Fraunhofer
IGB

FRAUNHOFER INSTITUTE FOR INTERFACIAL ENGINEERING AND BIOTECHNOLOGY IGB

ANNUAL REPORT 2019 | 20

An Initiative of the Federal Ministry of Education and Research

Science Year | 2020

BIOECONOMY

We combine BIOLOGY and ENGINEERING ...

… by developing biotechnological processes for resource-friendly production within a sustainable economy and technologies that are designed to maintain human health within a healthy environment.

Dr. Markus Wolperdinger

ANNUAL REPORT
2019|20

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2019 SELECTED R&D RESULTS

DEAR READERS,

Society currently faces major challenges – not least of which are escalating population growth, our wasteful, unsustainable use of global resources, an increase in so-called lifestyle diseases, and changes to our climate and environment that can no longer be ignored. In many places around the world, people are still without a guaranteed supply of clean water and healthy food. Similarly, we must strive to ensure that more of our energy comes from carbon-neutral sources and that more of our products are sustainable and environmentally sound.

We need new approaches to such challenges – approaches that spring from a convergence of previously separate disciplines and seek to provide interdisciplinary answers. Examples can already be found in concepts such as the bioeconomy, circular economy, sustainability, digitalization, personalized medicine, and decentralized manufacturing.

Fraunhofer IGB seeks to take on a leading role in the elaboration and implementation of such approaches and, together with our partners, develop the innovative solutions that will help society conquer the challenges it faces. To achieve this, we will continue to build upon our deep-rooted experience in process engineering and on our unique ability, developed over many years, to combine this experience with our expertise in biology – a combination that is truly one of our defining characteristics.

In the course of last year's reorganization of Fraunhofer IGB, we therefore deliberately realigned our activities on the basis of our new vision: "We combine biology and engineering." This marks the continuation of more than 60 years of successful work in research, development and implementation of new concepts at the "interface" of these various disciplines.

Our fund of expertise at Fraunhofer IGB has grown and developed over time. We have now refocused this know-how on three topics of global importance that are reflected in our business areas: Health, Environment, and Sustainable Chemistry. In this, we were guided by our mission statement: "With our applied and customer-focused research, we develop biotechnological processes for resource-friendly production within a sustainable economy and technologies that are designed to maintain human health within a healthy environment – in short: we develop sustainable technologies for human health and the health of our planet."

To this end, we have designated so-called innovation fields that straddle our business areas and our sites. This means we can push ahead with innovative ideas and the projects they spawn not only faster but also more efficiently. What defines these new innovation fields is their depth of focus, the expertise of the people who work in them, and their business potential.

We are now in our first year following restructuring. The reorganization of Fraunhofer IGB applied to our strategy, the scope of our research, and each of our sites. This process of change is not yet complete, but positive changes are very much in evidence. This year, for example, we have been able to acquire significantly more projects in industry than the year before, as well as set in motion various new projects. Our economic performance has improved substantially, and we have laid the foundations for further improvements.

Among a raft of successful projects, I would like to single out the following: the continuation of our long-established cooperation with industrial partners from abroad at our site in Leuna (Sustainable Chemistry), the opening in Israel of a Project Center for Drug Discovery and Delivery (Health), and the preparation for the launch in South Africa of an Innovation Platform for the Water-Energy-Food Nexus (Environment), which is scheduled to open officially in the first quarter of 2020. These and other exciting projects are presented in this year's annual report.

Yet most important of all for the successful and sustainable future of Fraunhofer IGB are our employees. We must therefore continue to work with and for one another – and continue to build upon this ethos in the future. I would like to extend my sincere and heartfelt thanks to all the staff of the institute and to all those who have supported our work. It is your efforts that have made possible the many positive changes of the past year.

I will be delighted if this annual report inspires you to deepen established partnerships or embark on new collaborative ventures with Fraunhofer IGB.

Markus Wolperdinger
Director

We combine BIOLOGY and ENGINEERING ...

... by specifically immobilizing biological cells such as microorganisms or biological recognition elements including enzymes, antibodies or receptors on technical carrier materials in order to use them as biosensors. One such example is that the cells or biological components react to an unwanted pollutant or toxin using a biological response that is converted into a physical signal. Biosensors can be applied in monitoring drinking water and environmental analysis as well as for quality control in food technology, medical technology or biotechnology.

Dr. Anke Burger-Kentischer, Dr. Michaela Müller

… by using energy-efficient physical processes for the cell disruption of microorganisms to extract functional ingredients. Cell disruption is carried out at room temperature by pressure change technology. In doing so, microorganism cells are destroyed, their ingredients however are not changed.

Dr. Ana Lucia Vásquez-Caicedo

… by analyzing substrates, metabolites and products of biotechnological conversion processes from the solid and liquid phase in real time and with low measurement noise. This enables us to completely map the course of biotechnological reactions. By means of analyses, process understanding is increased and data can be provided for both upscaling and (model-predictive) control of processes.

Dr.-Ing. Matthias Stier, Johann Barlach, Stephan Scherle, Steffen Görner

... by using bacteriophages specifically for the degradation of biofilms and thus selectively reduce the bacterial contamination of technical systems.

apl. Prof. Dr. Susanne Bailer

PROFILE

WE COMBINE BIOLOGY AND ENGINEERING

What can we do to put an end to the shameful waste of the planet's natural resources and to help combat climate change? How can we assure an equitable supply of food, water, and raw materials to the world's growing population? And what can we do to improve the accuracy of diagnostic methods used to detect infectious diseases and cancer, provide affordable and ethical drug testing, and develop personalized medicine for an ageing society?

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

Fraunhofer IGB seeks out answers to these questions by developing and optimizing 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, closed-loop processes based on the systems approach of bioeconomy and bioinspired, biointegrated and biointelligent ideas, in order to contribute to human welfare, a sustainable economy, and an intact environment.

What we stand for

Bioengineering as the basis of tomorrow's healthcare system

Under the heading "Smart Health Engineering" Fraunhofer IGB aims to develop new molecular- and cell-biological tools for the precise diagnosis of cancer and infectious diseases, and develop new approaches to personalized medicine. The IGB's test systems based on human cells and tissue are innovative models that allow the efficacity of new therapeutic drugs to be assessed with a high degree of certainty, and with the aim of replacing animal testing in the long term.

Climate-friendly/-adaptive processes and products

The IGB applies the bioeconomic approach to its research into sustainable methods of producing wholesome food and animal fodder. The same approach is taken toward biofuels, fine chemicals and primary raw materials – all of which contribute to the establishment of a sustainable, climate-friendly system of production. Our carbon-neutral solutions make use of renewable resources such as aquatic microalgae, and even carbon dioxide, which can be a useful raw material in decentralized production units. Other ways of reducing CO_2 emissions and mitigating climate change include exploiting biogenic waste streams. Their physical conversion is increasingly possible using renewable energies.

The circular economy and resource efficiency

Life on this planet is based on natural cycles. Fraunhofer IGB studies these cycles in order to develop efficient methods and innovative components of technological systems designed to preserve global resources – from the harvesting of raw materials and their processing into products to their end-of-life disposal or reuse. Recoverable resources include not only carbon,

but also nitrogen, phosphor, metals, and above all water. The IGB develops circular processes to extract recyclable or reusable materials from process water, industrial waste streams, wastewater, sewage sludge, fermentation waste, fire ash and slag, or to return them to production or the natural cycle.

Our vision: We combine biology and engineering

More than ever, innovative processes and products call for the convergence or constructive interplay of previously separate technical disciplines in a systems approach. One such systems approach, which the IGB is continuously enhancing, is bioeconomy. The institute works at the interface between biology and engineering, especially in biotechnology but also through the genetic engineering of viruses and bacteria, the combination of cell culture and interfacial engineering, or DNA sequencing using bioinformatic algorithms, and the interaction of biological systems with technical materials. In this way, the IGB paves the way to new approaches and innovative solutions for industrial value creation: in medicine and medical devices, the manufacture of sustainable chemical products from renewable raw materials, and the separation of contaminants from production media, water, and environmental depollution.

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. The 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.

BOARD OF TRUSTEES

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

Members (as of December 31, 2019)

Dr. Susanne Arbogast
(until June 30, 2019)
Indivumed GmbH

Prof. Dr. Sara Brucker
University Hospital Tübingen

Dr. Gerd Eßwein
(until December 31, 2019)

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

Dr. Jürgen Groß
Robert Bosch GmbH

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

Dr. Caroline Liepert
Ministry of Science, Research and the Arts of the State of Baden-Württemberg

Dr. Christian Naydowski

Prof. Dr.-Ing. Dr. h.c. Dr. h.c. Prof. e.h. Michael Resch
Institute of High Performance Computing, University of Stuttgart

Prof. Dr. Dr. h.c. Ralf Riedel
(until December 31, 2019)
Institute of Materials Science, TU Darmstadt

Prof. Dr. techn. Günter Scheffknecht
Institute of Combustion and Power Plant Technology, University of Stuttgart

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

MinDirig Dr. Jörg Wagner
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU)

MinR Dr. Joachim Wekerle
Ministry of Economic Affairs, Labour and Housing of the State of Baden-Württemberg

Dr. Günter Wich
Wacker Chemie AG

Prof. Dr. Karl-Heinz Wiesmüller
(until December 31, 2019)
EMC microcollections GmbH

Dr. Wieland Wolf
ProBioGen AG

Permanent guests

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

Prof. Dr. Dieter Jahn
(Chair of Board of Trustees 1999–2013)

Dr. Dr. h.c. Christian Patermann
Director ret. EU Commission, MinDirig. ret.

Dr. Joachim Schulze
JS BioConsulting GmbH

SERVICES AND INFRASTRUCTURE

Fraunhofer IGB is a research and development partner for customers from the business and public sector. We develop, implement and optimize processes, systems and new technologies – from feasibility studies to industrial implementation. Our R&D is accompanied by a broad range of analysis and testing services.

Infrastructure and laboratory equipment

Cutting-edge technologies and an extensive, modern equipment are indispensable to our scientific work – and an added benefit for you as our customer. Our laboratories are designed for work up to biological safety level S2. A new building commissioned in 2017 has, among other things, roll-to-roll coating plants and technical centers for aseptic work (foodstuffs), for the treatment of process waste water as well as for wastewater and sludge treatment on a pilot scale. At the Fraunhofer Center for Chemical-Biotechnological Processes CBP in Leuna, infrastructure for operating plants up to demonstration scale is available.

Spectrum of services

- Process, technology and product development
  - From laboratory to technical and pilot scale
  - Design, construction and demonstration of pilot plants and prototypes
- Analysis and testing services
- Studies and consultancy
  - Feasibility studies and technology analyses
  - Profitability studies and life cycle assessment

Quality systems and certified testing

For many years, standardized processes and procedures at Fraunhofer IGB have been safeguarding a reliable and consistent quality of our services and products. An efficient quality management system ensures that selected test procedures are accredited according to the international DIN EN ISO/IEC 17025:2018 standard. Our quality assurance system ensures that the statutory guidelines of Good Laboratory Practice (GLP) are complied with.

Accredited testing field

The accreditation of reference laboratories and test procedures of our analytics according to DIN EN ISO/IEC 17025:2018 guarantees that our proprietary, in-house test methods and procedures are validated and that the quality of our tests is assured even where no standardized methods are available.

Accredited analytical methods and test procedures:

- High-performance liquid chromatography (HPLC)
- Ion chromatography (IC)
- Gas chromatography (GC)
- Atomic emission spectrometry (ICP-OES)
- Electron spectroscopy for chemical analysis (ESCA/XPS)

Good laboratory practice (GLP) test facility

Several non-clinical tests are running at our category 9 GLP unit "Cell-based test systems for the determination of biological parameters" to support R&D projects that investigate biological parameters of samples using cell-based assays.

Examples are:

- Testing of bioactivity, cytotoxicity and immunogenicity of compounds using immune receptor-based assays
- Screening of TLR agonists/antagonists
- Testing of antimicrobial properties of substances or surfaces
- Detection of pyrogens and microbial residues (pathogen-associated microbial patterns, PAMPs)
- Detection of viruses

For detailed information on our analytical and testing services:

www.igb.fraunhofer.de/analytics

Analytics at a glance

Our broad range of physico-chemical and biological examination methods turns the institute into a versatile partner for various analysis issues.

Physico-chemical analysis

Quality control, food analysis, trace analysis, analysis of residues, environmental analysis, water analysis

Surface analysis

Chemical, physical and morphological characterization

Real-time process analysis

Integrated in chemical and biotechnological processes

Assessment of biodegradability

Aerobic and anaerobic degradation tests

Microbial evaluation

Testing of antimicrobial properties of surfaces

Biomolecular analysis

Diagnostic microarrays, multiplex PCR systems for detection of pathogens

Next-generation sequencing

De novo genome/transcriptome sequencing, metagenomics and meta-transcriptomics, microbiomics, next generation diagnostics (infectious diseases, COPD, etc.)

Cell-based test systems (see GLP test facility)

Bioactivity, cytotoxicity, immunogenicity

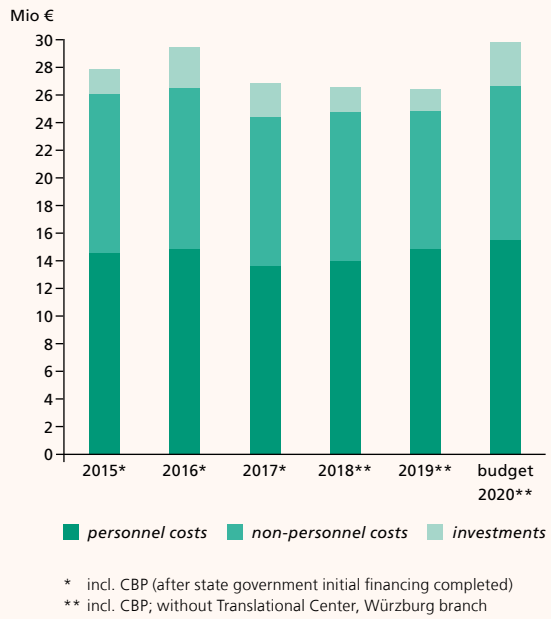
KEY FIGURES

Budget of Fraunhofer IGB

The total budget for 2019 amounted to 26.4 million euros, of which 25.2 million euros were allocated to the operational budget (personnel costs: 14.9 million euros; non-personnel costs: 10.3 million euros). A total of 1.25 million euros was spent on investments.

