Fraunhofer IGB

Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB

Sustainable Technologies for Human Health and the Health of our Planet

Annual Report 2023/24

The Fraunhofer-Gesellschaft

The Fraunhofer-Gesellschaft based in Germany is the world's leading applied research organization. Prioritizing key future-relevant technologies and commercializing its findings in business and industry, it plays a major role in the innovation process. It is a trailblazer and trendsetter in innovative developments and research excellence. The Fraunhofer-Gesellschaft supports research and industry with inspiring ideas and sustainable scientific and technological solutions and is helping shape our society and our future.

The Fraunhofer-Gesellschaft's interdisciplinary research teams turn original ideas into innovations together with contracting industry and public sector partners, coordinate and complete essential key research policy projects and strengthen the German and European economy with ethical value creation. International collaborative partnerships with outstanding research partners and businesses all over the world provide for direct dialogue with the most prominent scientific communities and most dominant economic regions.

Founded in 1949, the Fraunhofer-Gesellschaft currently operates more than 70 institutes and research units throughout Germany.

The impact of applied research goes far beyond its direct benefits to clients: Fraunhofer institutes enhance businesses' performance, improve social acceptance of advanced technology and educate and train the urgently needed next generation of research scientists and engineers.

Highly motivated employees up on cutting-edge research constitute the most important success factor for us as a research organization. Fraunhofer consequently provides opportunities for independent, creative and goal-driven work and thus for professional and personal development, qualifying individuals for challenging positions at our institutes, at higher education institutions, in industry and in society. Practical training and early contacts with clients open outstanding opportunities for students to find jobs and experience growth in business and industry.

The prestigious nonprofit Fraunhofer-Gesellschaft's namesake is Munich scholar Joseph von Fraunhofer (1787 – 1826). He enjoyed equal success as a researcher, inventor and entrepreneur.

▸ *www.fraunhofer.de/en*

Sustainable Technologies for Human Health and the Health of our Planet

Annual Report 2023/24

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Foreword

Dear readers,

2023 was a year filled with remarkable successes and important events for our institute. At the same time, it was characterized by a variety of internal and external challenges that had to be overcome.

We celebrated the 70th anniversary of the IGB and the 10th anniversary of our branches in Leuna and Straubing. These events provided the framework for many other successful events and activities. We were able to welcome high-ranking representatives from politics and industry on several occasions, at the "10 years of Fraunhofer CBP" ceremony in May at the Leuna site and also in July at our anniversary symposium "70 years of Fraunhofer IGB" in Stuttgart. Our guests particularly emphasized the IGB's ability and competence to combine biology and engineering, as well as our activities – especially at the Leuna site – of translating application-relevant technologies into industrial implementation.

Our employees were the main focus of the celebrations, as they are the reason for the institute's success. In the accompanying media campaign "70 years, 70 voices", they shared their stories throughout the year, the exciting topics they are working on and how they are helping to shape the future with their inventions and innovations. We were also delighted to have received numerous congratulatory messages from alumni, companions and partners from politics, industry and science, who looked back on our shared successes and forward with us.

An important milestone for our innovative activities in the field of CO_2 utilization – and thus an important contribution to achieving climate neutrality – was receiving financial support for the Center for Sustainable Fuels (ZENK) in Straubing, which is funded by the Free State of Bavaria with 11.9 million euros. At this center, which the IGB will operate together with Fraunhofer UMSICHT Sulzbach-Rosenberg over the next four years, we will develop application-relevant solutions for and with industry to close carbon cycles.

One outstanding success in our Health business area is the establishment of our new "Virus-based Therapies" branch in Biberach, which is being funded by the Baden-Württemberg Ministry of Economics, Labor and Tourism with 25 million euros over a course of five years. There, in close cooperation with our industrial partners, we will develop new technologies for the production and testing of viral therapeutics, especially against cancer.

In September 2023, we handed over the "Circular Bioeconomy for Germany" roadmap, which was developed under our leadership in collaboration with numerous other Fraunhofer institutes, to high-ranking representatives of the European Commission in the Directorate-General for Research and Innovation. With this roadmap, we have also sent a strong message at EU level for further promoting measures on the path to a sustainable bioeconomy.

At the IGB, we also provided a strong, interdisciplinary momentum for the bioeconomy through a collaboration between science and art: The installation "Circular" by Berlin artists Niklas Thran and Robin Woern, which we inaugurated in Stuttgart in December, presents biobased materials and products that are used at the IGB. The artwork was created as part of the Look@BioEconomy project, which was funded by the Fraunhofer Network for Science, Art and Design.

I would like to thank the institute's employees at our sites in Stuttgart, Straubing and Leuna – and recently also in Biberach – who have contributed greatly to our successes with their commitment, expertise and creativity. In the upcoming year, we will continue to consistently pursue our mission of providing technologies for human health and the health of our planet by further research and development in the areas of environment and climate protection, sustainable chemistry and health.

I would also like to thank our customers and partners for their excellent collaboration and their belief in us to drive innovation and, building on this, transform the economy. I trust you will find this report informative and I look forward to continuing to work with you on new and exciting projects.

Markus Wolperdinger
Director

Profile

Climate change and the excessive use of global resources are threatening our livelihoods, while the world's population continues to grow rapidly at the same time. In the industrialized countries, an aging society and diseases of civilization are dominating the situation, while infectious diseases are on the rise again worldwide – as the Corona pandemic has shown.

We combine biology and engineering

Our mission:
sustainable technologies for human health and the health of our planet

Fraunhofer IGB develops and optimizes processes, technologies and products in three business areas: Health, Sustainable Chemistry, and Environment and Climate Protection. In doing so, the institute relies on its unique combination of expertise in biology and the engineering sciences, unparalleled within the Fraunhofer-Gesellschaft. This allows us to design resource-efficient, circular processes based on the approach of bioeconomy and bioinspired, biointegrated and biointelligent solutions, in order to contribute to human welfare, a sustainable economy, and an intact environment.

Health

- Molecular precision diagnostics
- Drug development and personal care products
  - Cell-based test systems, immunoreceptor assays and production cell lines
  - Oncolytic viruses
  - Formulation, drug delivery and release
- Biomaterials for medical technology
- Pathogen detection and sterilization processes

Sustainable Chemistry

- Development and scaling of processes for the production of
  - Fine and specialty chemicals
  - Biopolymers and biobased materials
  - Ingredients for food, animal feed and cosmetics
- Technologies for the use of CO_2 and Power-to-X
- Functional materials and customized coatings

Environment and Climate Protection

- New water purification systems
  - Drinking water treatment
  - Process water treatment
  - Wastewater and sludge treatment
- Waste and wastewater as a resource
  - Recovery of nutrients and metals
- Integrated water, energy, waste and nutrient management
  - Water reuse
  - Hydroponics/bioponics
- Energy transition and sustainable mobility

Our vision: We combine biology and engineering

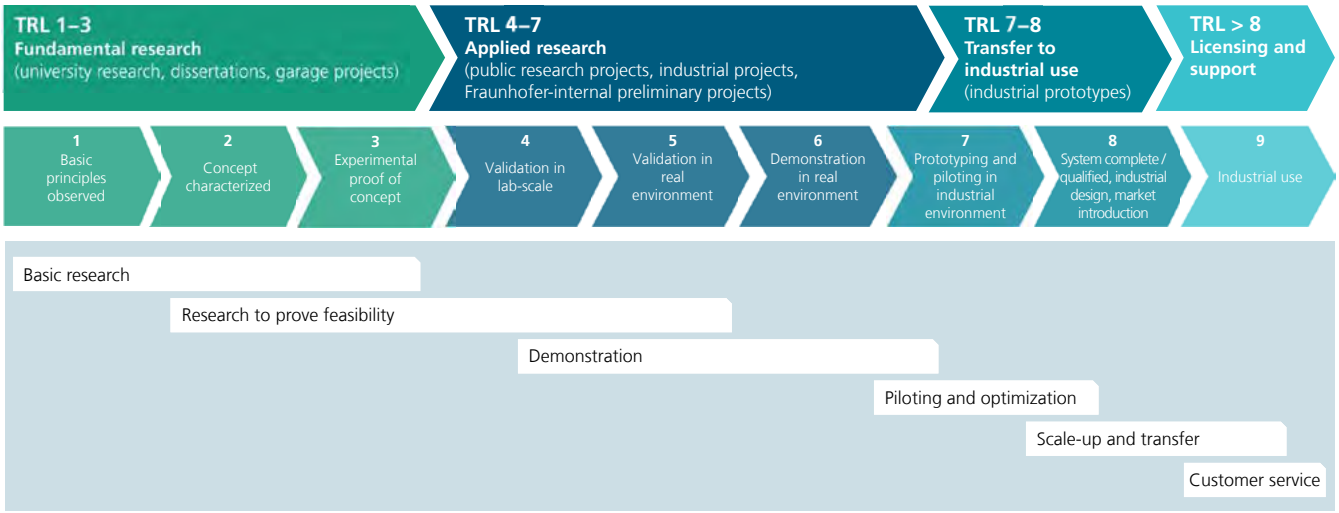
Now more than ever, innovative processes and products call for the convergence or constructive interplay of different disciplines in systems approaches. One such systems approach, which the IGB is continuously enhancing, is bioeconomy. By combining biology and engineering, especially in biotechnology and bioprocess engineering, but also through the genetic engineering of viruses and bacteria, the combination of cell culture and interfacial engineering, or DNA sequencing using bioinformatic algorithms, as well as through the interaction of biological systems with technical materials – the IGB paves the way to new approaches and future-oriented solutions for industrial value creation.

Partnering with industry and public authorities – from laboratory to pilot-scale applications

One of the IGB's main goals is to translate its research findings into economically viable, sustainable processes and products for industrial application. By doing so, the institute is helping to shape the society of tomorrow. Fraunhofer IGB provides its customers and partners with research and development services encompassing the entire material value chain, accompanied by a wide range of analysis and testing services. The ability to deliver end-to-end solutions, from laboratory to pilot-scale applications, and a demonstration of the developed processes, is one of the institute's strong points.

This all-round service makes the IGB a reliable partner for industrial companies, small and medium-sized enterprises operating in many different sectors, local authorities and special-purpose associations. It also performs contract research for the EU as well as Germany's federal and regional governments.

Research for the market



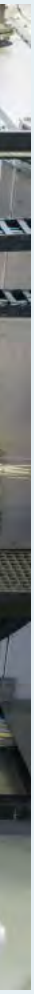
With research, development and transfer services through to market launch, we at the Fraunhofer IGB turn ideas into innovations.

TRL = Technology Readiness Level

▸ *www.igb.fraunhofer.de/biology-and-engineering*

Exchange at the technical center as part of the Advisory Board meeting on March 30, 2023 in Stuttgart

Advisory board



The Fraunhofer institutes are counseled by an advisory board whose members are drawn from industry, public authorities, and the scientific community.

Members

Prof. Dr. Uwe Bücheler
C. H. Boehringer Sohn AG & Co. KG

MinR Dr. Hans-Jürgen Froese
German Federal Ministry of Food and Agriculture (BMEL)

Prof. Dr. Elke Guenther
AIT Austrian Institute of Technology GmbH

Dr. Lorenz Mayr (Vorsitzender)
Mayr BioMedTech Consulting

Dr. Dr. h. c. Christian Patermann
Director (ret.) European Commission, MinDirig. (ret.) BMBF

Dr. Christian Renz
Baden-Württemberg Ministry of Economic Affairs, Labour and Tourism

Dr. Kathrin Rübberdt
DECHEMA e. V.

Dr. Elisabeth Saken-Braunstein
Baden-Württemberg Ministry of the Environment, Climate Protection and the Energy Sector

Dr. Joachim Schulze
JS BioConsulting GmbH

Dr.-Ing. Hannes Spieth
Umwelttechnik BW GmbH

Prof. Dr.-Ing. Ralf Takors
Institute of Biochemical Engineering, University of Stuttgart

Prof. Dr.-Ing. Wiltrud Treffenfeldt
LifeScience, BioTechnology, BioEconomy

Dr. Günter Wich
Industrial Biotechnology

Dr. Peter Wolfangel
Robert Bosch GmbH

Guest members

Prof. Dr. Herwig Brunner
(permanent guest)
Former Director of Fraunhofer IGB

MR Dr. Stefan Wimbauer
Bavarian Ministry of Economic Affairs, Regional Development and Energy

(as of December 31, 2023)

▸ *www.igb.fraunhofer.de/board*

Organization

Director

Dr. Markus Wolperdinger
Phone +49 711 970-4410
markus.wolperdinger@
igb.fraunhofer.de

Deputy Director

Prof. Dr. Steffen Rupp
Phone +49 711 970-4045
steffen.rupp@
igb.fraunhofer.de

Deputy Director

Dr.-Ing. Ursula Schließmann
Phone +49 711 970-4222
ursula.schliessmann@
igb.fraunhofer.de

Heads of innovation fields

Bioinspired Chemistry

Dr. Michael Richter
Phone +49 9421 9380-1020
michael.richter@
igb.fraunhofer.de

Sustainable Catalytic Processes

Dr. Arne Roth
Phone +49 9421 9380-1030
arne.roth@igb.fraunhofer.de

Functional Surfaces and Materials

Dr. Michaela Müller
Phone +49 711 970-4140
michaela.mueller@
igb.fraunhofer.de

Regenerative Resources

Dr. Ulrike Junghans
Phone +49 3461 43-9128
ulrike.junghans@
igb.fraunhofer.de

Industrial Biotechnology

Dr. Grzegorz Kubik
Phone +49 711 970-4102
grzegorz.kubik@
igb.fraunhofer.de

Virus-based Technologies

Prof. Dr. Susanne M. Bailer
Phone +49 711 970-4180
susanne.bailer@
igb.fraunhofer.de

In-vitro Diagnostics

Dr. Kai Sohn
Phone +49 711 970-4055
kai.sohn@igb.fraunhofer.de

Water Technologies and Resource Recovery

Dr.-Ing. Marius Mohr
Phone +49 711 970-4216
marius.mohr@
igb.fraunhofer.de

Membranes

Dr. Thomas Schiestel
Phone +49 711 970-4164
thomas.schiestel@
igb.fraunhofer.de

Cell and Tissue Technologies

Dr. Anke Burger-Kentischer
Phone +49 711 970-4023
anke.burger-kentischer@
igb.fraunhofer.de

Heads of service areas

Analytics – Stuttgart

Katharina Wasmer M.Sc.
Phone +49 711 940-4037
katharina.wasmer@
igb.fraunhofer.de

Analytics – Leuna

Florian Neumann
Phone +49 3461 43-9108
florian.neumann@
igb.fraunhofer.de

Occupational safety

Kai Pusch M.Sc.
Phone +49 711 970-4175
kai.pusch@igb.fraunhofer.de

Head of Administration

Sophie Vaaraniemi M.Sc.
Phone +49 711 970-4036
sophie.vaaraniemi@
igb.fraunhofer.de

Heads of business areas

Health

Prof. Dr. Steffen Rupp
Phone +49 711 970-4045
steffen.rupp@
igb.fraunhofer.de

Sustainable Chemistry

Dr. Christine Rasche
Phone +49 3461 43-9103
christine.rasche@
igb.fraunhofer.de

Environment and Climate Protection

Dr.-Ing. Ursula Schließmann
Phone +49 711 970-4222
ursula.schliessmann@
igb.fraunhofer.de

Branches

Fraunhofer Center for Chemical-Biotechnological Processes CBP, Leuna branch

Dipl.-Kfm. Holger Schilaske
Phone +49 3461 43-9120
holger.schilaske@
igb.fraunhofer.de

Bio-, Electro- and Chemocatalysis BioCat, Straubing branch

Dr. Michael Hofer
Phone +49 9421 9380-1010
michael.hofer@
igb.fraunhofer.de

University and political relations

Baden-Württemberg

Dr.-Ing. Ursula Schließmann
Phone +49 711 970-4222
ursula.schliessmann@igb.fraunhofer.de

University of Stuttgart

Prof. Dr. Günter Tovar
Phone +49 711 970-4109
guenter.tovar@igb.fraunhofer.de

Bavaria

Prof. Dr. Volker Sieber
Phone +49 9421 9380-1050
volker.sieber@igb.fraunhofer.de

Saxony-Anhalt

Dr. Christine Rasche
Phone +49 3461 43-9103
christine.rasche@igb.fraunhofer.de

Range of services

Sustainable technologies for healthy people in a healthy environment

We ensure quick and precise diagnostics in clinics

In medicine, it is crucial to detect pathogens and their antibiotic resistance or tumor markers as quickly and accurately as possible. To do this, we use state-of-the-art molecular biology methods such as next-generation sequencing and AI-based analysis methods.

We develop oncolytic viruses

We use viruses as therapeutics. Oncolytic viruses specifically infect cancer cells and stimulate an immune response to eliminate the tumor. We develop effective oncolytic viruses and processes for their efficient and reproducible production.

We provide preclinical test systems and formulations for your active ingredients

Medicine, pharmacy and personal care benefit from our innovative cell and molecular biology technologies. We develop preclinical in-vitro test systems and optimize processes for drug screening and formulation.

Industrial bioeconomy: sustainable production with renewable resources

Sustainable chemicals, materials and fuels can be produced from renewable raw materials, biogenic residues and CO_2. To this end, we develop and optimize the necessary processing and biotechnological, chemical, electrochemical and thermal conversion procedures and scale them up to pilot scale.

We detect microbial contamination

Whether on surfaces, in process media, in water or in the environment – we reliably detect microorganisms, viruses and their traces – for quality, process and product control all the way to environmental monitoring.

We ensure the sustainability of water management – also due to recycling

Clean (drinking) water is a valuable resource. That's why we develop water management solutions for municipalities, industry and agriculture and focus on recycling, which also enable the recovery of energy and valuable ingredients.

We efficiently separate substance mixtures for pure products

In synthesis and recycling processes, the aim is to recover valuable materials from material flows in as pure a form as possible. Our focus is on the selective and efficient separation of material mixtures and the processing of synthesis products – we develop membranes, adsorber particles, thermal and extraction processes for this purpose.

Your waste – our resource

We use a wide range of technologies to create solutions for the (re)use of industrial, agricultural and municipal waste streams. The focus here is on the recovery of valuable substances and nutrients as well as the production of biogas and biohydrogen.

Our material developments: functional and bio-inspired

With the help of functional layers, we equip materials with the desired properties to allow specific applications and avoid problem chemicals such as PFAS. We also take inspiration from nature and develop biobased polymers and materials with integrated biomolecular functionalities.

We remove pollutants completely

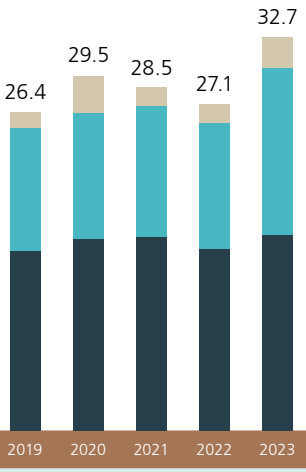
For the health of people and the environment, we protect our resources with the help of technologies and processes for the effective and efficient removal of non-degradable pollutants such as PFAS or drug residues.

