PRESS RELEASE

19 Fraunhofer Institutes demonstrate the feasibility of a bio-based circular economy

How Do We Want to Run Our Economy and Production?

The wastewater treatment plant is turned into a vegetable farm, bio-based substances recovered from waste are being utilized to prevent oxidative spoilage in food packaging or provide environmentally-friendly and safe water-repellent coatings on functional textiles. In the EVOBIO project coordinated by Fraunhofer IGB, 19 Fraunhofer Institutes are working on solutions for a sustainable economy by developing new concepts that utilize material flows in bioeconomy process cycles to produce optimized materials for innovative products.

From environmental pollution to climate change – the crises of our time are anthropogenic. The cost of agriculture designed for mass production is high and the careless use of coal, oil, and other fossil fuels is damaging. It is high time to answer the question of how we want to run our economy and production cycles without harming the environment, the climate, valuable ecosystems and, ultimately, people.

In the EVOBIO project, 19 Fraunhofer Institutes have combined their expertise and over a period of five months have developed concepts and modules for a new way of doing business. This is now demonstrated through the use of selected examples. "We want to rethink the industrial value chain, in which raw materials are processed into specific materials that can be used to manufacture products," says Dr. Markus Wolperdinger, director of Fraunhofer IGB. Together with Prof. Alexander Böker, director of Fraunhofer IAP, and Prof. Andrea Büttner, director of Fraunhofer IVV, he has driven forward the project as part of the Fraunhofer Strategic Research Field Bioeconomy. "By-products or residual materials should be avoided or – following nature's example – should be returned to the material and substance cycle without leaving any residues," says Wolperdinger.

Wastewater, Waste, and CO_2 as Resources

Value creation requires input materials – and a wastewater treatment plant is the place where all the biogenic residues and nutrients from human activity arrive. In a circular production system, this means that a wastewater treatment plant is the ideal supplier of all the substances needed for the production of new food. EVOBIO has already shown that this works, making the wastewater treatment plant a central component of a regional circular economy system.

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"Wastewater Treatment Plant of the Future"

The prerequisite for using the various substances is making them available, i.e. concentrating, separating, and processing them. The technical basis for this in the "Wastewater Treatment Plant of the Future" subproject was a pilot plant of a so-called high-load digestion system installed at a wastewater treatment plant in Ulm. This not only converts the sludge produced at a wastewater treatment plant into biogas as a regenerative source of carbon and energy, but also provides further usable material flows of sludge water and digestate. The sludge water is rich in valuable plant nutrients, especially phosphorus and ammonium. "We have developed concepts to recover the nutrients from this water produced during sludge dewatering and to process it as fertilizer. But we can also use the nutrient-rich sludge water directly," explains Dr.-Ing. Marius Mohr from Fraunhofer IGB. To this end, the researchers have pursued two different approaches: First, it serves as a growth medium for single-cell microalgae from Fraunhofer IGB, which use photosynthesis to produce plant-stimulating polysaccharides in the form of beta-1,3-glucans. These can help plants to defend themselves against fungal infections, such as powdery mildew, and thereby replace pesticides.

Secondly, Fraunhofer EMB investigated whether the nutrient-rich sludge water is also suitable for water-based vegetable cultivation – which does not require soil. For this purpose, special hydroponic systems were built in which lettuce now grows from seedlings within four weeks without further fertilizer applications. "In the water purified by the plant cultivation, we can subsequently raise edible fish in a connected aquaculture tank. The fish in turn produce nutrient-rich water again, allowing us to grow even more plants with the same water," says Dr. Johannes Bialon of Fraunhofer EMB. In this way, material cycles are closed and nutrients are used several times in a sustainable manner.

Purification and Monitoring of Wastewater

Using purified wastewater to grow food? To ensure that the water is also hygienically safe, it must be purified and constantly monitored. At Fraunhofer IGB and Fraunhofer IST, methods are available for purifying wastewater and in particular for effectively removing micro-pollutants that are difficult to degrade. In order to monitor water quality, Fraunhofer IMS is developing concepts for new, impedance-based inline sensors for the analysis of water. These not only continuously detect bacteria, but at the same time measure the concentrations of nutrient ions. For example, the sensors detect ammonium, nitrate, or phosphate by means of ion-selective membranes located directly on the surface of the microelectrodes. "The advantage of such sensors is that time-consuming calibrations and sampling are no longer necessary," summarizes Kunj Vora from Fraunhofer IMS. The detection of microorganisms is being carried out via selective biological components: For this purpose, Fraunhofer IGB is providing certain receptors of the human immune system that can detect microorganisms without the use of markers.