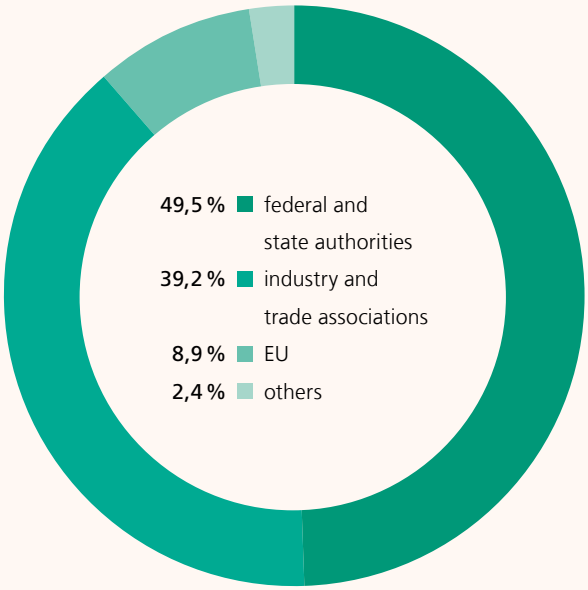
69.7 percent of the operational budget was financed from Fraunhofer IGB's own revenues generated from contract research projects. 39.2 percent of the institute's revenues came directly from industry.

Development of budget



* incl. CBP (after state government initial financing completed)
** incl. CBP; without Translational Center, Würzburg branch

Revenue from contract research 2019



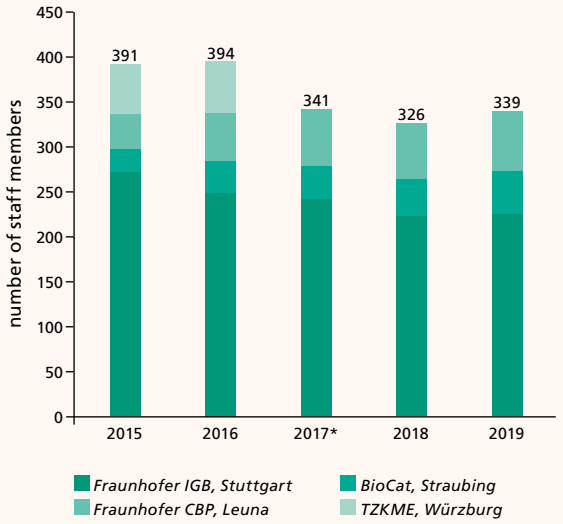
Personnel

At the end of 2019, Fraunhofer IGB (in Stuttgart and its branches in Straubing, and Leuna) had a staff of 339 of which some 80 percent were scientific or technical employees. Women made up 53 percent of the total.

The Institute of Interfacial Process Engineering and Plasma Technology IGVP at the University of Stuttgart counted a staff of 60 as of December 31, 2019, predominantly scientists and doctoral students as well as technical staff and student research assistants. Women constituted 28 percent of the total.

The employees of Fraunhofer IGB, of its branches, and of IGVP work together closely and have very culturally diverse backgrounds, with 28 staff members coming from 21 different countries outside Germany.

Development of staff numbers
as of December 31, 2019



* since 2017, without Translational Center, Würzburg branch

Staff composition as of December 31, 2019

	Fraunhofer IGB, (including branches)	**BioCat,** Straubing branch	**Fraunhofer CBP,** Leuna branch
Scientists	75	10	15
Technical staff	92	12	32
Doctoral students	8	2	1
Administrative and secretarial staff	45	8	6
Apprentices	8	1	1
Scholarship holders	8	0	0
Work students/Master students/student apprentices	32	4	5
Student research assistants	71	11	6
	339	**48**	**66**

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Jun.-Prof. Dr. Peter Loskill
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NETWORKS

Fraunhofer IGB is an active participant in numerous national and international research networks. Cooperative ventures with various universities and non-university research institutes, as well as interdisciplinary collaboration with other Fraunhofer Institutes, complement our own expertise and enable us to exploit synergies in developing new solutions for the needs of industry. We are also actively engaged in shaping research policies through championing strategic, economic, and sustainability standpoints.

Networking with universities

Basic research is a prerequisite for the applications of tomorrow. Fraunhofer IGB therefore maintains contacts with numerous universities. There is particularly close cooperation with the neighboring universities in Stuttgart and Tübingen, both through scientific collaboration and through professorial or other teaching commitments of Fraunhofer employees. Through connections of the IGB branch in Straubing with the Technical University of Munich and the Leuna branch with the Universities of Halle and Leipzig, our scientific network extends far beyond the region.

Fraunhofer IGB is particularly closely allied to the Institute of Interfacial Process Engineering and Plasma Technology IGVP at the University of Stuttgart through various teaching activities as well as a joint operation. In addition, we are networked with numerous other universities such as the Hebrew University of Jerusalem, Berkeley University and Stanford University as well as Stellenbosch University in South Africa, non-university research institutions and clinics.

Institute of Interfacial Process Engineering and Plasma Technology IGVP

The Institute of Interfacial Process Engineering and Plasma Technology IGVP at the University of Stuttgart is dedicated to interdisciplinary and cross-disciplinary research and teaching in the field of materials sciences, life sciences, process engineering and plasma technology. The IGVP is part of the Faculty 4 (Energy-, Process- and Bio-Engineering) and is structured in the research departments "Interfacial Engineering" and "Plasma and Microwave Technology". The institute has well-equipped laboratory and technical facilities both on the university campus and at Fraunhofer IGB.

Close cooperation of the IGVP with Fraunhofer IGB makes it possible to pursue projects from basic research to application. In 2019, the research budget accounted for 2.46 million euros. At the end of that year, a staff of 60 scientific, technical and administrative employees, among them 22 doctoral students, worked at the institute. In addition, 43 students have completed their master or bachelor thesis at the IGVP.

Contact

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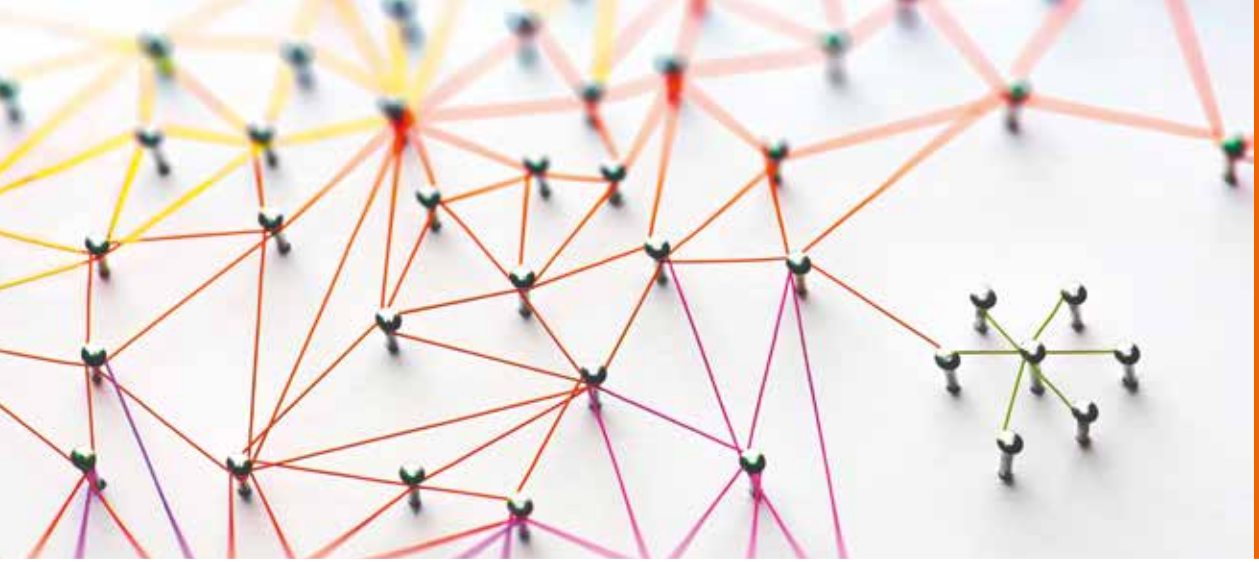

Fraunhofer Groups and Alliances

Fraunhofer Institutes working in related subject areas cooperate as groups, foster a joint presence on the R&D market and help define the Fraunhofer-Gesellschaft's business policy. Institutes or departments of institutes with complementary expertises collaborate in Fraunhofer "Alliances" to develop business areas together and offer market solutions along the entire value chain.

Fraunhofer IGB is an active member of the Fraunhofer Group for Life Sciences and, due to its strong focus on materials science, it also counts as an associated institute of the Fraunhofer Group for Materials and Components – MATERIALS. Furthermore, it is a member of various Fraunhofer Alliances and thus optimally integrated within the Fraunhofer network.

Fraunhofer Groups

- Fraunhofer Group for Life Sciences
  www.lifesciences.fraunhofer.de
- Fraunhofer Group for Materials and Components – MATERIALS (associated institute)
  www.materials.fraunhofer.de

Fraunhofer Alliances

- Fraunhofer Energy Alliance
  www.energie.fraunhofer.de
- Fraunhofer Food Chain Management Alliance
  www.fcm.fraunhofer.de
- Fraunhofer Additive Manufacturing Alliance
  www.generativ.fraunhofer.de
- Fraunhofer Nanotechnology Alliance
  www.nano.fraunhofer.de
- Fraunhofer Polymer Surfaces Alliance POLO®
  www.polo.fraunhofer.de
- Fraunhofer Cleaning Technology Alliance
  www.allianz-reinigungstechnik.de
- Fraunhofer Water Systems Alliance (SysWasser)
  www.syswasser.de
- Fraunhofer Technical Textiles Alliance
  www.textil.fraunhofer.de

In addition, Fraunhofer Institutes carry out joint activities within Fraunhofer internal research programs. Furthermore, the IGB is involved in the High Performance Centers "Mass Personalization" (Stuttgart) and "Chemical and Biosystems Technology" (Halle-Leipzig region).

For further information on IGB's networking activities:

www.igb.fraunhofer.de/network

For further information on CBP's networking activities:

www.cbp.fraunhofer.de/network

HIGHLIGHTS 2019

PROJECTS

Bavaria supports Laboratory for Technical Biopolymers

Biobased synthetic materials – from nature back to nature 1

Synthetic materials have become irreplaceable in many areas, but plastics and microplastics are polluting the oceans and groundwater everywhere. The use of biogenic raw materials for the production of high-performance polymers opens up the possibility of conserving fossil resources, reducing the increase of carbon dioxide in the atmosphere and reducing the pollution of our environment with non-degradable plastics. Furthermore, plastics with new properties can be produced from natural materials, as the example of transparent polyamides made of terpenes shows.

On January 9th, 2019, Bavaria's Minister of Economic Affairs, Hubert Aiwanger, presented a funding decision to the Straubing branch of Fraunhofer IGB amounting to approximately five million euros for the establishment of a laboratory for technical biopolymers. This enables the institute to advance the development of plastics from renewable resources and contribute to a sustainable economy in harmony with the protection of the climate and resources.

The laboratory covers the entire value chain for developing new plastics: From the identification of suitable biobased starting materials and the production of monomer building blocks, through polymerization and material development, to the investigation of recyclability and biodegradability. The aim is to establish and implement a cycle from natural substances via the use of the manufactured materials back to nature.

IGB successful in "Bioeconomy Room for Innovation"

Microalgae for biobased textiles and packaging films 2

The change from a fossil-based to a biobased economy is also the subject of the "Bioeconomy Room for Innovation", which are being funded within the "National Research Strategy Bioeconomy 2030" program of the German Federal Ministry of Education and Research (BMBF). By involving companies in the projects at an early stage, research results are to be specifically translated into bioeconomic innovations which, as drivers, accelerate the transformation process towards a sustainable, biobased economy.

With "New Food Systems" and "BioTexFuture – Production of biobased textiles based on sustainable raw material cycles", Fraunhofer IGB is represented in two funding measures of the rooms for Innovation.

BioTexFuture – Biobased textiles based on sustainable raw material cycles

The vision of this room for innovation is to completely replace fossil raw materials in the textile value chain with biobased ones. The focus is therefore on the targeted use of a sustainable, biobased raw material base. Based on this, BioTexFuture aims to map the application in the textile industry from biopolymer production to clothing manufacture throughout. In the AlgaeTex starting project, the IGB is developing the optimum parameters for the efficient cultivation of fatty acid-rich microalgae on a laboratory and technical scale and the transfer to the pilot scale in the Fraunhofer CBP pilot plant.

1

2

3

In addition, there is the basic scalability of algae production using artificial illumination. The fatty acid-rich algae biomass required for polymer synthesis in the project is to be produced and purified up to the FAME mixture (**F**atty **A**cid **M**ethyl **E**ster).

NewFoodSystems Room for Innovation

NewFoodSystems wants to ensure future nutrition and health with production processes that protect the climate and resources. Algae, insects, plants, and fish serve as suppliers of raw materials from which, after appropriate processing, marketable products for the feed and food industries are manufactured. In starting project 2, microalgae biopolymers such as starch, polyhydroxy butyric acid (PHB) and proteins will be developed for use in food, feed and food packaging and qualified for use in other applications.

Processes for the phototrophic, mixotrophic and heterotrophic production of algal biomass are being developed for both innovation rooms. For this purpose, residual material flows from food and feed production and lignocellulose processing (sugar mixtures) are to be evaluated as a source of carbon. IGB has already developed suitable processes for both fatty acid-rich and starch-rich algae.