Our in-vitro test methods detect harmful substances

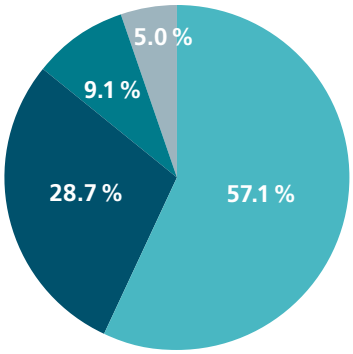
Our reporter skin enables precise detections of allergenic, toxicological or endocrine effects of substances on living in-vitro tissue. This way, we ensure the safety of cosmetics and chemicals for material development and detect harmful substances in the environment.

Key figures

Development of total budget in million euros



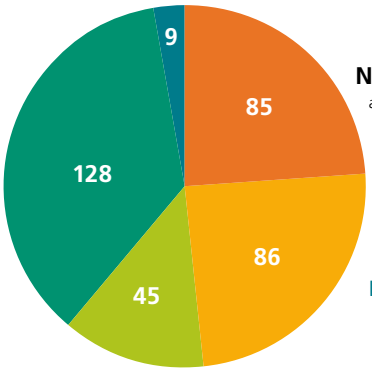
Revenue from contract research 2023



22 posts about female IGB researchers

805 followers
+30 % since 2022

6499 followers
+34 % since 2022



Numbers of staff members
as of December 31, 2023

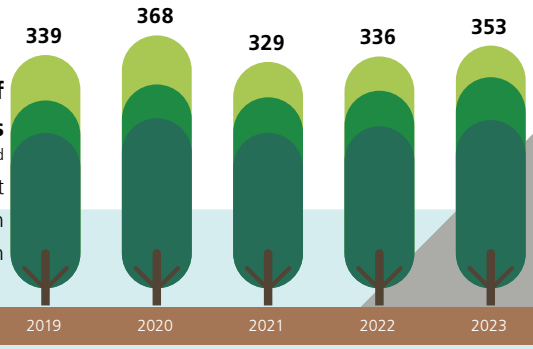
- Scientists
- Technical staff
- Administrative and secretarial staff
- Students (work students / master students / student apprentices / student research assistants)
- Apprentices

126 strategic cooperations

20 newly granted patents

Development of staff numbers
number at year-end

- IGB, Stuttgart
- BioCat, Straubing branch
- CBP, Leuna branch



50 % / 50 %

68 projects funded by German federal ministries

102 industrial projects

30 Fraunhofer internal projects

17 EU projects

10 projects funded by German states

9 projects with universities, municipalities or funded by foundations

2 workshops on shared leadership with **28** participants

3 Fraunhofer lighthouse projects

8 articles in the series remarkable women in the world of science

49 academic theses
6 dissertations
37 master theses
5 bachelor theses
1 work placement report

62 teaching activities

91 scientific publications

Highlights 2023

New research centers

Grant notification for the Bavarian Center for Sustainable Fuels (ZENK)

Against the backdrop of the climate crisis, solutions for sustainable mobility are needed. However, it's not realistic that every form of transport will be electric in the future – especially in the transport sector. For example, fuels are still needed in aviation, shipping, agricultural vehicles, construction machinery and heavy-duty transport. But these can also be climate-neutral, for example if they are produced sustainably with the help of CO_2, biomass and renewable electricity. This is exactly where the BioCat branch of the IGB in Straubing comes in: In collaboration with Fraunhofer UMSICHT in Sulzbach-Rosenberg, the IGB researchers in Straubing are now setting up a coupled pilot plant and development infrastructure for this purpose: the Center for Sustainable Fuels, or ZENK for short. The Free State of Bavaria is funding this project with 11.9 million euros. Hubert Aiwanger, Bavarian State-Minister for Economic Affairs, Regional Development and Energy, handed over the grant notification on June 29, 2023 during his visit to the BioCat branch of the institute.

Baden-Württemberg invests in new IGB branch "Virus-based Therapies"

Viral therapeutics are seen as a beacon of hope in the medical industry as they could alleviate or even cure diseases that have been insufficiently or untreatable so far, such as hereditary diseases or cancer. At Fraunhofer IGB, Prof. Dr. Susanne Bailer and her team of the Innovation Field of Virus-based Technologies, have been researching a virus platform technology for targeted medical solutions for a long time. Over the next five years, the institute will further expand its capacities: The state of Baden-Württemberg will enable the establishment of a new IGB branch office with a research focus on virus-based therapies at the Biberach site in the Upper Swabia/Biberach/Ulm region. In the future, it will be used to research tools for the development of new therapeutics against cancer and hereditary diseases and to develop methods for preclinical testing and their production on a larger scale. On October 12, 2023, Prof. Bailer, Prof. Steffen Rupp (Head of IGB's Business Area Health) and IGB Institute Director Dr. Markus Wolperdinger received the grant notification from State-Minister Dr. Nicole Hoffmeister-Kraut at the Baden-Württemberg State Parliament in Stuttgart. Its Ministry of Economic Affairs, Labor and Tourism is funding the establishment of the branch with 25 million euros.

Looking back on our anniversary year

2023 was a special year for Fraunhofer IGB – thanks to its round, 70th anniversary. To mark the occasion, the institute hosted a "birthday party" in the summer: the anniversary symposium "70 years for a better future" on July 10, 2023.

70 years of Fraunhofer IGB: anniversary campaign "70 years, 70 voices"

The institute's long success story would not be possible without the people who have helped build, shape and support Fraunhofer IGB. That's why the anniversary campaign "70 years, 70 voices" focused on precisely these personalities. Throughout the year, current and former employees and supporters – such as established partners, sponsors and long-standing customers – contributed with anniversary statements, memories and congratulations.

▸ *www.igb.fraunhofer.de/70-years*

Minister-President Winfried Kretschmann visits the Fraunhofer Campus Stuttgart

The first highlight of 2023 was the visit of Baden-Württemberg's Minister-President Winfried Kretschmann to the Stuttgart Technology and Innovation Campus S-TEC on the premises of the Fraunhofer institutes in Stuttgart. During his visit to Fraunhofer IGB, Kretschmann gained an insight into the fields of "Precision Medicine from Diagnostics to Therapy" and "Sustainability through Climate Neutrality and Bioeconomy". The IGB researchers paid particular attention to biorefineries for the treatment and recycling of wastewater and waste, which are also funded by the state. In addition, the High-Performance Center Mass Personalization, in which Fraunhofer IGB is involved, also introduced itself to the Minister-President. After his tour of the campus, Kretschmann was visibly enthusiastic about the innovative power experienced here: "As Minister-President, I have always remained a student and am therefore curious and inquisitive about all subjects that move us forward. For example, here in Stuttgart, where bright minds are working on the challenges of today and tomorrow and are thus making the country fit for the future."

Fraunhofer CBP celebrates its 10th anniversary

Bringing science into industrial application is in Fraunhofer's DNA. One place where these genes fully unfold is the IGB branch in Leuna in Saxony-Anhalt, the Fraunhofer Center for Chemical-Biological Processes CBP. For more than ten years now, processes to produce materials from renewable resources such as wood, straw, residues or CO_2, as well as piloting new processes in industrial biotechnology, have been developed and scaled up here. Due to their expertise in scaling up processes to pilot scale in particular, Fraunhofer CBP has established itself as a central player and driving force in the bioeconomy industry in Central Germany. Representatives from politics, economy and research honored this achievement on May 3, 2023 at a ceremony to mark the tenth anniversary of the institute.

Anniversary symposium at Fraunhofer IGB

The highlight of Fraunhofer IGB's anniversary year was the symposium "70 years of research for a better future" on July 10, 2023 at the institute's headquarters on the Fraunhofer Campus Stuttgart. Thus, the anniversary not only became a celebration of the institute's 70-year history, but also deliberately focused on professional exchange and a joint look ahead – together with collaborators and partners from 70 years of the institute's history. Among them were former institute directors, representatives of the Fraunhofer Executive Board and representatives of Baden-Württemberg's state politics. For example, Dr. Nicole Hoffmeister-Kraut, State-Minister for Economic Affairs, Labor and Tourism, emphasized the excellent collaboration between Fraunhofer IGB and the state in her keynote speech. State Secretary Sabine Kurtz from the Ministry of Agriculture, and State Secretary Dr. Andre Baumann from the Ministry of the Environment expressed similar sentiments.

New Fraunhofer President visits the Fraunhofer Campus Stuttgart

On August 15, 2023, Prof. Dr.-Ing. Holger Hanselka took over as the 11th President of the Fraunhofer-Gesellschaft. When he took office, he made it his goal to strengthen the dialogue with the institutes. The Fraunhofer Executive Board implemented this with the "Executive Board on Site" exchange format, a dialogue tour that took the new president to several Fraunhofer locations within his first months in office – including the Fraunhofer Campus Stuttgart. Here, he engaged in conversation with representatives of the institutes – including Dr. Markus Wolperdinger, Director of Fraunhofer IGB. During a guided tour of the institute's technical centers, Dr.-Ing. Marius Mohr, Dr. Carina Rohmer and Dr.-Ing. Ursula Schließmann then presented the research fields of Fraunhofer IGB to the president on the basis of project examples.

Artwork "Circular" inaugurated at IGB

The Look@BioEconomy project aimed to make the bioeconomy visible and to express the urgently needed transformation towards a sustainable, circular way of producing and working. To this end, Fraunhofer IGB, funded by the Fraunhofer Network "Science, Art and Design", announced an art competition. Here, the two Berlin artists Niklas Thran and Robin Woern realized their design for the installation "Circular". They impressed with the presentation of materials from bioeconomic research in floating glass panels. The five-meter-high installation was inaugurated on December 13, 2023 in the foyer of the modern pilot plant building at Fraunhofer IGB in Stuttgart. Here, it now allows all visitors of the institute a clear access to the topic of bioeconomy and the research work of Fraunhofer IGB in this area.

Protecting the environment also means protecting our health and preventing disease.“

Prof. Dr. Steffen Rupp
Head of Business Area Health

Circular Health

Balancing human and animal health with the environment and economy

Fraunhofer IGB is a founding member of the Fraunhofer Group for Resource Technologies and Bioeconomy VRB, which published a position paper on the concept of Circular Health in December 2023. The aim of the concept is to sustainably ensure the health of humans, animals and the environment through circular approaches in medicine, agriculture, nutrition and environmental sciences. We will briefly present the key messages of the Circular Health concept and demonstrate how the IGB contributes to it.

Our ecosystems are characterized by closely interlinked biogeochemical cycles, which also have a significant impact on human health. If they are disturbed, the effects are often difficult to calculate. A key objective of Circular Health is to identify and control factors that disrupt the balance of these cycles in order to simultaneously contribute to preventive health care and meet sustainability goals.

Circular Health is a cross-sectoral and transdisciplinary approach with the aim of balancing human and animal health with the environment and the economy. This is to be achieved through circular-based approaches in medicine, agriculture, nutrition, and environmental sciences. In doing so, essential features from two concepts, the One Health concept and the concept of a circular economy, will be taken up and combined.

One Health: a healthy environment for a healthy person

The term One Health was first used in 2003–2004, with the emergence of SARS (Severe Acute Respiratory Syndrome) and the worldwide spread of avian influenza H5N1, to describe how human health is inextricably linked to animal and environmental health.

One Health taken to the next level: circular instead of linear economy

The global (geo-)ecological challenges, which culminate in climate change and the loss of biodiversity and contribute to the destabilization of entire ecosystems with a massive burden on human health, can essentially be traced back to the linear and predominantly fossil-based economy. In order to ensure people's health, it is therefore imperative to observe circular principles and ecological cycles.

Circular Health prioritizes innovations in the food, agriculture and health industries, such as the development of sustainable food sources, the use of environmentally friendly pesticides and animal feed additives, and the containment of antimicrobial resistance (AMR) and zoonoses. By establishing circular production processes, raw material and residual material flows can also be reduced. In the future, sovereign and sustainable value cycles are expected to replace linear, fossil-based value chains in environmental and resource management and in the healthcare industry. With today's understanding of the diverse interrelationships, and an integrative management of the influencing factors, health risks and causes of disease can be minimized preventively.

The transition to a circular economy, taking into account the One Health principles, currently offers enormous opportunities to generate considerable added health value by reducing negative environmental impacts, which will be directly reflected in a reduction of the burden on health systems.

Circular Health at Fraunhofer VRB

Based on the competencies of the group, four strategic fields of action were defined for the implementation of the Circular Health concept:

- Food and raw material production
- Zoonoses and microbial resistance
- Value creation cycles in the healthcare sector
- Health and environment

▸ *www.vrb.fraunhofer.de*

The position paper on Circular Health (German) can be found on our website:

▸ *www.igb.fraunhofer.de/en/circular-health*

Contact
Prof. Dr. Steffen Rupp
Phone +49 711 970-4045
steffen.rupp@igb.fraunhofer.de

Food and raw material production

Future agricultural systems must be able to feed up to ten billion people and reliably supply them with biogenic raw materials. At the same time, it is likely that less and less arable land will be available. In order to preserve natural resources such as fertile soils, clean water and air, stop the decline in biodiversity and counteract climate change, agricultural production must be made more sustainable.

Sustainable plant cultivation and animal husbandry without antibiotics

Circular Health therefore focuses on the development of more sustainable production concepts and highly specific suitable active ingredients for plant cultivation and animal husbandry in order to reduce or completely avoid negative impacts. While new and innovative feeding systems are being developed in the field of animal husbandry, for example with antimicrobial ingredients, that are intended to enable largely antibiotic-free husbandry, the focus in the field of plant cultivation is on the development of biobased pesticides for which negative effects on humans, animals and the environment can be largely ruled out.

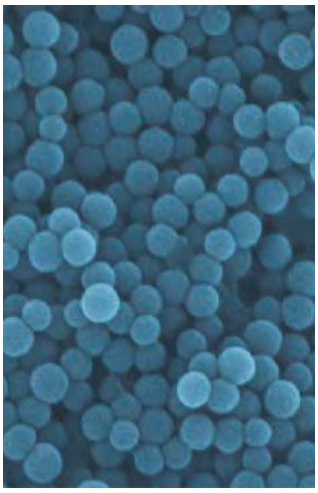
A key contribution to the effective application of the active ingredients is provided by their tailored formulation. New cultivation methods in hydroponic systems also enable the use of purified wastewater for fertilizing irrigation, while new biotechnological cultivation and utilization concepts for microalgae, insects and fungi enable the low-emission production of protein-rich food and feed.

Holistic use of biogenic raw materials

The holistic use of biogenic raw materials helps increase resource efficiency and close material cycles. Against the backdrop of increasingly scarce resources, this is crucial for ensuring the security of supply for society. One realized example of this is the new EthaNa® pilot plant at Fraunhofer CBP, which can be used to increase material value through gentle processing of rapeseed. Based on the principle of a biorefinery, it supplies high-quality rapeseed oil in pre-raffinate quality, and a rapeseed kernel concentrate, rich in high-quality proteins, secondary plant substances dissolved in ethanol, and rapeseed husks as other products.

▸ *www.cbp.fraunhofer.de/en/ethana*

Customized formulations for agriculture



Scanning electron microscope image of biodegradable, drug-loaded particles

Crop protection products such as pesticides, fungicides and herbicides, as well as plant growth regulators, are used in the agricultural food and raw material production to protect plants from diseases and pests and to increase crop yields. Agricultural production also has a direct impact on soil, water and the atmosphere. A modern and sustainable agriculture, which conserves resources, protects the environment and is economical at the same time, is possible when active ingredients are applied in a customized formulation.

Our development

At Fraunhofer IGB, we have established a wide range of different formulation technologies with which we apply active ingredients by coating, by embedding in hydrogels or by encapsulation in smallest particles.

On the one hand, encapsulation protects active ingredients from external influences, and on the other hand, we are able to release the encapsulated substances in a targeted manner by means of functional properties of the capsule material, if necessary:

- Pesticides encapsulated in microparticles reach the target organisms directly and in a controlled manner. Pests and weeds can thus be controlled in a targeted and effective manner and environmental impacts can be reduced.
- Fertilizers formulated in microcapsules provide nutrients in an easily plant-available form.
- Microparticles in coatings during seed seeding can provide nutrients or other substances to the seed, thus promoting germination and early plant growth.

Benefits and technological readiness

The formulation of ingredients enables the provision of active ingredients in a form that is easy to handle and ensures optimal availability. Encapsulation can significantly reduce the amount of active ingredient being applied. In addition, we can regulate the controlled release of the substance, for example only when it rains. For use in agriculture, we choose biobased and biodegradable polymers, such as chitosan, inulin or alginate, as capsule materials. After the active ingredients are released, they are simply degraded in the soil. The technological readiness level ranges between TRL 4 and 6, depending on the question and application.

Collaboration

With our comprehensive know-how in material selection and process control, we develop solutions for formulation issues from a wide range of fields of application, and customized formulations for our customers, such as microparticles and seed coatings. Feel free to contact us with your needs or ideas. We will furthermore support you in the industrial implementation.

Further information

www.igb.fraunhofer.de/formulations

Contact
Dr. Carmen Gruber-Traub
Phone +49 711 970-4034
carmen.gruber-traub@
igb.fraunhofer.de

Molecular detection system for human pathogenic viruses in wastewater

The global scarcity of high-quality freshwater is driven by an increased demand for crop irrigation, enhanced industrial and residential consumption and consequences of climate change. Hydroponic systems, utilizing treated wastewater for crop cultivation, have reduced fresh water requirements and at the same time contribute to water purification when plants absorb nitrogen and phosphorus as nutrients. As part of the quality assurance of hydroponic systems, the water used for irrigation must be tested for microbial contamination. Viruses, in particular, are challenging to detect using current methods, mainly due to their physical and biochemical properties.

Our development

In order to ensure the safety of treated wastewater utilized in irrigation, Fraunhofer IGB has developed a molecular detection system capable to detect human pathogenic viruses reliably. The detection method is based on qPCR technology. Usage of highly specific probes allows the detection of the most common human pathogenic viruses in wastewater without inhibitory effects, thus ensuring dependable quality assurance for wastewater and crops.

Benefits and technological readiness

The molecular detection system offers a rapid and automatable identification of human pathogenic viruses in wastewater. By utilizing both, highly specific probes and primers, the system reliably detects pathogens present in wastewater even with extensive water contamination. The validation of the molecular detection system for human pathogenic viruses was successful at a laboratory scale using real samples, achiving TRL 4–5.

We are currently developing techniques to adequately detect viruses even in large volumes. Increasing the concentrating of viruses in treated wastewater, coupled with subsequent molecular detection will lead to high sensitivity in virus detection.

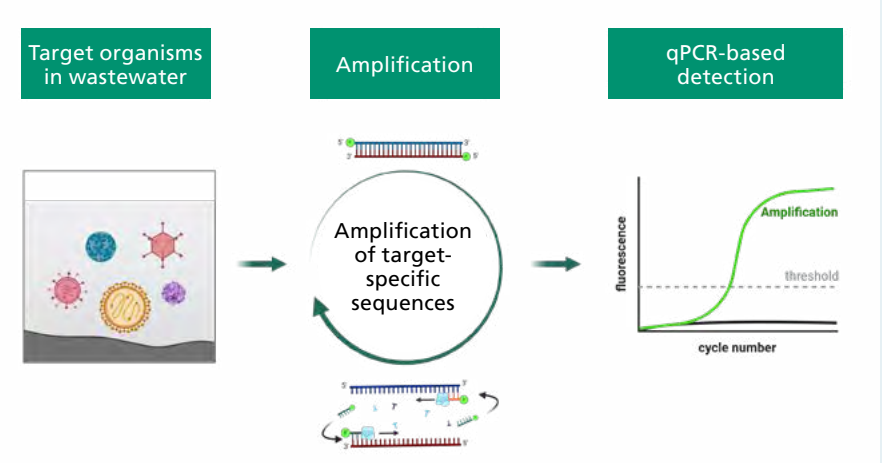
Collaboration

We are delighted to adapt our moleculardetection system for viruses, developed as part of the BMBF-funded joint project Hypowave+, to other microorganisms (viruses, bacteria and fungi) according to the customer's requirements. We are also happy to refine our methods for virus concentration specifically for alternate applications.

