Fraunhofer
IGB

FRAUNHOFER INSTITUTE FOR INTERFACIAL ENGINEERING AND BIOTECHNOLOGY IGB

An Initiative of the Federal Ministry of Education and Research

Science Year 2020|21

BIOECONOMY

# ANNUAL REPORT 2020|21

# CONTENTS

## 2020 SELECTED R&D RESULTS



*Our cover picture shows a demonstration plant for the production of biobased isobutene; read more in the article on page 42.*

# DEAR READERS,

when our last year's annual report was published at the end of March 2020, the first lockdown had just been decided in Germany. Since then, the COVID-19 pandemic has rapidly and permanently changed our lives, our daily routine and our business processes.

Looking back on this year, which was extraordinary in every respect, I would therefore like to thank our employees first and foremost. They found solutions to numerous previously unknown challenges and successfully carried out their work under difficult conditions – in the home office with childcare and "homeschooling", as well as at the Institute under the strict regulations of our protection and hygiene concept.

Despite the difficult underlying conditions, we can look back on a successful year. The Institute's positive development was driven by a stable economic output and an increase in publicly funded project activities.

We also provided important impetus in the Fraunhofer-internal activity program "Fraunhofer vs. Corona" in which many institutes are joining forces to develop innovative solutions to combat the pandemic. Projects in which the IGB is involved are presented in this report. These include new diagnostic detection methods that enable advanced testing strategies, assessment of the effectiveness of current protective equipment and concepts, and effective virus inactivation methods.

In addition, we were successful with excellent projects in the "Fraunhofer Innovation Program", which aims to contribute to the renewal process of the economy, and were able to pursue important future topics – in line with our strategic orientation. The focus here is on new technologies for climate neutrality and the circular economy, which we are tackling in the EVOBIO project, among others, in order to accelerate the transformation of the industry toward resilient, future-proof value cycles with new impetus.

This is also the context for our activities to generate green hydrogen as part of the ELP electrolysis test and trial platform, which we are currently setting up at the Fraunhofer Center for Chemical-Biotechnological Processes CBP at our Leuna site together with other Fraunhofer Institutes. With this platform, which will go into operation in the course of 2021, we are creating the basis for further developing hydrogen technologies, demonstrating their economic viability and testing them on an industrial scale.

The use of regenerative energies also plays a role in a growing number of projects at Fraunhofer IGB for the production of fuels and chemicals based on $CO_2$, which we are developing in line with our mission" Sustainable technologies for human health and the health of our planet". The EcoFuel and "Green Ammonia" projects presented in the report are being advanced at our Straubing branch, along with many other innovative projects, for example, the production of fine chemicals from animal feathers.

The IGB also set visible accents within the Fraunhofer-Gesellschaft in the past year. For example, we played a key role in shaping the Fraunhofer Strategic Research Field Bioeconomy and, as a founding member, the new Fraunhofer Group for Resource Technologies and Bioeconomy, which convened for its constituent meeting in January 2021.

Our vision "We combine biology and engineering" has thus been confirmed as forward-looking and resilient in the current pandemic and beyond. The consistent implementation of the measures identified in our strategy process, which we continued last year, makes a significant contribution to this.

I would like to thank all our customers and partners who have continued to work with us in a spirit of trust during these challenging times, often breaking new ground in the process. I am pleased if this annual report inspires you to deepen proven partnerships and enter into new collaborations with the IGB.

Markus Wolperdinger
Director

# PROFILE

Climate change and the excessive use of global resources are threatening our livelihoods, while at the same time the world's population continues to grow rapidly. 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 coronavirus pandemic has shown very recently.

## 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. 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.

## Our vision: We combine biology and engineering

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 innovative solutions for industrial value creation.

## Partnering 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.

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

# KEY FIGURES

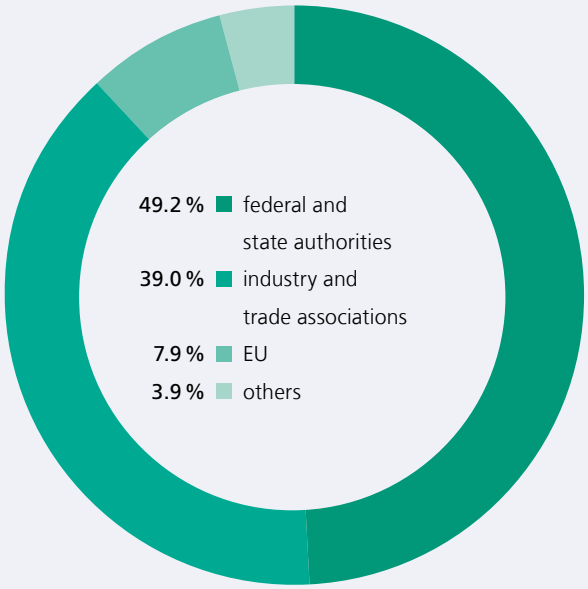
## Budget of Fraunhofer IGB

The total budget for 2020 amounted to 29.5 million euros, of which 26.5 million euros was allocated to the operational budget (personnel costs: 15.9 million euros; non-personnel costs: 10.6 million euros). A total of 3.0 million euros was spent on investments.

68.8 percent of the operational budget was financed from Fraunhofer IGB's own revenues generated from contract research projects. 39.0 percent of the institute's revenues came directly from industry.

**Development of budget**


**Revenue from contract research 2020**



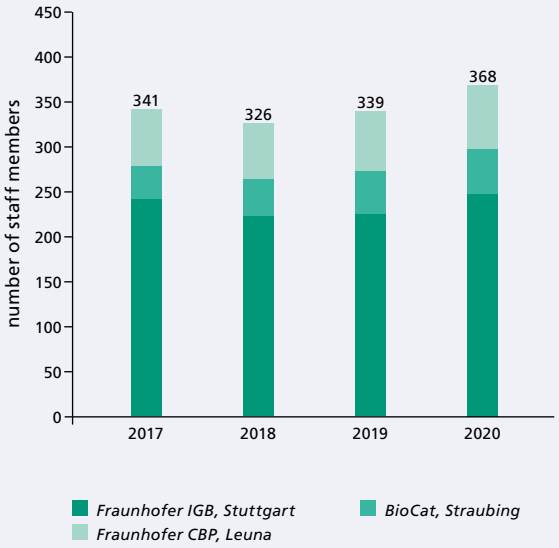
## Personnel

At the end of 2020, Fraunhofer IGB (in Stuttgart and its branches in Straubing, and Leuna) had a staff of 368 of which some 84 percent were scientific or technical employees. Women made up 51 percent of the total.

The cultural diversity at the institute and its branches is also remarkable: 26 employees come from 22 different countries outside Germany.

The close cooperation with the Institute of Interfacial Process Engineering and Plasma Technology IGVP at the University of Stuttgart, which is also partially housed in the Fraunhofer IGB premises, makes it possible to pursue projects from basic research to application. The IGVP counted a staff of 56 as of December 31, 2020, predominantly scientists and doctoral students as well as technical staff and student research assistants. Women constituted 29 percent of the total.

**Development of staff numbers**
as of December 31, 2020




**Staff composition** as of December 31, 2020

| | **Fraunhofer IGB,** including branches | **BioCat,** Straubing branch | **Fraunhofer CBP,** Leuna branch |
|---|---|---|---|
| Scientists | 80 | 13 | 15 |
| Technical staff | 100 | 17 | 36 |
| Doctoral students | 10 | 3 | 1 |
| Administrative and secretarial staff | 46 | 3 | 6 |
| Apprentices | 13 | 2 | 1 |
| Scholarship holders | 3 | 0 | 0 |
| Work students/Master students/student apprentices | 37 | 3 | 5 |
| Student research assistants | 79 | 9 | 7 |
| | **368** | **50** | **71** |

## Equal opportunities

The aspect of equal opportunities for women and men in the workplace is an important corporate objective of the Fraunhofer-Gesellschaft. At Fraunhofer IGB, we successfully implement this important concern as early as the recruitment of young researchers, for example by participating in the Fraunhofer Talent School.

To help employees balance family and career, we offer flexible working hours to a large extent and a childcare office at our Stuttgart site. In the area of career development, we support female employees in applying for the "Fraunhofer TALENTA" program, which addresses different levels of career development in the three program lines *start*, *speed up* and *excellence*.

Since 2014, 13 female scientists at the IGB have so far participated in and completed the TALENTA program. Participants benefit from the program in many ways: "I was able to invest the funding in further training that advanced me both personally and professionally," explains group manager Dr.-Ing. Susanne Zibek, who successfully completed the TALENTA *excellence* funding program in 2019.

Since then, the scientist has participated in the additional mentoring module of TALENTA *excellence*.

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# BOARD OF TRUSTEES

The Fraunhofer Institutes are advised by boards of trustees whose members are drawn from industry, public authorities, and the scientific community.

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Syncona Investment Management Ltd.

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

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

Dr. Peter Wolfangel
Robert Bosch GmbH

› *www.igb.fraunhofer.de/board*

# HIGHLIGHTS 2020

## PROJECTS

### EU-funded project EcoFuel for sustainable mobility
**Synthetic fuels from $CO_2$ – Using electricity from renewable energies**

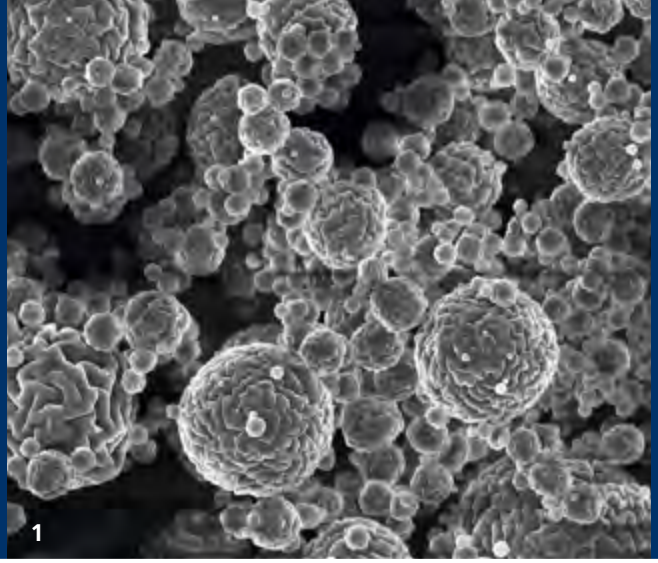
On January 1, 2021, the Horizon-2020-funded EcoFuel project started, involving Fraunhofer IGB as well as three other research partners, two SMEs, and three industrial companies. The aim of the project is to develop the next generation of renewable fuels produced from $CO_2$ using renewable energies. For this purpose, the project consortium intends to demonstrate a novel end-to-end process chain that significantly improves the energy efficiency of the production of synthetic fuel from $CO_2$ and water. The process chain includes capture of $CO_2$ from air, direct electrocatalytic reduction of $CO_2$ to light alkenes at mild conditions, thermocatalytic liquefaction of the alkenes, and hydrogenation and fractionation of the liquid products to produce fuels that meet relevant specifications.
*www.igb.fraunhofer.de/en/ecofuel*

### Fraunhofer innovation project in the Fraunhofer Strategic Research Field Bioeconomy
**EVOBIO – Biobased circular economy for sustainable value creation**

Around the world, value creation and production processes lead to harmful emissions and non-recyclable waste and wastewater. In the EVOBIO project coordinated by Fraunhofer IGB, 19 Fraunhofer institutes have developed solutions for a sustainable biobased economy. To this end, they have developed new process concepts with which material flows in bioeconomic process cycles can be utilized to produce optimized materials for innovative products. Here, for example, the wastewater treatment plant of the future provides raw materials for a renewed value creation, and biobased substances recovered from waste provide water-repellent coatings on functional textiles that do not harm people or the environment.
*www.igb.fraunhofer.de/press/evobio*

### Fraunhofer IGB coordinates new EU network
**Bio2Brain – Safe delivery of biopharmaceuticals to the central nervous system** **1**

17 project partners from academia and industry have joined forces in the Bio2Brain network, coordinated by Fraunhofer IGB, to conduct research on efficient drug delivery for central nervous system (CNS) disorders. The CNS of the human body is perfectly shielded by biological barriers that even medical agents can hardly overcome. The Bio2Brain network is testing new approaches to drug delivery as a solution to this challenge.
*www.igb.fraunhofer.de/press/bio2brain*



1

2

Green light for EU project TriAnkle

**Personalized 3D biomaterials for ankle injury regeneration**

In November 2020, the EU Commission gave the green light for funding the TriAnkle project. The research consortium of 12 partners from five European countries has received 5.9 million euros in EU funding since January 2021. The goal is to develop additive manufacturing processes for personalized implants that can be used in the therapy of tendon and joint injuries of the foot. Fraunhofer IGB formulates and develops the collagen and gelatin-based bio-inks needed for 3D printing the personalized implants. The IGVP at the University of Stuttgart is researching the crosslinking chemistry and 3D printing of the bio-inks developed at the IGB.
*www.igb.fraunhofer.de/press/triankle*

"Green" hydrogen for a sustainable chemical industry

**Groundbreaking ceremony for ELP electrolysis test and trial platform in Leuna**

Hydrogen is considered the energy carrier of the future – and rightly so, if it is "green" and produced from water using electricity from renewable sources. With the ELP electrolysis test and trial platform in Leuna, for which the ceremonial groundbreaking took place on August 6, 2020, Saxony-Anhalt and the Fraunhofer-Gesellschaft are taking on a pioneering role in establishing a sustainable chemical industry. For the production of green hydrogen on the ELP, the Fraunhofer Center for Chemical-Biotechnological Processes CBP in Leuna and the Fraunhofer Institute for the Microstructure of Materials and Systems IMWS in Halle (Saale) join forces. With the Hy2Chem scaling platform, hydrogen produced on a large scale is used for the sustainable production of basic chemicals and fuels.