IGB researchers secure EXIST funding
Spin-off company Variolytics 3

Under the name Variolytics, IGB engineers are planning a spin-off company to launch their real-time mass spectrometer developed at the IGB. The spin-off company will be funded for two years with 1.65 million euros from the "EXIST – Existenzgründungen aus der Wissenschaft" funding program of the German Federal Ministry for Economic Affairs and Energy (BMWi). The team of founders includes Dr. Matthias Stier, Steffen Görner and Stephan Scherle and Johann Barlach.

With the newly developed mass spectrometry system "Variolytics", up to thirty different substances or components can be analyzed in real-time. And this does not only apply to the gas phase but also to the liquid phase. This is a novelty on the spectrometer market, made possible by an innovative and patented inlet system. The new mass spectrometer thus opens up a whole range of previously inaccessible fields of application, also for the "Process Industry 4.0".

At Fraunhofer IGB it could be shown that the mass spectrometer can be successfully used in biotechnological applications to measure both reactant and product concentration simultaneously. This makes it possible to directly measure, monitor and control reactions. Areas of application for real-time analytics are the food, pharmaceutical, and chemical industries as well as water and environmental analysis.

INTERNATIONAL

New EU projects in Horizon 2020

Horizon 2020 is the eighth framework program for Research and Innovation of the European Union and, at the same time, the world's most extensive coherent research and innovation program with a funding volume of almost 80 billion euros for the period from 2014 to 2020.

Some projects involving Fraunhofer IGB were also selected for funding in the penultimate year of Horizon 2020.

imSAVAR 1

The project imSAVAR is an interdisciplinary EU consortium developing innovative model systems for the evaluation of immunomodulating therapeutics.

ImSAVAR is funded under the Innovative Medicines Initiative (IMI) public-private partnership and started its six-year research program on December 1, 2019. Under the scientific leadership of Fraunhofer IZI, Fraunhofer IGB participates in project management and coordinates the development of new types of immunocompetent *in-vitro* models with a focus on microphysiological systems, especially organ-on-chip platforms. In addition to these models, Fraunhofer IGB develops and establishes cell-based reporter gene assays using receptors of the immune system.

The amount of funding provided by the IMI amounts to 11 million euros. The industrial partners contribute to the same sum as in-kind contribution.

PREP-IBISBA

EU-IBISBA is a concept for building and establishing a European research infrastructure in industrial biotechnology and synthetic biology to provide translational research and innovation services to both the research community and industry.

The EU project PREP-IBISBA, an essential element of the ESFRI Roadmap (European Strategy Forum on Research Infrastructures), launched on January 1, 2020. Within four years all preparations for the implementation of EU-IBISBA are to be developed. These include transnational political elements as well as the selection of a suitable business model, the establishment of a long-term financial plan, and the identification of alternative legal frameworks. Fraunhofer IGB is involved in all these areas. Fraunhofer IGB is also involved in the ongoing project IBISBA 1.0, which develops the scientific and technical basis for EU IBISBA.

Liv-ad-on-a-Chip

Dr. Madalena Cipriano will be working on the mechanisms leading to insulin resistance as part of a two-year EU scholarship at Fraunhofer IGB from mid-2020. For this purpose, she will develop a microphysiological two-organ system (liver and white fat tissue, short WAT), which will be used as an *in-vitro* disease model for the metabolic syndrome and the non-alcoholic fatty liver disease.

1

Outlook

The year 2020 is also the last year of Horizon 2020 and, as in previous years, offers a variety of opportunities to submit project proposals by or with Fraunhofer IGB.

Furthermore, the structure, themes, and financial framework for the ninth framework program for research and innovation, "Horizon Europe", is becoming more and more concrete. Fraunhofer IGB is looking forward to the publication planned for autumn 2020 to participate with new project ideas next year.

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For further information on the Fraunhofer IGB EU-funded projects:

www.igb.fraunhofer.de/eu-projects

IGB establishes global future laboratories through sustainable cooperation with international partners

Sustainable scientific excellence is primarily the result of continuous exchange with the best in the world. It develops as a lasting and robust basis for the development of innovative solutions to global challenges – such as resource protection, climate and water conservation, health, and food security – if this exchange pursues joint long-term goals. Fraunhofer IGB is therefore intensifying and deepening its initiatives and projects with international partners and is continuously adding new ones.

GreenUp Sahara – with water-saving hydroponics

The "GreenUp Sahara" project is one of the new initiatives that breaks not only new ground in scientific and technological terms but also sets new standards in terms of its financing model. "GreenUp Sahara" aims to develop a water-saving hydroponic concept for vegetable cultivation in the Algerian desert. For this purpose, Marc Beckett from Fraunhofer IGB, together with his colleagues from the Fraunhofer Institutes UMSICHT and ISE, launched Fraunhofer's first crowdfunding campaign. They were supported by the fundraising team of Fraunhofer-Gesellschaft. The initial funding target of 15,000 euros at the start of the project was achieved through the support of 250 people. As a result, it will be possible to identify suitable materials for a scalable hydroponic system with the local engineer, Taleb Brahim, and the WFP (World Food Program) from December 2019. This represents the first step in the implementation of a sustainable hydroponic system for vegetable cultivation in desert regions. Funds are currently still being sought for further work by the ambitious team.
www.startnext.com/greenup-sahara

1

Fraunhofer Project Center for Drug Discovery and Delivery @ Hebrew University of Jerusalem, Israel 1

The Institute for Drug Research of the Hebrew University and Fraunhofer IGB can meanwhile look back on many success stories, which are the result of a trusting exchange with many joint projects. In May 2019, Fraunhofer President Prof. Reimund Neugebauer, Prof. Asher Cohen, President of the Hebrew University of Jerusalem, and Dr. Susanne Wasum-Rainer, Ambassador of the Federal Republic of Germany in Israel, opened the Project Center in a ceremony also attended by IGB Director Dr. Markus Wolperdinger. The declared goal of the center is to use innovative and efficient methods to identify lead structures and nanocarriers for new drug candidates to make them accessible for the therapy of infectious diseases, inflammatory processes, and autoimmune diseases. The joint developments support pharmaceutical companies in the development of new drugs in the pre-clinical phase and the identification of new active ingredients and formulations.

Water technologies for food production in Africa – WASTEC

In the joint project, "Energy-efficient and sustainable water supply technologies for desalination and microbial control in food production for Africa – WASTEC", scientists from the Fraunhofer-Gesellschaft and the University of Stellenbosch in South Africa have been researching since the beginning of 2019 how the know-how of the IGB and the technologies developed at the institute can be applied in the field of water treatment and water use in South Africa. The aim is to determine and improve the performance and stability of RO membranes. In particular, new strategies for controlling biofilms on RO membranes are to be developed. Long-term cooperation with the Water Institute of the University of Stellenbosch is also in the focus of the activities. On the Fraunhofer side, the SysWasser Alliance strengthens the consortium and thus opens up an even larger common thematic innovation space.

The cooperation between the University of Stellenbosch and the four Fraunhofer Institutes within the framework of the WASTEC project represents the initial phase for a long-term collaboration. This will be underpinned by the establishment of a joint Fraunhofer Innovation Platform FIP_WEF@SU in February 2020.

Fraunhofer Innovation Platform in Stellenbosch, South Africa

Significant challenges require strong partnerships. South Africa is a predominantly arid country and faces the enormous task of managing existing resources sustainably. This applies not only to scarce water resources but also to the expansion of renewable energy systems and food security. After numerous work meetings and based on the joint project WASTEC, the University of Stellenbosch and Fraunhofer-Gesellschaft want to found the "Fraunhofer Innovation Platform for the Water-Energy-Food Nexus" within the framework of a strategic partnership, for which financing for the partners was secured at the end of 2019. Needs-based technological and systemic solutions to promote water, energy, and food security are to be developed together in the newly established center.

Fraunhofer Innovation Platforms, like the Fraunhofer Project Centers, are science spaces built together with local partners according to the Fraunhofer model. They are established with local university partners and promote the exchange of know-how and technology transfer from science to practice. To achieve this, they work closely with the local industry and thus enable the promotion of applied and demand-oriented research and development.

2

On the Fraunhofer side, the IGB has taken over the leadership of the center for the next five years with Director Dr. Markus Wolperdinger and business area coordinator Dr. Ursula Schließmann. The official opening is planned for the first quarter of 2020. Besides the IGB, the Fraunhofer Institutes IOSB, IST, and ISE are also involved. The Fraunhofer Energy Alliance is associated as another partner. As a result, Fraunhofer and the University of Stellenbosch are establishing their cooperation on a sustainable basis beyond their collaboration in the WASTEC project.

Tree bark as the "refined" raw material of the future

The cooperation of colleagues from Fraunhofer IGB and CBP with the SCION Research Institute in Rotorua, New Zealand, continues to gain momentum after two joint working meetings in New Zealand and Germany. A concept for the sustainable recycling of bark waste and a first approach for the development of a networking structure of producers and users along a potential value chain of bark products has been established and will be further developed in joint projects. To this end, the international team of Fraunhofer and SCION scientists is writing a joint proposal that will be submitted to the new research program in New Zealand. In addition to the enormous potential for the environment that results from the joint activities, a sustainable partnership with one of the world's largest wood producers is being developed on this basis for the IGB.

Water and energy infrastructure for smart cities in India 2

With the "Smart Water Future India" project funded by the German Federal Ministry for the Environment (BMU), in which intelligent and sustainable water management strategies were developed for the city of Coimbatore in southern India, Dr. Marius Mohr, together with Indian experts, laid the foundations for providing urgently needed long-term solutions for needs-based water management in the region even beyond the project. For example, Mohr currently heads one of the Smart City Labs in Kochi, which was created as part of the Fraunhofer Morgenstadt initiative. The aim of this activity is to develop transferable and, at the same time, financially viable roadmaps to reduce greenhouse gases, strengthen resilience to the consequences of climate change and improve the quality of life of the local population. The City Labs, with their science-based analysis methods, are the core of the Morgenstadt tools. Continuity for joint activities is provided by a Memorandum of Understanding signed by the Indian Council of Scientific and Industrial Research CSIR and Fraunhofer-Gesellschaft during the Indo-German-Consultations. The event was attended by German Chancellor Dr. Angela Merkel, Federal Minister of Education and Research Anja Karliczek, and other high-level representatives of the ministries.

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1

PEOPLE

Sepsis diagnostics awarded SIK innovation prize

In cooperation with the University Hospital of Heidelberg, the IGB developed an innovative approach for the detection of sepsis pathogens. The participants were honored for this with an innovation award at the "Stuttgarter Intensivkongress" in February 2019. The award is granted for special achievements in the field of intensive care medicine. IGB scientist Dr. Kai Sohn and his team, together with Prof. Thorsten Brenner from the Department of Anaesthesiology at the University Hospital in Heidelberg, had applied for the prize. With their joint project for the clinical testing of a diagnostic method based on next-generation sequencing, they beat 26 competitors to secure first place.

G-BiB: IGB team wins first place in international business plan competition 1

With a business idea developed at the IGB, three students working at the IGB and the IGVP took part in the international Global Biobased Businessplan Competition 2019 (G-BiB). Their efforts were crowned with success: The "EBS – Engineering Biosurfactants" team, consisting of Amira Oraby, Fredy Baron and Thomas Galonska – all Master's and PhD students in Dr. Susanne Zibek's research group –, won the final of the competition in Düsseldorf on September 4th and was thus able to celebrate first place and the associated prize money of 7500 euros. The award is presented by the BIG BioInnovation Growth mega-cluster, a German-Belgian-Dutch initiative to promote innovation in biotechnology. As part of the G-BiB competition, the cluster called on young researchers to submit innovative business ideas for the sustainable production of biobased chemicals, materials and fuels. The students had to create a business plan and present it in several rounds of pitches.

CESIO congress award for Amira Oraby

In June 2019 international experts for surfactants from research and industry met at the CESIO 11th World Surfactant Congress in Munich. This congress is hosted by CESIO, the European Committee for organic surfactants and their intermediate products. The latest edition of the event was also attended by researchers from the IGB, including Amira Oraby, who is a PhD student in the innovation field of "industrial biotechnology" and is researching the production of biosurfactants. Within the scope of the lecture program she gave a lecture on "Integrated process design and optimization for the production of the biosurfactants cellobiose lipids from Ustilago sp. on renewable feedstocks". For this presentation she was awarded the CESIO 2019 Oral Presentation Award in the category "Technical & Applications".

Felix Derwenskus receives bioeconomy poster prize

Since 2013, numerous universities and research institutions in Baden-Württemberg – including Fraunhofer IGB – have cooperated in the Baden-Württemberg Bioeconomy Research Cluster. Its aim is to promote the transition to a sustainable way of doing business in the sense of the biobased economy at state level. The 4th status seminar of the research cluster took place at the University of Hohenheim at the beginning of 2019. Several researchers from the IGB also attended the conference and contributed to the accompanying poster exhibition. Proven to be particularly popular, the poster by IGB scientist Felix Derwenskus on "Microalgae biorefinery – cascaded fractionation of microalgae ingredients for food and feed applications" was awarded a poster prize at the event.

IGB receives Fraunhofer Family Logo

In the summer of 2018, the Fraunhofer-Gesellschaft created the Fraunhofer Family Logo as an internal quality seal to recognize institutes that are an exemplary advocate of family-friendly working conditions. After all, a healthy work-life balance and thus a well-functioning work-life balance is of great importance to many employees when choosing their workplace. The IGB also received this internal seal of quality in 2019. A total of 40 Fraunhofer institutes had applied for the award. The IGB is one of 16 institutes that actually received an award. In the opinion of the judges, the IGB's success in creating a framework for flexible working and a welcoming culture for women and men with children through a wide range of day care services was a strong point in favor of the Institute.