Further information

www.igb.fraunhofer.de/en/hypowave-plus

Contact
Jens Wetschky M.Sc.
Phone +49 711 970-4215
jens.wetschky@
igb.fraunhofer.de



Following the isolation of target organisms from wastewater, their genomic material is amplified using specific probes. Subsequently, qPCR is employed to detect the presence of existing viruses.

Automated pathogen diagnostics for the detection of insect and food pathogens

Further information

www.igb.fraunhofer.de/en/futureproteins

Contact
Jens Wetschky M.Sc.
Phone +49 711 970-4215
jens.wetschky@
igb.fraunhofer.de

Until today, the provision of protein for livestock in agriculture and aquaculture primarily relies on soy or fishmeal. However, the breeding of beneficial insects as an alternative source of protein has gained substantial attention. By requiring minimal water and land resources, the production of insect proteins emerges as more resource-efficient and cost-efficient compared to conventional protein feed components. One of the biggest challenges in the industrial production of beneficial insects is the detection of insect and food germs. Their presence poses risks not only to insect farming but also to livestock industry utilizing insect protein as feed.

Our development

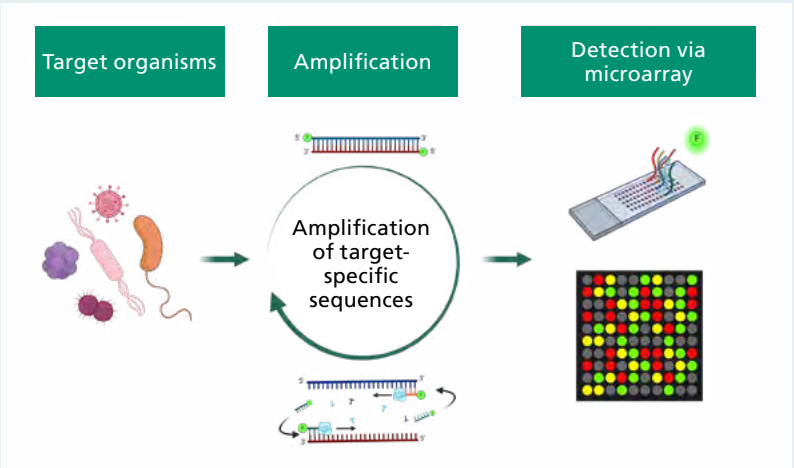
In order to ensure the safety of insect breeding and livestock, Fraunhofer IGB has developed an efficient detection system for monitoring insect breeding facilities. This system enables the simultaneous and reliable detection of various infectious agents. It involves the amplification of specific DNA sequences of various pathogens, fluorescence-labelling, binding to a microarray via probe followed by optical read-out.

Benefits and technological readiness

The combination of the selected amplification method with microarray technology results in a multi-parallel detection system for pathogens that isefficient, automatable and cost-effective. This monitoring tool offers simplicity and reliability in both handling and evaluation. We have developed and validated the detection system for application in insect breeding in a laboratory setup as well as in field operations (TRL 4–5).

Collaboration

The unique combination of pathogen detection functionalities allows for the adaption of the system to different pathogens (viruses, bacteria and fungi) and the development of DNA-based microarrays for the multi-parallel detection of microorganisms tailored to the customer's requirements. Our technology offers a monitoring system for various applications, capable for simultaneous detection of multiple pathogens, designed to fulfill the unique requirements of our customers.



Amplification and fluorescence-based labeling of specific DNA sequences from different pathogens, precisely positioned on a microarray with a probe.

Zoonoses and microbial resistance

In order to sustainably ensure the health of humans, animals and the environment in the long term, it is essential to develop innovative solutions to ward off biological hazards from the environment. These dangers include zoonoses as well as pathogenic microorganisms that have become resistant to antibiotics.

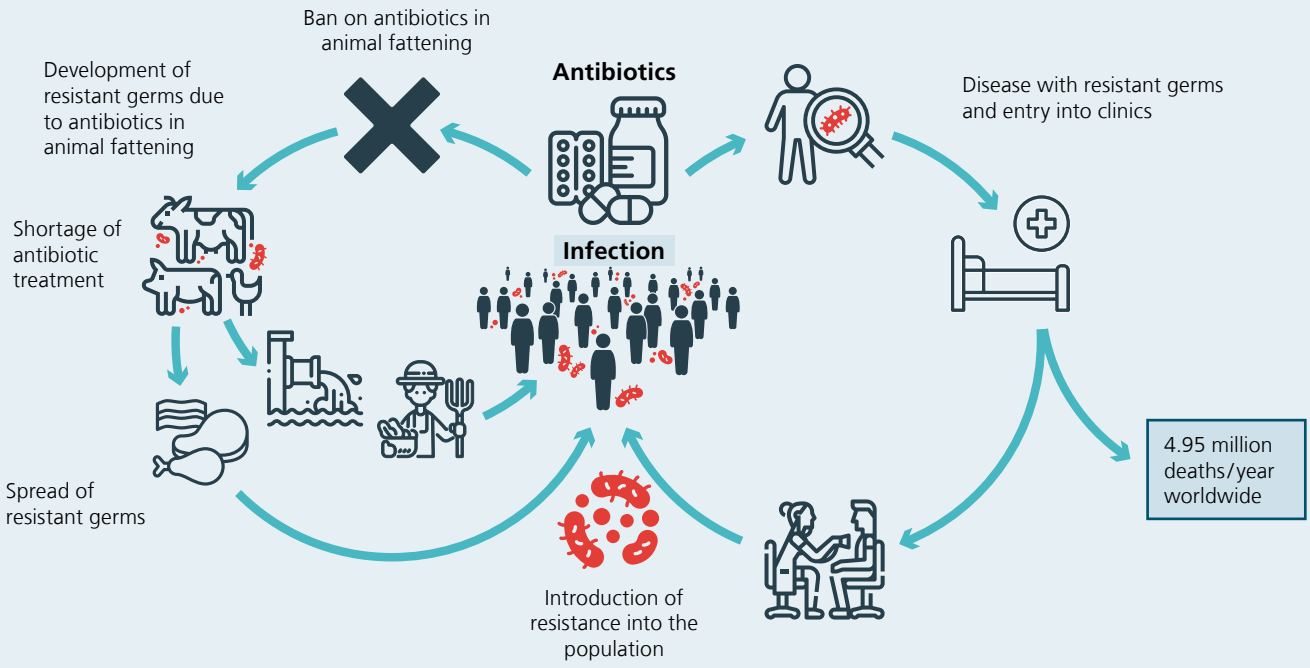
Strategies for monitoring and controlling pathogens and resistance

Microbial resistance to antibiotics has spread rapidly around the world and poses one of the greatest threats to humanity, especially as fewer and fewer new antibiotics are developed. A major cause of the development of resistance is the non-specific and uncritical use of antibiotics in medicine and livestock farming, and their uncontrolled release into the environment as a consequence to that. The aim of Circular Health is to develop new methods to reduce the use of antibiotics in livestock farming and thus counteract the development of microbial resistance.

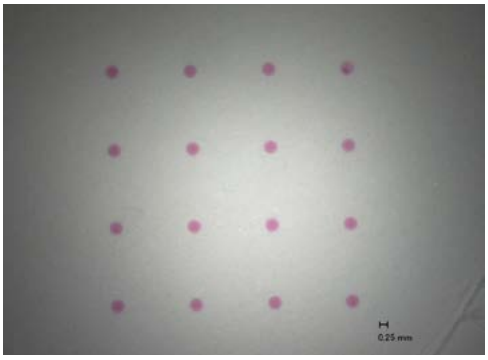
This includes the design of specific test systems for the development of veterinary therapeutics. A large number of the veterinary therapeutics used today originate from human medical development and are therefore often only effective to a limited extent in animals. In addition, if resistance develops, they can only be used to a limited extent in humans.

Various methods developed at the IGB for the diagnosis of pathogens and resistance in human and veterinary medicine as well as for environmental monitoring, make it possible to monitor the development of resistance and emerging pathogens. The use of bacteriophages offers a selective approach to reducing antibiotic-resistant bacteria, which is being pursued at the IGB.

Reducing the use of antibiotics in livestock farming can counteract the development and spread of microbial resistance.



Nanogel biosensors for quick and safe pathogen diagnostics



The pathogen DNA is printed on the chip at several points in a hydrogel spot and thus stabilized. As a result, the test system becomes more sensitive and can be extended to different pathogens.

An important tool for detecting and treating diseases caused by viruses and bacteria is their rapid and reliable identification. Since the Corona pandemic, rapid antigen tests have also become widely known and used more frequently among the population. But this example demonstrates the crux of many tests: rapid antigen tests provide results quickly, but with great inaccuracy; PCR tests, however, are more accurate, but take considerably longer.

Our development

Fraunhofer IGB, in cooperation with the Fraunhofer Institute for Production Technology IPT and the Fraunhofer Center for Manufacturing Innovation CMI in Boston (USA), has developed an alternative that is both fast and accurate. In our approach, we use the RT-LAMP technology (reverse transcription loop-mediated isothermal amplification) for the rapid amplification of the viral or bacterial RNA for subsequent detection. The highlight: by combining it with our patented, printable hydrogel, the test becomes much more sensitive and many pathogens can be detected simultaneously (multiplexing).

Benefits and technological readiness

Our solution distinguishes itself from other current products because of various advantages:

- Fast and accurate result
- No sample preparation required, which means that tests could also be carried out at home
- Printing process enables spatial multiplexing allowing testing for many different pathogens within one examination

The feasibility of our approach has been successfully demonstrated (TRL 3–4). The next step is to optimize the sensor layout and transfer it to cost-effective, scalable production processes.

Collaboration

Since we developed the system as a modular system, it is easily adaptable to customer-specific issues such as new pathogens. If you are interested in the joint development of a market-ready product, please do not hesitate to contact us.

We see areas of application wherever information is needed quickly about whether and with which pathogens a person is infected. This can be the case, for example, at entrance controls in areas with an increased risk of infection (hospitals, care facilities). By adjusting the pathogen spectrum on the sensor, our system is also suitable for monitoring microorganisms in the environment and food production or for quality control in pharmaceutical production.

One of the main functions of our patented hydrogel is the stabilization of biomolecules (proteins, enzymes). The hydrogel therefore also offers great advantages for the development of other products, e.g. other test assays, formulations or surface modifications.

Further information

www.igb.fraunhofer.de/en/omnitest

Contact
Dr. Achim Weber
Phone +49 711 970-4022
achim.weber@
igb.fraunhofer.de

Precision diagnostics of microbial resistance and resistance development

Microbial resistance to antibiotics is a global problem and its diagnosis is of great importance to determine the most effective treatment for infections and to curb the spread of resistant organisms. Currently, laboratory tests include complex microbiological and cell biological analyses, which are time consuming and costly. Due to the risk of contamination and its low accuracy, new methods of detection are urgently needed.

Our development

The resistance of bacteria to antibiotics is mediated by corresponding resistance genes. The molecular biological method of next-generation sequencing, a high-throughput sequencing of nucleic acids, therefore opens up new possibilities for the detection of resistance as well as for the monitoring of resistance from a large number of biological samples. With our technologies optimized at Fraunhofer IGB, we select specific target regions, e.g. several microbial resistance genes, which are amplified in the first step and detected in the second step by means of next-generation sequencing. This way, we can quickly and specifically analyze microorganisms and microbial resistance – in critically ill patients, but also in complex samples from the environment or wastewater treatment plants.

Benefits and technology readiness

Currently used technologies require prior cultivation of microorganisms. Our technologies bypass this step and enable resistance detection even at low initial levels. The In-vitro Diagnostics department at Fraunhofer IGB can look back on a wealth of experience with a wide variety of samples and applications. A patent has already been granted for our method for comprehensive sequencing, and a patent has been filed for the method for targeted amplification of various target regions and subsequent sequencing. We are currently breaking new ground in the detection of resistance by analysing RNA and cell-free nucleic acids.

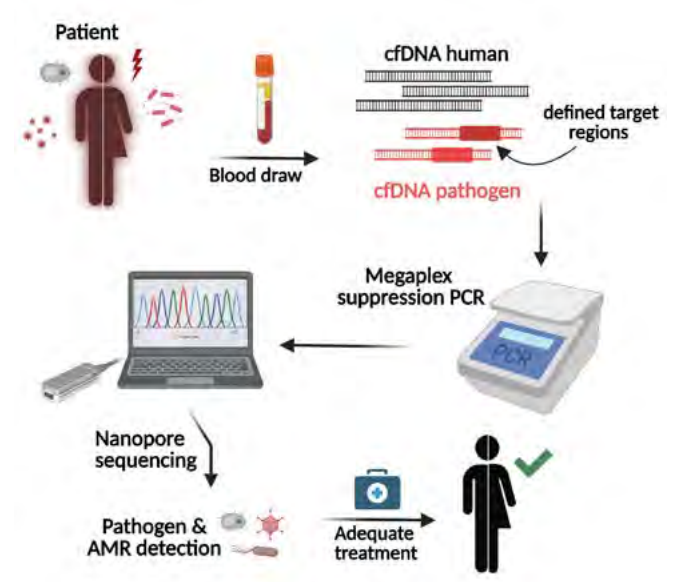
Collaboration

We analyze the metagenome and resistance profile of a wide variety of sample types as part of research projects or on behalf of customers. Our technologies are also suitable for the examination of extremely demanding samples, e.g. from the environment, wastewater treatment plants, or from patients. Through the close integration of molecular biological methods for sample preparation, the creation of sequencing libraries and in-depth bioinformatic analysis, we are able to offer customized solutions for complex problems.

Further information

www.igb.fraunhofer.de/ngs-microbial-resistance

Contact
Dr. Kai Sohn
Phone +49 711 970-4055
kai.sohn@igb.fraunhofer.de



Method for the targeted detection of defined resistance markers. Suppression PCR is used to amplify a wide variety of target regions in a targeted manner and to provide real-time sequencing and bioinformatics using multiplexing methods (created with BioRender.com).

In-vitro canine skin equivalent for testing veterinary therapeutics

Large sums of money are often spent on the treatment of pets. Dogs, for example, have an above-average predisposition to get skin diseases because their epidermis is thinner and hardly keratinized. 10–15 percent of all dogs in German households suffer from atopic dermatitis. Therapeutic agents against this skin disease are also used without prior testing for efficacy, often with minimal or no evaluated benefit. Human therapeutics are also administered, although the pharmacodynamics and toxicological effects of active substances differ greatly from species to species.

Our development

At Fraunhofer IGB, we have successfully developed an in-vitro canine skin equivalent for standardized testing of veterinary therapeutics and care products. For this purpose, cells (fibroblasts, keratinocytes) were isolated from canine skin biopsies, which are obtained during medically necessary operations. The cells were genetically immortalized and used to build canine skin equivalents that are physiologically very similar to in-vivo canine skin.

The canine skin equivalents are available at Fraunhofer IGB for the testing of active ingredients and care products and have the following characteristics:

- Representation of typical physiological skin conditions in the canine skin model, e.g. epidermal differentiation and barrier function
- Use for medium to high throughput drug screening
- Accurate and reproducible detection of substances that cause typical pathological skin conditions (e.g. skin irritation)

Benefits and technological readiness

Due to the use of immortalized cells, the in-vitro canine skin equivalent of Fraunhofer IGB (TRL 9) differs from the only competing product by a high donor-independent reproducibility with an in-vivo like differentiation of the cells. The testing of active ingredients can be carried out quickly, easily and reproducibly at any time and replaces in-vivo investigations. In addition, the canine skin model is suited for various types of active ingredient application (topical, systemic).

Collaboration

Due to the high level of technological readiness, we can offer various services and further developments. Feel free to contact us to discuss your needs and our services.

- Testing of veterinary pharmaceuticals and canine fur care products in our laboratories at Fraunhofer IGB
  - Transdermal ingredient studies
  - Skin penetration studies
  - Mode of action of pharmaceuticals and active ingredients
  - Wound healing studies
  - Toxicological evaluation of chemicals and products
  - Analysis of environmental influences on skin physiology, e.g. UV and IR irradiation
  - Basic research into the physiology and biochemistry of canine skin
- Construction of the models at Fraunhofer IGB and delivery to the customer
- Sale of the in-vitro test system to companies in the animal health sector
- Establishment of disease models, e.g. for atopic dermatitis or for customer-specific questions

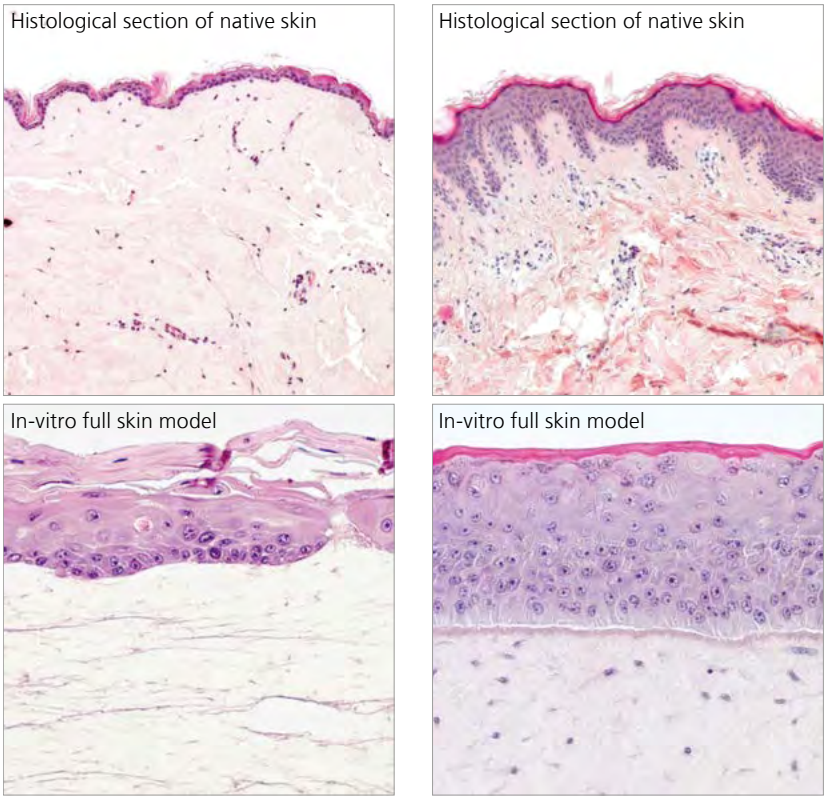
Further information

www.igb.fraunhofer.de/en/wowwowskin

Contact
Dr. Anke Burger-Kentischer
Phone +49 711 970-4023
anke.burger-kentischer@igb.fraunhofer.de

Canine skin

Human skin



Histological sections of native canine skin and human skin (top left and right). The in-vitro canine skin equivalent (bottom left) shows the typical morphology of a canine in-vivo skin (top left).