Utilization of Biogenic Residual Materials

Another usable material stream is the solid fraction that remains after sludge dewatering at the wastewater treatment plant. This, as well as other agricultural residues, is being processed in the subproject "Utilization of Biogenic Residues" in order to obtain valuable resources for the material production of the next value-added step. A new technology developed by Fraunhofer UMSICHT, so-called thermo-catalytic reforming (TCR®), is facilitating this process. "In the absence of oxygen and at temperatures of around 500°C, the organic substances are converted and simultaneously separated into solid and volatile components," explains Dr.-Ing. Robert Daschner. In the project, the sewage sludge produced at the sewage treatment plant thus provided biochar with a high carbon content, synthesis gas – which is catalytically converted to methanol thanks to a process gas purification system optimized in the project at the Sulzbach-Rosenberg (UMSICHT) and Straubing (IGB) sites – and also a bio-oil that resembles crude oil in its composition. "We have already been able to extract phenols from this oil fraction with high purity. These are suitable as additives for the chemical-technical industry," says Dr. Thomas Herfellner of Fraunhofer IVV. In addition, his team has used new efficient extraction processes to produce high-purity functional proteins from rapeseed extraction meal, which will be processed into new materials in the next step.

New Materials from Alternative Resources

Based on the raw materials produced in the material-flow subprojects from wastewater or waste, as well as other biogenic raw materials, high-performance alternatives for petrochemical materials are being developed in the materials-related subprojects, in some cases with new and additional functions. The focus of the developments is on bio-based polymer blends using novel additives, as well as coating formulations for various applications.

Oxygen Barrier Coatings from Proteins

In a first example, proteins produced from rapeseed extraction meal were used as oxygen barrier layers for food packaging. "We are using the great potential that plant by-products and residues from the food industry have to produce new materials. These proteins can be applied in a wide variety of areas due to their diverse properties," explains Dr. Cornelia Stramm of Fraunhofer IVV. For use in packaging materials, proteins were extracted from rapeseed in the material-flow subprojects and a purely plant-based coating was produced. "We also see the new protein coating as a substitute for protein coatings of animal origin, such as whey protein. The dense network that proteins exhibit in their dried state makes it possible to create oxygen barrier layers, which are important for the protection of packaged foods. The first measurements of the barrier properties against oxygen show comparable values to those obtained with whey protein layers," explains Dr. Cornelia Stramm.

Protein-based Nanofibers

To produce innovative protein-based nanofiber materials, starting materials are formulated from various raw materials, such as kidney beans and rapeseed. "At Fraunhofer IMWS, we use these, for example, to develop filter materials, coating agents, or wound dressing materials," explains Magdalena Jablonska. The electrospinning technique, which has been further developed in recent years, enables the processing of isolated proteins from plant by-products into nanofibers. "We microstructurally characterize the spun nanofiber nonwovens made from canola protein using high-resolution technologies and investigate them in terms of biological interactions, such as interaction with cells. We are also evaluating the materials with regard to their cytotoxicity and biocompatibility," Magdalena Jablonska adds.

Microencapsulation of Biogenic Additives

In addition to bio-based polymers, bio-based and biogenic additives are also important for the green economy. Many natural substances, such as essential oils or enzymes, are known for their antibacterial, oxidative, and antioxidant or UV-absorbing effects. However, direct integration of such substances into polymer materials and processes is generally difficult because the substances are often in liquid form, highly volatile, reactive, or unstable. At Fraunhofer IAP, biogenic substances are therefore microencapsulated. "In the project, we encapsulate essential oils so that they can be integrated into coatings or extruded polymer composites," explains Dr. Alexandra Latnikova from Fraunhofer IAP.

Optimized Products Made from Bio-based Materials

Fibers Made from Bio-based PEF

Especially in the packaging sector, bio-based polyethylene furanoate (PEF) is considered to be a promising substitute for petroleum-based polyethylene terephthalate (PET). PET also dominates the world fiber market, with annual PET fiber production of more than 50 million tons. Dr. André Lehmann, expert in fiber technologies at Fraunhofer IAP, explains: "In the EVOBIO project, we are synthesizing and characterizing PEF tailor-made for fiber applications on a pilot scale. The starting material is furan dicarboxylic acid. The PEF obtained in this way can be spun and post-treated using conventional melt spinning technology, which greatly simplifies potential establishment in the marketplace." The researchers are also developing shape memory polymer foams with bio-based fibers and particles.

Water-repellent and Water-vapor-permeable Functional Textiles

Proteins with water-repellent properties are being exploited by Fraunhofer researchers in the finishing of functional textiles. Materials that repel water and snow whilst exhibiting breathable properties perform well when people are hiking, jogging, or skiing. Usually, halogenated hydrocarbons, such as fluorocarbons, are used to finish these functional materials. However, these can accumulate in human tissue and are suspected to cause long-term damage to health. Their disposal also causes problems,

as they are very difficult to break down and thus remain in the environment for a long time.