1

TRADE FAIRS AND EVENTS

Fraunhofer IGB looks back on an eventful year of trade fairs and events in 2019. The strategic reorientation of Fraunhofer IGB was reflected by the thematic priorities of various events and conferences in which representatives of the institute participated or which were organized by the IGB itself. For example, the first conference of the Competence Center for Biointelligence, in which the IGB is significantly involved, focused on the topic "Biological Transformation". The new guiding principle of the IGB "We combine biology and engineering" was a common thread throughout numerous events. Furthermore, bioeconomy was of great importance.

3rd Joint Symposium on Nanotechnology

Together with the German Federal Institute for Risk Assessment (BfR), Fraunhofer Nanotechnology Alliance organizes a nanotechnological expert symposium every two years, which is held at different locations. Due to its active role in the Nanotechnology Alliance, Fraunhofer IGB assumed the role of host this time. The main topics of the symposium ranged from the use of nanotechnology in the field of medicine, applications in the food industry or water purification to its use in the energy and construction sectors.

Conference "Biointelligent Products and Production – The Sustainable Industrial Revolution"

Since the beginning of 2019, around 40 representatives of renowned research institutions in the Stuttgart area have been working together intensively and on an interdisciplinary basis in the Biointelligence Competence Center to jointly shape the paradigm shift in Biological Transformation. In the middle of the year, the participants met for the first time for a joint expert conference. The central topic was "Biointelligent products and production – the sustainable revolution of the industry". In this context, the participants dealt with the question of how the needs of our society can sustainably be met in the future. Bioeconomy, a central field of expertise of the IGB, was placed at the center as a comprehensive system approach.

2

ManuFUTURE Workshop

Under the motto "The future of sustainable value creation systems", the European Technology Platform ManuFUTURE and the Fraunhofer-Gesellschaft organized a workshop on the Biological Transformation of the European manufacturing industry in Brussels at the end of June. The event brought together around 40 experts from industry, politics, and research to discuss how materials, structures, and processes of living nature can make manufacturing sustainable in the future. In this context, IGB Director Dr. Markus Wolperdinger spoke about the importance of using biowaste and renewable raw materials to achieve a climate-neutral circular economy. Together with Prof. Thomas Bauernhansl, Director of Fraunhofer Institute for Manufacturing Engineering and Automation IPA, Wolperdinger presented the modi of the Biological Transformation being pursued: bioinspired, biointegrated and biointelligent.

Day of Bioeconomy 1 + 2

As part of the "Innovations in the Life Sciences" series of events, the Fraunhofer Group for Life Sciences brings together experts from science, industry, and politics with a focus on bioeconomy. Against this background, the "Day of Bioeconomy" was held in Berlin in September 2019. In addition to the presentation of selected developments from the range of topics of bioeconomy, current challenges for research policy were discussed. High-ranking participants from industry, politics and associations also had the opportunity to talk directly to the drivers and actors of bioeconomy. The IGB, one of the central actors of the event, gave presentations on the topics "Bioeconomy as a strategy for German industry", "Water – the basis of bioeconomy" and "BioACCEPT – Biological approaches for recycling management, production, and technology".

Current exhibitions*

BIOKET**
March 10–12, 2020, Lille (France)

Energy Storage**
March 10–12, 2020, Düsseldorf

Analytica
March 31 – April 3, 2020, Munich

IFAT**
May 4–8, 2020, Munich

9th Bioeconomy Conference**
June 17–18, 2020, Halle (Saale)

Bioabfallforum (Biowaste Forum)**
June 30 – July 1, 2020, Stuttgart

3rd International Bioeconomy Congress Baden-Württemberg**
September 21–22, 2020, Stuttgart-Hohenheim

BIO World Congress
September 20–23, 2020, Raleigh, North Carolina (USA)

Colloquium on Wastewater and Waste Treatment**
September 24, 2020, Stuttgart

SEPAWA**
October 23–25, 2020, Berlin

parts2clean
October 27–29, 2020, Stuttgart

* Subject to alternations
** With reference to the Science Year 2020 Bioeconomy

1

2

K – Plastics for Future 1 + 2

Every three years the plastics and rubber industry meets in Düsseldorf at the K, the world's largest trade fair for the industry. The focus is always on current market requirements and the social changes which the industry has to keep up with. Application-oriented research provides innovative solutions for the associated challenges. The institute showed plasma-treated and plasma-coated materials such as anti-ice coatings and presented a rapid test method for material characterization based on plasma weathering. Another highlight at the IGB stand, which attracted great interest from visitors, was the synthesis of building blocks for biobased plastics from natural residues: The biobased polyamides Caramid-R® and Caramid-S®, produced using a new patented process, are representatives of a new class of polyamides with outstanding thermal properties.

Training course "Algae biotechnology and its potential for a sustainable bioeconomy"

Algae are microscopically small "plants" that can be used as a raw material for a variety of foods and sustainable food production. Their use is, therefore, one of the most promising trends in the food and feed industry, but also of interest for cosmetics or biobased materials. The IGB has many years of expertise in the field of algae biotechnology. For the second time, the institute invited participants to a two-day advanced training course on "Algae biotechnology and its potential for a sustainable bioeconomy". The aim of this advanced training course was a practical introduction to algae biology. The focus was on the cultivation and growth of the plants and the subsequent molecular and metabolite analysis under laboratory conditions in both small and large breeding and extraction facilities.

For further information and current events see:

www.igb.fraunhofer.de/events

An Initiative of the Federal Ministry of Education and Research

Science Year | 2020

BIOECONOMY

SCIENCE YEAR 2020

Bioeconomy is topic of the Science Year 2020

As a sustainable form of economic activity, bioeconomy is the economy of the future, and a transformation is inevitable. Our current economy based on fossil raw materials is reaching its limits. Global population growth and rising living standards are presenting us with new challenges – from anthropogenic climate change and the littering of the oceans to dwindling natural resources. We therefore urgently need to learn how to live and manufacture more sustainably. Bioeconomy provides the necessary solutions.

Fraunhofer IGB is partner in the Science Year 2020

For more than 40 years, Fraunhofer IGB has been researching the development and utilization of biological resources, processes and systems in order to provide methods for a sustainable, biobased economic system oriented on natural material cycles.

Learn more about our concepts and strategies to combat climate change. Find out about current projects in which we are developing processes for manufacturing sustainable and biodegradable products. Find out about our activities to use alternative resources such as microalgae, renewable raw materials and biogenic residues, to recycle valuable materials or recover them for reuse. You are also cordially invited to our events and lectures.

www.igb.fraunhofer.de/bioeconomy

Visit us at the MS Science

Washing powder, washing-up liquid, skin creams, shampoos – they all contain surfactants. A large part of them is still produced from crude oil. The industry is therefore increasingly relying on surfactants from renewable raw materials, although these are mostly chemically produced. Fraunhofer IGB is investigating methods to produce biosurfactants on a biotechnological basis – using fungi. In this way, cellobiose lipids and mannosylerythritol lipids can be obtained, which are more versatile and better degradable than synthetic surfactants. The IGB is working to optimize the production process in order to increase the yield and reduce production costs.

On board the MS Wissenschaft, we will be demonstrating our bio-washing machine in summer 2020, which makes biology in detergents visible and tangible: fungi that produce biosurfactants and the natural raw materials such as wood and oilseeds that provide the basis for the biosurfactants.

MS Wissenschaft is the floating Science Center of the German Federal Ministry of Education and Research. Every year, the exhibition ship tours Germany for four months to introduce the fascinating world of science to a broad public. In June 2020, the MS Wissenschaft sets sail again – under the flag of the current Science Year Bioeconomy.

1

PROMOTION OF YOUNG TALENT

To be successful in the long term, it is of crucial importance for research institutions to secure qualified young talents. This is another reason why Fraunhofer IGB is committed to promoting young talent – to get young people interested in applied research.

The IGB participates in several recruiting events organized by the Fraunhofer Institute Center in Stuttgart. Within this framework, school children can find out about MINT subjects (mathematics, computer science, natural science and technology) at Fraunhofer in Stuttgart and students can learn more about career entry, and career opportunities at Fraunhofer.

Girls‘ Day 1

Girls' Day is a nationwide day of action to promote girls and young women in scientific and technical professions. It is intended to help overcome traditional gender and role stereotypes and to inspire girls for MINT professions at an early age. This is because the proportion of women in supposedly typical “male professions” is still too low today. The Stuttgart-based Fraunhofer Institutes have been taking part in the Girls' Day since 2003 and on this day they open their laboratories and workrooms to students interested in applied science. In this context, the IGB offered a guided tour of the institute on plasma technology.

Fraunhofer Talent School 2

The “Talent School”, which lasts three days, serves as a career orientation for pupils. Participants can try out scientific work themselves in practice-oriented workshops. This gives young people a direct insight into the world of applied research. At the Talent School held last year from March 29 to 31, 2019, a total of 70 schoolchildren visited the Fraunhofer Campus in Stuttgart. The IGB participated with the workshop “CSI Stuttgart”. Under expert guidance, the participants solved a fictitious criminal case by convicting the perpetrator with the help of DNA characterization they had carried out themselves.

2

Fraunhofer HiWi-Days

The Fraunhofer-Gesellschaft offers students the opportunity to take the first career steps while still at university. As research assistants, abbreviated HiWis (student assistants), they can gain professional experience at an early stage and work on application-oriented research projects – and thus lay the foundations for a career later on. With the HiWi-Days, which take place once a year, Fraunhofer also allows their student assistants an opportunity to look beyond the "horizon" of their institute and to get to know other Fraunhofer units and new topics. To show the full spectrum of Fraunhofer research, the event will take place at different locations. In May 2019, Stuttgart was next. The program offered the participants numerous career and specialist workshops for further education and guided tours of the institutes.

BOGY – Career and study orientation at secondary school

Choosing the right profession is one of the most important decisions in the lives of young people. For this reason, secondary school students in Baden-Württemberg complete one-week BOGY short internships (vocational and study orientation at the secondary school) between the 9th and 11th grade, which are intended to provide them with an orientation at an early stage. Fraunhofer Institute Center Stuttgart supports this initiative. Students with an interest in science and technology should be able to gain an insight into the world of applied research and find out about study, job entry, and career opportunities. For this reason, the Institute Center arranges several BOGY internships at the Stuttgart institutes every year. In 2019, the IGB accepted one female and one male student.

An integrated degree program at Fraunhofer IGB

Fraunhofer not only offers young academics an entry into professional life – non-university training is also a priority. The same applies to the IGB: At the end of 2019, the institute and the IGVP, its partner institute at the University of Stuttgart, employed a total of nine trainees. Also, seven young men and women have completed their apprenticeships in the course of this year. Fraunhofer also attaches great importance to equality and the promotion of women, especially in the MINT sector. It is therefore particularly gratifying that about two-thirds of the apprentices are female. The choice of occupations that require an apprenticeship is broadly diversified. Office management clerks learn their profession in the Administration Department and IT specialists are trained in the IT Department. In the scientific field, the institute trains biology and chemistry laboratory assistants. In administration, the trainees pass through several stations within three years in order to get to know the different administrative work areas of a research institute. All trainees acquire the necessary qualifications for a later career in research or industry. Besides, the IGB also supports its trainees if they wish to study after completing their training.

For further information on promotion of young scientists and training:

www.igb.fraunhofer.de/career

We combine BIOLOGY and ENGINEERING ...

... by providing biological molecules of the natural tissue matrix with cross-linkable chemical groups in order to produce specifically adjustable hydrogels as “bio-inks”. The “bio-inks”, enriched with cells, can be specifically brought into a three-dimensional structure using 3D printing techniques. Such printed tissue models will enable individual diagnostic and pharmacological tests. In the future, as biological implants, they may also act to stimulate damaged tissue to regenerate or substitute them.

Dr. Achim Weber

... by combining the heterogeneous catalytic or electrocatalytic conversion of the greenhouse gas CO_2 to simple C_1 intermediates with a biotechnological conversion (more precisely, by fermentation). In this way, CO_2 is converted into methanol or formic acid, resulting once more in the conversion of these compounds into high-quality products.

Dr. Arne Roth

… through bioengineering and scaling up of biotechnological processes for the production of biobased basic, fine and platform chemicals (for further processing in the chemical industry or in the field of cosmetics, cleaning agents and plastics or adhesives).

Dr.-Ing. Katja Patzsch

… by developing a novel forming process for the production of miniaturized, tailor-made membranes as porous structures for the fixation and supply of human cells in microphysiological *in-vitro* tissue models. While the porous membrane structure is permeable for the transport of signal molecules for cell-cell interactions, it offers structure for the formation of a locally fixed, functional tissue. With such a carrier and supply structure, we aim to reproduce tissue as physiologically and miniaturized as possible and create novel test systems, e.g. for the development of pharmaceutical agents.

Dr. Thomas Schiestel, Jun.-Prof. Dr. Peter Loskill

... by using DNA probes as biosensors on a test strip. In this way, the pathogens in question can be quickly and specifically diagnosed molecularly on site – even without a laboratory.

apl. Prof. Dr. Susanne Bailer

MACHINE LEARNING FOR ALGAE CULTIVATION

Microalgae produce a variety of interesting ingredients and are therefore an ideal source for food, feed, cosmetics and fine chemicals. Although the basic mechanism of microalgae growth has been well studied, there are only a few mathematical models that can be used to model microalgae growth. Such models are particularly important for the large-scale cultivation of microalgae and serve as a basis for a robust, predictive control system. An essential component of this system are algorithms that enable automated optimization of microalgae growth. So-called machine learning has been widely used for prediction and optimization in different areas. To predict the growth behavior of the microalgae *Phaeodactylum tricornutum* in outdoor cultivation, so-called Support Vector Machines (SVM) were used. The results show that the SVM-based model can predict the growth rate of *Phaeodactylum tricornutum* with a correlation coefficient of 88%. At the same time, a model with Monod kinetics yields a correlation coefficient of 82%. These two models will be further validated on both laboratory and pilot scale in order to establish a model-predictive control for microalgae production.

Introduction

The needs of climate and environmental protection as well as the growing world population contribute to the fact that our economic system based on fossil resources, is reaching its natural limits. With the Paris Climate Change Convention 2015, the international community has adopted a consensus to reduce the emission of greenhouse gases and environmental degradation. One way to counteract these problems is the use of microalgae, which use carbon dioxide as a source of carbon in order to grow. Cultivation in aqueous media also offers the possibility of saving agricultural land.