Value-creation cycles in the healthcare sector

Due to the linear economy, the healthcare sector is characterized by its high demand for resources and a large ecological footprint. It causes around five percent of global greenhouse gas emissions and is responsible for up to ten percent of waste generation. A large portion of this waste consists of plastics, partly due to the increasing use of single-use products.

In contrast, the concept of Circular Health consists of a comprehensive implementation of circular economy principles. Based on a detailed analysis of the situation, products in the healthcare sector will have to be optimized in the future, taking into account the entire product life cycle and including all stages of the value chain. For example, both the use of biobased polymers and the implementation of recycling strategies offer solutions for greater sustainability in healthcare.

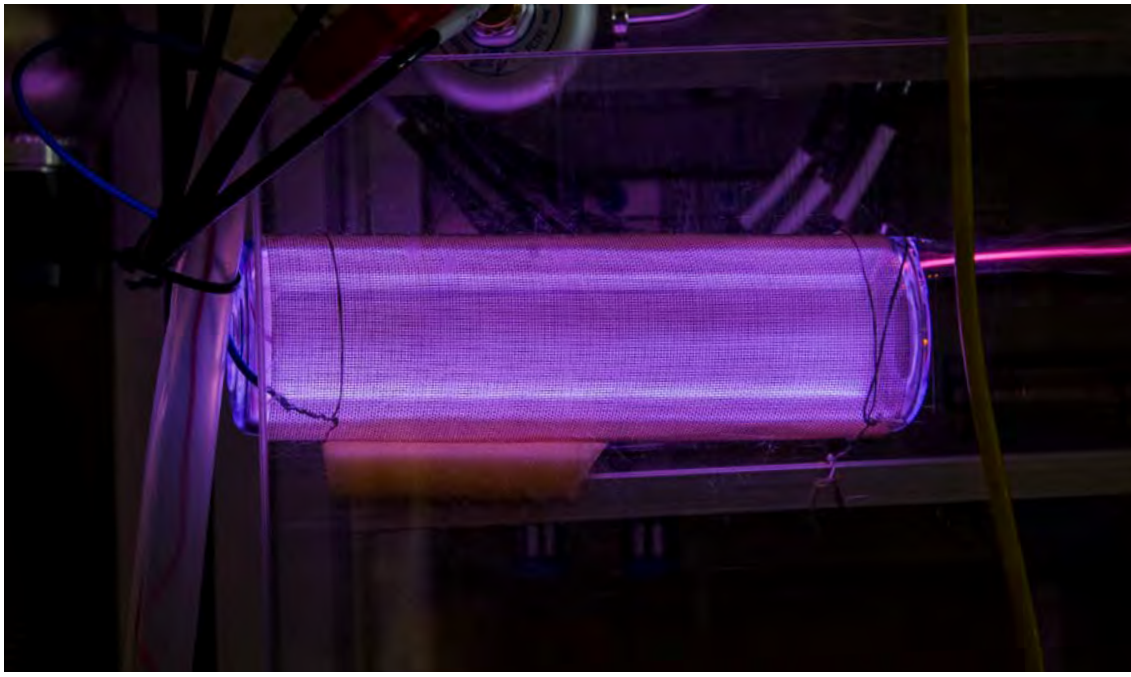
"Dry" processes for cleaning and disinfection, for example using plasma and UV-C, effectively contribute to reducing emissions.

At the BioCat institute branch in Straubing, a miniplant for the industry-oriented presentation of biobased polyesters and polyamides was also put into operation in 2023. We are currently researching biobased polyamides, poly(meth)acrylates and plastic additives, such as biobased plasticizers and nucleating agents. In addition, we offer our customers services in the field of polymer analysis and materials testing. Tests for the biodegradability of liquid substances are currently being established.

Further information

www.igb.fraunhofer.de/cleaning-and-disinfection

www.igb.fraunhofer.de/en/ltbp



UV radiation from specially developed excimer plasma lamps can be effective against bacteria and spores.

Health and environment

Pharmaceuticals are essential for human and animal health, but increased consumption and their often uncritical use lead to an increase in harmful and permanent residues in the environment, which can have undesirable effects on organisms, populations and ecosystems. Surface and groundwater as well as soils are particularly affected by this. Another problem is the development of resistance, which is facilitated by the excessive, non-specific and careless use of antibiotics.

Reducing problematic chemicals in the environment

Technical solutions for the collection and elimination of pollutants, e.g. PFAS or drug residues, from wastewater provide a remedy to reduce the harmful effects of persistent substances via drinking water (see article on PFAS, page 46). At the same time, it is important to minimize the input of pollutants and pharmaceuticals into the environment and to focus on the development of environmentally friendly, biodegradable pharmaceuticals. For this purpose, methods are needed for the rapid and comprehensive assessment of the environmental hazard potential of new active substances.

Strategies against climate change and biodiversity loss

Essential for human health is a healthy environment that is characterized by a high level of biodiversity. This is because the ecosystems that build on this diversity produce clean air, drinking water, food and active ingredients. Since biodiversity has declined dramatically in recent decades, there is an acute need for action to reduce or completely avoid anthropogenic contributions to biodiversity loss.

In order to protect and preserve biodiversity, we are primarily concerned with the development of circular value chains to reduce waste and greenhouse gases, of strategies and methods to reduce anthropogenic pollution in the environment, and of new food concepts for sustainable intensification of agriculture.

Cell-based test systems for assessing the safety of pharmaceuticals, pesticides and biocidal products

Further information

www.igb.fraunhofer.de/cell-and-tissue-technologies

Contact
Dr. Anke Burger-Kentischer
Phone +49 711 970-4023
anke.burger-kentischer@igb.fraunhofer.de

In addition to pesticides and biocidal products, which are released into the environment when used as intended, pharmaceuticals and their residues also pollute the environment. They enter the food chain through drinking water and agricultural products and thus harm not only ecosystems but also humans. It is therefore crucial to minimize their entry into the environment and to develop more environmentally friendly or biodegradable ingredients. Furthermore, it is essential to provide methods for a fast assessment of their hazard potential – even at high-throughput rates.

Our development

This is exactly what we are working on at Fraunhofer IGB. The Cell and Tissue Technologies department is developing specific in-vitro model systems to test pharmaceutical ingredients, cosmetic preparations, but also chemicals such as pesticides and biocidal products, and to assess their hazard potential for humans and the environment. The test systems range from simple cell-based 2D assays to organoids and complex 3D tissue models, depending on the scientific question.

We achieve the outstanding predictivity of our in-vitro model systems primarily through the following core technologies:

- Targeted development of cell-based reporter test systems that can be used to detect local effects (e.g. sensitization) as well as broader physiological effects (e.g. toxic effects caused by endocrine mechanisms)
- Use of selected receptors (immune and hormone receptors) that act as biosensors for point-of-care diagnostics by binding specific ligands

Benefits and technological readiness

Our specific reporter cells are based on primary cells from healthy donors. Isolated directly from the original tissue, these cells – in contrast to commercial cell lines from tumor tissue – resemble the in-vivo state of the cells and exhibit normal physiology. Through targeted immortalization, the isolated primary cells can be continuously cultivated and are therefore reproduceable and available without restriction. Due to these properties, they are ideally suited as model systems for investigating the effects of active ingredients and toxic substances on cells and characterizing their hazard potential. By using cell-based test systems, we can realistically simulate the in-vivo situation and analyze cell reactions in real time.

Cell-based assays, particularly those based on reporter cells, are also highly efficient and save time and money thanks to photometric evaluation methods. Reporter gene assays are invaluable for investigating gene expression or the activation of cell signaling pathways. The activation of cell signaling pathways is detected and measured by quantifying the expression of the reporter gene. Our reporter gene assays enable us to pursue very specific questions in real time, for example whether and to what extent substances trigger allergic reactions or lead to harmful effects.

Various cellular test systems are available at Fraunhofer IGB for investigating different substance effects. Most of them are ready for industrial use, while others are still in the early stages of development. The chart provides an overview.

Collaboration

The established cell-based test and screening assays using reporter systems have been patented and are available to our customers and project partners exclusively for contract analyses or via out-licensing. With our expertise, we are happy to develop further models according to the specific requirements of our customers. Our technologies can be used for numerous applications in medicine, pharmacy and veterinary medicine, in environmental biotechnology, in industrial biotechnology and for biotechnological processes in general.

Contract testing of pharmaceuticals, pesticides, biocidal products

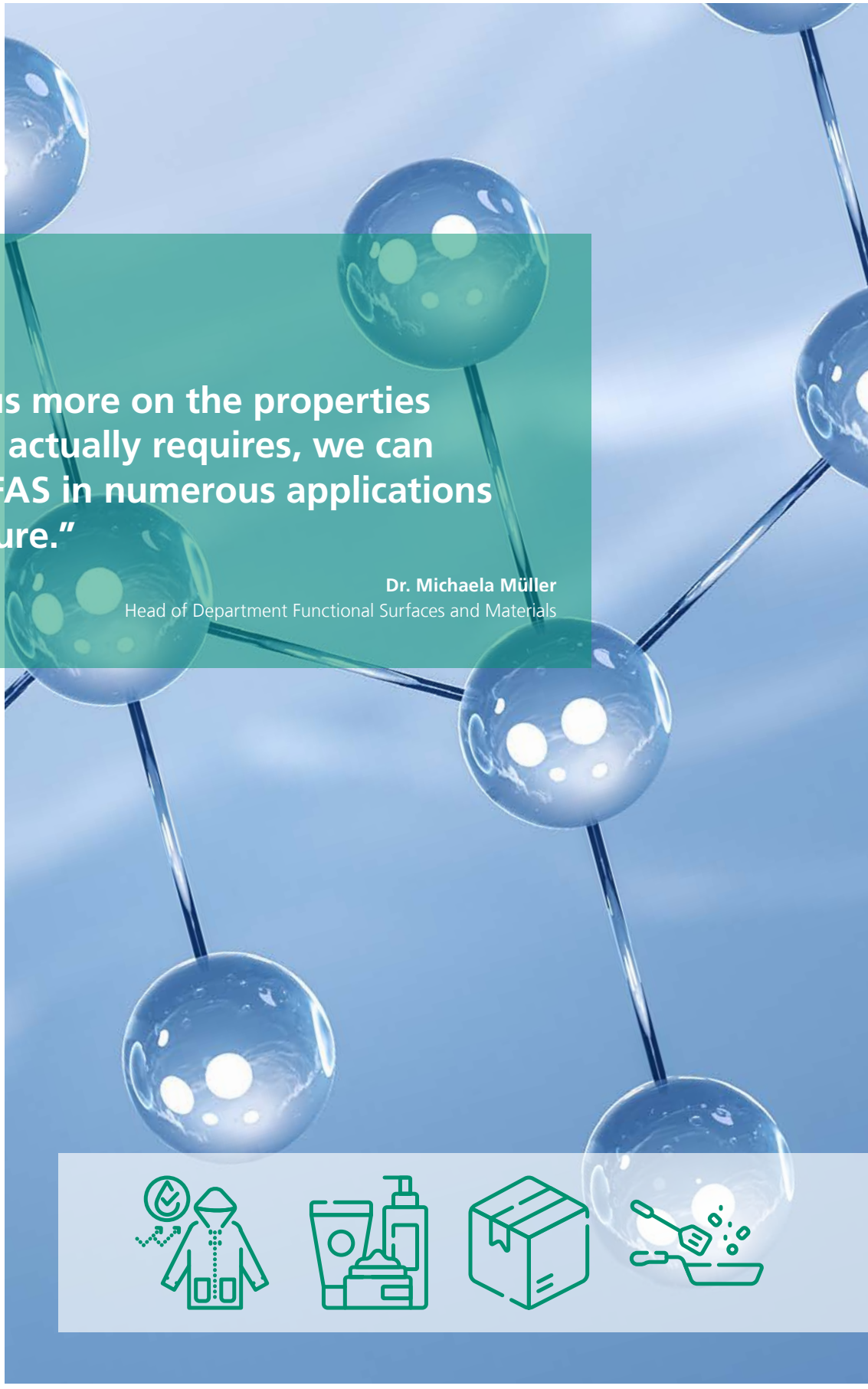
- Screening of new substances and substitutes
- Studies on the release of active ingredients
- Studies on the effect on skin and intestine
- Mode of action of pharmaceuticals and active ingredients
- Studies on wound healing
- Toxicological evaluation of chemicals and products
- Analysis of environmental influences on skin physiology

Establishing customized reporter gene assays for customer-specific questions

- Detection of molecular substance reactions
  - Effect-centered (e.g. for the detection of ER stress)
  - Substance-centered (e.g. for combinatorial detection of metabolic and endocrine effects of per- and polyfluorinated alkyl substances, PFAS).
- Detection of effects on the central nervous system
  - Detection of neurotoxins, e.g. by means of acetylcholine receptors
- Detection of effects on the cardiovascular system
  - Detection of cardiotoxins, e.g. using HER2 receptors
- Detection of carcinogenic effects
  - By means of growth factor-specific receptors, e.g. EGF receptor
- Detection of teratogenic effects
  - By means of certain nuclear receptors, e.g. PPARd

Test systems established at Fraunhofer IGB for analyzing different effects of substances

Test system	Tested substance effect	Technology readiness level
Sensitization in cell-based assays and in 3D full-thickness skin models	Triggering allergic reactions	TRL 9
Inflammation in cell-based assays and in 3D full-thickness skin models	Triggering inflammatory reactions	TRL 9
Toxicity in cell-based assays	Proof of cytotoxic effect	TRL 9
Endocrine effect in cell-based assay	Harmful effects that are triggered by influencing the endocrine system	TRL 2
Combinatorial metabolic and hormonal effects (peroxisome proliferator-activated receptor, leptin receptor and estrogen receptor)	Harmful effects that are triggered by influencing the endocrine system	TRL 2
Combinatorial effects of cell stress in cell-based assays	Triggering of ER stress, oxidative stress and inflammatory reactions	TRL 8



If we focus more on the properties a product actually requires, we can replace PFAS in numerous applications in the future.“

Dr. Michaela Müller
Head of Department Functional Surfaces and Materials

The problem of PFAS

Solutions for substitution and elimination

Dr. Michaela Müller, Head of Department "Functional Materials and Surfaces", represented Fraunhofer IGB at the "dialogue day" of the Chemistry Alliance on October 12, 2023, among other things with her lecture "PFAS substitution: What is realistic, what is wishful thinking?".

Per- and polyfluoroalkyl substances, or PFAS for short, play a key role in numerous branches of industry due to their properties and wide range of applications. The downside is that they are not degradable and accumulate in the environment, animals and humans. Since some PFAS substances have been proven to be harmful to our health, politicians are discussing an EU-wide ban. Researchers at Fraunhofer IGB are therefore working on harmless alternatives that can be used to substitute PFAS. In addition, the institute is developing various solutions to remove PFAS from water. These were also the focus of the "22nd wastewater colloquium" at Fraunhofer IGB "PFAS und Spurenstoffe im Brennpunkt" (PFAS and trace substances in the spotlight) in September 2023. Experts from the Fraunhofer Chemistry Alliance, including Dr. Michaela Müller from Fraunhofer IGB, discussed possibilities for PFAS substitution as well as material and technical development goals in a dialog with user industries in October 2023.

Whether it's pans, rain jackets, food packaging or firefighting foam – numerous everyday products contain per- and polyfluoroalkyl substances, or PFAS for short. This is a group of versatile organic chemical compounds in which the hydrogen atoms have been replaced by fluorine atoms, either completely (perfluorinated) or partially (polyfluorinated). This gives them uniquely combined properties, such as being water, grease and dirt repellent, which which is why they are interesting for numerous industries and products. PFAS plastics such as polytetrafluoroethylene (PTFE, trade name Teflon™) are very stable both chemically and thermally: surfaces treated with them also have friction-reducing and non-stick properties. PFAS are versatile – as sealing materials, corrosion protection coatings, additives for lubricants, but also as ingredients in cosmetics.

Fraunhofer Chemistry Alliance

Fraunofer IGB is a member of the Chemistry Alliance, whose institutes conduct research on a variety of PFAS-relevant issues and who thus provide a uniquely broad range of expertise.

- *www.chemie.fraunhofer.de/en.html*

Statement of the Fraunhofer Chemistry Alliance

- *www.chemie.fraunhofer.de/content/dam/chemie/dokumente/Position-Paper_PFAS_Fraunhofer.pdf*

Fraunhofer magazine 4/23 "PFAS: the Poison of the Century"

- *www.fraunhofer.de/en/research/current-research/pfas.html*

PFAS – danger to the environment and our health

But where does their bad reputation come from? Some PFAS representatives can now be detected in groundwater and humans, among other things. This requires a differentiated view of the different PFAS.

Smaller PFAS molecules such as perfluorooctane sulfonic acid (PFOS) have been shown to be toxic to humans and the environment. The low-molecular PFAS can accumulate in animal tissue and thus also end up on the dinner table in humans. The chemicals enter the human body through food or drinking water, with significant health effects ranging from damage to organs to cancers or developmental disorders.

For this reason, many countries already have limit values for certain PFAS in drinking water. With the amendment to the German Drinking Water Ordinance, which came into force in mid-2023, the limit values for PFAS in water will be reduced in two stages over the next few years. Specific bans also illustrate stricter regulations: for example, for perfluorooctane sulfonic acid (PFOS), the use of which is limited to a few essential areas of application in accordance with the Stockholm Convention on the Control of Persistent Organic Chemicals in the Environment.

In the case of higher-molecular plastics such as PTFE, their stability and thus non-degradability in the environment is the biggest problem. At present, it is simply not known or foreseeable what will happen to these materials in the environment in a hundred years' time, and whether they will perhaps be converted into toxic substances after all.

In order to comply with the precautionary principle prevailing in Germany and the EU, further regulation of such persistent materials is being discussed. It must be taken into account that low-molecular PFAS are used in the production of fluoroplastics, which can also be released into the environment.

Fraunhofer IGB – partner for substitution and removal of PFAS

In view of the threat of a PFAS ban or massive restrictions on the production, use and supply of industrial chemicals, manufacturers and users alike are faced with an acute need for action. Fraunhofer IGB supports companies in the search for suitable substitute materials for their products, in the development of tailor-made coatings, and in the evaluation of new substances and materials with regard to possible effects harmful to the environment and our health.

Fraunhofer IGB also offers a wide range of technical solutions for the elimination of PFAS and other micropollutants from wastewater in order to reduce harmful health effects, for example in our drinking water. In addition to membrane adsorbers and adsorber particles for concentration and separation, the institute is researching various advanced oxidation processes (AOP) to achieve a degradation of the persistent substances.

Contact
Dr. Michaela Müller
Phone +49 711 970-4140
michaela.mueller@igb.fraunhofer.de

Substitution: harmless alternatives to PFAS

As part of the debate about the environmental and health hazards of PFAS, major producers have already announced a withdrawal from the production of these compounds. It is therefore foreseeable that some fluorochemicals will either be significantly more expensive, or they will no longer be available on the market at all in the future. So there are many good reasons to look for alternative materials.