Within the project, the Fraunhofer researchers have succeeded in generating the functionality of water repellency with simultaneous water vapor permeability using bio-based materials. Absorbent papers coated with a combination of a polyglucosamine and a hydrophobic and thus water-repellent protein serve as a demonstrator for the special properties. Polyglucosamine is obtained from chitin, for example from the shells and carapaces of crabs, shrimp, or prawns. "Papers coated in this way are hydrophobic, do not absorb water, and are also highly permeable to water vapor," explains Dr. Michaela Müller of Fraunhofer IGB. Since the substrate, i.e. the base material on which the functional layer is applied, plays a decisive role, test series are now being carried out on relevant textiles and the long-term stability under various environmental influences is being investigated.

Is the Market Ready?

Bioeconomy products are not entirely new. However, for the comprehensive approach being pursued for the first time in the EVOBIO project, established value chains must be further developed into value networks that communicate with each other. Are companies ready for this and how can they be transferred to industrial implementation? What new business models are needed to turn wastewater treatment plants and companies that produce biogenic residues into producers of secondary raw materials and other usable materials? EVOBIO is answering these underlying questions in order to develop a conceptual approach for exploiting the new processes in the bioeconomy.

"Based on technology environment analyses, we evaluate the usefulness and feasibility of the technical solutions, as well as their transfer potential in so-called transfer planning, while we use acceptance analyses to focus on the question of the extent to which our results are considered valuable by companies," explains Urban Kaiser of Fraunhofer IMW. In addition, various business model scenarios are developed and then evaluated and prioritized in terms of their feasibility and economic viability.

The highlighted examples represent only a sample of all the new approaches being pursued in the project. Dr.-Ing. Ursula Schließmann from Fraunhofer IGB, who is coordinating the overall project, summarizes: "We were able to demonstrate the basic feasibility of many technologies within a short time in the project. These need to be further developed in follow-up projects".

The EVOBIO Project

The project "Evolutionary bioeconomic processes EVOBIO – Integrative use of material flows for the production of optimized materials for innovative products in bioeconomic process cycles" started in August 2020 under the management of the Fraunhofer

Institutes IGB, IAP, and IVV. It is being funded by the Fraunhofer Innovation Program and coordinated by Fraunhofer IGB.

The EVOBIO Approach

The EVOBIO concept is a bioeconomy approach based on the use and production of biological resources, such as microorganisms, microalgae, plants, and wastewater, and the use of innovative processing technologies. Simultaneously, products are being designed in such a way that they can be broken down into individual molecules or elements that can be recycled or reused. As a result, the consortium is utilizing biological building blocks and principles. Over the course of evolution, nature has produced highly complex optimized structures that can be used to unlock new properties and refine materials even for high-tech applications.

Participating institutes and research units

- Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB
- Fraunhofer Institute for Applied Polymer Research IAP
- Fraunhofer Institute for Process Engineering and Packaging IVV
- Fraunhofer Research and Development Center for Marine and Cellular Biotechnology EMB
- Fraunhofer Institute for Building Physics IBP
- Fraunhofer Institute for Structural Durability and System Reliability LBF
- Fraunhofer Institute for Chemical Technology ICT
- Fraunhofer Institute for Wood Research, Wilhelm-Klauditz-Institut WKI
- Fraunhofer Institute for Microelectronic Circuits and Systems IMS
- Fraunhofer Institute for Microstructure of Materials and Systems IMWS
- Fraunhofer Institute for Microengineering and Microsystems IMM
- Fraunhofer Institute for Molecular Biology and Applied Ecology IME
- Fraunhofer Institute of Optronics, System Technologies and Image Exploitation IOSB, Applied Systems Engineering Division
- Fraunhofer Institute for Surface Engineering and Thin Films IST
- Fraunhofer Institute for Silicate Research ISC
- Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT
- Fraunhofer Institute for Non-Destructive Testing IZFP
- Fraunhofer Center for International Management and Knowledge Economy IMW

The treated nutrient-rich wastewater from the wastewater treatment plant is used in the EVOBIO project for the hydroponic cultivation of lettuce. © Fraunhofer EMB

Fraunhofer Strategic Research Field Bioeconomy

In the Fraunhofer Strategic Research Field Bioeconomy, Fraunhofer researchers study biological systems and make the material streams, materials, structures, and principles of nature usable for technological solutions. To create a sustainable future, we need innovations that provide the right balance between environmental issues and the interests of the economy and society. The bioeconomy is a key driver of the transition toward a sustainable and climate-neutral economic system. It opens up the potential for sustainable solutions that simultaneously preserve resources and create prosperity.

The spokespersons of the Fraunhofer Strategic Research Field Bioeconomy are Dr. Markus Wolperdinger, director of Fraunhofer IGB, and Prof. Alexander Böker, director of Fraunhofer IAP. Prof. Andrea Büttner, director of Fraunhofer IVV, is deputy spokesperson.