South Africa: Sustainable solutions in the fight against water scarcity

**Fraunhofer Innovation Platform at the University of Stellenbosch** **2**

As a predominantly arid country, South Africa faces the enormous task of managing existing resources sustainably. In addition to scarce water resources, this also concerns the expansion of renewable and decentralized energy systems as well as food security. In 2020, the University of Stellenbosch and the Fraunhofer-Gesellschaft established the "Fraunhofer Innovation Platform for the Water – Energy – Food Nexus" as part of a strategic partnership. Together, this long-term cooperation aims to develop tailored technological and cross-sectoral solutions for water, energy and food security – for the benefit of people and the environment.
*www.igb.fraunhofer.de/press/fipstellenbosch*

Innovative technologies for recycling organic waste

**Franco-German consortium awarded contract for pilot plant in the Paris region**

The Franco-German consortium, which includes partners Tilia GmbH (Leipzig), GICON – Großmann Ingenieur Consult GmbH (Dresden), France Biogaz Valorisation (Strasbourg), Fraunhofer IGB (Stuttgart) and DBFZ (Leipzig), has been awarded the contract to build a pilot plant for the joint treatment of organic residual waste and sewage sludge in the greater Paris area. If the pilot project proves successful, from 2025 a large-scale industrial plant will, among other things, process up to 76,000 metric tons of organic residues per year into biogas and fertilizer in an environmentally friendly manner.
*www.igb.fraunhofer.de/en/cometha*

1

# APPOINTMENTS AND PRIZES

Bioeconomy Council of the Federal Government

**Dr. Markus Wolperdinger appointed to German Bioeconomy Council**

In 2020, the Bioeconomy Council of the Federal Government started its third working period. On the occasion of the constituent meeting of the new Council, Federal Research Minister Anja Karliczek and Federal Agriculture Minister Julia Klöckner welcomed the newly appointed members on December 7. With Dr. Markus Wolperdinger, who is also the spokesperson of the Fraunhofer Strategic Research Field Bioeconomy, the Fraunhofer-Gesellschaft is also represented in this forward-looking body. In January 2021, Wolperdinger was elected vice chair of the Bioeconomy Council.

Advisory Council Sustainable Bioeconomy Baden-Württemberg

**Dr. Markus Wolperdinger becomes Co-Chairman of the Bioeconomy Advisory Board of Baden-Württemberg**

On November 4, 2020, the inaugural meeting of the Sustainable Bioeconomy Advisory Board, which advises the state of Baden-Württemberg on the implementation of the state's Sustainable Bioeconomy Strategy, took place. Dr. Markus Wolperdinger, director of the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB, was also appointed to the panel as a bioeconomy expert. Together with Professor Dr. Iris Lewandowski, Chief Bioeconomy Officer at the University of Hohenheim, he chairs the advisory board.

EXIST Research Transfer Variolytics at Fraunhofer IGB

**Variolytics wins audience award of the Hightech Award CyberOne 2020** 1

At the Hightech Summit 2020, which took place as a hybrid event on October 1, 2020, the start-up Variolytics, a spin-off from the Fraunhofer IGB financed by the EXIST program of the German government, was able to convince the audience and win the audience award endowed with 3000 euros. With its new mass spectrometer platform technology, Variolytics generates optimized measurement data in real time to more accurately map and better control processes in biotechnology, chemistry or environmental applications.
*www.igb.fraunhofer.de/en/variolytics*

2

# NETWORKS

Personalized products at low price

## Continuation of the High Performance Center Mass Personalization 2

The work of the Stuttgart-based Mass Personalization High Performance Center focuses on evaluating the experiences and scientific results from the pilot phase (Phase 1). Since March 2021, a continuation of the content-related work as well as the adaptation of the organizational structures, a holistic profile sharpening and the development of the business model have formed the preparation for a long-term stabilization of the high performance center as an innovation core for business, science and society within the framework of the "Transfer Campaign" funded by the BMBF and the Fraunhofer-Gesellschaft.
*www.igb.fraunhofer.de/mass-personalization*

Opportunity of the coal phase-out for a more resilient economy

## BioEconomy HUB: Shaping structural change with the bioeconomy

The decision to phase out coal poses a challenge to federal states like Saxony-Anhalt to initiate a fundamental structural change. A decisive factor in guaranteeing the future viability of the regions concerned is to strengthen their innovative power. The Fraunhofer Center for Chemical-Biotechnological Processes CBP in Leuna and the BioEconomy Cluster in Halle are therefore committed to working together with partners from research, business and politics to promote companies in the bioeconomy sector by establishing a BioEconomyHUB and to establish Central Germany as a global bioeconomy hotspot.
*www.cbp.fraunhofer.de/en.html*

Sustainable value creation

## Fraunhofer Strategic Research Field Bioeconomy

Bioeconomy is one of the seven Fraunhofer Strategic Research Fields in which the Fraunhofer-Gesellschaft concentrates its pre-competitive research on projects with high commercial potential, thus promoting impact on society and across multiple sectors. Dr. Markus Wolperdinger is one of the spokespersons of the Strategic Research Field Bioeconomy, in which the transformation to a sustainable and climate-neutral economic system is being advanced.

Roll-to-roll processes

## Network R2RNet bundles expertise for continuous functionalization of surfaces

Roll-to-roll (R2R) processes, in which films, textiles or flat membranes, for example, are functionalized, play an important role in numerous industrial processes. In the R2RNet network, founded on June 10, 2020, 21 European partners from industry, research institutes and universities are pooling their expertise in the continuous functionalization of surfaces using roll-to-roll processes. This is intended to promote the exchange of experience and to facilitate access to these technologies and corresponding equipment. The network was initiated by the Fraunhofer Institutes for Applied Polymer Research IAP and for Interfacial Engineering and Biotechnology IGB.
*www.igb.fraunhofer.de/en/r2rnet*

› *www.igb.fraunhofer.de/network*

› *www.cbp.fraunhofer.de/network*


1

# EVENTS

### Global Bioeconomy Summit 2020

From November 16 to 20, 2020, the "Global Bioeconomy Summit 2020", the international flagship event for bioeconomy, took place as a digital event. Sabine Krieg, Dr. Christine Rasche and Dr.-Ing. Tino Elter led the workshop "New Technologies as Accelerator of a Sustainable Bioeconomy" in the Science & Innovation thematic area. Gerd Unkelbach represented the institute in the "Moving Towards a Sustainable and Circular Economy Bioeconomy Strategy" workshop in the "Bioeconomy Strategy Development" discussion.

*www.igb.fraunhofer.de/en/gbs2020*

### Fraunhofer Solution Days 2020
### IGB presents solutions for the healthcare industry

"Because knowledge creates perspectives" – this was the motto of the digital Fraunhofer event in fall 2020. At the Fraunhofer Solution Days' Health Day in October 2020, institutes of the Fraunhofer Group for Life Sciences presented innovative solutions for current challenges in diagnostics and medicine. Dr. Kai Sohn presented a new approach to infection diagnostics in his lecture "Next-Generation Diagnostics" as well as in the virtual exhibition. Here, the institute also presented human cell assays for infection diagnostics and drug development. The exhibition can be visited virtually until the fall of 2021.

*www.igb.fraunhofer.de/en/fsd2020*

### Bioeconomy and sustainable production systems
### Bioeconomy Day 2020 of the Fraunhofer Group for Life Sciences 1

The bioeconomy is the focus of the 2020/21 Year of Science, which has been extended to the end of 2021 due to the COVID-19 pandemic. The Bioeconomy Day of the Fraunhofer Group for Life Sciences under the title "Bioeconomy and Sustainable Production Systems" took place as a hybrid event on October 1, 2020. The symposium brought Fraunhofer researchers together with numerous experts from politics and industry to inform and discuss current developments in the bioeconomy. The event also marked the opening of the "Fraunhofer Shaping Bioeconomy" exhibition, in which Fraunhofer presented innovative solutions for a sustainable, biobased economy at the Fraunhofer Forum Berlin.

2


3

IGB exhibit on board the MS Wissenschaft

**Biosurfactants – Bioeconomy in the spin cycle** **2 + 3**

Despite the coronavirus pandemic, the MS Wissenschaft, the exhibition ship of the German Federal Ministry of Education and Research, set sail in the summer of 2020. In keeping with the theme of the Science Year 2020/21 under the flag of the bioeconomy, so that Fraunhofer IGB also signed on to the MS Wissenschaft. There, the institute used the example of an interactive washing machine to show how biobased surfactants for detergents and cleaning agents can be produced with fungi. Due to the extended Science Year 2020/21, the MS Wissenschaft will go on voyages again from April 2021 and show an interested audience that a sustainable economy based on renewable raw materials is possible.
*www.igb.fraunhofer.de/ms-science*

**BIOKET biomass conference**

Due to the Corona pandemic, the 2020 BIOKET biomass conference has been postponed from spring to summer 2020 and is purely virtual. In 2021, BIOKET was also held as a digital event – but this year with numerous different formats: Presentations, breakout sessions, innovation tours and workshops were available via video-on-demand for three weeks, and visits to the digital exhibition booths were possible over three days. Fraunhofer IGB will also make the presentations available afterwards on its website for those interested.
*www.igb.fraunhofer.de/en/bioket*

Online congress

**3rd International Bioeconomy Congress Baden-Württemberg**

The 3rd International Bioeconomy Congress Baden-Württemberg took place as an online event from September 21-22, 2020, co-organized by Dr.-Ing. Ursula Schließmann and Dr. Markus Wolperdinger from Fraunhofer IGB as members of the congress advisory board. Under the title "The Contribution of Bioeconomy to the Green Deal", experts addressed the question of how innovative products, processes and principles as well as regional cycles can contribute to achieving the sustainability development goals in order to mitigate climate change, reduce environmental pollution and increase resource efficiency.

› *www.igb.fraunhofer.de/en/events*

# HEALTH

**Our focus**

The rapid increase in the acquisition and analysis of genome-wide data and the enormous potential for cell manipulation have led to the emergence of data-driven diagnostics and fundamentally new therapies, which already enables precision medicine – i.e. health care customized to the needs of the individual patient. At Fraunhofer IGB, our objective is to develop and enhance the enabling technologies required for precision medicine and thereby help improve the standard of medical care for patients while also reducing the costs of the health-care system.

# SMART HEALTH ENGINEERING AND ENABLING TECHNOLOGIES FOR PRECISION MEDICINE

## Target markets

Fraunhofer IGB seeks to partner companies in the fields of diagnostics, medical engineering and drug development.

### Diagnostics

Fraunhofer IGB has extensive experience in **high-throughput sequencing** for the diagnosis of sepsis, endocarditis and intraamniotic infection, and also for microbiome studies. Prospective multicenter research trials are currently conducted to validate our diagnostic procedure for sepsis.

### Drug development

In the field of drug development, we develop **human test systems** that enable an evaluation of the effects and side effects of highly specific drug candidates at the preclinical stage of research, which would otherwise be impossible on the basis of animal testing. These test systems are based on in-vitro systems, ranging from three-dimensional in-vitro models based on human tissue to organ-on-a-chip systems, including components of the immune system. Our wealth of experience in molecular cell technology has enabled us to develop highly precise receptor-based assays for drug validation and production cell lines for biologics.

At Fraunhofer IGB, our many years of experience in **virus engineering** enable us to develop novel and innovative therapies based on customized viruses for targeted prevention (vaccines) and therapies (oncolytic viruses).