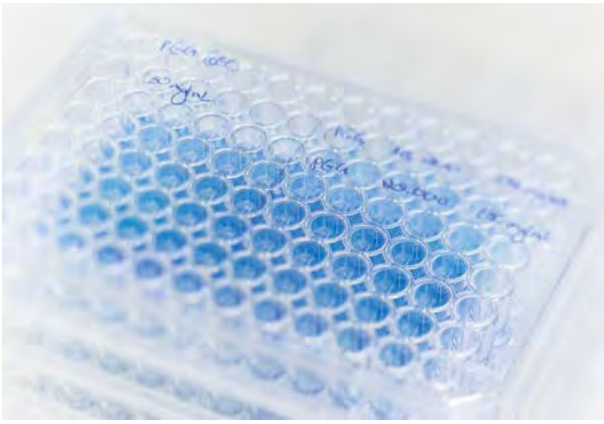
But what are the alternatives? Fraunhofer IGB is working intensively on the question of which materials are suitable for this purpose. It is already clear that there will be no material that can replace fluoropolymers for all different applications. Rather, in the future, for example in the development of coatings, the intended application with the respective required properties must come more into focus.

Fluorine-free membrane materials and coatings

The institute conducts research on several technologies and processes for the substitution of PFAS, especially in the field of coatings. These include plasma technology, in which water-repellent coatings, for example on single-use items, are realized with fluorine-free gases that are harmless to humans and the environment. We have also been able to successfully develop water-repellent finish for textiles using modified biobased chitosan or certain fungus-produced proteins, hydrophobins. Furthermore, Fraunhofer IGB is currently doing research on membrane materials, for example for filtration and the energy transition. In doing so, the institute supports companies in material development as well as in the adaptation or conversion of their manufacturing and processing processes.

Efficacy-based testing of PFAS alternatives

In the case of PFAS, environmental and health effects only became apparent decades after they were approved. This shows how important it is to carry out a comprehensive and specific ecotoxicological and human toxicological assessment of new substances at a very early stage, ideally already in the development phase.



Based on its expertise in the field of in-vitro cell and tissue models, Fraunhofer IGB has therefore set itself the goal of developing screening test procedures, that can be used during development to evaluate possible PFAS alternatives. Cell-based assays established at the IGB can be used to test new substances for classic toxicological endpoints such as effects on cell proliferation or toxicity. With specific, specially developed and patented reporter cell assays as well as complex 3D in vitro tissue models, especially of the skin, targeted adverse effects on metabolic processes in cells and tissues can also be detected, and thus, for example, immunomodulating, sensitizing, cell stress-inducing or pro-inflammatory effects can be detected (see article on Circular Health, p. 36). The department of Cell and Tissue Technologies, headed by Dr. Burger-Kentischer, is currently working on the establishment of specific reporter cells, for example for the targeted detection of the effect of PFAS on lipid metabolism or for the detection of endocrine (hormone-like) effects.

Substitution of PFAS with new materials and coatings

Continuous finishing with a PFAS-free non-stick layer in the roll-to-roll process

According to the current status, materials with high chemical stability, e.g. Teflon™, will also be severely restricted in their approval in the future. Some manufacturers are already discontinuing the production of fluorinated compounds, so that some necessary PFAS precursor molecules will no longer be available on the market in the future. A suitable replacement must therefore be found for the current applications of these materials.

Our development

Fraunhofer IGB has been an expert in the field of functional surfaces and materials for decades, including functions achieved via PFAS coatings. We use our expertise in the field of polymers, surfaces and coating technologies to offer our customers solutions that can be implemented quickly for their specific problems. The developed coatings are applied under laboratory conditions at Fraunhofer IGB using plasma processes, other chemical vapor deposition processes or wet chemicals. In doing so, we focus on a chemically stable (covalent) bond between material and coating, as this is crucial for the long-term and successful use of the substitution materials.

Coatings for the substitution of PFAS

- Hydrophobic finish with non-stick plasma polymers
- Friction-reducing and chemical-resistant finishes
  - Parylene
  - Hydrocarbon/organosilicon based plasma coatings

Benefits and technological readiness

Our approach to realizing optimal substitution materials is to select the material, that is as similar to the required profile as possible, to fine-tune the desired properties by coating the material surfaces. For example, in the case of a sealing ring (O-ring), this means that the bulk properties, e.g. the required shore hardness and ductility, are supplied by the bulk material. Other required properties, e.g. slippage and a barrier against swelling of the material, are produced by means of coatings.

Because components of the new coatings of many applications are already on the market today, we are entering at a high technology readiness level (TRL) for individual components. One challenge is the adaptation of the adhesion mediation between material and layer, whereby the leap to TRL 7 is also quickly achieved. Thanks to our know-how in material science – supported an advanced surface analysis – industrially feasible solutions are quickly within reach, even when using completely new materials and substances.

Collaboration

In order to substitute PFAS, we first discuss the exact operating conditions of the materials to be replaced with our clients or partners and generate a specific requirement profile accordingly. It is often found that PFAS were used as highly stable compounds even without extreme requirements. In such cases, there are many alternatives without PFAS. For applications under harsh conditions (chemistry, temperature, abrasion, etc.), however, we dig deeper into our bag of tricks and proceed as described above to select the material and determine the coatings.

After implementing the concepts in the laboratory, the results are validated directly in application with our partners. If necessary, this is followed by an optimization phase before we scale the technology and transfer it to manufacturers or coaters.

Further information

www.igb.fraunhofer.de/pfas-coatings

Contact
Dr. Jakob Barz
Phone +49 711 970-4114
jakob.barz@igb.fraunhofer.de

Hydrophobic treatment of textiles with biobased chitosan

Chitosan, which can be obtained as a residue from insect breeding, industrial fermentation or fishery waste, is already being used in the textile industry as a biobased and environmentally-friendly sizing agent. Due to its chemical structure – with binding points for further functionalities – the renewable biopolymer is also suitable for sustainable refinement and fluorine-free hydrophobic treatment of cotton, polyester and blended fabrics.

Our development

In the HydroFichi and ExpandChi projects, which were funded by the German Federal Ministry of Education and Research, we at Fraunhofer IGB and our partners from the textile industry were able to develop chitosan-based, water-repellent finishes. With only low to medium requirements, the chitosan-based hydrophobic equipment can replace PFAS in applications. The technology used is based on a modification of the chitosan backbone with activated structures or molecules that exhibit the desired hydrophobic properties. In this case, chitosan acts as a matrix. The cross-linking on the textile is then carried out either chemically or with biobased cross-linkers. When possible, the cross-linkers were functionalized biotechnologically.

Benefits and technological readiness

In addition to the water repellant effect (left figure) of the coated textile, which lasts even after several washes, the finish also improves the abrasion resistance of the textile fabric. The all-in-one formulation can be applied to the fabrics using processes common in textile technology, even on a larger scale (right figure). A large textile sample will be presented at the 2025 World Expo in Osaka. Research shows few incompatibilities with other formulation ingredients. This allows the combination of water repellency with other finishes.

Collaboration

We have already successfully adapted the water-repellent, chitosan-based finish to other materials (paper and cardboard), which is very interesting for the packaging industry. With appropriate research, we can produce customized derivatives of chitosan for other applications, such as adhesive coatings or biobased binders for the wood processing industry. In addition, the chemical and biotechnological modifications developed in the ExpandChi project can also be transferred to other polysaccharides for the production of further functionalities. We are happy to investigate further applications and utilization strategies on behalf of our customer or in a funded project.

Further information

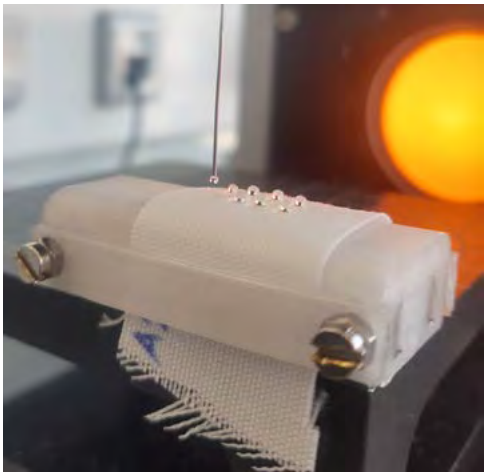
www.igb.fraunhofer.de/chitosan-coating

Contact
Dr. Achim Weber
Phone +49 711 970-4022
achim.weber@
igb.fraunhofer.de

Dr. Thomas Hahn
Phone +49 711 970-4159
thomas.hahn@
igb.fraunhofer.de

Left:
Hydrophobic equipment

Right:
Scaling at Knopf's Sohn



Hydrophobic surfaces by using hydrophobic proteins

Further information

www.igb.fraunhofer.de/hydrophobic-proteins

Contact
Dr. Michael Richter
Phone +49 9421 9380-1020
michael.richter@
igb.fraunhofer.de

In order to specifically adjust the hydrophobicity of surfaces, proteins from fungi could be a biological alternative to fluorinated hydrocarbons in certain cases. In the department of Bioinspired Chemistry at the BioCat branch in Straubing, so-called hydrophobins – functional proteins that naturally occur in fungi – were produced recombinantly for this purpose. By fusing them to anchor proteins (natural cellulose binding domains), the hydrophobic proteins are able to bind themselves to cellulosic surfaces in a site-directed manner.

This provides a toolbox with various proteins that can give material surfaces water-repellent properties without chemical or physical pre-functionalization, or possibly also improve the compatibility of material surfaces, for example in adhesive and plastic applications.

On behalf of our customers, we are investigating how we can equip your surfaces with our existing toolbox of functional proteins according to your requirements and realize this advantage of biologization through protein functionalization.

Fluorine-free membranes for filtration and energy transition

When using technical membranes, fluorine-containing materials are used in many applications, for example in seals and pipes of membrane systems. Partly due to their special (electro-)chemical stability, membranes based on fluorine-containing polymers are also used directly in various areas of application.

Fraunhofer IGB is working on the substitution of fluorine-containing membranes for the following applications:

Filtration

Polyvinylidene fluoride (PVDF) membranes have a significant market share here, which is due to the high performance of the membranes on the one hand and the stability against chemical cleaning on the other. Although there are already fluorine-free alternatives, e.g. based on polyethersulfone, these usually show lower performance. Fraunhofer IGB is working on further optimizing the performance of these alternative membranes. We are investigating the use of green solvents in particular.

- *www.igb.fraunhofer.de/en/green-membranes*

Elektrochemistry

In fuel cells or in membrane electrolysis, fluorine-containing ionomers have been used almost exclusively due to their outstanding electrochemical stability, so far. In this area, fundamental work on new membrane materials is still necessary. Fraunhofer IGB is working on the development of alternative materials to minimize the fluorine content of the membranes. Our approach focuses on the development of so-called mixed-matrix membranes, which can be used, among other things, to minimize membrane crossover.

- *www.igb.fraunhofer.de/hydrogen-technologies*

Humidifier membranes

Membrane humidifiers are preferred for water management in fuel cells. In the FLUID project, fluorine-free humidifier membranes are being developed (BMWK 03EN5030B)(BMWK 03EN5030B), while Fraunhofer IGB is developing both flat and hollow fiber membranes. At the same time, we can also continuously coat membranes on roll-to-roll lines with suitable separating layers. On our test benches, we can furthermore determine the performance of these membranes in realistic driving cycles.

- *www.igb.fraunhofer.de/humidifier-membranes*

Continuous production of fluorine-free flat membranes by casting a polymer solved in a green solvent

Further information

www.igb.fraunhofer.de/membranes

Contact
Dr. Thomas Schiestel
Phone +49 711 970-4164
thomas.schiestel@
igb.fraunhofer.de

Removal of PFAS from water

But what about the PFAS that are already in circulation and can be detected in soils, waters and groundwater? As already mentioned, PFAS are released into the environment during the production of fluorine-containing plastics or the use of extinguishing foam. To a not inconsiderable extent, PFAS are also introduced into the environment through abrasion of plastic products and coated textiles. One problem is PFAS-containing waste in landfills, where the fluorinated substances are leached into the leachate.

This calls for water treatment processes that can be used to purify contaminated water. However, filtering with activated carbon is a common process that binds harmful PFAS but does not eliminate them, so that the remains must be disposed of or stored as hazardous waste.

Goal: complete degradation of micropollutants

Fraunhofer IGB uses its expertise to pursue strategies or technologies that do not only remove PFAS (and other trace or micropollutants) from water, but in the best case completely dismantle them. In principle, this is possible with various AOP (Advanced Oxidation Processes) methods, including plasma-based or photocatalytic methods.

Technologies for the degradation of the chemicals, which have already been successfully demonstrated on a laboratory and pilot plant scale, including with real water samples, now need to be scaled up and evaluated with partners under the real conditions of industrial sites and further developed for widespread use in acute damage cases or in production plants.

Treatment and recovery of PFAS contaminated water by means of atmospheric water plasma treatment

Groundwater and soils have been contaminated with harmful PFAS at numerous sites.

Our development

With atmospheric water plasma, we have a process at our disposal that enables the elimination of PFAS from groundwater, seepage and wash water. Plasma water treatment is characterized by the fact that the contaminants can be broken down and thus eliminated. This eliminates the need for downstream, and sometimes cost-intensive, disposal, as is required with cleaning technologies that merely immobilize PFAS.

Benefits and technological readiness

By forming short-lived species with high energy and numerous OH radicals in the plasma, it is possible to break the stable C-F compounds of PFAS. Another advantage is the wide range of applications of water plasma technology: We have already been able to successfully remove other trace substances, such as drug residues, pesticides and herbicides.

With our pilot plant (TRL 5), we have already investigated water purification by means of plasma treatment on real water samples and achieved major purification results with high energy efficiency in the plasma process of up to 15 mg/kWh for PFAS-containing water samples.

Collaboration

For further development, we are interested in collaborating with affected stakeholders in order to optimize the plasma process parameters for the respective problem case with regard to the cleaning results. The aim is to build a demonstration plant that is suitable for decentralized use in the open field under real conditions.

Further information

www.igb.fraunhofer.de/en/atwaplas

Contact
Dr.-Ing. Georg Umlauf
Phone +49 711 970-4142
georg.umlauf@
igb.fraunhofer.de

Plasma reactor for purifying water on a laboratory scale

Independent technology comparison in water treatment: established and new, green and efficient methods

Further information

www.igb.fraunhofer.de/en/aop

Contact
Dr. Benjamin Wriedt
Phone +49 711 970-4008
benjamin.wriedt@
igb.fraunhofer.de

As a precautionary measure and due to new limit values for micropollutants, proposed in the new EU directive, numerous municipal wastewater treatment plants are currently being expanded to include a so-called fourth treatment stage. After mechanical, biological and chemical treatment, the remaining residues of drugs, pesticides or industrial chemicals are removed. In many industries, internal water recycling is also becoming increasingly popular in order to comply with regulatory requirements, to increase sustainability, and to reduce energy consumption and costs.

Selecting the best technology for individual requirements

When deciding on the right technology that fits individual customer needs, Fraunhofer IGB offers technology and company-independent consulting. Specified target parameters are compared with the market and process engineering framework conditions to obtain a holistic, sustainable and future-proof concept.

Furthermore, Fraunhofer IGB holds the necessary technical equipment and expertise to treat representative samples of customers' real wastewater on a laboratory scale, using various established and novel technologies. In addition to the determination of common sum parameters, the investigations can be combined with specific analyses of individual substances on request. This ensures both the efficiency of the method and compliance with the guidelines.

The results of the analysis are used to evaluate energy requirement, treatment time and method efficiency in order to derive a recommendation for the appropriate treatment procedure. In addition, Fraunhofer IGB offers the development of specific application and dosage recommendations for existing systems as well as a determination of the oxidation potential of the technology of an existing plant as service measurements.

New technologies for greater efficiency and sustainability

In current, some publicly funded projects, Fraunhofer IGB is researching alternative and new, innovative technologies for water treatment, which enables a comparison with established technologies in customer-specific applications. Key roles are not only the investment and operating costs as well as the pure mining performance but also the environmental balance and potentially harmful transformation products.

Currently, the processes of ozonation and activated carbon filtration are predominant in an industrial context. However, these can be energy-intensive and relatively expensive and sometimes only lead to separation and subsequent landfilling, but not to a degradation of

Left:
Dr. Benjamin Wriedt gave a lecture at the "wastewater colloquium" on the topic of "UV- and sunlight-driven photocatalysis".

Right:
During the subsequent tour, Dr. Jakob Barz demonstrated the pilot plant setup for the removal of trace substances from water, using plasma technology.

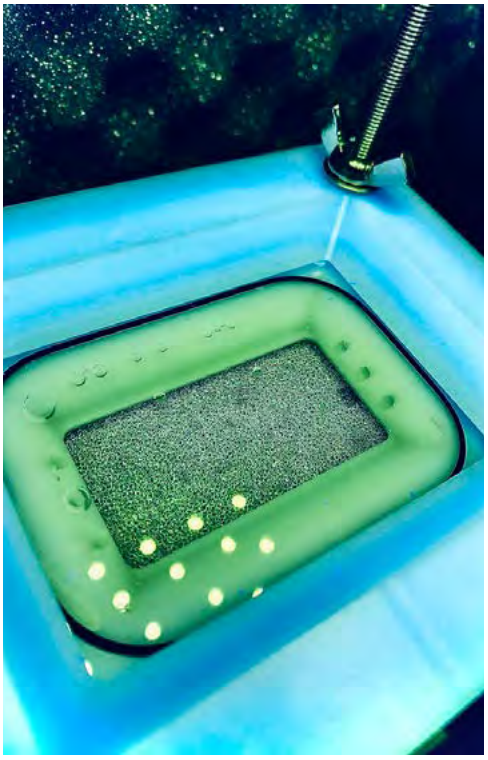
the pollutants. A promising class of methods in this context are Advanced Oxidation Processes (AOP).

For this purpose, Fraunhofer IGB operates laboratory facilities for dynamically controlled UV-C/H_2O_2 treatment and oxidation with diamond electrodes. Furthermore, various components for highly efficient photocatalysis treatment, which can be operated with either UV-A LEDs, visible light LEDs, sunlight or a combination, are being tested.