Microalgae produce a variety of substances with high value-added potential such as health-promoting omega-3 fatty acids, carotenoids with antioxidant effects, pigments or polymeric storage substances. Therefore, they are an excellent sustainable source for the production of food, cosmetics, chemicals, pharmaceuticals and biofuels. Because of economic and ecological aspects, microalgae should be cultivated outdoors and on a large scale, using natural daylight as an energy source. The cultivation of microalgae was carried out at Fraunhofer IGB in so-called flat panel airlift bioreactors (FPA). The major challenge here is that no robust and proven fully automated control system for the algae reactors has yet been established [1]. This is mainly due to the lack of models that can control the algae growth and product formation in their cells.

The aim of the research work at Fraunhofer IGB is to introduce data-based algorithms – generated by machine learning methods – to control the cultivation of algae in order to develop an economical, ecological and robust algae production process on an industrial scale. To achieve this goal, we are developing data-driven models not only for efficient production of algal biomass but also for their intracellular products.

A reliable model will be developed that can well describe and predict algae growth for the automated and robust control of algae production processes. Data-based control is not yet widely applied to algae cultivation as in other areas such as fluid dynamics [2] and bioinformatics [3]. Most of the modeling of algae growth has been successfully completed at Fraunhofer IGB.

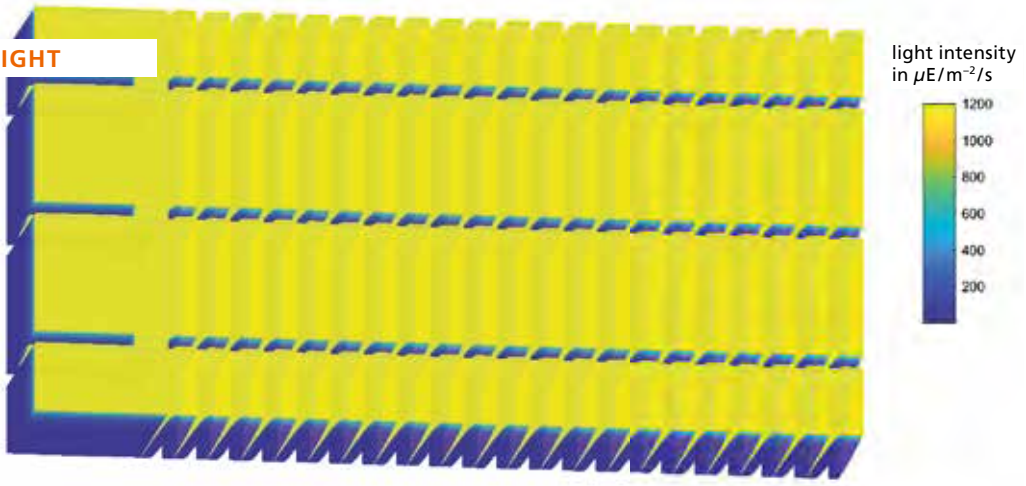
Concept and results

The modeling and control of the cultivation of microalgae is known to be more complex than that of bacteria or yeasts [1]. This is mainly due to its complex growth behavior and the lack of robust online monitoring methods for the growth of microalgae.

Improving monitoring of algae growth

The most popular method for monitoring the growth of microalgae is the OD (optical density) sensor, which measures the light adsorption, scattering caused by algae cells to calculate the biomass concentration. However, algae cells can change their size, shape and pigment content under different growth conditions, which has a major effect on the accuracy of measurements with the OD sensor. The other challenge in the cultivation of microalgae is the big difference of the growth behavior in the laboratory and outdoors, as the conditions for large-scale outdoor cultivation are much more complicated than in the laboratory. Therefore, our focus is on improving online monitoring and modeling of large-scale microalgae cultivation with data-driven methods.

To improve online monitoring, we are already optimizing the calibration of existing OD sensors with cultivation data under different conditions. However, OD sensors are very expensive and require an enormous investment for large-scale algae cultivation. For this reason, we are also developing other methods, for example using camera, RGB and soft sensors to estimate the biomass concentration. The goal is to develop a robust, cost-effective online monitoring system for the growth of microalgae with a minimum number of sensors in the cultivation system.



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Modeling of algae growth

Besides monitoring, modeling the growth of microalgae is a cornerstone for improving the productivity of a cultivation. To achieve the highest possible productivity, microalgae should be cultivated with high cell density. However, this also leads to the so-called "self-shading" effect of microalgae, which is very difficult to describe in a model. To overcome this challenge, we have simulated the light distribution in our FPA reactor based on the Lambert-Beer law, as shown in Figure 1. This simulation of the light distribution was then used in modeling with the Monod model, which provided a correlation coefficient of 82% for the prediction of algae growth in outdoor cultivation.

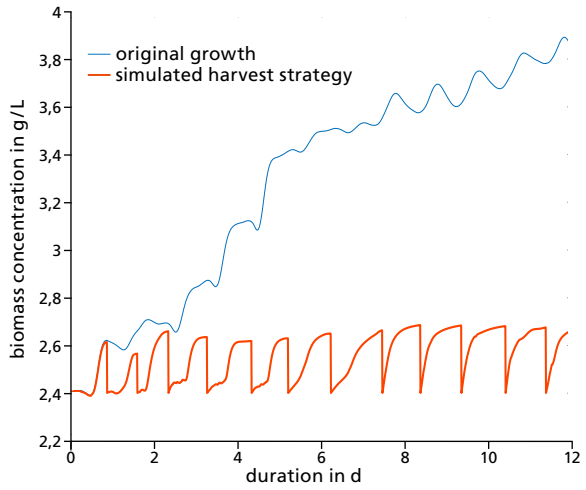
In addition, we used a machine learning algorithm called Support Vector Machine (SVM) to predict the algae growth rate with a correlation coefficient of 88%. Both SVM and Monod models can then be used to optimize the control of microalgae cultivation. The Monod kinetic model provides a better understanding of algal growth with biological sense, while the SVM model promises a better prediction. Therefore, we will combine the advantages of both methods in our future control system.

Algae cultivation with LEDs

In order to develop a control system for large-scale microalgae cultivation, a cultivation system using LED lighting is first being developed on a laboratory scale. Here, the optimal light supply is automatically adjusted with a control system based on the models and leads to better productivity and product contents. The advantage of LEDs is the possibility to achieve optimal lighting conditions the whole day, maximizing the use of whole reactor volume. On the other hand, the cost of LEDs has been greatly reduced, and electricity from renewable sources is also available to achieve sustainable production.

Optimization of the harvesting strategy

Another important aspect for cultivation is to optimize the harvest strategy. In outdoor cultivation, the harvest strategy should be dynamically adapted to the weather conditions. When light intensity is too high, we can increase the cell density in the reactors to protect algae from light inhibition conditions. On the other hand, we can harvest part of the algae biomass at low light intensity, so that all the algae cells will have more light available to growth. In this way, we can take full advantage of sunlight and still achieve the best productivity for the prevailing environmental conditions. An example of harvest strategy improved by our model is shown in Figure 2.



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Outlook

The work carried out so far shows the possibility of predicting algae growth under complex outdoor conditions with a SVM-based model. The final goal is to develop a predictive model for microalgae production. It is clear that our model has the potential to control and optimize algae production on a large scale. However, the biggest challenge is the lack of reliable and inexpensive online sensors to monitor the content of the ingredients in algae cells. Therefore, our next step is to analyze the content of the ingredients offline in the laboratory, and find the correlation to other available online measurements using mathematical methods. For example, a video camera or other optical sensors could be used for online detection of the color spectrum. A soft sensor can be developed with the online image data to estimate the concentration of the pigment in the cell using a machine learning model. Last but not least, the framework for using data-driven methods to optimize microalgae cultivation can also be applied to other bioprocesses, which means that our work is not only useful for microalgae, but also for other applications in biotechnology.

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1 *Simulation of light distribution in a FPA reactor.*
2 *Example of an optimized harvest strategy in outdoor cultivation. The blue line represents the original growth of microalgae without any harvest strategy, in which 1.2 g/L biomass is formed in 12 days. The orange line shows the amount and the timing to harvest microalgae, which produces 1.77 g/L more than the one without a harvest strategy after 12 days.*

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.

Fraunhofer IGB is actively involved in the development of:

- Innovative, nucleic acid-based diagnostic procedures, particularly in the field of high-throughput sequencing
- Materials for medical devices
- Human test systems for drug development
- Viral vectors and their production
- Quality-control systems for medical devices and drug development

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. Multicenter research trials are currently being 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. 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

Rounding off activities at Fraunhofer IGB is our work in the field of medical devices, which covers surface analytics and the development of **functional surfaces and materials**. Here, 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 conserving the material of the sterilization vessels.

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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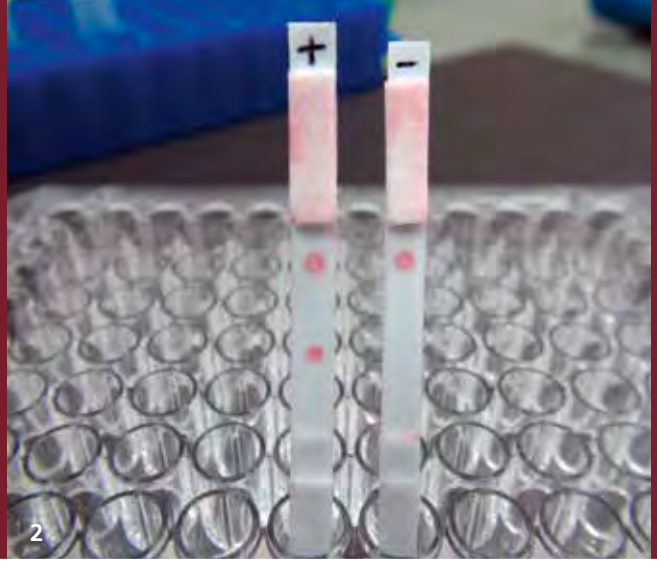

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Infection diagnostics 3.0

Reliable and timely diagnosis of pathogens in critically ill patients still poses major problems for intensive care medicine. Classical methods for pathogen identification usually are based on microbiological detection of the pathogen using so-called blood cultures with subsequent identification of the corresponding species using microscopic, biochemical or mass spectroscopic methods. Disadvantages of the microbiological approach are low detection rates and longer times required for an unambiguous diagnosis.

By establishing a diagnostic procedure based on high-throughput sequencing (NGS) of microbial DNA from circulation of patient blood, Fraunhofer IGB has already been able to establish a procedure for the reliable diagnosis of pathogens in the past, which has a detection rate five to six times better than that of culture-based procedures.

With the help of latest single molecule DNA sequencing technologies of the third generation (Fig. 1), this method has now been further developed so that real-time analysis of microbial DNA is already possible during sequencing. Consequently, the identification of pathogens can be reduced to six to eight hours. Thus, the reliability of sequencing-based diagnostics can be combined with the speed advantage of real-time analysis in order to provide patients with optimal antibiotic therapy as quickly as possible in the future.

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Development of a lateral flow assay for the nucleic acid-based molecular detection of pathogens

A lateral flow assay (LFA) is a rapid chromatographic test method. It does not require infrastructure or equipment and is therefore suitable for use in many applications as a point-of-care test (POCT). Chemical or immunological LFAs exist for some time, the best-known being the pregnancy test. However, there is still the need for the development of nucleic acid-based LFAs (NALFAs), which could pave the way for the molecular detection of pathogens at the point-of-care. NALFAs would enable the rapid implementation of specific therapeutic measures and inhibit further spread of pathogen.

In cooperation with the High-Performance Center for Mass Personalization, researchers in the innovation field of Virus-based Technologies have now developed a NALFA to detect herpes simplex virus (HSV-1) as proof of concept. To this end, the genomic DNA of the virus was specifically amplified by means of a polymerase chain reaction and modified for detection in an LFA. Here, modification of the genome target sequences and their hybridization with the immobilized and complementary capture DNA generates a color signal that indicates the presence of the specific pathogen (Fig. 2). Based on these results, further developments are conceivable, including isothermal amplification of the pathogen genome as well as the parallel detection of several pathogens on one strip. The aim is to create a fast, device-independent POCT for the detection of pathogens, which can be used in regions with poor medical infrastructure.

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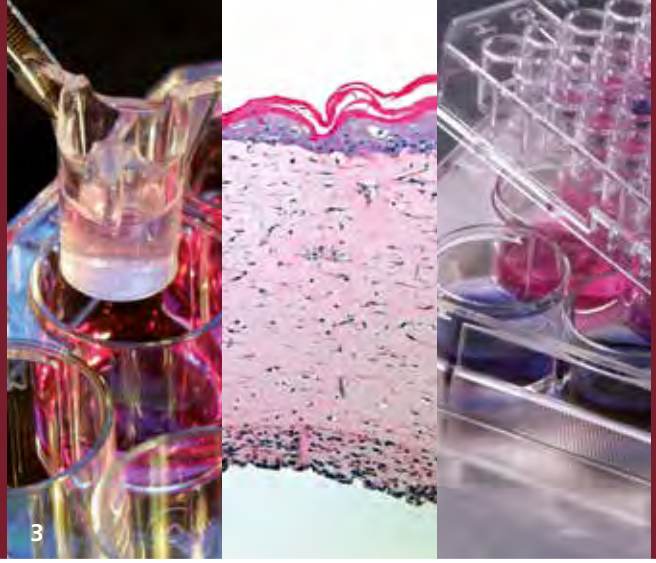

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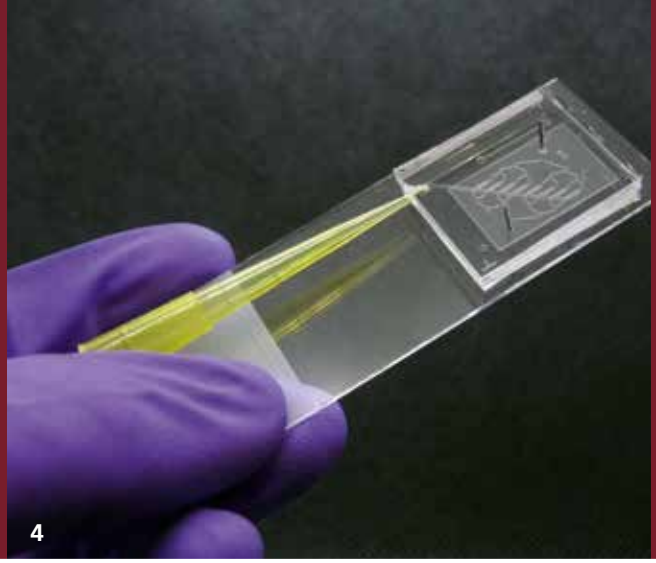

4

Development of test systems to screen for psoriasis therapeutics using bicyclic genetically encoded libraries

The incurable, inflammatory skin disease psoriasis affects 2 percent of the world's population. Therapies have significant side effects such as systemic weakening of the immune system or limited patient response. Toll-like receptors (TLR) of the innate immune system play a key role in inflammatory skin diseases. For example, keratinocytes show increased TLR expression in psoriasis. In the Psobibi project, TLR antagonists for topical application are identified, synthesized and validated as an alternative to systemic psoriasis treatment.