For targeted **drug delivery and release**, we formulate active ingredients in, for example, a matrix consisting of biobased polymeric or silicate materials.

### Medical engineering

Our work at Fraunhofer IGB in the field of medical devices, covers surface analytics and the development of **functional surfaces and materials**. We focus on coating technologies, advanced materials and bio-inks for medical applications. In addition, we develop plasma and UV sterilization processes that enable highly effective disinfection and removal of pyrogenic residues while protecting the material of the sterilized devices.

In our **GLP test facility**, we conduct nonclinical, category-9 tests ("cell-based test systems for the determination of biological parameters") for all the fields named above. These include bioactivity, cytotoxicity and immunogenicity tests.

We also operate **clean rooms (ISO 5)** for work in compliance with GMP guidelines.

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## CoSE – Corona rapid test for self-application

The consortium of the anti-corona project CoSE Jump Start, consisting of partners from applied science and industry, is developing a cost-effective, widely applicable rapid test for SARS-CoV-2 for in-house use through to market maturity.

Thus, the aim of the project is to make SARS-CoV-2 diagnostics possible, especially for countries in which the opportunities and capacities for PCR laboratory tests are currently limited, for example in third world countries. For this purpose, the consortium has designed a method that takes up the principle of antibody-based rapid tests – such as the pregnancy test – but is based on the highly specific detection of viral RNA.

The rapid test (Fig. 1) is comparable to PCR-based detection but without amplification of the viral RNA. It is based on the detection of SARS-CoV-2 RNA using the binding of a variety of modified DNA probes in combination with an antibody-coupled enzymatic color reaction. The strip test is designed for self-administration and can be performed without the involvement of medically trained personnel or a laboratory environment.

Up to now, a one-step sample preparation consisting of viral RNA digestion and hybridization with ssDNA has been established. Further, various suitable hybridization probes for the detection of viral RNA have been identified and tested for their suitability. Merging these results, first test strips have been constructed and their functionality demonstrated.

The work on the development of the rapid test was initiated within the framework of the CoSE Jump Start project funded by the Fraunhofer action program "Fraunhofer vs. Corona" and has been continued within the BMBF-funded CoSE project focusing on the implementation of the rapid test for SARS-CoV-2 detection.

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## CoV-2-KomET – High-throughput diagnostics of SARS-CoV-2

A prerequisite for the assessment of new infections with SARS-CoV-2 is testing as comprehensively as possible. For current approaches, SARS-CoV-2 nucleic acids are transcribed into DNA molecules using a so-called reverse transcription, multiplied by a quantitative polymerase chain reaction and analyzed. The sample throughput of the qRT-PCR devices is limited, as is the availability.

In order to be able to provide comprehensive testing, the throughput would have to be increased considerably. What is needed is a technological leap that allows the analysis of at least 1,000 – 10,000 tests per run. Within the framework of the subproject "High-throughput diagnostics of SARS-CoV-2", the IGB, in cooperation with the Fraunhofer Institutes for Cell Therapy and Immunology IZI and for Manufacturing Engineering and Automation IPA, intends to develop, validate, and test a method using clinical samples that is capable of increasing the sample throughput by at least one order of magnitude compared to the standard method. For this purpose, a new method for the diagnosis of SAR-CoV-2 and further viral pathogens of respiratory infections is to be developed with high-throughput sequencing (next-generation sequencing, NGS) of nucleic acids and combined with corresponding laboratory automation of sample handling.

For this novel approach, the researchers take advantage of the high-throughput potential of modern sequencing technology: the various patient samples are not to be analyzed individually, but rather an entire pool – consisting of samples from thousands of patients – is to be sequenced simultaneously. To ensure that the nucleic acid sequences present in the respective patient samples can be correctly assigned to the respective patients, they are labeled with a specific oligonucleotide sequence, representing a molecular barcode. In laboratory experiments, the IGB has already demonstrated that this patient-specific labeling works for SARS-CoV-2, for various influenza viruses and for the respiratory syncytial virus.

For sample preparation, the NGS method uses already established methods of automated extraction of clinical samples. The equipment for high-throughput sequencing is also already available in many university hospitals and central laboratories, so that a prompt transfer to practical use would be possible.

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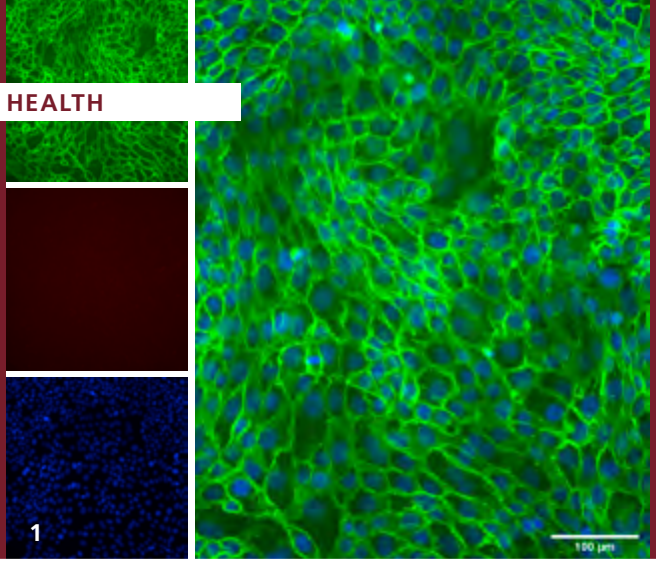

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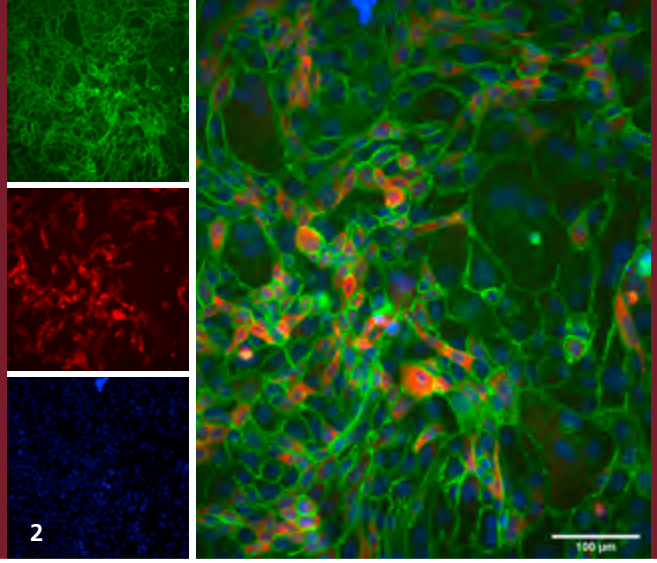

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## C19 lung chip – Drug repurposing using a COVID-19 infection model in an immunocompetent lung-on-chip platform

One of the few chances of quickly having a therapeutic against the coronavirus SARS-CoV-2 is the repurposing of already approved drugs. Therefore, investigations just need to prove their effectiveness. However, clinical studies are difficult to conduct in the current situation and animal models for COVID-19 are severely limited. Due to the complexity of SARS-CoV-2 infection, the lack of knowledge about the exact pathogenesis and the special importance of the human immune system, organ-on-chip systems offer a new possibility of testing drugs in non-clinical studies in a meaningful way.

In the anti-corona project "C19 lung chip" a COVID-19 infection model is being developed based on the already established immunocompetent lung-on-chip system of the company Dynamic42. The infection model will replicate the pathogenesis of COVID-19 and will be used to test the efficacy of up to 40 different drugs or drug combinations from Fraunhofer libraries and the candidates identified in the anti-corona projects CoroVacc and ISE-CoV-2-Screen.

To achieve this, the Fraunhofer Institutes IGB, IZI (Fraunhofer Institute for Cell Therapy and Immunology) and IME (Fraunhofer Institute for Molecular Biology and Applied Ecology) together with the industrial partner Dynamic42 are pooling their expertise in the development of human organ on chip models, the application of these models for pharmaceutical studies and the establishment of infection models for research on the SARS-CoV-2 virus. The model will subsequently be made available to interested companies for testing their own active substances.

*www.igb.fraunhofer.de/en/c19-lung-chip*

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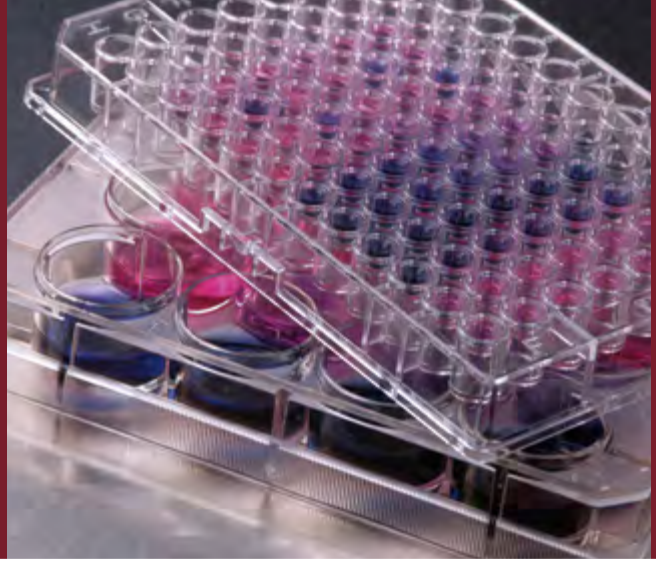
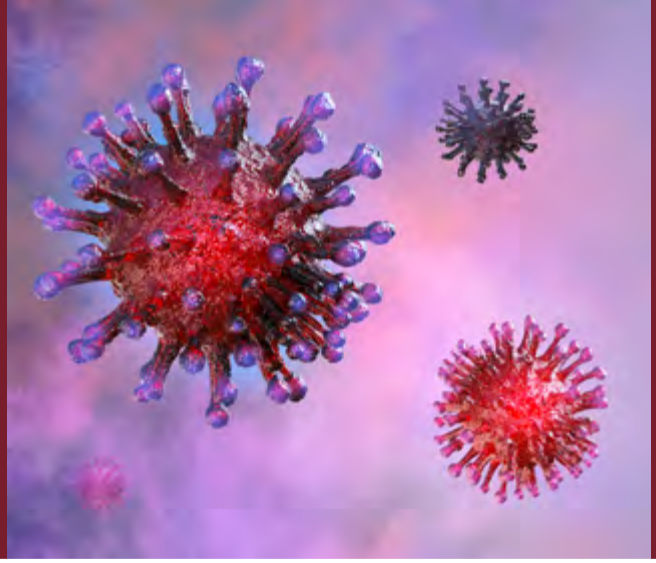
**1** *Non-infected lung epithelium.*

**2** *SARS-CoV-2 infected lung epithelium.*





## ISE-CoV-2-Screen – Test systems for the identification of specific anti-corona molecules

In the anti-corona project ISE-CoV-2-Screen Fraunhofer IGB is identifying therapeutic substances for the treatment of COVID-19 patients. The focus is on molecules that have already been approved for another indication or are at least at an advanced stage of development (repurposing of drugs). In this project, Fraunhofer IGB collaborates with the Fraunhofer Project Center for Drug Discovery and Delivery at the Hebrew University (FPC_DD@HUJI).

Already approved active molecules of the pharmaceutical database DrugBank were pre-selected using computational chemistry. These have the following properties *in silico*:

1. Blocking an interaction of the docking molecules of the SARS-CoV-2 virus by binding to the so-called viral spike proteins,
2. Blocking an interaction at the host cell receptors by blocking the host cell ACE2 proteins, and
3. Blocking viral 3C-like protease, which has a key role in viral mutation and replication.

When screening 14,245 modeled compounds, 69 potential candidates were identified that possess at least two of the above multi-targeting properties.

Subsequently, the pre-selected active molecules are validated in adapted *in vitro* test systems. These consist of human cells overexpressing the target receptor ACE2 of the virus or genetically modified reporter cells overexpressing viral spike proteins or 3C-like proteases. Initial *in vitro* testing confirmed inhibitory effects of the *in silico* drug candidates.

By combining both methods, *in silico* design and *in vitro* testing, we expect that a number of promising molecules will be finally identified for further rapid development towards therapeutic medicine against SARS-CoV-2.

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## DRECOR – Drug repurposing for corona with drug delivery systems for drug candidates targeting SARS-CoV-2

In order to quickly provide therapeutics for the treatment of patients suffering from COVID-19, drugs already approved for other indications can be screened to determine whether they are also suitable for the treatment of a SARS-CoV-2 infection. This approach is known as repurposing.

