implants or bio-based textile coatings.

Recovery of raw materials contributes to climate neutrality

Typically, carbon dioxide is produced when organic carbon is removed through a sewage treatment plant. The method developed as part of the project reduces emissions of this global warming gas. "At the same time, we also produce raw materials that help replacing petroleum-based products. In this way, the sewage treatment plants of the future can make an important contribution to climate neutrality," Tamang explains.

The KoalAplan project

Municipal wastewater as a source of ammoniacal nitrogen, hydrogen and bioplastic — the Büsnau biorefinery

Project partners:
- German Technical and Scientific Association for Gas and Water (Deutscher Verein des Gas- und Wasserfaches, DVGW) research center at the Engler-Bunte-Institut of the Karlsruhe Institute of Technology (KIT) (coordination, production of the acidic, particle-free hydrolysate, production of hydrogen by means of microbial electrolysis)
- Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB (PHA production)
- CUTEC Clausthal Research Center for Environmental Technologies at Clausthal University of Technology, Wastewater Process Engineering department (scientific support and carbon footprint)
- Hamburg University of Technology (TUHH), Institute of Technical Microbiology (production of hydrogen by means of microbial electrolysis)
- Umwelttechnik BW GmbH, state agency for environmental technology and resource efficiency in Baden-Württemberg (public relations and utilization of results)
- University of Stuttgart, Institute for Sanitary Engineering, Water Quality and Solid Waste Management — teaching and research sewage treatment plant (ammonium recovery)

Project funded by:
- Ministry for the Environment, Climate and Energy Sector of Baden-Württemberg
- Co-funded by the European Union

Fig. 1 Polyhydroxyalkanoate (PHA) plastic produced from organic acids

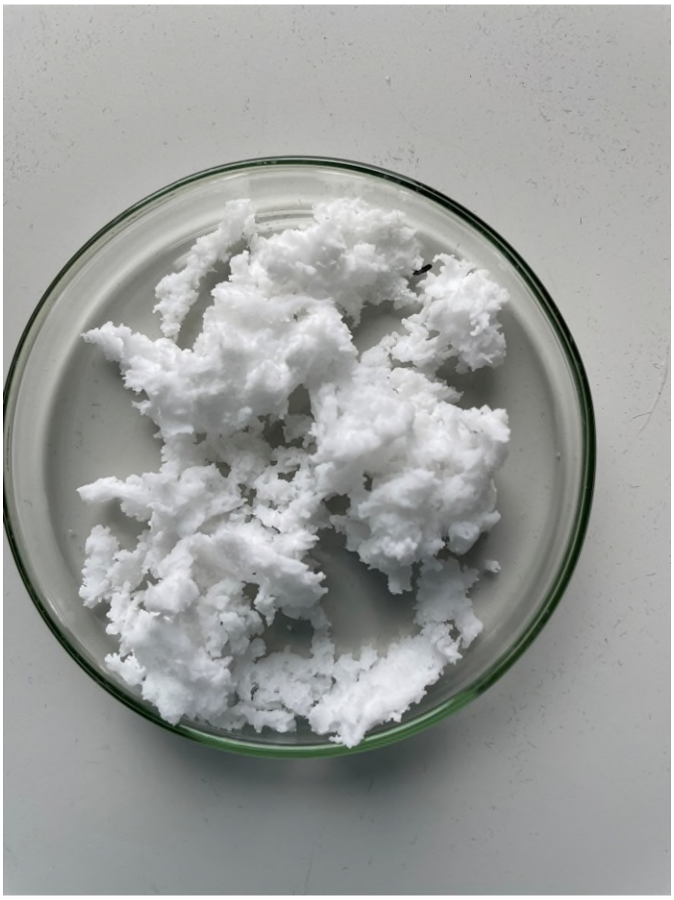

Fig. 2 The specially adjusted, versatile PHA product PHBV features excellent mechanical properties.