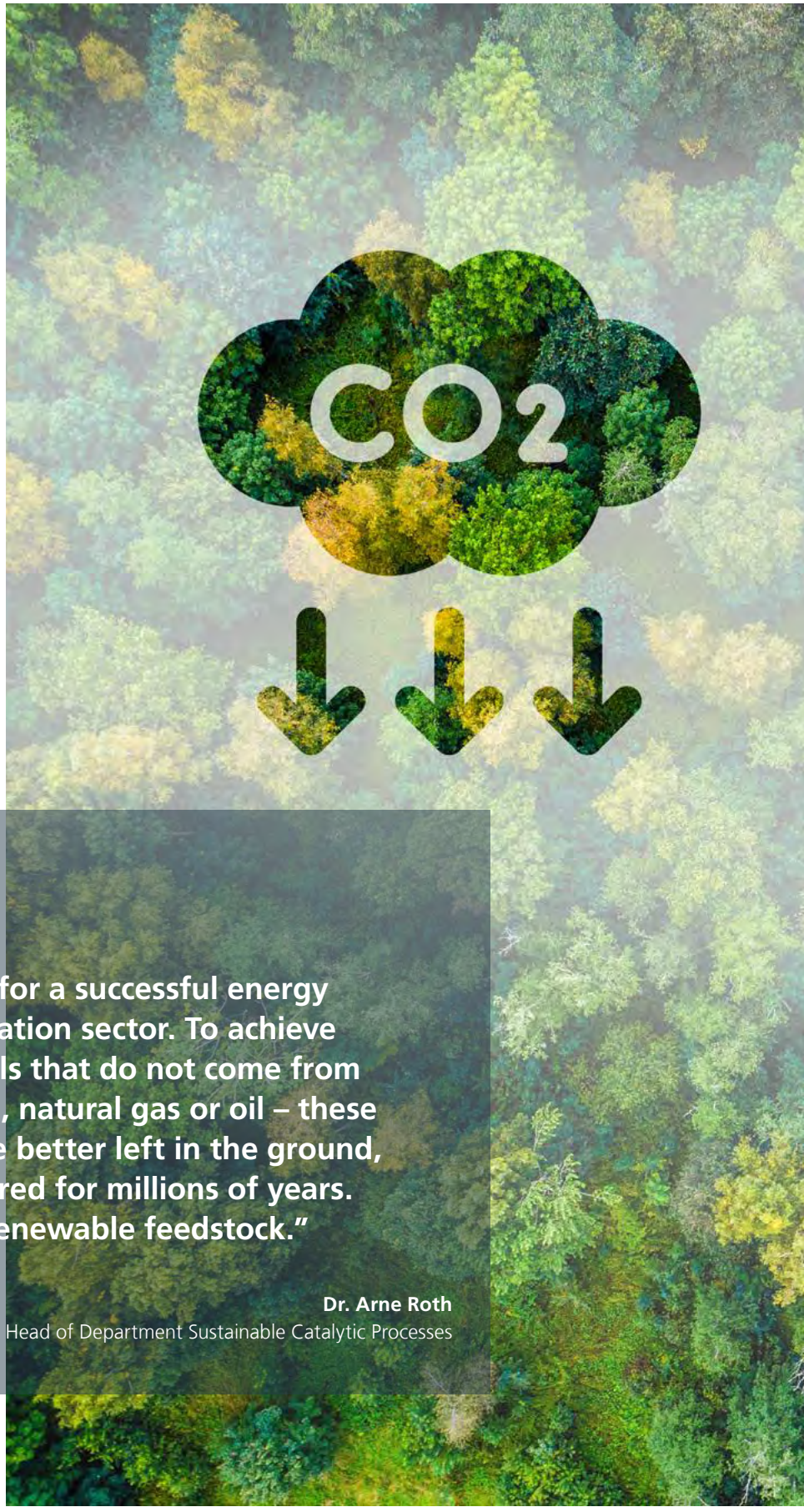
Understanding and optimizing treatment processes and saving costs

In order to find the best individual solution for a body of water to be treated, containing pollutant concentrations ranging from a few hundred mg/L to a few ng/L, a component-specific efficiency determination study can be carried out at Fraunhofer IGB. This reveals which component of the process has the greatest optimization potential. The evaluation is based on newly developed, dynamic measurement methods for the photon concentration in the reaction chamber (actinometry), the scavenging potential (OH radical concentration) and the effective treatment time (residence time distribution).

Identified factors can be, for example, a change in the reactor geometry, better mixing conditions, catalyst optimization or a requirement-driven adjustment of the operating parameters. This way, a significant increase in treatment performance – often by one or two orders of magnitude – and an increase in reliability combined with a reduction in costs is possible.



A metal foam coated with titanium dioxide as a photocatalyst is activated with high-power LEDs.



Synthetic fuels are crucial for a successful energy transition in the transportation sector. To achieve this, we need raw materials that do not come from fossil sources, namely coal, natural gas or oil – these conventional resources are better left in the ground, where they have been stored for millions of years. Instead, we use CO_2 as a renewable feedstock."

Dr. Arne Roth
Head of Department Sustainable Catalytic Processes

CO_2 as raw material for sustainable chemistry

Technologies for the development and use of CO_2

Carbon is ubiquitous in the biosphere and a central building block of all organic matter. But carbon is also the basic element of numerous materials in everyday products – from fuels and plastics to cosmetics and pharmaceuticals. Currently, these are mainly produced from fossil raw materials such as oil and natural gas.

Due to the advancing climate change with increasingly dramatic consequences, greenhouse gas emissions must be avoided urgently, through savings in resource consumption and increased efficiency, but especially by replacing fossil raw materials with renewable alternatives. The transition from fossil fuels to renewable energy and raw materials is known as defossilization or defossilation.

Fraunhofer IGB – your partner for the defossilization of your processes

Fraunhofer IGB supports you in developing processes and process cascades that can be used to produce fuels, platform chemicals, plastics and other chemical products from renewable resources in a climate-neutral way.

CO_2 – from greenhouse gas to resource

Carbon dioxide (CO_2) is increasingly seen not only as a climate-damaging greenhouse gas, but also as a promising carbon source for the synthesis of a wide range of chemical products – in other words, as a raw material. The corresponding general approach of Carbon Capture and Utilization (CCU) is about binding the carbon in CO_2 in products through technical conversion processes.

Circular carbon economy through recycling CO_2

CO_2 is produced during all combustion and oxidative degradation processes of organic materials, such as microbial decomposition of biogenic substances, our respiration and alcoholic fermentation. The greenhouse gas CO_2 is therefore unlimitedly available and can be utilized as raw material for innovative process technologies, driven by renewable energy. Reuse of carbon in the form of CO_2, known as chemical carbon recycling, helps build a sustainable circular carbon economy and reduce the use of fossil resources.

How to successfully reuse CO_2

CO_2 is a low-energy and chemically quite inert compound that can only be induced to a chemical reaction with high energy input and suitable catalysts. As the energy transition progresses, renewable energies are increasingly available to chemically activate CO_2 and use it as a sustainable carbon source.

In a first step, CO_2 must be separated and purified from industrial process gases (so-called point sources) or directly from the air (direct air capture, DAC). Relevant point sources are, for example, process gases from breweries, waste incineration and biogas plants, cement plants or blast furnaces in the steel industry.

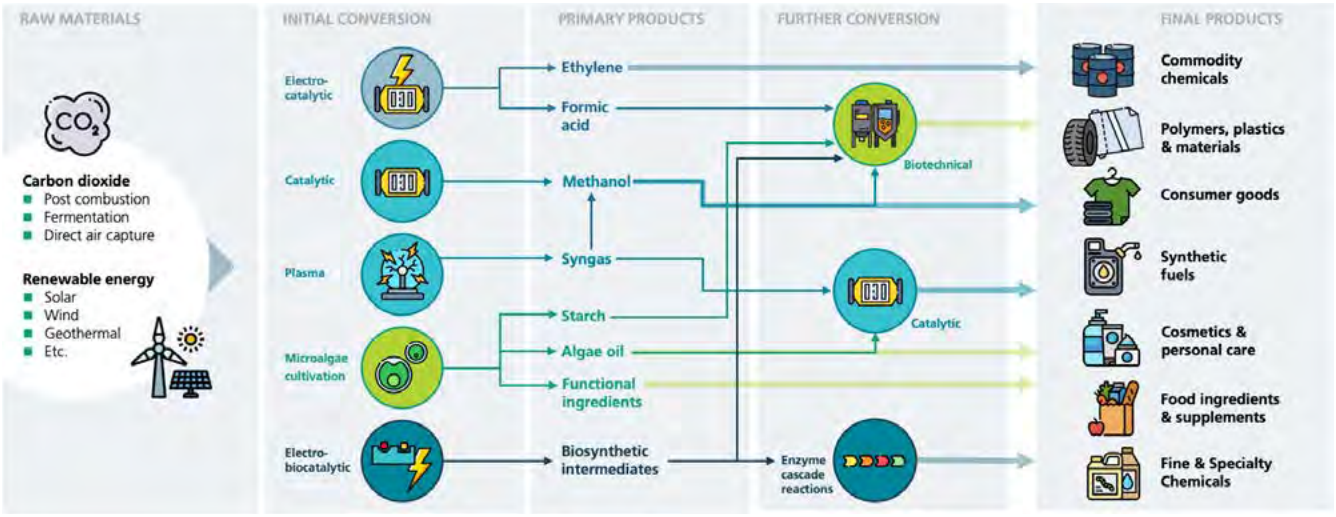
Sector coupling through chemical energy storage

With just a few chemical or electrocatalytic conversion steps, basic chemicals (e.g. methane, methanol, ethene) or synthetic fuels can be produced from CO_2. Compounds such as methane or methanol are also easy to store and transport and can function as chemical energy carriers/storage media. For this reason, they play an essential role in the energy transition and link the energy sector with the chemical and transport sectors.

Contact
Dr. Arne Roth
Phone +49 9421 9380-1030
arne.roth@igb.fraunhofer.de

CO_2 conversion technologies and products made from CO_2

Fraunhofer IGB pursues various approaches to convert CO_2 and offers intelligent solutions for the production of a wide variety of products from CO_2 through advantageous combination of (electro-)chemistry, process engineering and synthetic biotechnology. Our goal is to further develop these technologies into economically viable processes in collaboration with our industrial partners.



At Fraunhofer IGB, we are pursuing various technological approaches to convert CO_2 into a variety of possible products.

Basic chemical methanol

Chemical (thermocatalytic) conversion of CO_2 with hydrogen

Further information

www.igb.fraunhofer.de/en/power-to-x

www.cbp.fraunhofer.de/chemical-processes

Contact
Dr. Ulrike Junghans
Phone +49 3461 43-9128
ulrike.junghans@igb.fraunhofer.de

Dr. Arne Roth
Phone +49 9421 9380-1030
arne.roth@igb.fraunhofer.de

As an important platform chemical, methanol is a raw material for various significant products in the chemical industry as well as the transport sector. These include olefins such as ethylene and propylene, aromatic compounds and polymer building blocks, as well as synthetic fuels (petrol, diesel, kerosene).

Our development

We are researching thermocatalytic methanol synthesis, converting CO_2 from industrial point sources (exhaust gases from cement plants, biorefineries, etc.) with the help of stable catalysts. In contrast to high-purity CO_2, these exhaust gases contain various trace components in addition to CO_2, e.g. oxygen, ammonia or sulphur compounds, which can significantly impair the performance and lifetime of the applied catalysts. In our research, we investigate the influence of such catalyst poisons and develop measures to protect the valuable catalyst.

Benefits and technological readiness

The synthesis of methanol is an industrially established process (TRL 9). The conventional process is based on synthesis gas as the starting material, i.e. a mixture of hydrogen and carbon monoxide (CO), which is produced from fossil resources (coal or natural gas). The direct synthesis of methanol from CO_2 and hydrogen is not yet as far advanced, but nevertheless at the brink of industrial application. The advantage of the direct process route is the avoidance of an upstream, technically demanding process for converting CO_2 to CO.

The influence of possible catalyst poisons in CO_2 streams from industrial point sources is currently still insufficiently investigated. There is a need for development in order to provide stable and resilient catalysts for CO_2-based methanol synthesis. In particular, investigations into the upstream process integration of methanol synthesis with different technical CO_2 sources are highly relevant.

Collaboration

We aim to advance our research and development on methanol synthesis with partners from across the value chain: companies that can provide CO_2 as a raw material from industrial process gas streams, that are working on the development or production of suitable catalysts, that are already active in the field of methanol production, or that use methanol feedstock for further processing. To this end, we offer our partners infrastructure from laboratory to pilot scale for integrated process development.

Pilot plant for methanol synthesis

Basic chemical: formic acid

Electrocatalytic conversion of CO_2

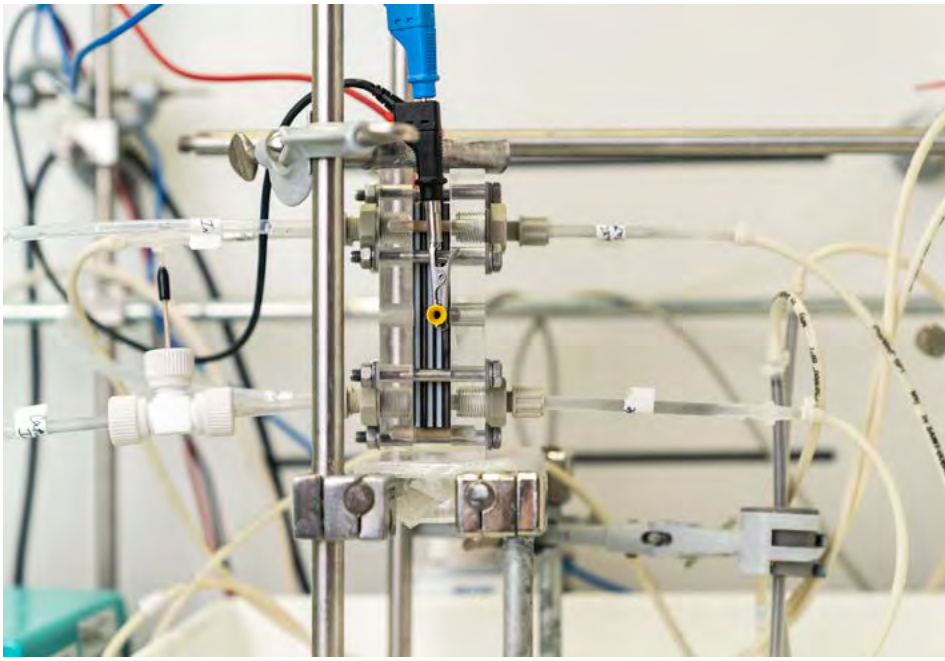
The direct electrocatalytic reduction of CO_2 in an electrochemical cell offers an attractive alternative to thermocatalytic conversion with hydrogen. Various reduction products are possible, whereby we at Fraunhofer IGB concentrate on the electrocatalytic synthesis of formic acid and its salts.

Our development

For the electrochemical synthesis of formic acid and formate salts from CO_2, we use gas diffusion electrodes coated with various electrocatalysts. Our research encompasses both the formulation of the catalysts and the optimization of the process conditions according to industrially relevant criteria. For example, we use flow cells for continuous process control and work at the highest possible current densities. Catalyst stability is also an important target parameter. Depending on the application, different cell concepts are used.

Benefits and technological readiness

Compared to thermocatalytic processes, direct electrocatalytic reduction of CO_2 offers one significant advantage: No hydrogen has to be provided. In electrocatalytic processes, the reduction of CO_2 is carried out by direct electron transfer at the electrode surface. This eliminates the need for a chemical reducing agent and potentially enables higher energy efficiency. However, in electrocatalytic CO_2 reduction, several product formation pathways compete with each other: In addition to formic acid, possible reduction products include carbon monoxide, ethene and methane. Another important side reaction is the formation of hydrogen. Since most side reactions occur in a similar potential window, the applied electrocatalyst is of great importance in order to channel the reaction along the desired reaction pathway and thus maximize the yield of the target product. The electrochemical synthesis of formic acid is still in the research stage, and commercial application has not yet taken place. The research landscape is very dynamic, and various electrochemical cell concepts are currently being developed.



Electrochemical flow cell with which we investigate the reduction of CO_2 to formic acid.

Collaboration

We are very interested in collaborating with partners from the field of material development (electrodes, membranes) and the chemical industry (production or use of formic acid or formate salts).

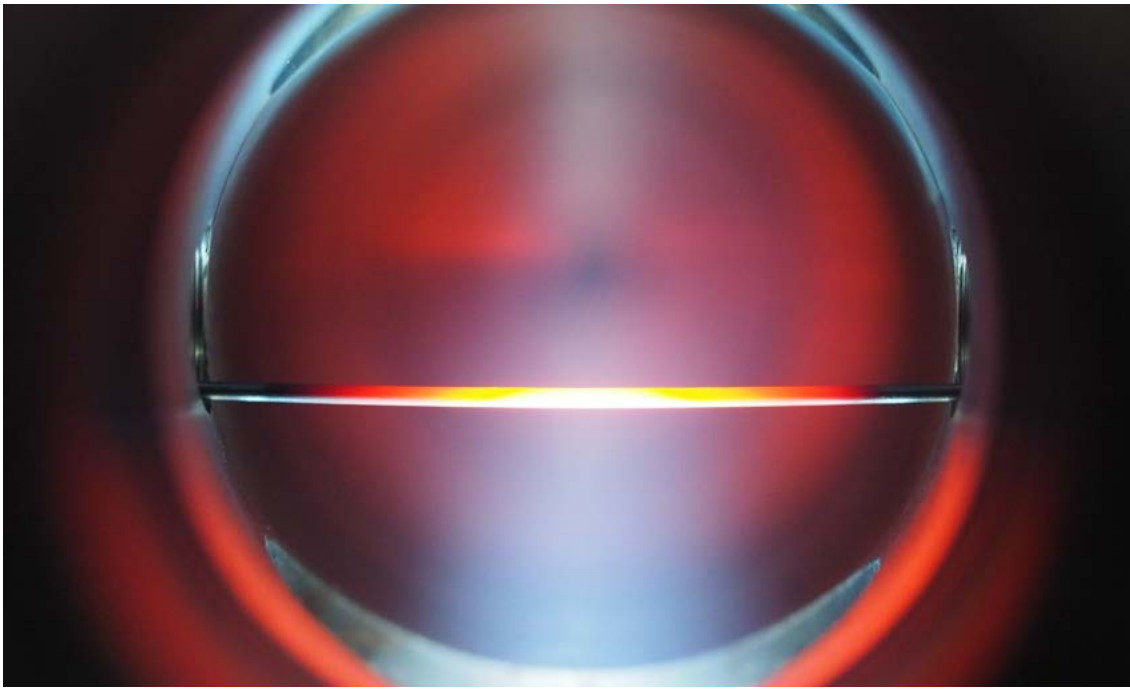
Further information

www.igb.fraunhofer.de/sustainable-electrosynthesis

Contact
Dr. Arne Roth
Phone +49 9421 9380-1030
arne.roth@igb.fraunhofer.de

Synthesis gas

Conversion of CO_2 by plasma membrane reactor



Membrane in plasma

Further information

www.igb.fraunhofer.de/en/co2-plasma

Contact
Dr. Thomas Schiestel
Phone +49 711 970-4164
thomas.schiestel@
igb.fraunhofer.de

An innovative method for activating the CO_2 molecule is the use of a plasma torch. Here, energy is supplied in the form of microwaves and carbon dioxide is split into carbon monoxide and oxygen. To prevent a recombination to carbon dioxide, it is beneficial to remove the oxygen from the system. Carbon monoxide, a component of synthesis gas, can be used as a starting product for the synthesis of platform chemicals.

As part of the PiCK (03SFK2S3D) and NexPlas (03SF0618C) projects funded by the German Federal Ministry of Education and Research, membranes, that are suitable for this application, were developed at Fraunhofer IGB. These membranes are characterized by a large specific surface area, high O_2 permeation, stability in a CO_2 atmosphere, and high thermal shock stability. In the meantime, initial attempts to scale the process have also been successfully carried out.

Fraunhofer IGB is continuing to work on optimizing the membranes and scaling up the process.

Sustainable transport sector

Synthetic fuels

In many areas of the transport sector, fuels will continue to be needed in the future, even if all cars are electrically powered. The majority of aircraft and ships, for example, will remain dependent on fuel for the foreseeable future. In order for these means of transport to become climate-neutral, sustainable fuels based on renewable feedstock must be available in large quantities, i.e. fuels that do not cause additional release of carbon into the active carbon cycle.

Our development

At the Straubing branch of Fraunhofer IGB, we are working on the development of processes for the production of synthetic fuels from CO_2. To this end, we are currently setting up the Center for Sustainable Fuels (ZENK), funded by the Free State of Bavaria. Since methanol is the key intermediate in our approach of CO_2-based fuel synthesis, the research is closely linked to our work on methanol synthesis. Methanol, produced from CO_2 and hydrogen, is then converted into light alkenes (olefins), which in turn are processed through oligomerization and hydrogenation to yield so-called middle distillates, i.e. fuels like diesel and kerosene. In addition to methanol, other alcohols, such as ethanol or isobutanol, can also be used for the production of synthetic fuels. Our research on synthetic fuels ranges from the development of the individual process steps to the identification of the challenges at their interfaces to the integration of the process steps into an industrially applicable process. The scale-up of these processes up to pilot scale will then take place at the institute branch in Leuna, Fraunhofer CBP.