The Fraunhofer Institute for Molecular Biology and Applied Ecology IME has already identified several drug candidates against SARS-CoV-2 from a repurposing library. In order to improve the efficacy of these candidates and to reduce possible side effects, the release of these drugs should take place as specifically as possible at the site of infection. Based on the criteria of biological activity, mechanism of action, pharmacokinetics, and physicochemical properties, five drug candidates were selected for further investigation of suitable formulations for application to the respiratory tract.

In parallel with the identification of the drug candidates, Fraunhofer IGB has developed tissue- and cell type-specific nanoparticular drug delivery systems for these drugs together with FPC_DD@HUJI. The partners are drawing on experience in formulating antiviral compounds against HSV-1 (herpes simplex virus) for safe transport and targeted release in human 3D tissue models. These formulations are based on liposomal release systems, which will now be investigated in combination with the drug candidates.

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## CoroVacc – Development of a SARS-CoV-2 specific vaccine based on attenuated carrier viruses

Further spread of COVID-19 can only be stopped and the associated protective measures in the population and the economy eased if a large part of the population is immune to the virus. The greatest hopes here lie in the development of vaccines to prevent a resurgence of the epidemic and to provide lasting protection for people who are not yet infected.

In the the anti-corona project CoroVacc, the Fraunhofer Institutes IGB and IZI aim to develop an attenuated SARS-CoV-2 specific vaccine virus. For this purpose, they combine the competencies in virus engineering (IGB) with vaccine development through to testing in animal models (IZI). Attenuated viruses are highly effective because they induce both the humoral (formation of pathogen-specific antibodies) and the cellular (T-cell-mediated) immune response.

Due to a modular approach, the SARS-CoV-2 specific carrier virus can be developed and tested for its vaccination effect even at short notice. As soon as the first preclinical results are available, the CoroVacc platform virus will be offered to interested companies for further development.

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## Modular PAPR – Modular filtered air supply for the protection of medical personnel and for respiratory support of patients

Medical staff in hospitals must be protected especially against infection with the SARS-CoV-2 coronavirus. At the beginning of the pandemic, protective equipment became scarce in many places due to the rapid spread of the virus, so that disposable products had to be used several times. Today, the need for low-cost, rapidly manufacturable yet effective protective equipment remains, especially in pandemic hot spots and emerging and developing countries.

In the anti-corona project "Modular PAPR", Fraunhofer IGB is therefore developing a modular and reusable powered air purifying respirator which provides filtered, virus-free breathing air. For this purpose, first suitable electronic components were selected and a circuit was developed to control the incoming and outgoing air flow via fans. Subsequent flow measurements were performed to characterize the fans.

We conducted initial tests regarding the filter effect with medical filters, various everyday filters (HEPA vacuum cleaner filters, pollen fleece) and textile fabrics. As expected, medical filters showed the best filter performance. However, similar performance was also achieved with some filters from the everyday range.

To protect COVID-19 patients from secondary infections and to reduce the viral load in the room air, the second development stage of the PAPR also filters the wearer's exhaust air. In the third development stage, our PAPR (Fig. 1 and 2) enables non-invasive individual respiratory support for patients with mild respiratory distress who do not yet require full ventilation. For this purpose, sensors for flow and pressure measurement are connectable to the printed circuit board.

The key aspects in the development of the PAPR are its modular design and the use of components that are also available in large quantities in the corona crisis and were not originally intended for medical purposes. We have therefore selected a readily available scuba mask as the basis. All components are joined via connectors that can quickly be produced via rapid prototyping methods such as 3D printing and laser cutting.

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## ELPEDES – Electrolytic production of $H_2O_2$ as the core of a plant for the decentralized, self-sufficient production of disinfectants in hospitals for their own use

Hydrogen peroxide ($H_2O_2$) is an essential component of intensive disinfectants. In critical situations, however, their availability on the market is limited. The production of hydrogen peroxide solutions for disinfectants, for example in hospitals, for their own use is therefore of great importance for a self-sufficient, secure operation of these facilities.

One solution to this problem is offered by the production of hydrogen peroxide solutions directly on site. Fraunhofer IGB has developed an electrolysis cell (Fig. 1) for the decentralized electrochemical production of hydrogen peroxide from (air) oxygen and water. The core component of this cell is a gas diffusion electrode (GDE) at which the production of hydrogen peroxide from gaseous oxygen and water takes place in a targeted manner.

In the ELPEDES anti-corona project, Fraunhofer IGB is optimizing the electrochemical production of $H_2O_2$ by further developing the electrolytic cell and the process control in order to generate the required $H_2O_2$ concentrations by means of electrosynthesis, and to integrate these into a plant concept including filling. This will make the facility requiring $H_2O_2$ independent of supplies from the market and will also enable it to produce its own specific formulations.

The next goal is a prototype that can be tested by potential users on site and with which users can produce their disinfectants fully automatically and independently of external conditions.

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## Demo-medVer – Decentralized mobile medical care

In the "Demo-medVer" project, six Fraunhofer institutes are developing an integrated system of mobile, decentralized medical care. To this end, autonomously operating, fully and partially mobile platforms are to be developed, built and tested.

Fraunhofer researchers are relying on a modular design for technical implementation. Above all, the individual components of the modular system can be individually adapted to different requirements: Depending on the country of deployment (industrialized, emerging or developing country), the reason for deployment (pandemic, environmental disaster) or crisis responders (e.g. THW, Doctors Without Borders, general medical care) and the existing infrastructure, technologies such as the production of disinfectants or water treatment and equipment components, e.g. an intensive care room, are combined in a tailored manner.

Fraunhofer IGB is a project partner in the sub-project MATSE (mobile, self-sufficient test platforms for use in emerging countries) and is responsible for the provision of hygienically safe water. The IGB is also responsible for developing a wastewater treatment concept. Solutions are being developed here that enable medical care to be provided independently of the existing infrastructure. In addition, the IGB is developing recommendations for antiviral and antimicrobial surface materials for the various application areas in Demo-medVer. As part of the Fraunhofer innovation platform FIP-WEF@SU, IGB is also working with the University of Stellenbosch in South Africa to identify needs for the use of such mobile systems in emerging economies. Various application scenarios will also be investigated and transmission models developed.

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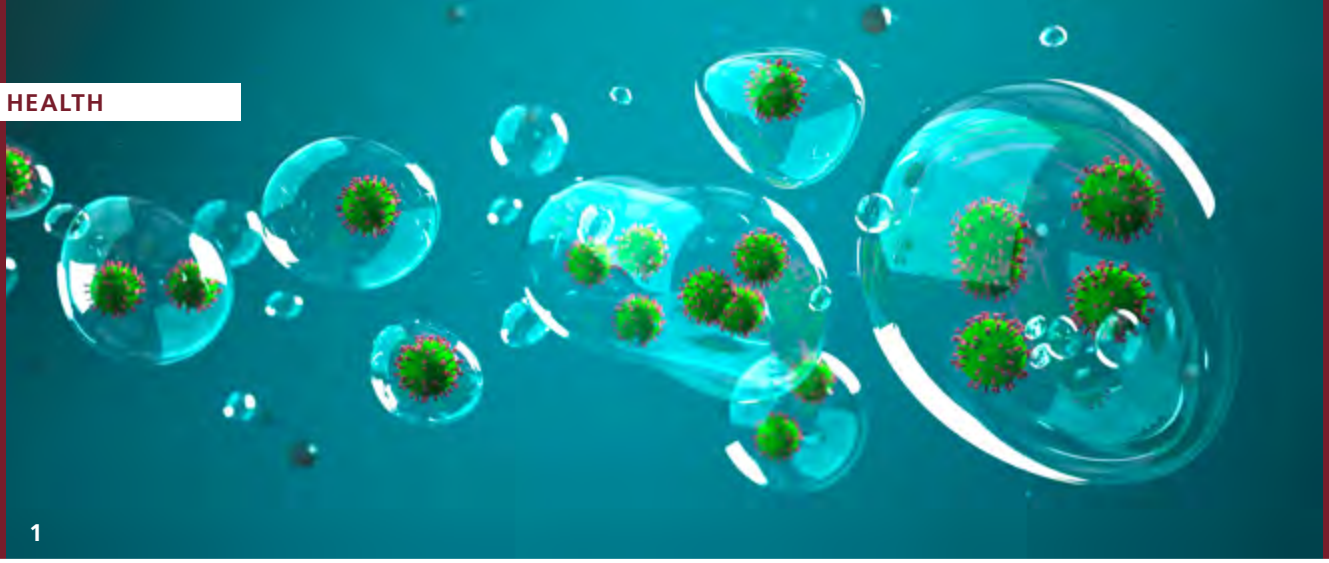

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## AVATOR – Reduction of infections via aerosols by thermal virus inactivation

The speed at which viruses such as SARS-CoV-2 spread can be significantly slowed down by interrupting transmission chains. According to current knowledge, SARS-CoV-2 is transmitted mainly by droplet infection (Fig. 1). The greatest danger is posed by virus containing aerosol clouds, i.e. tiny droplets suspended in the air.

This is where the "Virus Grill" project comes in, which is being developed by Fraunhofer IFAM in Dresden: The thermal inactivation of viruses by heating the air is intended to reduce the probability of infection via aerosols. For this purpose, the germ-bearing ambient air is sucked in and heated in a device called "Virus Grill" before the hygienized air is then re-cooled and released back into the environment.

The disinfection of the air is to be achieved by using and combining various technologies. At Fraunhofer IGB, aerosol clouds of SARS-CoV-2 surrogate viruses are simulated and generated to test the functionality of the "Virus Grill" by analyzing the active vs. inactive viruses.

Virus Grill is a subproject of the "AVATOR – Anti-Virus Aerosol: Testing, Operation, Reduction" project coordinated by Fraunhofer IBP and funded in the "Fraunhofer vs. Corona" program. In addition to technologies for purifying the indoor air, AVATOR investigates the spread of aerosols and derives hygiene concepts for different scenarios. The developments will ultimately be tested in laboratory environments and then validated in real environments.

Especially educational institutions, hospitals, care facilities, hotels, and other forms of accommodation, railway and aircraft operators, manufacturing companies and office-based firms will receive answers with regard to hygiene issues as well as practical solutions to prevent the spread of aerosol infections.

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## ViProTeFa – Developing and establishing a virus protection test facility

With the rapid spread of SARS-CoV-2, the worldwide need for protective equipment against viruses has skyrocketed. One of the ways to remedy the crisis is that non-medicinal industries are now producing protective masks or textile mouth and nose covers.

But how to test whether the new equipment actually protects against the novel coronavirus? Who tests how a textile face mask has to be washed to be free of viruses and thus reusable? It is a fact that at the moment there is neither a test contamination for SARS-CoV-2 nor a test procedure with which the cleaning or protective effect can be realistically tested. Both are urgently required.

In the anti-corona project ViProTeFa, the Fraunhofer Institutes IPA and IGB therefore want to establish a worldwide unique test facility for the qualification of protective devices and measures. In addition to the identification and production of a SARS-CoV-2 equivalent test virus as a test impurity, this includes establishing standardized sampling methods, constructing various applicators and a sterilizable test chamber, as well as the establishing standardized analytical methods. The aim is to develop a widely recognized standard or norm.

Tests can then be carried out regarding issues of retention rates of different respiratory protection systems and filters, the washing of reusable articles (clothing, textile face masks) through to the cleaning of surfaces (door handles, switches) using a relevant contamination. In addition, the virus protection test facility can support manufacturers of protective equipment not only in the development but also in the approval of their medical devices.

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# SUSTAINABLE CHEMISTRY

**Our focus**

Faced with environmental regulations, international competition and new legislation, the chemical industry has little option but to continuously improve its production processes. The Sustainable Chemistry business area provides solutions for ways of doing business that are not only economic but also more ecological. Our prime objective is to develop highly efficient conversion processes – in terms of both energy and resources – based on renewable raw materials, waste materials or $CO_2$, coupled with intelligent solutions for downstream processing.

# DEVELOPING AND SCALING UP PROCESSES FOR THE PRODUCTION OF SUSTAINABLE CHEMICALS, FUELS AND MATERIALS FROM BIOGENIC RAW/WASTE MATERIALS AND $CO_2$

## Target markets

Fraunhofer IGB is a partner for industrial companies that produce, process or use chemicals, companies in machine and plant engineering and engineering companies. We focus on the following areas:

### Fine and specialty chemicals

Given our enormous expertise in the field of interfacial engineering, we are particularly interested in product groups such as **surfactants** and **coating systems**. We also focus on the synthesis and characterization of substances and materials for which an interaction with biological systems plays an essential role. Examples here include **additives for agriculture** such as plant boosters made of microalgae, which positively impact cell growth in agricultural crops.