Screening of libraries requires the individual testing of substances. In this project, a genetically encoded fragment-based platform technology from the company 48Hour Discovery is used for screening for peptides that bind to multiple TLRs. These phage libraries comprise more than 10^9 linear and cyclic peptides, which are screened simultaneously and in competition to each other via cell-based TLR reporter gene assay (EP 2 041 172) and via a cell-free system at Fraunhofer IGB. Thus, TLR-binding peptides can be found in just one procedure and identified by phage coding using deep sequencing.

Hit peptides are provided by EMC microcollections GmbH and their antagonistic effect is validated at the IGB via the cell-based reporter gene assay. These antagonists will be investigated with human 3D *in-vitro* skin models complemented by TLR overexpressing reporter gene skin cells (EP 2795318A1) and psoriasis biopsies in topical application (Fig. 3).

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Centrifugal heart-on-chip (HoC): A versatile platform for cardiac µ-tissue generation and analysis

Despite considerable research efforts, cardiovascular diseases still constitute a major cause of death. Novel biological breakthroughs such as the emergence of human induced pluripotent stem cells (iPSCs) and the generation of engineered cardiac tissue models offer immense potential for pharmaceutical R&D as well as precision medicine. Current model systems, however, require large amounts of cells and rely on complex cell injection protocols, hampering the adoption of the technologies and fulfillment of their promises.

We have developed a centrifugal heart-on-chip (HoC) platform with the potential to be a widely-applicable, user-friendly tool. The platform allows for a parallelized generation of cardiac µ-tissues, mimicking a minimal functional unit of the heart muscle. It is based on simple centrifugation steps utilizing basic infrastructure present in all cell culture laboratories (Fig. 4). The HoC provides a physiologically relevant *in-vitro* model which can be utilized for drug testing or disease modelling. In the next project stage, we will integrate read-out capabilities for the in situ determination of contractile forces and electrophysiological parameters as well as introduce external stimuli to improve tissue maturation.

All in all, the novel centrifugal HoC represents a fit-for-purpose system which can be used by any laboratory and tailored for each specific application. This downscaled physiological model system offers unprecedented opportunities in cardiovascular research harnessing the true potential of iPSC technology.

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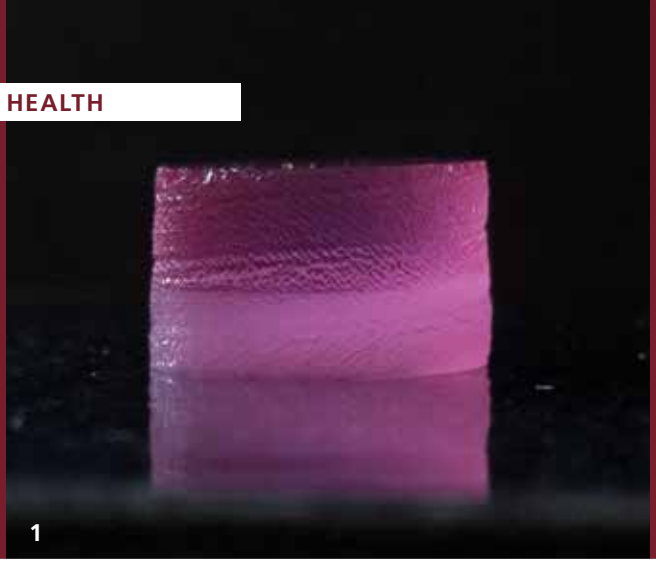

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Hybrid hydrogels – Personalized regeneration of cartilage tissue

There is great interest in personalized therapies for the treatment of injuries or age-related degeneration of cartilage tissue. The aim is the creation of customizable, biobased cartilage implants that is matched to type-specific requirements such as weight and physical agility of the patient and support the formation of new cartilage. In order to realize such cartilage replacement materials, gait analyses were carried out in the Dyna Implant project by Fraunhofer IPA and the necessary physical properties of the tissue replacement to be implanted were simulated biomechanically.

Fraunhofer IGB produced gelatin-based hybrid hydrogels that simulate the natural tissue environment of cartilage cells and thus promote the biofunctionality and matrix production of the cells. An additive process was developed to combine hydrogel solutions with a gradient of cartilage-specific proteoglycans to form a biomimetic zonal hydrogel (Fig. 1). The cell-containing hydrogels were produced with a mechanical strength of up to 170 kPa and subsequently cultivated under dynamic compression in a bioreactor designed by the IPA.

The fixation of the tissue equivalents to the natural tissue represents a further challenge in the treatment of cartilage defects. To bond the developed cartilage materials to the biological tissue, the hydrogel surfaces were modified and achieved initial adhesion both with and without commercial tissue adhesives. The active principle was the application of surface modifications with blood coagulation-promoting properties.

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We combine BIOLOGY and ENGINEERING ...

... by engineering viruses at the genome level. In this way, we can program tailor-made viruses and viral platform vectors for therapeutic use and produce them biotechnologically, for example to combat cancer.

apl. Prof. Dr. Susanne Bailer

... by culturing human tissue cells in an artificial, microphysiological environment. The functionality of the organs is reproduced in our organ-on-chip systems, as we demonstrate with beating heart or seeing retinal tissue, amongst other examples. This makes them suitable for non-clinical screening of pharmaceutical drugs, cosmetics and chemicals as well as for basic biomedical research and personalized medicine – leading to a reduction of animal testing.

Jun.-Prof. Dr. Peter Loskill

... by combining high-throughput DNA sequencing and bioinformatics. This enables innovative, novel diagnostic platforms – Next Generation Diagnostics.

Dr. Kai Sohn

SUSTAINABLE CHEMISTRY

Our focus

Faced with increasingly stringent environmental regulations, international competition and the introduction of 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 synthesis processes that are highly efficient – in terms of both energy and resources – and based on renewable raw materials, biogenic waste materials or carbon dioxide, coupled with intelligent solutions for work up the resulting products.

Fraunhofer IGB is active in the development of:

- Pretreatment and fractionation processes for raw materials
- Industrial biotechnology processes for selectively converting materials by means of enzymatic or fermentation processes
- Chemocatalytic, electrochemical and electrobiological processes and their combination with biotechnological processes
- Power-to-X processes for the utilization of regenerative produced redox equivalents in synthesis processes
- Customized thin films and functionalized surfaces

Fraunhofer IGB is helping to drive the transformation of the process industry, especially in the chemicals sector, and contributes to all four segments of the bioeconomy: food, animal feed, sustainable chemical products and bioenergy (see the Environment business area).

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 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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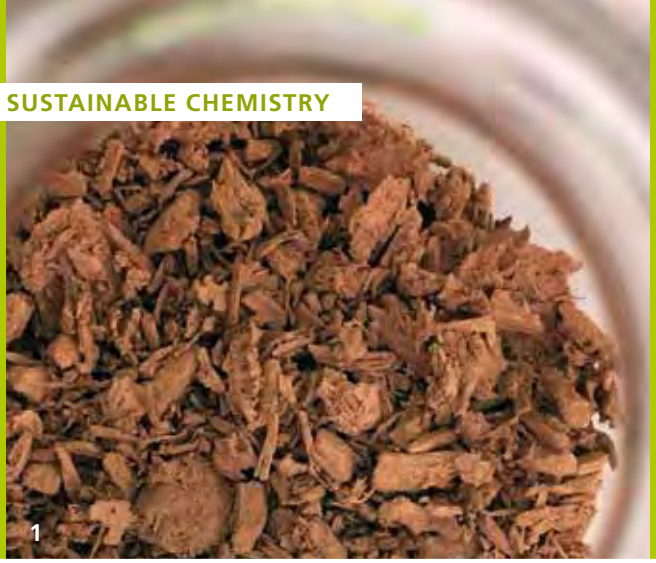

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Scale-up of cellulase production to 1 m³ scale

The organosolv process developed at Fraunhofer CBP produces cellulose (Fig. 1), which can be enzymatically cleaved by cellulases into fermentable sugars. In order to increase the economic efficiency of the overall process, a fermentation process was developed and scaled to obtain cellulases from *Penicillium verruculosum*. This allowed cellulase production to be integrated into the overall process, avoiding the cost-intensive use of commercial enzymes.

P. verruculosum cellulases are not yet available on the market and are characterized by an increased level of β-glucosidases. β-glucosidases are more effective in splitting smaller oligomers such as cellobiose, which leads to higher sugar yields.

The fermentation process was developed in cooperation with the Saxon Institute for Applied Biotechnology e. V. (SIAB). After the successful establishment of cellulase fermentation on the 40 L scale at SIAB, the scaling up to 1 m³ was carried out at Fraunhofer CBP. The sterile, batchwise addition of cellulose as a solid material and its mixing represented the greatest challenges. A comparable productivity was achieved when the scale was increased. It was also shown that the cellulase produced is very well suited for the enzymatic hydrolysis of beech wood cellulose. In addition, a higher sugar yield of approx. 25% compared to commercially available cellulases (CTec 2) was demonstrated.

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High-value products from beech wood

The company HV-Polysaccharides GmbH & Co. KG developed a hydrothermal extraction of xylan from beech wood chips (Fig. 2) at lab scale, which is now scaled up to the 500-liter scale at the lignocellulose biorefinery pilot plant at Fraunhofer CBP within the XyloSolv project. The further aim of the project is the combination of this aqueous extraction with Organosolv pulping for total utilization of all wood components. The sequential processing allows the production of high purity xylan and lignin which makes them potential feedstock for pharmaceuticals or food supplements.

Process development and optimization already lead to a significant reduction of ethanol required for the xylan isolation from the aqueous extract compared to the lab procedure. Both hydrothermal extraction and downstream processing were improved and allow efficient production of larger quantities of xylan for application tests.

Further efforts are being made in optimizing the hydrothermal extraction and especially the process combination to improve resource and energy efficiency. Simultaneously, a production facility is being designed in cooperation with HV-Polysaccharides GmbH & Co. KG and Glatt Ingenieurtechnik GmbH. Hence, after the successful end of the project, the first industrial biorefinery based on beech wood is to be realized.

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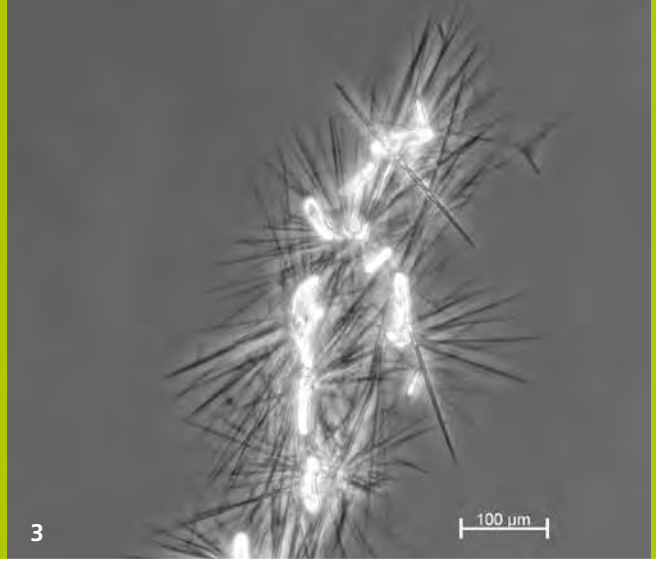

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SurfGlyco – Improved strategies for the biotechnological production of tailor-made biosurfactants

Surfactants are surface-active molecules that are used in large quantities in numerous products. Market studies postulate a global annual consumption of up to 20 million tonnes by 2021. In the cosmetics and personal care market, in particular, consumer awareness of the use of biobased products has increased. Therefore, companies have already established chemically synthesized surfactants based on renewable raw materials. However, the rather unsustainable production of most of the oils needed for their manufacture requires alternatives, which have been investigated in the SurfGlyco project.

Fraunhofer IGB focused on the optimization of the microbial production of biosurfactants from sugars as the sole carbon source. After selecting microorganisms that synthesize so-called cellobiose lipids (CL), the fermentation process was optimized and transferred to a bioreactor system to provide CL samples for application tests conducted by the project partners. Beyond that, we established methods for product recovery that either use non-toxic solvents such as ethanol or do not use organic solvents at all. Our partners have made progress in using CLs in indicative prototype formulations. The work opens up the possibility of using CLs as multifunctional additives in cosmetic or personal care products. This is due to their ability to disperse lipophilic and hydrophilic substances in oil and water. Furthermore, the CLs showed potential as emulsion stabilizer and thickener. This points to future broad applicability in formulations of various kinds.