Benefits and technological readiness

The production of synthetic fuels from CO_2 is particularly space- and resource-efficient. The individual process technologies are already quite well developed, but not yet in an integrated process chain and with synthetic transportation fuels as the target product. Important research questions that we are pursuing at Fraunhofer IGB concern the use of CO_2 from technically relevant sources, in particular from industrial exhaust gases as so-called point sources. Impurities from the upstream industrial processes can significantly impair the performance and lifetime of the catalysts for CO_2 conversion. Therefore, our work is particularly concerned with process integration and the use of CO_2 from technical sources. This also opens up opportunities to combine biomass-based processes, which often produce CO_2-rich gas streams (e.g. fermentation processes), with the use of CO_2 for fuel synthesis. This way, different material flows can be optimally used in the sense of a biorefinery.

Collaboration

In our research and development on synthetic fuels, we would like to collaborate with partners from science and industry who are active in the areas of raw material supply (CO_2, renewable energy), fuel production (catalysts, plant engineering, refineries) and fuel use (logistics, engines, aircraft construction, airlines, shipping companies, etc.). Important questions concern process integration, the relationship between process control/parameters and fuel quality, fuel quality/specifications, CO_2 purity, new catalysts and other exciting issues related to synthetic fuels.

Versatile plant for developing processes for the conversion of gaseous reactants, e.g. CO_2 and hydrogen

Further information

www.igb.fraunhofer.de/synthetic-fuels

Contact
Dr. Ulrike Junghans
Phone +49 3461 43-9128
ulrike.junghans@
igb.fraunhofer.de

Dr. Arne Roth
Phone +49 9421 9380-1030
arne.roth@igb.fraunhofer.de

New possibilities of CO_2-based value chains

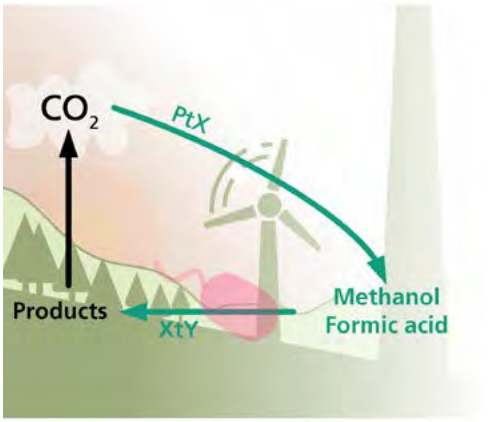
Power-to-X-to-Y cascade processes: combining Power-to-X and industrial biotechnology

Further information

www.igb.fraunhofer.de/microbial-catalysis

Contact
Dr. Jonathan Fabarius
Phone +49 9421 9380-1022
jonathan.fabarius@
igb.fraunhofer.de

Innovative concepts are needed to reduce CO_2 emissions in the future. One possible solution are Power-to-X-to-Y cascade processes (PtXtY), which combine technical CO_2 reduction with the biotechnological synthesis of valuable products.



Linking Power-to-X and CCU processes along with their advantages in terms of scalability and sustainability with the synthetic potential of industrial biotechnology – that is the major goal of our research on Power-to-X-to-Y process cascades. The principle is based on chemical or electrochemical conversion of CO_2 to methanol or formic acid and the subsequent fermentative conversion of these soluble C_1 compounds by methylotrophic or formatotrophic microorganisms. The CO_2-based substrates methanol and formic acid replace sugar as a conventional substrate in biotechnology and enable fermentation independent of food-relevant raw materials.

Our development

In addition to our work on chemical and electrochemical CO_2 reduction (see above), the research focus in the field of Power-to-X-to-Y process cascades primarily lies on the development of suitable microbial production strains. We use metabolic engineering methods and systems biotechnology approaches to create tailor-made cell factories that specifically convert C_1 substrates into, e.g., organic acids, amino acids, diamines. These, in turn, can be used as monomers for the production of various and diverse plastics. Furthermore, we work on the interfaces between technical CO_2 reduction and fermentative downstream process and coordinate process control and material flows in such a way that process integration is as smooth and efficient as possible.

Benefits and technological readiness

By combining Power-to-X with industrial biotechnology to create Power-to-X-to-Y process cascades, the recycling of CO_2 in CCU applications is no longer limited to the synthesis of simple products (“X”), such as methanol or formic acid. Rather, they can serve as raw materials for future (bio)refineries, in which more complex and valuable platform chemicals (“Y”) are produced through suitable process cascades. The advantage of using methanol and formic acid as substrates lies primarily in their solubility in water, which allows for comparatively easy fermentation. The current technological readiness of this approach is still at research level. We are currently working specifically on the development of high-performance production strains and efficient fermentation processes in order to achieve product yields and concentrations of industrial relevance.

Collaboration

In the field of microbial strain development and downstream processing (DSP), we collaborate with partners from the scientific community in particular. However, we are also looking for collaboration with partners from industry for the application of biotechnological processes and for the application of biotechnologically synthesized products. These products are of particular interest to companies in the chemical industry, such as producers of “green” polymers or products made from sustainable platform chemicals.

Recyclable materials from biomass

Biotechnological utilization of CO_2 with microalgae

Microalgae offer many advantages and opportunities when it comes to using carbon dioxide as a resourcel. To a large extent, they combine the simplicity of cultivating single-celled organisms with the ability to form biomass and valuable ingredients from CO_2, light and a few minerals, which otherwise only land plants and macroalgae are able to do. In addition, microalgae offer a great diversity of species and are thus also natural producers of a variety of interesting ingredients, such as carotenoids, proteins, oils and others.

Our development

At Fraunhofer IGB, we are researching how we can use this incredible potential for the cost-effective production of various products, which can be used, for example, in the textile industry, plant fortification or food industries.

To this end, we specialize in researching the following three aspects:

1. The development of innovative photobioreactors that enable cost-efficient cultivation of microalgae independent of usable agricultural land
2. Cultivation methods for a variety of microalgae for the production of a wide variety of products
3. Effective harvesting and product isolation from microalgae biomass

Benefits and technological readiness

In all of our developments, we build on more than two decades of experience, during which we have developed several technologies, including photobioreactor systems and cultivation processes, from idea to industrial maturity. Our interdisciplinary team has already successfully cultivated more than 15 different strains of microalgae and is particularly experienced in the use of waste streams as sources of nitrogen and phosphorus, as well as in the use of various sources of CO_2. Our focus on artificially lit photobioreactors using renewable energy continues to allow us to produce microalgae and their diverse compounds independently of climate and light conditions, as well as fertile soil.

Collaboration

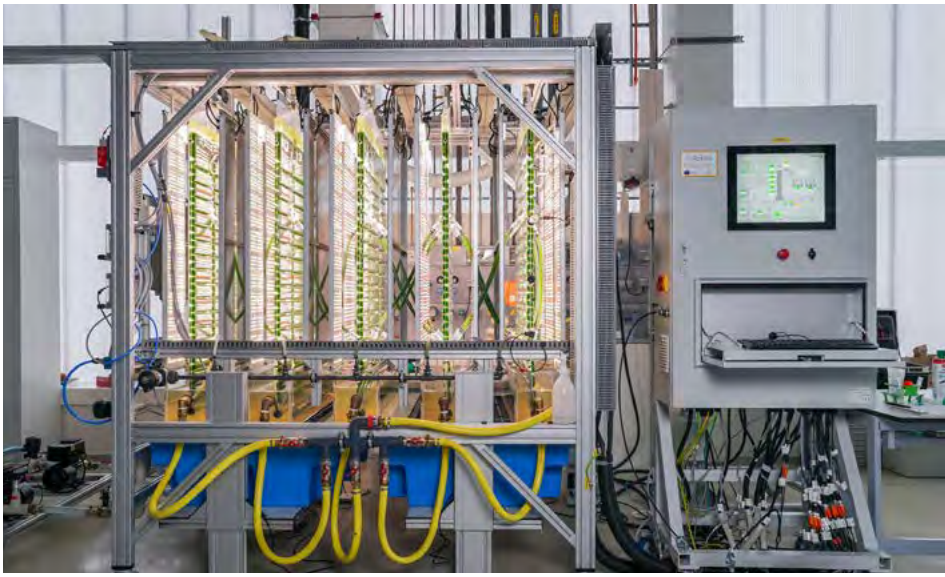
By using CO_2, microalgae production can be linked to industrial processes. Together with partners in science and industry, our main focus is on the development of technologies and value chains to harness the potential of area-independent, decentralized microalgae production for various sectors.

Further information

www.igb.fraunhofer.de/algae-biotechnology

Contact
Konstantin Frick M.Sc.
Phone +49 711 970-4074
konstantin.frick@
igb.fraunhofer.de

Artificial illumination of the algae cultures with LEDs can significantly increase the biomass yield.



Fine and specialty chemicals via modular enzyme cascades

Electrobiocatalytic fixation of CO_2

Further information

www.igb.fraunhofer.de/biohybrid-materials

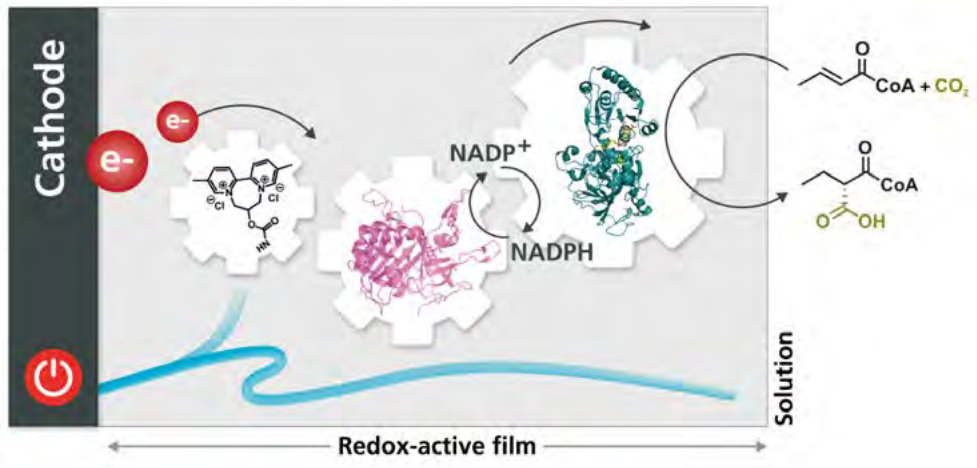
Contact
Dr. Michael Richter
Phone +49 9421 9380-1020
michael.richter@
igb.fraunhofer.de

Even energetically disadvantageous biosyntheses, such as the reduction of CO_2, can be driven forward by adding electrical energy. Electrobiocatalytic synthesis modules allow the combined use of renewable electricity, CO_2 as a C_1-building block and individual enzymes or enzyme cascades based on nature's model. The approaches require an interdisciplinary know-how of material and polymer chemistry, electrochemistry and biotechnology.

The challenge in bioelectrocatalysis is realizing an efficient electron transfer from the electrode to the enzyme. This can essentially be done via two mechanisms, direct electron transfer from the electrode surface to the enzyme or mediated electron transfer from the electrode via a redox mediator. In addition, the stability of the enzymes on the electrode architectures (directly on material surfaces or in redox-active hydrogels) must be ensured. In this case however, access is given to new reaction pathways that can convert CO_2 in an aqueous environment at low concentrations without increased pressure.

Our development

In collaboration with the Max Planck Institute for Terrestrial Microbiology in Marburg, we have established a novel synthesis module for electrobiocatalytic CO_2 fixation on a laboratory scale in recent years. Two synthesis steps take place: enzymatic cofactor regeneration of NADPH and selective NADPH-dependent CO_2 fixation. The development in the field of bioelectrocatalysis will be continued and expanded in ongoing projects. For example, we are currently investigating ways of using CO_2 for the production of monomers (diamines) and for the diversity-oriented synthesis of fine and specialty chemicals via enzyme cascades.



The enzyme for the regeneration of the cofactor is attached to the electrode alongside the enzymes for CO_2 fixation in the redox hydrogel.

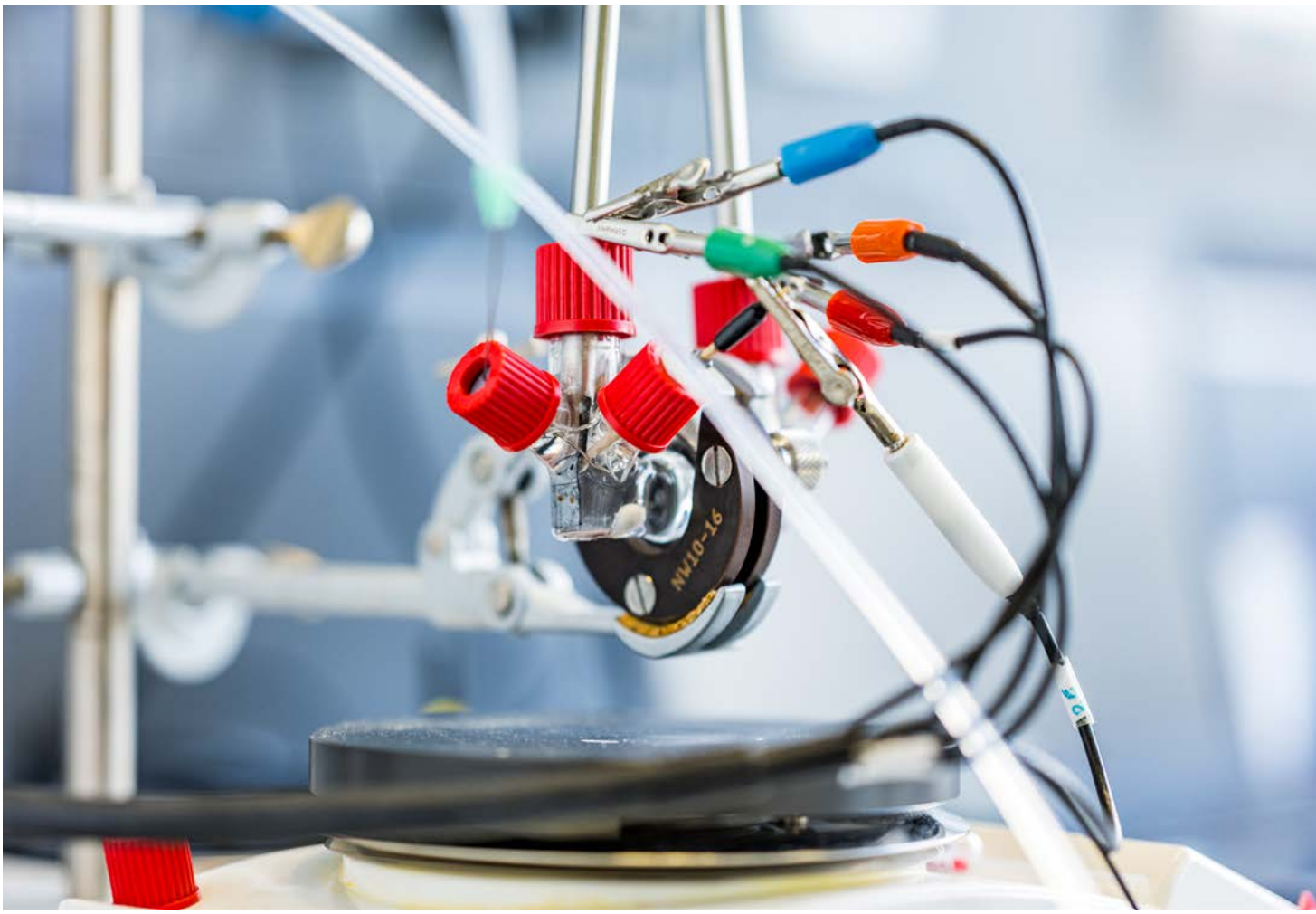
Benefits and technological readiness

The novel approach enables the fixation of CO_2 on a biochemical substrate under mild reaction conditions and to use it in finely tuned enzyme cascades for the production of valuable fine chemicals. This opens up new ways for the production of intermediates for a cascading continued use in biotechnological processes into fine chemicals or bulk materials such as monomers (e.g. diamines). In all these processes, the use of CO_2 is the embodiment of a green process in the sense of green chemistry: due to the balance between reaction speed and selectivity of the catalytic process under mild conditions, as well as the use of electrons only, the pure form of a reducing agent. At the moment, our research in the field of bioelectrocatalysis is still on a laboratory scale.

Collaboration

Our goal is to bring sustainable technology to advanced TRLs in the near future. The scaling of electrobiocatalytic processes, together with downstream processing, is one of the key challenges for this future technology, which we seek to tackle in research projects with interested partners.

Experimental setup for the development of bioelectrocatalytic CO_2 fixation methods



Scaling and piloting of new processes for chemistry and biotechnology

Transferring the manufacturing process to a larger scale is an essential step in bringing new sustainable products to market. With its expertise in scaling up a variety of processes and its own pilot plants, Fraunhofer IGB supports companies in launching green products.

In light of climate change and a scarcity of resources, the chemical and process industry is also facing a fundamental upheaval. Fossil resources need to be replaced by regenerative resources such as renewable raw materials, biogenic residues or CO_2 in order to reduce greenhouse gas emissions and international dependencies.

Challenges due to the raw material transition and the circular economy

For this resource transition, existing production processes must either be adapted to the new raw material or, if that isn't possible, they have to be reconstructed. Plant-based biomass, for example, must be fractionated, solvents and process parameters must be adapted and plants must be restructured. At the same time, new methods for quality control and safety assessment of the developed processes and their products are required. In addition, companies are required to increasingly abide the principles of the circular economy.

Scaling and piloting as the key to the market

Scaling plays a key role in the development of new resources for the transformation to a green economy. This is because new processes must work both on a small scale, and also on an industrial level. Pilot plants support companies in scaling up their manufacturing processes and thus in bringing new products to market.

Together with partners from the Fraunhofer Chemistry Alliance, Fraunhofer CBP invited companies to a "piloting day" in Leuna, in November 2023. Fraunhofer experts demonstrated how ideas can be implemented quicker using best-practice examples.