### Biopolymers and biobased polymers

We also develop biopolymers for use as packaging for foodstuffs or for medicinal products (see Health business area). By using advanced **coatings** or the special **functionality of biobased monomers**, we are able to create new properties for materials. Examples here include the transparent Caramid-R® polyamides that Fraunhofer IGB has developed from terpenes. Based on renewable materials such as sugar, rapeseed oil or algal lipids, we have also been able to demonstrate other biotech methods of synthesizing feedstocks for the production of plastics. Such raw materials include e.g. short- and long-chain dicarboxylic acids and fatty acid epoxides.

### Food, animal feed and cosmetics

Given their antioxidant, immunostimulant or antimicrobial properties, **functional ingredients made of microalgae** can be used as animal feed or food supplements. The same is true of certain byproducts from the agricultural and food industries. For this purpose, we develop **cultivation methods** and **product-friendly separation methods** for extraction and purification. In addition, we develop new physical processes to stabilize and preserve food, cosmetics, active ingredients and plant extracts.

### Power-to-X and chemical $CO_2$ recycling

The ready availability of renewable electrical energy means that the chemical and energy sectors will increasingly merge in the future. This is because the redox equivalents generated in power-to-x processes can be used for synthesis. Fraunhofer IGB is building the **electrolysis test and trial platform ELP** at the Fraunhofer location in Leuna and the **Hy2Chem** scale up platform for chemical synthesis with regenerative hydrogen so as to be able to depict – as in other areas – new technological developments right up to the demonstration scale.

### Modular plant engineering

Various factors are driving the growth of modular plant engineering in the processing industry. These include increasingly **shorter development and implementation timescales** coupled with the need to increase the **efficiency, adaptivity and flexibility** of processes and thereby achieve **simple scalability** to meet fluctuating demand. Given the wide range of engineering expertise available at Fraunhofer IGB, we have been able to incorporate aspects of modular plant engineering in our development of new processes right up to the demonstration scale – as already shown in the Fraunhofer consortium MODAB.

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## Ecological insulation material made from rapeseed hulls and biobased epoxy resin

Conventional processing of oilseeds consists of cleaning, drying and dehulling of the seeds, followed by heating, crushing and pressing, and extraction. Finally, the vegetable oils are refined and the meals are dried. On an industrial scale, the dehulling of soybean and sunflower seed in particular is implemented commercially, but canola seed (Fig. 1) is also dehulled for further processing on a large scale today. However, the process still has room for improvement in terms of yields, hull sizes and degree of dehulling and is therefore still the subject of current research projects.

In the "DaeRpa" project, funded by the state of Saxony-Anhalt, an innovative approach to the use of rapeseed hulls as an insulating material (Fig. 2) is to be investigated. In general, insulation materials based on renewable raw materials can nowadays keep up with the technical data of conventional insulation materials in most applications. However, there is potential and need for optimization, especially with regard to the reduction of thermal conductivity or flammability. Complete cavity filling, which is necessary for optimum insulation properties, also places high demands on the material used.

In order to optimize the properties of the rapeseed hulls for use as insulation material, the material will be refined as part of this research project. To this end, the rapeseed hulls are additionally coated with a biobased coating, which is intended above all to strengthen the physical and microbial stability as well as the fire-retardant effect, in order to ultimately supply the rapeseed hulls as a product stream from the processing of rapeseed for increased added value. The use of new biobased epoxy resin systems envisaged in the DaeRpa project is especially innovative in the coating of rapeseed hulls. Particularly original here is the application of the rapeseed hulls as an epoxy component and also as a hardener component for the direct solidification of the biobased epoxides. This is to be realized in the project by means of a chemical modification of the rapeseed hull surfaces.

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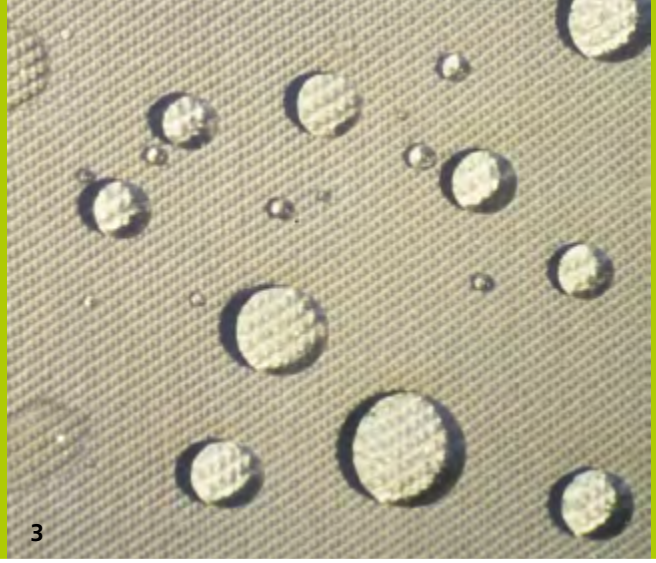

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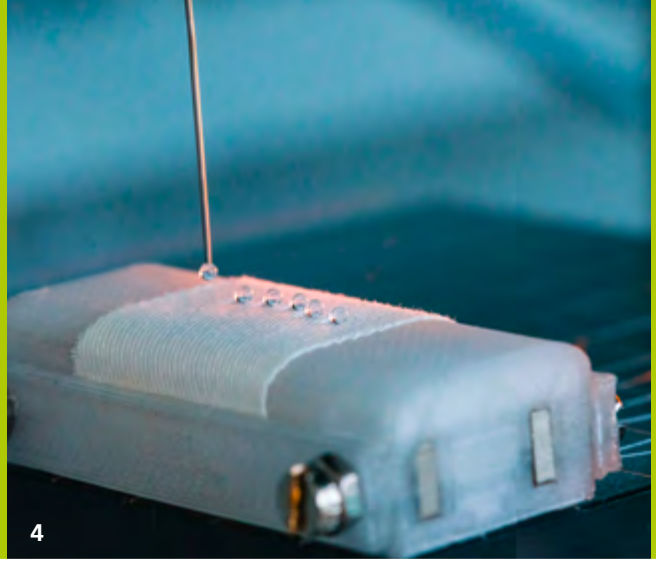

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## Chitosan in the textile industry – From sizing agent to functional carrier

Due to its chemical structure, the renewable biopolymer chitosan lends itself to derivatization and coating. Thus, chitosan is also used in the textile industry as a biobased and environmentally friendly sizing agent. If chitosan is used in the finishing of textiles, the textile surfaces can also be hydrophobized due to the functional groups of the biopolymer.

In laboratory tests, textile fabrics coated by Fraunhofer IGB showed significant hydrophobicity (Fig. 3) after finishing. Chitosan was successfully tested in textile finishing processes and was partly essential as a template for hydrophobicity. In the course of our investigations, the chemical and biotechnological functionalization of chitosan was optimized with a wide variety of biobased educts. Enzymes were also used for the first time for hydrophobic finishing of the tissues. They therefore represent a unique selling point in the hydrophobization of textiles. The finishes were evaluated by means of standardized tests, but also with specially designed test rigs and methods. Contact angle measurements with values of over 140° (Fig. 4) and permanent water repellency confirmed the success of the finishing.

From the textile industry's point of view, the end of the line has not yet been reached for chitosan as an anchor molecule for hydrophobization. On the contrary, studies show that the polysaccharide can be used as a substitute for synthetic polymers in a wide variety of textile processes. The IGB will therefore continue to focus on modifying the chitosan molecule and optimizing formulations in order to develop biobased marketable products. This will make it possible to replace other petrochemical textile auxiliaries with new bioeconomic products.

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## BioActiveMaterials – Sustainable and biobased packaging materials for foods safety

Packaging protects food and thus helps to reduce food waste. On the other hand, it also requires materials for production and has to be disposed of after use. Therefore, there is a great need to replace conventional mineral oil-based food packaging with biobased materials while still ensuring the safety of the packaged goods.

In the BioActiveMaterials project, active coatings were developed on paper and, from these, initial demonstrators of typical packaging materials (sealed bags, wrapping paper) (Fig. 1). In addition to the functionality of the coated papers, their recyclability was also investigated. At Fraunhofer IGB, we have developed various biobased coatings that provide a barrier to oxygen, water vapor and mineral oils as well as possessing antioxidant and antimicrobial properties. For this purpose, combinations of different protein layers and waxy coatings containing natural waxes such as carnauba, beeswax or candelilla wax as well as natural antioxidants (Fig. 2) were investigated. The latter serve to stabilize the films and can provide additional protection of the packaged goods through their antioxidant and antimicrobial properties. For the production of homogeneous coatings, protocols were developed for the formulation of long-term stable and easily processable aqueous dispersions. Papers coated with these dispersions were produced on a pilot coating line of the project partner.

The investigation of the barrier properties of the best combinations showed 5 $cm^3/(m^2*d*bar)$ for the oxygen transmission rate and 500 $g/(m^2*d)$ for the water vapor transmission rate. A good barrier effect was measured with regard to mineral oils. Printing on the coated papers is possible.

Long-term resistance to water, on the other hand, is not yet given; further optimization is necessary for this. Alternatively, the wax-containing dispersions developed could also be applied directly to foodstuffs – as edible coatings. This is to be investigated in further joint efforts.

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## Specialty chemicals from customized functional keratin proteins

Plastics and specialty chemicals are now ubiquitous and irreplaceable in many areas. Up to now, fossil sources have usually had to be used as starting materials for their synthesis. Henkel AG & Co. KGaA and Fraunhofer IGB are taking a new approach by using keratin, the main component of animal feathers, as a biopolymer raw material.

Feathers are still largely untapped as a biobased raw material for industrial use (Fig. 3). The largest share of the industrially relevant quantities of feathers produced per year in Europe's poultry farms is processed into animal feed or disposed of as waste. However, the keratin contained in feathers, a water-insoluble fibrous protein, could serve as a starting point for oligomer fractions.

At the Straubing branch of Fraunhofer IGB, research is being conducted into making feather waste usable for specialty chemicals: A hydrolysis process is first used to obtain shortened polymers – oligomers – to bring the protein chains into solution and crosslink them for later use. Following the development of initial manufacturing protocols in Straubing, large-scale production of the oligomer fractions will take place at the Fraunhofer Center for Chemical-Biotechnological Processes CBP in Leuna. Henkel is planning future applications in the adhesives sector.

The KERAbond project "Specialty chemicals from customized functional keratin proteins" is funded by the German Federal Ministry of Food and Agriculture (BMEL) based on a resolution of the German Bundestag. The project is coordinated by Henkel AG & Co. KGaA.

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## ALIGN – biobased aromatics from lignin

Lignin, the second most abundant terrestrial polymer, is the only sustainable source of biobased aromatics. To date, however, lignin has only been used in limited quantities for the extraction of aromatics. Conventional lignin extraction processes are often optimized for fractionation and purification of cellulose for pulp production. Since lignin is regarded as a by-product in this process and complex purification steps usually have to be established for high-quality material utilization, most of the lignin produced in pulp mills is currently only utilized for energy.

The aim of the ALIGN project is therefore to use lignin extraction processes that preserve the structure and functionality of lignin. In combination with innovative chemical and biotechnological conversion routes, this should enable the production of functionalized bioaromatics for use in resins as well as natural vanillin for food.

In the project, various lignin derivatives were produced in combination with tailored purification strategies such as membrane fractionation and used very successfully in fully biobased phenolic resins. Furthermore, Fraunhofer CBP successfully scaled up the lignin-first process established by KU Leuven to pilot scale (Fig. 1). In this process, highly functionalized phenolic monomers and oligomers next to pure cellulose/sugar fractions were obtained from beech wood chips.

In particular the developed purification strategies are now being tested, for their applicability on an industrial scale.