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BioDiMet – Selective sustainable methylation for a diversity-oriented synthesis of bioactive substances

Development of a sustainable method for the synthesis of novel bioactives will help to meet demand in the various markets of the pharmaceutical, agrochemical and fragrance/aroma industries. BioDiMet is an ERA CoBioTech project. Its objective is to develop a modular and robust methyltransferase toolbox that can be used for the selective synthesis of novel bioactives for pharmaceutical applications. For this purpose, Fraunhofer IGB is developing chemoenzymatic cascade reactions involving S-adenosylmethionine (SAM)-dependent methyltransferases (MTs) combined with a cofactor supply system. This method of synthesis follows the biosynthesis strategy from nature and is therefore ideal for use in conjunction with biobased molecules. By contrast, the use of conventional synthetic methods of methylation is not particularly practicable under similar conditions. The BioDiMet project is being conducted by a leading global consortium comprising seven expert teams from five countries. This work comprises three technology platforms: the synthesis of novel methyl acceptors, the development of new methyltransferases and the provision of SAM analogues.

To date, the project has demonstrated new reaction cascades, developed dozens of new methyltransferases, established a rapid analytic method for methylation reactions and synthesized novel methyl acceptor substrates for pharmaceutical applications. These various modules will now be combined in order to set up an exclusive methyltransferase toolbox for use in industry.

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Added value through innovative thermal treatment of lignocellulosic residues

The industrial use of residual materials offers great opportunities for a circular economy if the residual materials are processed to sustainable products using innovative processes. Critical factors for the utilization of lignocellulosic residues include material quality, stability, storage and energy density. Therefore, Fraunhofer IGB has developed an innovative thermal process that offers an efficient way of treating residues and allowing at the same time the production of green chemicals.

In an atmosphere of superheated steam and in the absence of oxygen, wood-based material is treated at temperatures of 220–300°C. The existing moisture is first removed by evaporation, after which first the hemicellulose and then some of the cellulose and lignin decompose. The purposes of torrefaction are to increase the mass-related energy density, enlarge the transport and storage capability as well as reduce the technical effort in subsequent grinding or pelleting. The resulting solid product is considered an ideal additive fuel for power plants with pulverized coal firing or as a raw material for biorefineries for the production of chemical products.

The volatile components that arise during torrefaction can be separated and used as raw material for the production of basic chemical building blocks. In the Valorkon project, we are developing processes to valorize the resulting chemicals such as acetic acid, furfural, 5-HMF or methanol (Fig. 1). The technology can also be used for various solid residues such as solid manure, fermentation residues or sludge.

www.igb.fraunhofer.de/torrefaction

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Insect biorefinery: Utilization of chitin, fats and proteins

Currently, some representatives of the insect kingdom are being bred commercially under controlled conditions in order to obtain different product streams. Especially the commercially produced insect proteins have great potential as an alternative to soya protein and are already used as fish feed, for example.

Fraunhofer IGB is pursuing the concept of an insect biorefinery in which all material flows after insect breeding are used to create value. In the ChitoTex project, we were pioneers with regard to the chitin purification from insect skins (Fig. 2). We have succeeded in producing high-purity chitosan, using it as a sizing agent to protect yarns during weaving in the textile industry. Insect fat is a local source and contains medium-chain fatty acids providing an alternative to tropical fats such as coconut fat or palm kernel oil. Furthermore, the fats extracted from the larvae could be successfully used for the production of mannosylerythritol lipids, microbially produced biosurfactants.

In future, Fraunhofer IGB would also like to exploit the insect-based protein, for example for the production of protein films, in order to provide a biodegradable alternative to synthetic plastics. Thus, a sustainable insect biorefinery concept is realized by a holistic use of insect-based products, such as protein, fat and chitin.

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SusPackaging – Sustainable production of polyhydroxyalkanoates (PHA) for packaging materials

Plastic pollution and accumulation of microplastics in the oceans are increasingly gaining public awareness and spurring the cosmetic and food industries on to meet the demand for environmentally responsible packaging concepts. Thus, SusPackaging aims to initiate a green value chain for the production of biodegradable, biobased packaging materials. Polyhydroxyalkanoates (PHA) are biodegradable biopolymers that have properties similar to conventional plastics. PHAs are naturally produced by bacteria as intracellular storage granules that serve as a source of carbon and energy and may comprise up to 90% of the cell dry weight. Currently, high cost of production and downstream processing results in PHAs being uncompetitive compared to conventional oil-derived polymers.

During this project, Fraunhofer IGB has evaluated the production of different PHA molecular variants through selection and isolation of microorganisms able to transform sustainable carbon sources like methane from the biogas production, sugars derived from cellulose and hemicellulose from forestry and agricultural residues, and glycerol resulting from biodiesel production. Additionally, a highly efficient, solvent-free downstream processing approach is being developed. The use of pressure change technology (PCT) and supercritical fluids for cell disruption and material recovery has been adapted for this application (Fig. 3). The physical-chemical properties of the materials obtained, correlation to key quality requirements, and a life cycle potential analysis are being studied in cooperation with our project partners.

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Functional ingredients from algae for health-promoting food and as plant strengthening agent in viticulture

The MIATEST project deals with the production of functional ingredients from diatoms and their application in different areas. At Fraunhofer IGB, the production of the ingredients as well as their extraction and purification are optimized.

In the field of microalgae cultivation, the cultivation conditions significantly influence the composition of the biomass. For example, the chrysolaminarin content can be increased from $<5\%_{w/w}$ to $>30\%_{w/w}$ by adjusting the cultivation conditions. Together with the State Research Institute for Viticulture and Fruit Growing, the application of chrysolaminarin as a plant strengthening agent in viticulture is being tested. The aim here is to find an alternative to existing copper-based fungicides against fungal diseases. The University of Hohenheim is carrying out experiments on the application of the microalgae biomass in the field of human nutrition. Apart from chrysolaminarin, these experiments are mainly focused on the pigment fucoxanthin and eicosapentaenoic acid, an omega-3 fatty acid.

Fucoxanthin, in particular, has led to considerable interest in the industry, as it shows antioxidant, anti-inflammatory, anti-cancer and weight-reducing properties. At Fraunhofer IGB, a process for obtaining highly pure fucoxanthin (>90%) has already been developed in another project.

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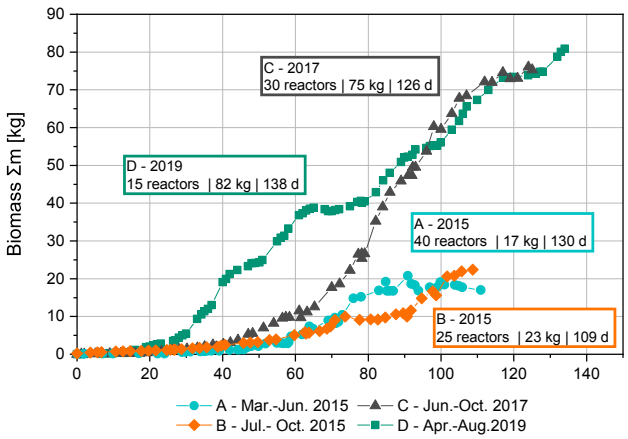

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Evaluation of a biorefinery approach for the production of fucoxanthin and EPA with microalgae

The overall objective of the FuTuReS project is the economic and ecological characterization of a process for the co-production of the carotenoid fucoxanthin (Fig. 1) and the omega-3 fatty acid eicosapentaenoic acid (EPA) with the diatom *Phaeodactylum tricornutum* on an industrial scale in Germany.

For this purpose, the microalgae were previously cultivated photoautotropically in flat-panel airlift photobioreactors (FPA) at Fraunhofer CBP in Leuna. The intended evaluation is based on existing, empirical process data. It should take into account not only potential value-added chains for the use of recycling and nutrient-rich streams of residual materials, such as nitrogen, phosphate, and CO_2, but also the supply of surplus electricity from biogas and photovoltaic plants in agriculture. Especially when there is a lack of light, e.g., at night, the excess energy can be used in particular for additional artificial illumination to significantly increase biomass productivity in photobioreactors.

P. tricornutum is a diatom that, due to its cultivation conditions, is particularly suitable for phototrophic production in Central European latitudes. Its high EPA, fucoxanthin, and protein content ensures a very high added overall value.

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Scale-up of microalgae-based processes and customized production of functional ingredients

For the production of tailor-made microalgae biomass of *P. tricornutum*, a diatom containing significant amounts of laminarin as the major storage product, a two-stage process was developed at Fraunhofer IGB and established at the Fraunhofer CBP pilot plant facilities in Leuna, Germany. Laminarin is an energy and carbon storage molecule in *P. tricornutum* and is of interest for the application in the food, feed and agricultural sector as it has immunomodulatory properties. In the first stage, biomass was produced under optimum growth conditions. In the second stage laminarin accumulation was induced by N-limitation starting with 5 g dry weight per liter (DW/L) and the final harvest concentration was achieved at 10 g DW/L. Under these nutrient deprived conditions, not only biomass concentration doubled but laminarin accumulated up to 25%$_{w/w}$ of dry weight. The biomass contained also >1% fucoxanthin and >3% EPA. After harvesting, fresh culture media was provided to a small amount of culture and the cycle started again. The culture recovered after every subsequent cycle even in spite of 10 days in disadvantageous conditions. For this two-stage process, an accelerated scale-up strategy was established starting in a 30 L flat panel airlift reactor (FPA) with artificial illumination. This pre-culture was transferred to a novel 900 L (5 × 180 L FPAs) modularized greenhouse reactor composite and then transferred to a final production volume of 2700 L in additional 10 × 180 L FPA reactors outdoors for a long-term production experiment. From April to September over 80 kg biomass were produced with half the production volume compared to previous experiments with an average productivity of 0.4 g/L*d (Fig. 2).

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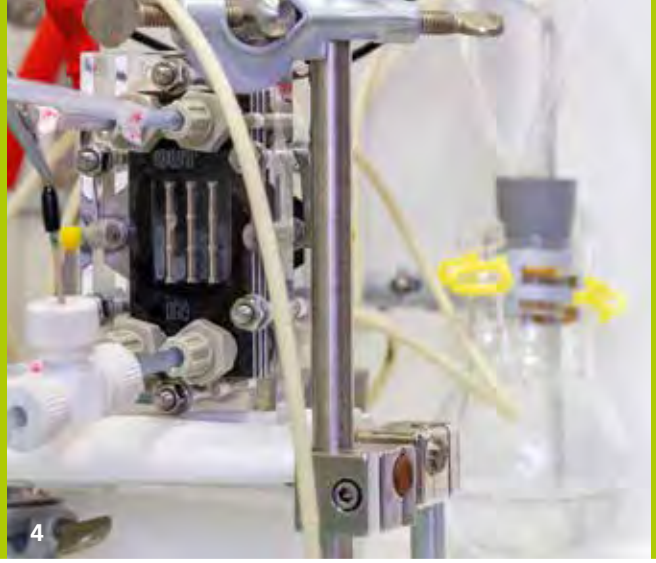

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CELBICON – Coupling electrochemistry and biotechnology to convert CO_2 into value-added chemicals

The development and deployment of processes to utilize the greenhouse gas carbon dioxide (CO_2) will be a central building block of a future climate-neutral and resource-efficient circular economy. Researchers from Fraunhofer IGB have developed and validated such a process chain in collaboration with partners from academia and industry in the course of the EU-funded project CELBICON.

Adsorption of CO_2 from air (direct air capture, DAC) is the first process step, achieved in a pilot plant provided by project partner Climeworks (Switzerland). The captured CO_2 is then converted electrochemically into formic acid. For this step, Fraunhofer IGB has developed tin-based electrocatalysts and a phosphate-buffered electrolyte. Furthermore, Fraunhofer IGB has designed and constructed an automated demonstration plant (Fig. 3) featuring an electrolytic cell from project partners Gaskatel (Germany) and Hysytech (Italy), in which the electrochemical conversion of CO_2 captured from air into formic acid could be tested in a relevant operational environment. In the CELBICON project it was also demonstrated that electrochemically generated formic acid can be applied as substrate in a fermentation process to yield a product from the terpenoid metabolism. A fed-batch process at 10 L scale has been developed, enabling promising biomass yields based on optimized operational parameters. Product purification was successfully established, and it was demonstrated that 14% of the fed formic acid can be converted into a terpenoid dye.

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Synthesis of hydrogen peroxide in an electrochemical cell

Hydrogen peroxide (H_2O_2) is an important chemical product. At present, 95% of the world's annual H_2O_2 production of about 2.2 million tonnes is based on the anthraquinone process – a costly method and impractical for routine on-site application at small scale.

An alternate synthetic pathway is the electrosynthesis of H_2O_2, which is cost-efficient and applicable on both large and small scales. In collaboration with the University of Southampton, Fraunhofer IGB researchers recently published a review article describing various approaches to design and assess electrode materials for H_2O_2 electrosynthesis. One such approach is the partial reduction of oxygen (O_2) at cathodes featuring either noble metal alloys or doped carbon. Alternatively, H_2O_2 can be prepared by oxidizing water (H_2O), using efficient anodic catalysts based on metal oxides, such as $BiVO_4$, and other materials. The main challenge in the latter approach is to suppress the thermodynamically favored oxygen evolution reaction. As part of the EU-funded CO_2EXIDE project, the task of Fraunhofer IGB and project partners is to develop active and selective catalysts for simultaneously synthesising ethylene (C_2H_4) through cathodic reduction of CO_2, and hydrogen peroxide through anodic oxidation of water. Both products are used in a subsequent reaction step to generate ethylene oxide (C_2H_4O). Thus, the CO_2EXIDE approach enables the efficient production of three important platform chemicals – ethylene, hydrogen peroxide, and ethylene oxide – from the educts CO_2, water and electric energy, hence from abundant and entirely renewable resources (Fig. 4).