Fermentation plant for cultivating various microorganisms (cascade from 10 L to 10,000 L)

Various reasons for partnerships with Fraunhofer CBP

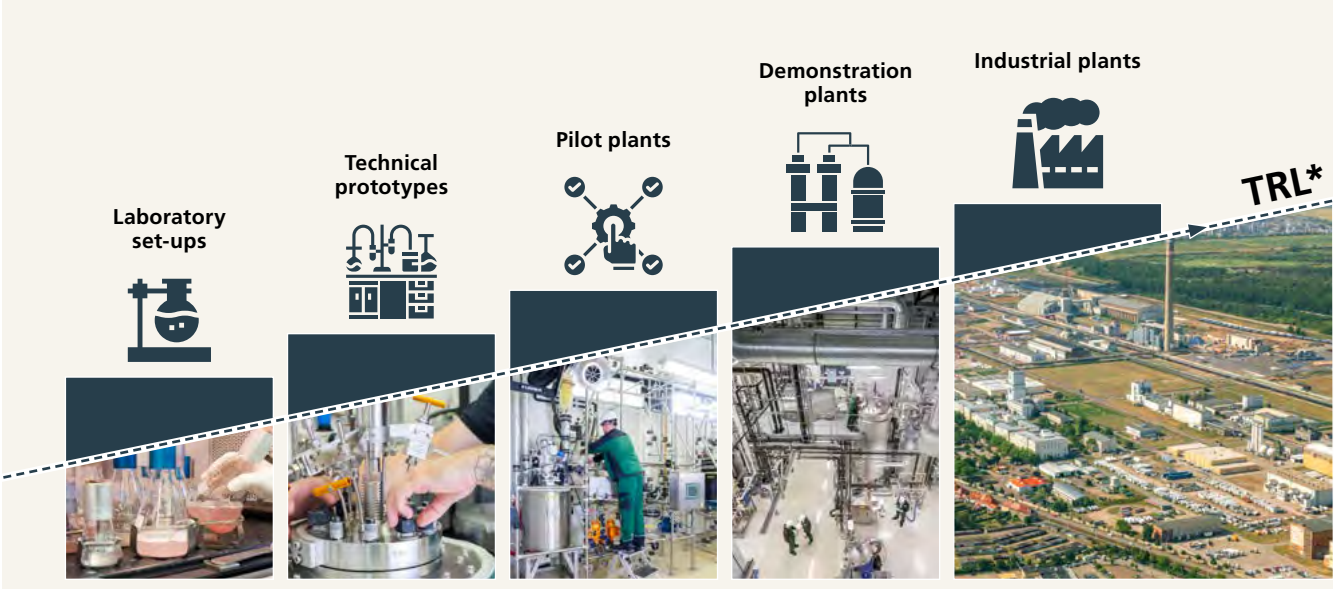
- Scaling of processes developed in the laboratory
- Provision of data for constructing the next technology stage
- Integrated process development and optimization, including the integration of external equipment for direct process comparison
- Process verification and show cases, such as investor rounds
- Provision of data for techno-economic evaluation and life cycle analysis of processes
- Synthesis of sample quantities for application tests
- Joint IP development

Pilot plants: sample production, process optimization, industrial plant design

The production of sample quantities, larger product quantities on a kilogram scale for application tests, is often only possible with pilot plants.

These are also essential in order to increase the efficiency and thus the cost-effectiveness of the developed processes. The process data generated during pilot operation can be used to identify weak points in the equipment, improve process control and obtain mass and energy balances. Optimized operating modes, such as the recirculation of solvents or the recovery of process heat, help to save operating resources and reduce costs. Eventually, based on the process data in the pilot plant, the industrial plant can then be designed as economically as possible and investment costs will be minimized.

Contact
Dr. Christine Rasche
Head of Business Area Sustainable Chemistry
Phone +49 152 06384199
christine.rasche@igb.fraunhofer.de



*Technology Readiness Level

In order to be able to manufacture larger product quantities, newly developed processes are gradually transferred to a larger scale. Upscaling results in differently dimensioned plants with increasing production capacities each. Once an idea has been successfully implemented on a laboratory scale, the first technical prototypes are primarily used to test the quality and functionality of the product.

Fraunhofer IGB – your partner for scaling processes and technologies

Support all the way to market launch

Fraunhofer IGB develops new processes and supports companies with its expertise and technical equipment in the scaling of processes as well as the design and construction of pilot plants: from technical implementation and commissioning to questions of process safety, regulatory issues, sustainability and cost-effectiveness. In addition, we provide you with state-of-the-art infrastructure and apparatus technology with our own pilot plants. This not only saves you costs, but also reduces development risks.

Screw press for pre-dewatering the solid phase after digestion

Scaling platform with pilot plants at Fraunhofer CBP, Leuna

With its modular reactor and plant technology at the Leuna site, Fraunhofer IGB has a unique interface of the industrial application of biotechnological and chemical processes. This allows us to map complete process chains – from raw material preparation and various material conversion processes to product separation and purification – and to optimize processes on behalf of customers. This currently includes the areas of lignocellulose biorefinery, oilseed biorefinery, fermentation, chemical conversion and material separation and purification.

Lignocellulose biorefinery: mild fractionation for optimal product properties

The advantage of renewable raw materials compared to fossil resources is the higher functionality of their constituents. In order to preserve these functionalities and make them usable in products, the processing of chemically complex raw materials must be carried out under the mildest possible conditions to prevent the functionalities from being altered during or after fractionation or separation.

The Organosolv process is one such mild process for the fractionation of raw and residual materials containing lignocellulose. At Fraunhofer CBP, we are exploring alternative fractionation processes on a pilot scale, specifically the Organosolv process, in order to be able to utilize these materials with the highest possible quality and obtain optimal product properties.

The pilot plant (TRL 5–6) is available for examinations for customers or in projects, for instance to investigate the use of new, innovative and environmentally friendly liquid phases, to develop efficient washing steps or a method for obtaining lignin fractions with a narrow molecular weight distribution, and to provide sufficient quantities of samples for partners. In doing so, all components of lignified biomass can be utilized and, in addition to cellulose, lignin and hemicellulose or sugar can also be obtained as products.

Further information

www.cbp.fraunhofer.de/lignocellulose-biorefinery

Contact
Dr. Robert Hartmann
Phone +49 3461 43-9111
robert.hartmann@
igb.fraunhofer.de

Oilseed biorefinery: complete utilization of rapeseed & co.

Decanter for the separation of fine and suspended particles

In order to extract the oil from seeds in industrial practice nowadays, they are either processed at high temperatures and pressures, or extracted with hexane. The remaining 50 percent of the seeds remain mostly unutilized. At Fraunhofer CBP, the EthaNa process has been further advanced as a sustainable alternative for oil separation, and a pilot plant has been set up in which oilseeds can be processed using a mild, ethanolic extraction.

In the EthaNa® pilot plant (TRL 5–6), 100 kilograms of seeds are processed in batches to produce larger sample quantities of products for further characterization on commission or in projects. Oil is not the only gained product, a protein-rich rapeseed concentrate, that can be used in food or animal feed, is also obtained and thus represents an alternative to animal products. Furthermore, molecules can be isolated from the ethanolic phase. They can then be used as food supplements or in cosmetic products. The use of ethanol as a solvent also allows "organic" certification, while the use of hexane is increasingly regulated.

So far, the EthaNa process has been developed for rapeseed, but it can also be applied to other seed raw materials. Feel free to contact us if you are interested!

Further information

www.cbp.fraunhofer.de/oilseed-biorefinery

Contact
Dr. Robert Hartmann
Phone +49 3461 43-9111
robert.hartmann@igb.fraunhofer.de

Upscaling chemical processes for the production of bio- and CO_2-based chemicals

Fraunhofer CBP uses chemical processes to develop bio- and CO_2-based commodity and fine chemicals. Technical equipment is available for process engineering development and scaling, including a variety of standard reactors (stirred tank and tubular reactors) from laboratory to pilot scale.

Our distinctive feature is the combination of this unique equipment with the experience of our employees in upscaling chemical processes in the context of bioeconomy.

In collaboration with the integrated analytics laboratory and thanks to a diverse range of downstream processing options (distillation, membrane separation, extraction, etc.), our systems can be used to quickly and effectively scale up, optimize and/or further develop processes for customers and start-ups across the entire process chain at a single location – up to a technology readiness level of 5 to 6.

To achieve this, we adapt the flexibly deployable systems to the respective customer's wishes or project requirements. The development can be carried out jointly both in the form of contract research on behalf of our customers and as part of publicly funded research projects.

Further information

www.cbp.fraunhofer.de/chemical-processes

Contact
Dipl.-Ing. Jakob Köchermann
Phone +49 3461 43-9105
jakob.koechermann@igb.fraunhofer.de

Biotechnology module consisting of plants for cultivating microorganisms and product processing

Upscaling biotechnological processes for the production of sustainable chemicals and food

Biotechnology, especially fermentation, offers outstanding opportunities to produce chemicals and alternative proteins in an efficient and sustainable way. Genetically modified microorganisms allow us to combine production processes, which usually require a number of manufacturing steps or the extensive use of fertile soil, in a comparatively simple process – and in a confined space.

The Industrial Biotechnology at Fraunhofer IGB supports the implementation of innovative biotechnological procedures in industry by optimizing and scaling up such fermentation processes. To this end, we investigate aspects such as media composition, feeding strategies and common process parameters, e.g. pH, temperature, mixture, etc., in our laboratories and pilot plants. However, we not only research the effective cultivation of a variety of microorganisms, we also pay particular attention to the downstream processing of fermentation broths in order to efficiently isolate the products produced.

In partnership with universities, research institutes, and especially companies in the private sector, we have supported a multitude of new processes on their way to industrial viability over the past few years.

In this regard, the following product areas are of particular interest to us:

- Bulk and specialty chemicals, e.g., organic acids or dyes for use in the chemical industry
- Alternative proteins for use in food, e.g., recombinant milk or other animal proteins

Further information

www.cbp.fraunhofer.de/biotechnological-processes

Contact
Sandra Torkler M.Sc.
Phone +49 3461 43-9123
sandra.torkler@
igb.fraunhofer.de

Further information

www.cbp.fraunhofer.de/downstream-processing

Contact
Dipl.-Ing. Jakob Köchermann
Phone +49 3461 43-9105
jakob.koechermann@
igb.fraunhofer.de

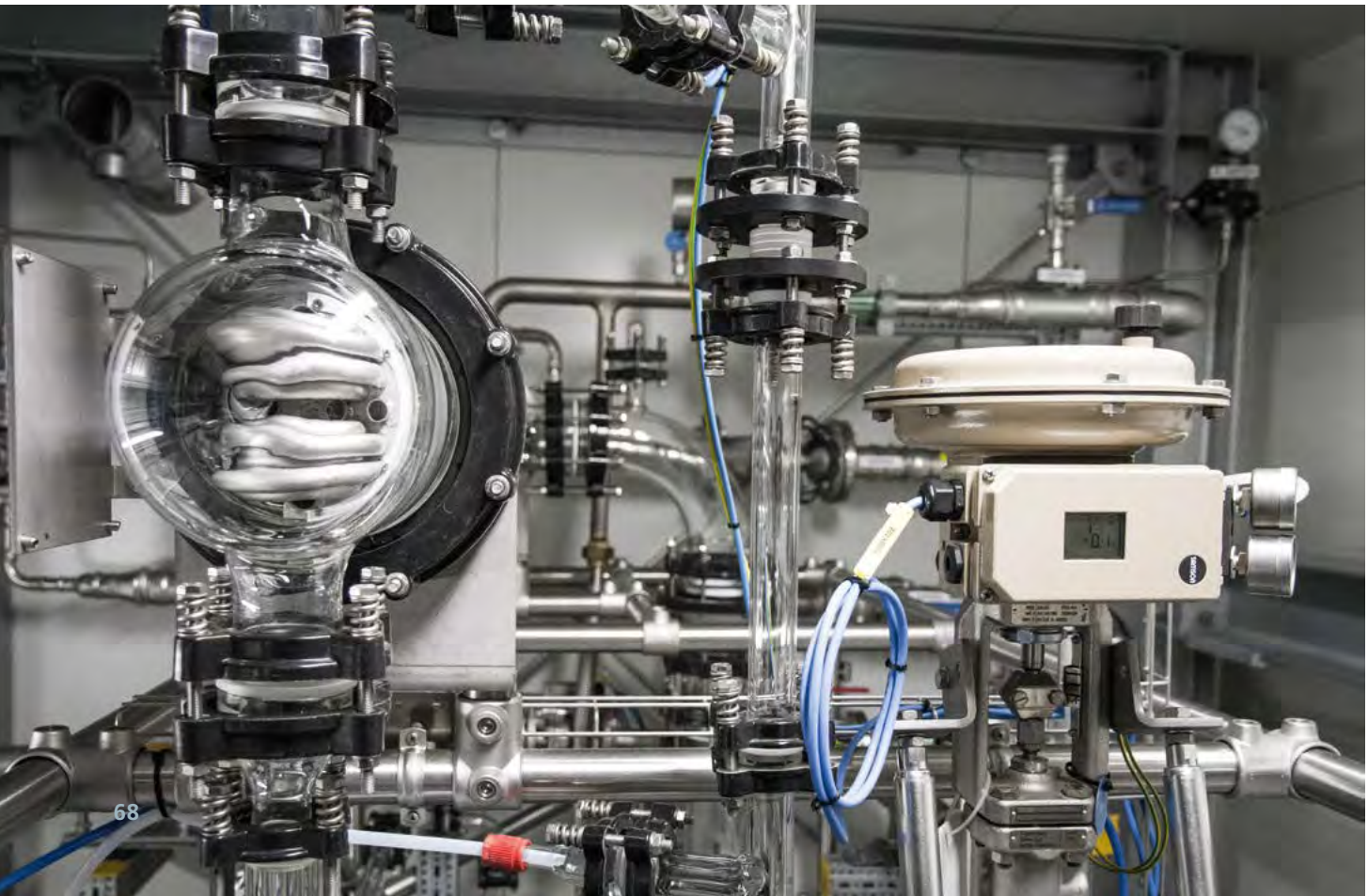
Versatile systems for optimal downstream processing

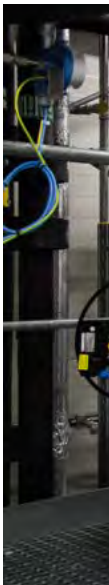
Fraunhofer CBP develops the necessary downstream processes to ensure that a product can be processed in the required purity of the product mixtures from chemical conversion or culture media during biotechnological conversion and that corresponding product samples can be provided for application-related characterization.

For customer and/or project-specific product processing, a variety of laboratory and pilot-scale facilities are available at the CBP. Our distinguishing feature is our ability to map the entire process chain from raw material to product at one location.

Since product processing plays a decisive role in the efficiency of the overall process chain, downstream processing is an integral part of process development at Fraunhofer CBP. Our systematic approach includes the development and selection of suitable processes, the simulation and modeling of separation tasks and their implementation on a pilot scale. Industrial feasibility is assessed and optimized on a laboratory scale.

Vacuum rectification





How to work with us

Benefit from our expertise, infrastructure and competent staff

Development and piloting on behalf of the customer

We transfer your processes to pilot scale – with our existing plants or by adding the necessary equipment

- Selection of the right equipment
- Process design for optimal interaction of all steps
- Optimization with regard to product yield and quality, material and energy efficiency
- Support up to transfer to a contract manufacturer or up to system design

XyloSolv – scaling a sequential extraction process for the production of high-value intermediates from beech wood

Using a hydrothermal process, xylan can be extracted from beech wood. At Fraunhofer CBP, this process was transferred to the 500-liter scale and combined with the ethanolic Organosolv extraction process to additionally extract the lignin and fiber fractions, thus enabling the material use of all wood components. By way of this sequential processing, xylan and lignin can be obtained in a previously unavailable high-purity quality, making applications in the pharmaceutical industry or as food supplements possible.

▸ *www.cbp.fraunhofer.de/en/xylosolv*

“With our experience, trained personnel and strategic cooperation with companies from the plant construction and engineering sectors, we ensure that the data obtained in the pilot plant can be transferred to large-scale production.”

Dr. Christine Rasche,
Head of Business Area Sustainable Chemistry

The Fraunhofer CBP pilot plant can process up to 70 kilograms of wood and produce 8 kilograms of xylan per batch.

Funded research and development projects

We demonstrate new processes in a funded project with a pilot plant.

- Identification of suitable funding measures and necessary partners
- Development of project structures
- Possible coordination of joint projects
- Scaling in existing CBP plants or conceptual design and new construction of necessary plants
- Joint marketing and licensing with shared IP

Development and piloting of pectin extraction from sugar beet residues – Pro-Pec

Sugar beet, a domestic crop, is cultivated for the production of sugar. Until now, the sugar beet residues left over after sugar production are used as low-grade animal feed. However, they contain pectins that could be used in pharmaceuticals.

In order to gain further products from sugar beet and thus increase their material value, the Pro-Pec project is developing a process with which pharmaceutically relevant pectins can be extracted from processed sugar beet. These must not exceed a certain molecular weight and can only have a low degree of acetylation. At Fraunhofer CBP, tests were initially conducted on a laboratory scale after which the most promising process was tested on the pilot plant of the lignocellulose biorefinery. Successfully: pectins with the desired properties were also obtained on a pilot scale. The next step will be to further optimize extraction on a pilot scale and balance energy and mass flows.

From left to right: precipitated pectin, dried pectin, ground pectin, raw material – sugar beet after sugar extraction

This ambitious process development for the targeted extraction of specific pectins was made possible on the one hand by the flexible equipment at the CBP to test extractions under a variety of conditions, and on the other hand by the analytics provided by the project partners to correlate the extraction conditions with the pectin properties.

▸ *www.cbp.fraunhofer.de/en/pro-pec*

Contact
Dr. Robert Hartmann
Phone +49 3461 43-9111
robert.hartmann@igb.fraunhofer.de

Infrastructure and research operation of customer-owned plants at our center

You use our know-how and our accompanying infrastructure to build your own demonstration plant at our center.

If our own pilot plants do not meet your needs, we offer our expertise in operation and process optimization for your own specific plants, which are built at Fraunhofer CBP under your leadership.

Circular economy of plastics – plastic-to-oil

In April 2022, Fraunhofer CBP started a R&D project as a direct order from PRUVIA. Its aim was to demonstrate the MLM-R® pyrolysis technology developed by PRUVIA for recycling plastic waste. The demonstration plant (TRL 7–8), characterized by its high energy efficiency and cost-effectiveness thanks to innovative process control and energy recovery, was put into operation at Fraunhofer CBP at the end of 2023.

The patented MLM-R® pyrolysis technology allows the fossil naphtha, used in plastic production, to be thermochemically recovered from plastic waste, thus enabling a complete circular economy for plastics.

In the project, Fraunhofer CBP provided the infrastructure for the construction of the innovative demonstration plant. The plant is owned by the customer PRUVIA and they were also responsible for the construction of the plant. In close cooperation with PRUVIA, Fraunhofer CBP will continue to operate the plant as a research and development platform, and perform process analysis for PRUVIA. The process technological data and results gained with regard to feedstock analysis, energy and process optimization can then be used by the customer for life cycle assessments and the design of the industrial plant.

Contact
Dr. Ulrike Junghans
Phone +49 3461 43-9128
ulrike.junghans@igb.fraunhofer.de

MLM-R® pyrolysis technology demonstration plant

Publications

Dissertations

De Azpiazu Nadal, I.
Proton-conducting (blend) membranes based on sulfonated/phosphonated and basic polymers,
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University of Duisburg-Essen

Wegat, V.
Engineering of FLS and RuMP pathway modules for synthetic methylotrophy in yeast,
Technical University of Munich (TUM)

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Editorial team
Dipl.-Wirt.-Ing. (FH) Antje Hetebrüg,
Lisa Kern M.A. (pictures),
Dipl.-Betriebswirt (DHBW) Jan Müller M.A.,
Dipl.-Des. Thaya Schroeder M.Sc. (pictures),
Dr. Claudia Vorbeck,
Sarah Zimmermann
and the scientists referred to as authors or contact persons.

Translation
Elif Tuc

Layout and production
Dipl.-Des. Thaya Schroeder M.Sc.

Editorial address
Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB
Dr. Claudia Vorbeck
Nobelstrasse 12, 70569 Stuttgart, Germany

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Fraunhofer Institute
for Interfacial Engineering
and Biotechnology IGB

Nobelstrasse 12
70569 Stuttgart
Germany

Phone +49 711 970-4401
Fax +49 711 970-4200
info@igb.fraunhofer.de

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