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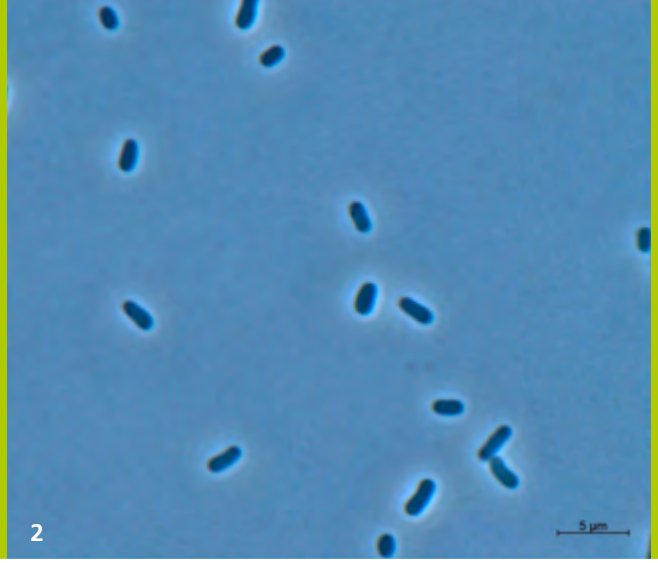


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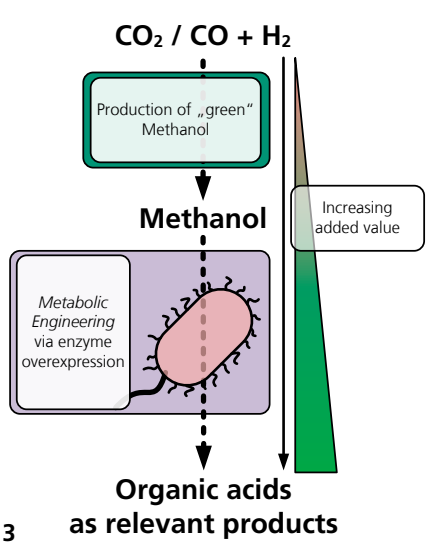


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## Biotechnological production of organic acids from methanol

"Green" methanol produced from $CO_2$ and renewable energy offers high potential as a key feedstock for a sustainable chemical industry. Against this background, we have been working on the development of a biotechnological production route for organic acids from methanol as part of the Fraunhofer joint project EVOBIO.

Methylotrophic microorganisms are a promising platform for the utilization of methanol in microbial fermentation processes. In EVOBIO, we have harnessed the bacterium *Methylorubrum extorquens* AM1 (Fig. 2) to selectively produce simple difunctional organic acids from methanol using metabolic engineering methods. Such acids are used, for example, in the cosmetics industry and medical technology and as polymer building blocks (Fig. 3).

To establish the fermentation platform, the work initially focused on engineering a suitable bacterial production strain. Initial production strains were identified by introducing heterologously expressed enzymes into *M. extorquens*. Building on these first generation strains, the production of organic acids from methanol was investigated. Testing of 13 enzymes from seven donor organisms showed that ten of the introduced enzymes had relevant *in vivo* activity in *M. extorquens*. The resulting strain variants were finally evaluated in fermentation experiments with methanol as the sole carbon source. In follow-up projects, the developed production strains will now be specifically optimized to obtain effective biocatalysts that are suitable for use in an industrial environment and meet the requirements of future commercial production.

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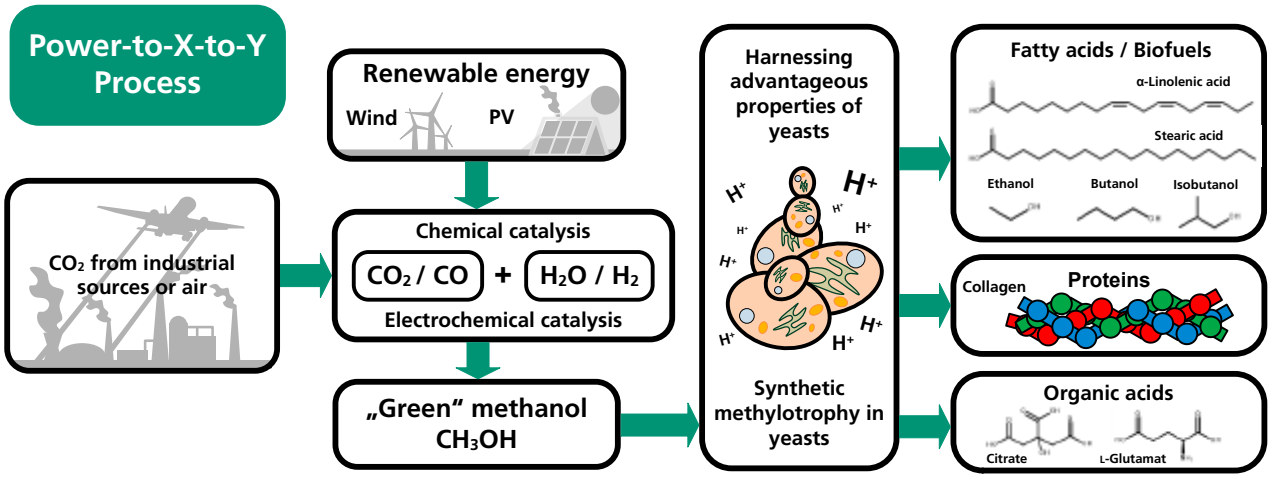


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## Methylotrophic yeasts for industrial biotechnology

Process cascades for the synthesis of chemical products from the raw material $CO_2$ are key technologies for a climate-friendly economy. Appropriate approaches for industrial biotechnology using synthetic methylotrophic yeasts as production strains have been described by Fraunhofer IGB scientists in the journal "Trends in Biotechnology".

The starting point of such biotechnological processes is the catalytic conversion of $CO_2$ to simple $C_1$ products such as methanol or formic acid. These substrates can be fermentatively converted into marketable chemical products or fuels by methylotrophic yeasts and other microorganisms. The approaches pursued at the Fraunhofer IGB's Straubing branch represent a new generation of biotechnological production processes (Fig. 1) which, in contrast to conventional methods, do not require the use of sugars or other biogenic raw materials. Thus, they are highly scalable – without the ecological and socio-economic risks of intensified use of biomass and biogenic raw materials.

Methylotrophic yeasts offer great potential as industrial production organisms due to increased tolerance to low pH and the availability of established techniques for genetic modification. Another advantage is the ability of yeasts to restrict the formation of toxic intermediates to organelles such as peroxisomes. This intracellular compartmentalization supports the development of robust production strains for efficient utilization of methanol. Thus, synthetic methylotrophic yeasts are versatile organisms for a sustainable circular economy. At the Straubing branch of Fraunhofer IGB, intensive work is being done on the development of synthetic methylotrophic yeasts as biotechnological production strains.

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## New biorefinery concept for the extraction of functional ingredients from microalgae

In the production of biobased products, the downstream processing of microbial biomass represents a significant cost factor. Up to now, the process steps cell disruption and extraction/fractionation have been carried out separately in terms of time and space, which affects both the yield and the stability of the high-value ingredients.

The aim of the EPI-CES project is to integrate and intensify the downstream process chain (cell disruption, extraction and separation) of microalgae (Fig. 2) to enable competitive biomass processing and production of functional ingredients.

A process was developed at Fraunhofer IGB for the production of the microalgae *Phaeodactylum tricornutum,* which was then scaled up at Fraunhofer CBP. At the IGB, eicosapentaenoic acid (EPA), fucoxanthin and chrysolaminarin are recovered from the algal biomass by breaking down the cells using pressure change technology (PCT). By using inert process gases and low temperatures, this technology is particularly suitable for releasing sensitive intracellular metabolites and for preserving their functional properties.

For the recovery of water-soluble chrysolaminarin, the aqueous phase is separated after cell disruption. The constituents fucoxanthin and EPA remaining in the wet biomass are isolated by pressurized liquid extraction (PLE). We were able to achieve the highest extraction (over 90 percent) for fucoxanthin and EPA using ethanol.

After optimization of the individual process steps, an integrated concept will be developed and demonstrated in a laboratory plant. The economic potential and the ecological added value of the process will be determined on the basis of a techno-economic evaluation and a comparison with existing technologies.

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## A novel process for the production of biobased isobutene

Isobutene is an important petrochemical feedstock. At the Fraunhofer Center for Chemical-Biotechnological Processes CBP in Leuna, the Global Bioenergies S.A. company has built a demonstration plant (Fig. 1) that for the first time produces isobutene from renewable raw materials instead of petroleum.

In contrast to petroleum-based production, the novel process uses fermentative production. Various first- and second-generation sugars currently serve as starting materials and are converted into the small but multipotent molecule isobutene by genetically modified microorganisms.

The metabolic pathway from sugars to isobutene was developed by Global Bioenergies S.A. using molecular biology methods. Fermentatively produced isobutene serves as a feedstock for biobased fuel additives, and for various components of cosmetics.

The demonstration plant with a 5000-liter fermenter was built for the purpose of scaling up and optimizing the process previously developed by Global Bioenergies in the laboratory. Fraunhofer CBP supported the construction and commissioning of the plant and has been operating the demonstration plant on behalf of the company since 2017. The scientific evaluation and validation of the process campaigns are carried out in close cooperation between Fraunhofer CBP and Global Bioenergies. In this way, the process is continuously further optimized in terms of process technology.

Unique in Europe is the directly connected product purification for liquefaction of the pure isobutene. Due to the aerobic fermentation process in combination with the highly flammable isobutene, special focus is placed on safety engineering. In recent years of research, sufficient quantities of isobutene have already been generated to validate further processing and use in biobased fuels as well as cosmetics, and to advance their market readiness.

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## Biotechnological production of ferulic acids as a precursor for flavorings

Ferulic acid is the starting material for aroma substances such as vanillin and is mainly responsible for the taste of wheat beer. During the brewing process the acid is converted into the typical wheat beer aroma. It occurs in different forms in many different plants. Up to now, however, this promising natural substance is only extracted from production residues of corn, wheat or rice with the aid of solvents and heat.

A simpler and more cost-effective way to produce ferulic acid using recombinant microorganisms is proposed in the BMBF project FeruBase. The project partners Martin Luther University Halle-Wittenberg (MLU) and the Leibniz Institute of Plant Biochemistry (IPB) have jointly succeeded in isolating the enzymes that are important for the production of ferulic acid. A first process for the production has also already been developed. To this end, *E. coli* bacteria have been modified to produce the enzymes needed for the synthesis of ferulic acid. In the FeruBase project, ferulic acid serves as the starting substance for both health-promoting substances and flavorings. In addition, so-called bitter-masking substances are to be produced that can be added to food. Once the production process at MLU has been optimized to such an extent that the target products can be produced on a laboratory bioreactor, the process will be transfered to industrial scale at Fraunhofer CBP (Fig 2).

Demand for the natural substance is already high. It forms the basis of biotechnological processes for the production of vanillin, which is already added to food, particularly in Asia, and is even used as a spice. Due to its antimicrobial properties, the plant substance is also in demand not only in medicine but also in the cosmetics industry.

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## Production of "green" ammonia

"Green" ammonia from renewable sources will be an important pillar for the synthesis of globally relevant products in the future. As a "Power-to-X" product, green ammonia contributes significantly to the coupling of various sectors, helping to create a stable renewable energy landscape. At the same time, ammonia is an easily storable and transportable compound enabling export options from areas where regenerative energy is abundantly available.

Ammonia is needed in huge quantities especially for the production of fertilizers and is used as an intermediate product in the chemical industry or can serve as a hydrogen storage material. The stored hydrogen is released on demand by thermal decomposition. Furthermore, ammonia is a very promising maritime fuel free of sulfur and carbon. Since 2020, some ship manufacturers have started to equip new cargo ocean liners with ammonia-compatible engines.

Fraunhofer IGB has been working on green ammonia production as a future technology for several years. Back in November 2018, the Green Ammonia project started on behalf of the fertilizer manufacturer OCP and in collaboration with the Fraunhofer Institute for Microstructure of Materials and Systems IMWS, with a focus on evaluating new technologies for the sustainable production of ammonia.

In the second phase of the project, which was successfully completed in 2020, Fraunhofer IGB and IMWS supported OCP and Green Energy Park (GEP) in laying the foundation for the construction of a demonstration plant for the synthesis of green ammonia in Morocco. With a planned production capacity of about four tons per day, this would be the first plant of its kind on the African continent for testing and techno-economic evaluation of the process chain in realistic intermittent operation.

Fraunhofer IGB's green ammonia production activities are of strategic importance in the context of the political agenda in many regions of the world. In the advancing global energy transition, ammonia is expected to play a significant role as a storable and transportable energy vector with an already existing infrastructure.

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HC
O2
H2O feed

# ENVIRONMENT

## Our focus

At Fraunhofer IGB in the business area Environment, systemic solutions are developed that provide integrated environmental protection for industry and for city and regional authorities, both in Germany and abroad. Our activities in this field comprise the development of new ideas and processes as well as individual solutions and products. Our aim is to achieve the greatest possible efficiency in the use of resources by following the concepts of the circular economy and sustainability.

# SUSTAINABLE RESOURCE MANAGEMENT FOR INDUSTRY, MUNICIPAL AUTHORITIES AND AGRICULTURE

## Target markets

### Smart infrastructure for smart cities

In particular, we focus on developments in the area of smart infrastructure. This requires a holistic consideration of all the aspects of municipal infrastructure, covering the areas of **water, energy, food and waste**. Fraunhofer IGB has many years of experience in **integrated water management** on the municipal and regional level, as well as in the use and development of new methods made available through the increasing **digitalization** of the water sector. This work focuses on the development of integrated strategies to help cities, towns and neighborhoods cope with heavy rainfall, drought and other extreme weather events caused by climate change.

### Production and treatment of drinking water

Water vapor in the atmosphere is a source of high-quality drinking or process water. Current research at Fraunhofer IGB is focusing on the use of **efficient adsorption systems that capture atmospheric water and, when required, release this as water** for drinking and other purposes.
We have many years of expertise in the investigation of bacterial contamination and in the determination of the efficacy of individual disinfection steps. We specialize in the identification of bacteria and fungi as well as in the analysis of **biofilms** and how to reduce or avoid them in technical systems.

### Treatment of process water, wastewater and sludge

Based on our many years of experience in this field, the IGB offers both **biological** and **physico-chemical methods** and solutions for wastewater treatment and sludge conditioning for industry and municipalities. Our portfolio also includes **customized membranes, filters and adsorbents**, which will play an important role in the growing future markets for water and wastewater treatment systems.

### Water monitoring

A further important activity at Fraunhofer IGB is the development of **sensors and monitoring systems** for use in measuring and assessing harmful substances in the soil and in water. Here, we are mainly concerned with the **biological components of biosensors, the functionalization of sensor surfaces, analytics, automation and data analysis**.

### Biogas

Biogas is a key enabler in the energy transition, because it can be produced independently of the sun and wind and can be stored for a long period of time. Our method of **high-load digestion** for the efficient production of biogas from sewage sludge has already been implemented at a number of municipal wastewater treatment plants. We also develop specific solutions for the conversion of biowaste to energy. These range from fermentation tests to the design of plants on a technical scale and the optimization of agricultural biogas plants in terms of **productivity and efficiency.**

### Secondary resources, raw materials and water reuse

With its development in **biotech and physico-chemical processes for recovering valuable materials and nutrients (P, N)** from sewage and other sources of waste as well as for the **reuse of treated wastewater**, Fraunhofer IGB makes important contributions towards the establishment of a sustainable **bioeconomy** inspired by the natural cycles of materials. One example is our ePhos® system, an electrochemical process for the recovery of phosphorus from wastewater rich in phosphates. Its efficiency has been demonstrated at the pilot plant scale.

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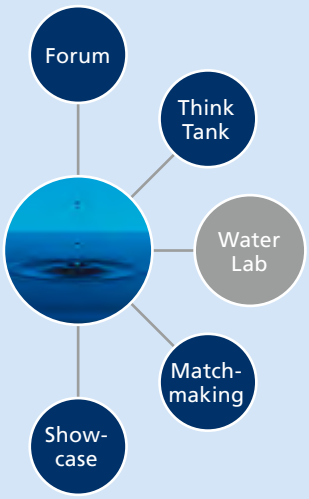


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## Cooperation with India through Water Innovation Hubs

India's fast-growing cities face complex challenges in the expansion and modernisation of water supply and wastewater disposal systems (Fig. 1). Many German companies have specialised knowledge and technologies that can contribute to addressing these challenges. However, these technology providers often have difficulties to establish themselves on the Indian market. The AQUA-Hub project aims at bridging these challenges through increased collaboration (Fig. 2) and exposure to solutions "Made in Germany" solutions. AQUA-Hub builds on the demands communicated by the German and Indian stakeholders, assessed in the predecessor project "Smart Water Future India".

Water Innovation Hubs will be realised in the two "Smart Cities" Coimbatore and Solapur and will be accompanied by demonstrations of German monitoring technology to act as showcases for increased market awareness. The Water Innovation Hubs serve to promote Indo-German cooperation in the water sector and provide support in initiating business relationships. In addition, they serve as an anchor centre for demonstration projects. In Coimbatore, for example, the implementation of an online water monitoring system for local surface waters is pursued. The IGB is responsible for the selection of parameters and sensor technology, technical advice on the conception as well as the evaluation of the analyses and derivation of recommendations for action.

In Solapur, the local Innovation Hub is linked to the pilot project Smart Water Quality Monitoring in Solapur. In the course of the project, potentials for a sustainable business model of the Water Innovation Hub as well as the transferability to other regions in India will be investigated.

Fraunhofer IGB is coordinating the project in close cooperation with the project partners Umwelttechnik BW GmbH and the Institute for Social-Ecological Research (ISOE).

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## High-load digestion for Ulm-Steinhäule

The wastewater of the city of Ulm and its surroundings has been treated at the Steinhäule site for over 60 years. The treatment plant treats the wastewater of about 220,000 residents as well as industrial and commercial wastewater, which also corresponds to a population equivalent of about 220,000. Part of the treatment plant is also a sludge incineration plant; however, there is no sludge digestion so far. This is about to change.

The sewage treatment plant association of Ulm has commissioned Fraunhofer IGB to carry out tests on the fermentability of the sludge of their sewage treatment plant. Based on the data generated here, a high-load digestion can then be designed that converts the biodegradable portion of the sludge into biogas very efficiently. On the one hand, this reduces the volume of sludge produced, which spares the capacity of the incineration plant. On the other hand, the biogas produced can also be used for energy, which has a positive effect on the energy balance of the wastewater treatment plant.

Since there has been no sludge digestion at the treatment plant so far, the operating personnel wanted to gain experience at a pilot plant before the industrial-scale plant is realized. Fraunhofer IGB has, therefore, set up a pilot plant for high-load digestion in a hall at the Steinhäule wastewater treatment plant in a second project (Fig. 3) and put it into operation in December 2020. This plant is designed so that it can later be used at other locations. It served as the technical basis for Fraunhofer's internal EVOBIO project. On the basis of the concepts developed in EVOBIO, we are currently working with our colleagues in Ulm to find solutions for recycling the nutrients redissolved in the sludge water.

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## Removal of micropollutants from wastewater by a photocatalytic process

The contamination of water sources by organic trace substances such as pharmaceuticals, industrial chemicals, pesticides, or releases from consumer products has recently attracted much attention. Studies have shown that many of these substances, even in low concentrations, can have a negative impact on human health and the ecosystem through long-term exposure.

Wastewater from sewage treatment plants is one of the most important sources of organic micropollutants. Their efficient removal from such effluents is therefore becoming increasingly important, and the development of suitable energy-efficient processes is currently the object of intensive research.

At Fraunhofer IGB, the oxidative degradation of micro-pollutants was evaluated by means of a photocatalytic process. It was shown once more that the activation of the photocatalyst titanium dioxide by irradiation in the UVA range leads to the degradation of various organic substances, such as diclofenac, carbamazepine, sulfamethoxazole or ibuprofen. Through the additional dosage of $H_2O_2$, the degradation rates of these substances could be increased to more than 80 percent.

The described method is thus a sustainable alternative to conventional processes such as ozonation. Together with the manufacturer of the oxidation reactor (Fig. 1), PMK Kunststoffverarbeitungs GmbH, this technology is to be scaled up. Additionally, the method and the oxidation reactor are available for degradation tests at the IGB.

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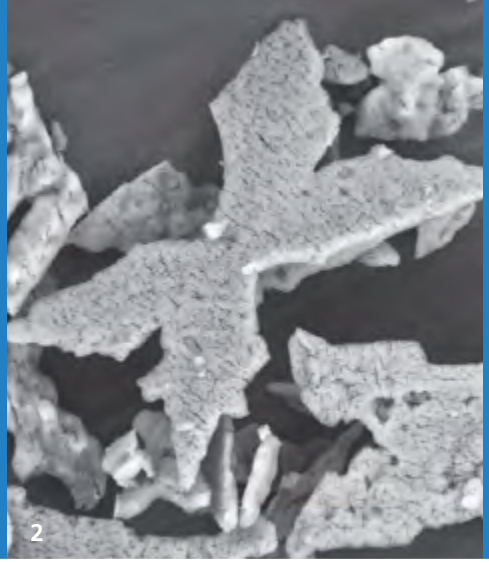

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## Nutrient recovery and desalination

Fraunhofer IGB develops innovative technologies for the recovery of nutrients from wastewater and organic residues such as sewage sludge, digestate, liquid manure or waste from the food industry. In this process, nutrients are precipitated as struvite (magnesium ammonium phosphate, Fig. 2) with the aid of the ePhos® process so that they are directly available as fertilizer in agriculture.

Phosphate precipitation is achieved by electrolytic magnesium dosing and pH adjustment without the addition of salts or alkalis. As part of feasibility studies, the process was tested at two locations in Germany on wastewater treatment plants (Fig. 3). The process was used for treating centrate water from digested sludge dewatering. The phosphorus concentration in the water was reduced by phosphorus conversion to struvite by an average of more than 80 percent in each case.

One of the current development focuses is on combining ePhos® technology with electrochemical separation processes, such as electrodialysis. Such separation processes can either be used as a pre-treatment to concentrate the nutrients or downstream of the ePhos® process. In the latter case, for example, residual loads of nitrogen and potassium can be concentrated into liquid fertilizer in the course of the ePhos® process. The process is also to be supplemented by further process modules in order to recover ammonium in a targeted manner in the future. These technologies are being used and further developed in the AbonoCARE project, among others.

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## "GreenUp Sahara" – Hydroponics for growing vegetables in desert regions

In the Algerian Sahara, thousands of people have been living in refugee camps for over 40 years. They are exposed to extreme climatic conditions that make traditional agriculture impossible. Fresh food is hardly available and securing a healthy diet is extremely challenging.

In cooperation with the United Nations World Food Programme (WFP), the Algerian agricultural engineer Taleb Brahim has developed a water-saving hydroponic system (Fig. 1) that enables the cultivation of barley grass as animal fodder (Fig. 2). This gives the population better access to meat and milk from the goats and camels. The technology has already been successfully replicated in Jordan and Chad. Hydroponics is very productive and requires 90 percent less water than soil-based cultivation.

Together with local stakeholders, Fraunhofer wants to further develop the hydroponic barley system in order to enable the cultivation of vegetables and herbs. This requires a hydroponic nutrient solution and since commercial hydroponic fertilizers are difficult to access for the people in the refugee camps, the biggest challenge is to produce such a nutrient solution at the lowest possible cost using only the locally available scarce resources.

In a current project, Fraunhofer scientists are investigating the suitability of residual materials, such as blood and bone meal from animal husbandry, for use in hydroponic systems, as well as the necessary or possible processing steps for the residual materials. In addition to the concentration of the individual plant nutrients, microbial parameters also play an important role due to hygiene requirements.

In 2021 the team plans to conduct plant trials at Fraunhofer UMSICHT. Here, the nutrient solutions created will be tested for their suitability for hydroponic vegetable cultivation.

With the results and experience from GreenUp Sahara, Fraunhofer IGB is contributing to the development of the global hydroponics platform H2Grow, a network and knowledge platform launched by the World Food Programme.

For the initial financing of the project idea, the Fraunhofer-Gesellschaft used the concept of crowdfunding for the first time. The project team would like to thank over 200 supporters. In November 2020 the project received the Fraunhofer Alumni Award.

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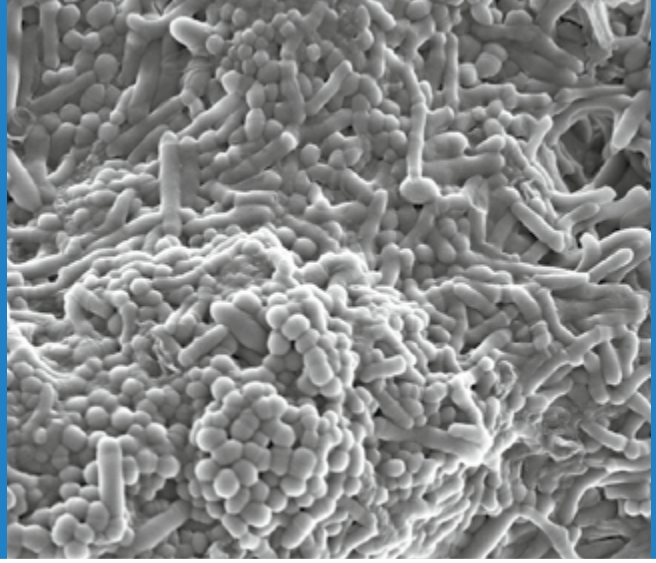

## "Positive" biofilms as an opportunity for the recovery of reusable materials

Biofilms are usually associated with negative connotations because they are, i.e. the reason for plaque that destroys dental teeth or growth on facades that causes unwanted coloration. Due to these negative effects, large amounts of work and money are used to combat these problems.

At Fraunhofer IGB, we look at these biofilms from a different perspective. Biofilms adapt fast and effectively to extreme conditions, which make them tougher and complicate the killing of these microorganisms. These specific characteristics allow us to use them to our advantage and integrate them into our research.

The IGB uses biofilms to optimize existing processes and to develop new technologies. For example, biofilms are used in combination with excess electricity in microbial fuel cells to generate specific materials. Additionally, autotrophic biofilms are able to metabolize $CO_2$ into different products, thus creating a dual advantage. New process engineering and biofilm reactors are used by us to not only continuously improve biologic wastewater treatment techniques but also integrate biofilms in other biotechnological settings.

Biofilms are ideal to positively influence waste and material streams: high-value raw and reusable materials are converted from presumed waste materials and are again integrated into existing product cycles. Future research requires the investigation of new microorganisms and processes that can be used effectively under varying conditions and environments.

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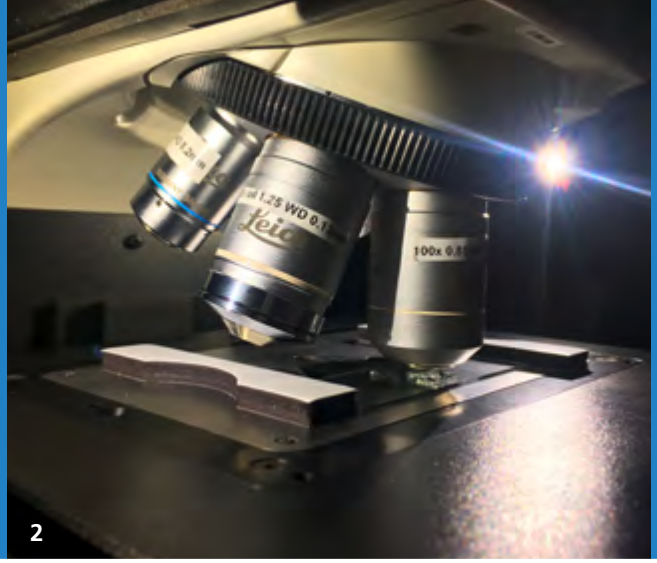
2

## Raman microscopy for characterization of biological samples and materials

Similar to infrared spectroscopy, molecular vibration bands can be captured using Raman spectroscopy. Here, chemical and biological samples are irradiated using monochromatic light of a laser. The resulting scattered light can then be detected and analyzed spectroscopically.

With the confocal inVia™ Qontor Raman microscope from Renishaw (Fig. 1 and 2), Fraunhofer IGB has the opportunity to use an automated and highly flexible microscope for research. The system is equipped with two Leica microscopes that allow measurements in the upright position (with chamber) and inverse in transmission. For maximal flexibility, the system can use a 532 nm (max. 50 mW) and 785 nm (max. 300 mW) laser as well as a CARS unit (coherent anti-Stokes Raman spectroscopy). The CARS unit offers the opportunity to filter unwanted fluorescent signals resulting from the sample. Being one of the first, Fraunhofer IGB can perform measurements with a laser and CARS-unit almost simultaneously on the same sample.

The most common application of Raman microscopy is the analysis of chemical compounds (e.g. materials, catalysts, liquids, etc.) In the past, the IGB looked at different hydrogels. Additionally, band behavior from Raman microscopy allows the non-destructive identification of the chemical composition of an unknown sample. Here, Fraunhofer IGB was able to determine the formation mechanism of chemical corrosion in a copper sample and thus was able to exclude a biological reason for material destruction.

In the field of biological research, Raman spectroscopy is gaining increased significance as well. The main field of application of the technology is the analysis of cell systems because the analysis can be performed without sample preparation and it is non-destructive. Current research at IGB includes differentiation of microorganisms in biofilms, differentiation of live and dead cells as well as quantification of microorganisms in fluidic systems.

*www.igb.fraunhofer.de/en/raman*

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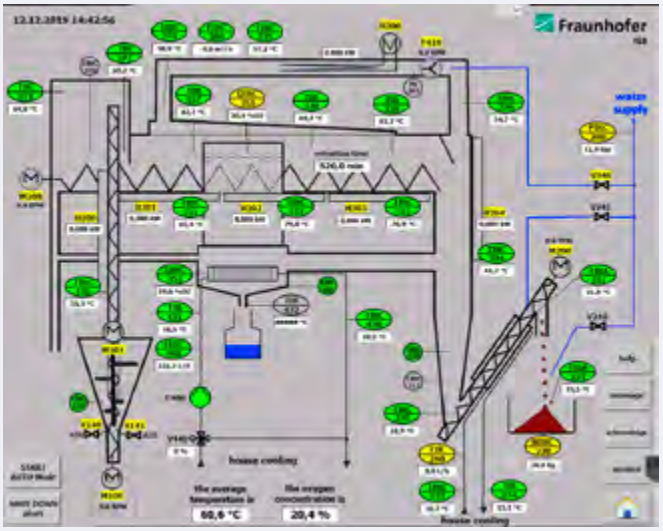



# TECHNOLOGY SCALE-UP AND TRANSFER

Research for the market – the transfer of results from application-oriented research into industrial practice is a key-objective of Fraunhofer IGB's strategy. Task of IGB's team Technology Scale-up and Transfer is the exploitation of technologies and processes developed in-house or jointly with industrial partners, as well as their translation into the industrial dimension and readiness.

The translation of research results into industrially relevant solutions is always carried out with the aim of optimally positioning the respective solution in the market. Through system-focused product development, we ensure the comprehensive functionality of apparatus and systems, maximize customer benefits, shorten development times, reduce manufacturing costs and minimize investment risks.

## From invention to innovation

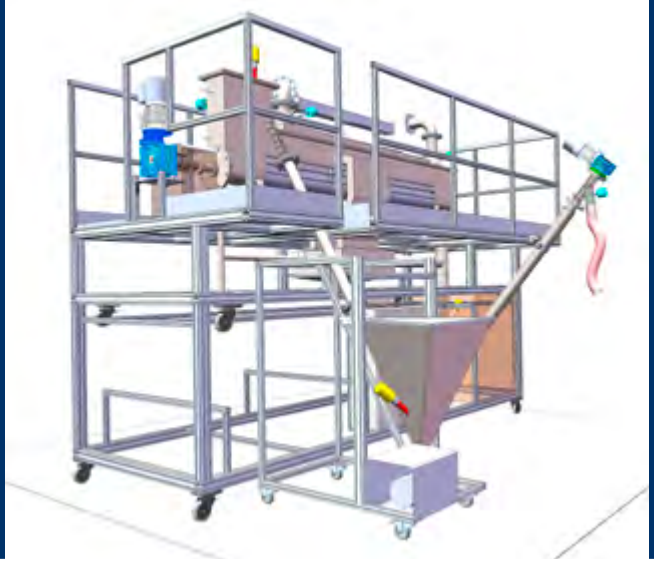
The team in Technology Scale-up and Transfer evaluates the industrial feasibility of new technologies at an early stage and readiness-level and develops concepts for their exploitation. This is done in close cooperation with the research units at the IGB and our industrial partners. In the implementation of innovations we support our partners and industrial customers in the realization, scale-up and plant operation up to technology readiness level (TRL) 9.

For the technical realization of demonstrators and prototypes, a team of experts in the fields of mechanical, electrical and software engineering provides a comprehensive portfolio of engineering competencies and methods based on the principles of methodical design.

Our services range from the conceptual and detail design of components and systems at early laboratory and demonstration plant scale-up to the construction of pilot and prototype plants for the validation of their industrial suitability as well as their integration into existing plant and process systems. For technologies that were initially developed for a specific application, we also identify further potential uses in other business areas. In this way, we also provide horizontal technology transfer.

Based on our many years of experience and broad expertise, we also provide solutions to many questions relating to the industrial design of technical systems, for example:

- Development methodology: Quality Function Deployment QFD, Value Engineering, Rapid Prototyping, Rapid Product Development
- Hygienic Design, CIP, etc.
- Regulations for certifications: ATEX, FDA, DVGW, etc.
- Initiation and handling of approval procedures (e.g. BImSchG)



## Equipment and competences

For the design and engineering of technical solutions we use SolidWorks® as 3D-CAD design software. This is directly linked to various numerical simulation programs via data interfaces. Here we mainly use COMSOL MultiPhysics® for the theoretical modeling of multiphase processes such as the behavior of solid particles in a fluid flow as well as other software tools.

To implement the concepts in demonstrators and prototypes, we have our own workshops, laboratories and pilot plants as well as a network of industrial partners.

Combined competencies:

- Mechanical engineering
  - Mechanical and plant engineering including apparatus engineering
  - Technical mechanics including fluid mechanics/fluid dynamics
  - Technical thermodynamics
  - Construction materials including knowledge of their processing (welding, bonding, etc.)
  - Materials handling and conveying techniques
- Electrical and software engineering
  - Automation
  - Software engineering (implementation of operational algorithms)
  - Information technology (data acquisition, management and evaluation, Big Data)
- Cross-section techniques
  - Separation techniques (mechanical, thermal)
  - Disintegration techniques (mechanical, thermal)
- Innovation management
  - Project management
  - Business evaluations and return on investment calculations (LCC, CAPEX, OPEX)
  - Utilization and marketing strategies

## References

Ongoing projects range from superheated steam drying plants, process water treatment plants to integrated nutrient recovery plants. Some key examples are listed below:

- Design, construction and 24/7 operation of pump test stands for a leading international manufacturer of pumps
- Design and construction of a semi-mobile plant for testing pumps for abrasion
- Design and construction of a prototype plant in "full scale" to our "water-out-of-air" technology together with the commercializing investor
- Design, construction and operation of a part-scale pilot plant for biomass conditioning (sewage sludge and bio-waste) and nutrient recovery for the waste management company SIAAP of the city of Paris in collaboration with the innovation field Water Technologies and Resource Recovery
- Construction and commissioning of a demonstration plant for high-load digestion of sewage sludge at the wastewater treatment plant of the city of Ulm in cooperation with the innovation field Water Technologies and Resource Recovery

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# THE FRAUNHOFER-GESELLSCHAFT

The Fraunhofer-Gesellschaft is the world's leading applied research organization. With its focus on developing key technologies that are vital for the future and enabling the commercial exploitation of this work by business and industry, Fraunhofer plays a central role in the innovation process. Based in Germany, Fraunhofer is an innovator and catalyst for groundbreaking developments and a model of scientific excellence. By generating inspirational ideas and spearheading sustainable scientific and technological solutions, Fraunhofer provides science and industry with a vital base and helps shape society now and in the future.

At the Fraunhofer-Gesellschaft, interdisciplinary research teams work together with partners from industry and government in order to transform novel ideas into innovative technologies, to coordinate and realize key research projects with a systematic relevance, and to strengthen the German and the European economy with a commitment to creating value that is based on human values. International collaboration with outstanding research partners and companies from around the world brings Fraunhofer into direct contact with the key regions that drive scientific progress and economic development.

Founded in 1949, the Fraunhofer-Gesellschaft currently operates 75 institutes and research institutions. The majority of our 29,000 staff are qualified scientists and engineers who work with an annual research budget of 2.8 billion euros. Of this sum, 2.4 billion euros are generated through contract research. Around two thirds of Fraunhofer's contract research revenue is derived from contracts with industry and publicly funded research projects. The remaining third comes from the German federal and state governments in the form of base funding. This enables the institutes to work on solutions to problems that are likely to become crucial for industry and society within the not-too-distant future.

Applied research also has a knock-on effect that is felt way beyond the direct benefits experienced by the customer: Our institutes boost industry's performance and efficiency, promote the acceptance of new technologies within society and help train the future generation of scientists and engineers that the economy so urgently requires.

Our highly motivated staff, working at the cutting edge of research, are the key factor in our success as a scientific organization. Fraunhofer offers researchers the opportunity for independent, creative and, at the same time, targeted work. We therefore provide our employees with the chance to develop the professional and personal skills that will enable them to take up positions of responsibility at Fraunhofer, at universities, in industry and within society. Students who work on projects at Fraunhofer Institutes have excellent career prospects in industry by virtue of the practical training they enjoy and the early experience they acquire of dealing with contract partners.

The Fraunhofer-Gesellschaft is a recognized non-profit organization that takes its name from Joseph von Fraunhofer (1787–1826), the illustrious Munich researcher, inventor and entrepreneur.

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*www.fraunhofer.de/en.html*

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Variolytics GmbH: page 16
Witte, Heiner / Wissenschaft im Dialog: page 19

All other photographs and figures

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