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SynLink – Synthetic e-fuels as a key enabler for sector linking

In power-to-X processes, surplus electricity from renewable energy generation is used for the electrochemical production of basic chemicals. The fundamental idea here is the substitution of molecules previously obtained from crude oil and natural gas in the chemical and refinery industries by chemically identical molecules which are obtained from CO_2, water and renewable energy. One such molecule is methanol, which is currently produced in Europe mainly by steam reforming from natural gas and is used e.g. as a fuel additive. A conversion of the upstream feed streams in methanol synthesis to renewable molecules would avoid 1.53 metric tons of CO_2 emissions per ton of methanol produced.

In the "SynLink" project, the entire value chain from synthesis gas production using H_2O, renewable electrical energy and CO_2 (from air adsorption) to the chemo-catalytic production of fuels to application tests of these fuels in enginge test stands (PKW) is being investigated for the first time both technically and economically and partially demonstrated on the Fraunhofer Leuna Electrolysis Platform ELP.

Within this project, Fraunhofer CBP is working on the further development of methanol synthesis from CO_2-rich synthesis gas, first on a laboratory scale (TRL 3) and and then with the process scale up in pilot plant (TRL 6) (Fig. 1). The integration of the Co-SOEC process with the methanol pilot plant will be investigated and its technological feasibility tested. Sample quantities of up to 500 liters are to be made available for application testing.

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Mixed matrix composite membranes for gas separation

So far, the industrial use of technical separation membranes has been largely limited to liquid filtration. The reasons for this are in particular inadequate separation properties and high membrane costs. Due to their inherent energy efficiency, membranes offer enormous potential for the separation of gases.

In the MEGA project, mixed matrix membranes were developed with great potential for gas separation. Microporous framework compounds (zeolites, MOFs) with defined pore sizes were embedded in polymer matrices and are therefore suitable for the separation of gas molecules by size exclusion. For this purpose, porous PVDF hollow fiber membranes were coated with appropriate polymer dispersions by continuous dip coating (Fig. 2). The layer thickness of the mixed matrix layer in the range from 500 nm to 5 µm could be controlled via the viscosity of the dispersion and the coating speed. The use of nanoparticular framework compounds (< 100 nm) is decisive for the quality of the layers. By controlling the layer thickness, only small amounts of material are required for the coating.

The mixed matrix membranes show improved separation properties compared to pure polymer coatings. The water vapor permeability of polyvinyl alcohol layers increased about almost 100 percent to 7000 barrers by adding SAPO-34 particles. By selecting suitable polymer-MOF combinations, the separation properties of the membranes can be adapted as for partitioning of carbon dioxide in waste gases.

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We combine BIOLOGY and ENGINEERING ...

… by complementing the toolbox of chemical synthesis with a bioinspired approach. In doing so, we provide unique access to new biobased substances and materials that are suitable for a wide range of technological applications.

Dr. Michael Richter

… through the material use of biogenic, regenerative resources for the synthesis of chemicals. In doing so, we can map entire value-added chains from laboratory to pilot plant scale and create the prerequisites for implementing climate-friendly synthesis processes in industry.

Ulrike Junghans

… by cultivating microalgae with bioprocess engineering know-how in photobioreactors to produce complex biological substances. Due to their functional properties, they are suitable as valuable food supplements or can be used as pigments in cosmetics.

Felix Derwenskus, Gordon Brinitzer, Dr. Ulrike Schmid-Staiger

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.

Fraunhofer IGB is active in the development of:

- Innovations and solutions in water management and water treatment
- Processes for generating biogas from organic waste and residues
- Solutions that recover and reclaim nutrients from wastewater, organic waste and residues
- Processes for drying/torrefaction of organic waste fractions to produce soil conditioners
- Separation processes on the molecular and atomic level for the recovery of precious metals, and rare earth compounds

With our biological and biotechnological developments, further empowered by the latest digital innovations, Fraunhofer IGB drives innovation in environmental technology and the industrial transformation towards a sustainable and circular bioeconomy.

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 drinking water 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 approaches. 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, Fraunhofer 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 important roles 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. We have key expertise in the **biological components of biosensors, the functionalization of sensor surfaces, analytics, automation and data analysis**.

Biogas

As one key source of **regenerative and dispatchable energy**, biogas is a key enabler in the transition towards a sustainable energy system. This is also because biogas can be stored for a long period of time, which means it can be used to generate power according to demand. 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 developments 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 wastewaters rich in phosphates. Its efficiency has been demonstrated at the pilot plant scale.

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Streets of the Future: Environmental Monitoring

As part of a complex urban structure, planning and designing street spaces for the future is essential, especially regarding its adaptation to climate change, urbanization, digitalization, resource scarcity and growing energy demand.

The aim of the "Future Streets" research project is to support municipalities in planning and implementation of resource-efficient model streets in a modern and efficient manner. For this purpose, future demands and the possible uses and requirements of the street space are evaluated from different perspectives (mobility, ecology, economy, social affairs, technology, infrastructure, governance). The two partner cities Ludwigsburg and Erlangen serve as real laboratories for testing this sustainable street design.

In the work package "Environmental Monitoring", Fraunhofer IGB supports the planning and piloting of the model streets (Fig. 1). We will determine pollutant concentrations in the air and in rainwater. The results will shed light on the interactions between pollutants in the air and in rainwater. With the help of sensors and information technology the effects of the innovations on the model streets will be evaluated. Particular attention will be paid to the use of street rainwater, aiming to develop a multiplication effect for the sensible use of rainwater.

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Morgenstadt Global Smart Cities

In recent years, the Fraunhofer Morgenstadt network has supported many developments in the field of Smart Cities, mainly in Europe. However, especially in the context of climate change, the challenges for urban development outside Europe are much greater. Due to different framework conditions, they also require alternative approaches compared to Europe.

For this reason, as part of the international climate protection initiative (IKI) of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), the methodology for the city analysis of the Morgenstadt City Lab is now being adapted to the conditions in emerging countries. In this context, the Morgenstadt City Labs will be carried out in the following three exemplary cities: Kochi (India), Saltillo (Mexico) and Píura (Peru). The aim is to use these analyses to identify potential actions for climate protection and adaptation to climate change in the three cities.

Fraunhofer IGB is involved here in the field of water supply, wastewater treatment and flood protection. It also manages the City Lab in Kochi, not least because of its many years of experience in India (see p. 27). In Kochi (Fig. 2) and Saltillo the two-week onsite assessments are scheduled for the first half of 2020. Here important parties from the respective cities are interviewed and initial ideas for measures are developed on the basis of a deeper understanding of the interdependencies in these cities.

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Process control of blue-green infrastructures in Leipzig

Leipzig is a growing metropolis; the development of further residential areas in the city center is therefore an important goal of urban development. However, structural redensification and the consequences of climate change (heat, heavy rainfall) place an enormous burden on the water and energy infrastructure. The city's parties involved are thus confronted with new planning and legal issues.

The BMBF-funded joint project "Leipzig Blue-Green – Blue-Green Quarter Development in Leipzig" is intended to show, using the example of the large-scale project "Eutritzscher Freiladebahnhof" (Eutritzsch Free Loading Station), how a runoff-free and resource-efficient urban quarter can be designed. Blue stands for water, green for plants as an element of urban infrastructure. The aim is to develop new, transferable blue-green technologies and planning tools as well as a sensor-based, robust process control.

Fraunhofer IGB is investigating how the combination of blue-green technologies can be controlled equally robustly and efficiently and how the operation and maintenance of the system architecture can be ensured sustainably. In this context, the IGB's experience in process automation and handling of measurement data can be transferred to the urban district level. In a first step, elements such as green roofs will be automated on the campus of the Helmholtz Center for Environmental Research Leipzig, e.g. by controlling the runoff based on weather forecasts. The results are then transferred to the planned quarter.

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Water reuse in agriculture – HypoWave project successfully completed

Since 2016, Fraunhofer IGB has been involved in the joint research project HypoWave, which investigates the extent to which treated municipal wastewater can be used in hydroponic plant cultivation for the production of high-quality vegetables or cut flowers. The developed processes have been piloted on a sewage treatment plant in Wolfsburg (Fig. 4) over three vegetation periods. In addition, various replication and implementation options have been analyzed and developed in case studies involving local stakeholders in Belgium, Portugal, Northern and Central Germany. In 2019, the results of Hypowave were shared with the professional community at several events. With the use of treated wastewater, two objectives can be achieved: the purification of wastewater, especially regarding nitrogen and phosphorus elimination, and optimal plant growth through good water and nutrient supply. Adequate quality management is necessary to ensure a good supply of micronutrients to the plants and to comply with microbiological hygiene requirements. For example, irrigation water should be sanitized using suitable disinfection measures, e.g. UV, ozone or membrane filtration. Opportunity windows for the implementation of the HypoWave concept are situations in rural areas susceptible to water scarcity and where the wastewater infrastructure has to be adapted or (re)developed. Water reuse can also be integrated into wastewater treatment plants that are planning a fourth treatment stage, and is suitable in principle for city expansions and new district buildings. In this way, conflicts over the use of water resources, which are becoming more acute due to climate change and overexploitation, can be defused.

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Reactor for the elimination of micropollutants in wastewater by oxidation

The degradation of man-made pollutants in low concentrations, so-called organic trace substances or micropollutants, is increasingly gaining priority in water treatment. In Switzerland, the corresponding expansion of larger wastewater treatment plants is already mandatory, in California and other industrialized regions it is partly implemented as a precautionary measure. In municipal wastewater treatment plants, activated carbon adsorption and ozone treatment are currently the state of the art for the removal of trace substances. For industrial wastewater streams, process water and private households, a wide range of other technologies are being researched and are finding their market under the respective legal regulations and requirements.

The oxidative degradation of micropollutants on a titanium dioxide catalyst (Fig. 1), activated by UVA-LEDs (light emitting diodes), has been investigated at Fraunhofer IGB on behalf of PMK Kunststoffverarbeitungs GmbH from Geisingen-Gutmadingen and compared with advanced oxidation using hydrogen peroxide and mercury UVC emitters – a classical AOP process. For this purpose, the performance of the catalyst was demonstrated first followed by optimization of the operating parameters. Volume flow, irradiance and oxidizing additives were varied according to the statistical design of experiment. The degradation of drug residues was demonstrated at the optimized operating point. The specific methods and the oxidation reactor of PMK Kunststoffverarbeitungs GmbH are now available at the IGB for degradation studies.

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NextGenBiogas – Flexible production of bioenergy can contribute stability for power grids

If biogas is to play an integral part in any future energy system, it is vital to find ways in which it can be produced on a flexible basis and thereby made available on demand. This will also help secure the viability of biogas as a renewable, biogenic source of energy.

The objective of the NextGenBiogas collaborative research project is to develop a flexible process for the production for biogas on demand for the purposes of flexible power generation. Use of bioengineering methods in a two-stage process will make it possible to ramp up methane production significantly more quickly than is possible with current technology and research. Instead of using the substrate or the actual biogas as an energy-storage medium, the energy is stored in the form of easily convertible organic acids – e.g. acetic acid – which are produced in the first stage of the two-stage biogas process. In parallel, the microbiome is being characterized by means of next-generation sequencing.

The project promises to bring the following benefits: optimization of biogas production, higher process stability, reduction of required gas storage capacity, increased security, and extra stability for the power grid. It will pave the way for a flexible production of bioenergy on demand.

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We combine BIOLOGY and ENGINEERING ...

... by optimizing the efficiency of biogas plants – i.e. the productivity of biogas-producing micro-organisms – through process engineering.

Dr. Brigitte Kempter-Regel

... through the use of microorganisms for the purification of wastewater. To this end, we develop efficient bio-engineering processes and combine them with a holistic understanding of systems, such as production processes and urban systems. In this way, we utilize wastewater and waste streams as resources – for generating purified water, energy and nutrients.

Dr.-Ing. Marius Mohr

... by assessing the hygiene status of technical surfaces or antimicrobial material surfaces with standardized microbiological assessment methods.

Bryan Lotz

INNOVATION FIELDS

FRAUNHOFER-GESELLSCHAFT

Research of practical utility lies at the heart of all activities pursued by the Fraunhofer-Gesellschaft. Founded in 1949, the research organization undertakes applied research that drives economic development and serves the wider benefit of society. Its services are solicited by customers and contractual partners in industry, the service sector and public administration.

At present, the Fraunhofer-Gesellschaft maintains 74 institutes and research units. The majority of the more than 28,000 staff are qualified scientists and engineers, who work with an annual research budget of more than 2.8 billion euros. Of this sum, more than 2.3 billion euros is generated through contract research. Around 70 percent of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Around 30 percent is contributed by the German federal and state governments in the form of base funding, enabling the institutes to work ahead on solutions to problems that will not become acutely relevant to industry and society until five or ten years from now.

International collaborations with excellent research partners and innovative companies around the world ensure direct access to regions of the greatest importance to present and future scientific progress and economic development.

With its clearly defined mission of application-oriented research and its focus on key technologies of relevance to the future, the Fraunhofer-Gesellschaft plays a prominent role in the German and European innovation process. Applied research has a knock-on effect that extends beyond the direct benefits perceived by the customer: Through their research and development work, the Fraunhofer Institutes help to reinforce the competitive strength of the economy in their local region, and throughout Germany and Europe. They do so by promoting innovation, strengthening the technological base, improving the acceptance of new technologies, and helping to train the urgently needed future generation of scientists and engineers.

As an employer, the Fraunhofer-Gesellschaft offers its staff the opportunity to develop the professional and personal skills that will allow them to take up positions of responsibility within their institute, at universities, in industry and in society. Students who choose to work on projects at the Fraunhofer Institutes have excellent prospects of starting and developing a career in industry by virtue of the practical training and experience they have acquired.

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.

Figures are for January 2020.

www.fraunhofer.de

Fraunhofer headquarters in Munich, Germany.

Cell and tissue technologies

On the one hand, the innovation field focuses on the development and establishment of human *in-vitro* test models such as organ-on-chip platforms, 3D tissue models and cell-based 2D assays. On the other hand, those models are applied for the preclinical testing of drugs, the determination of toxicity and allergenicity of, e.g., cosmetics and chemicals, as well as for clinical applications in personalized medicine.

The field of innovation has many years of expertise in the development of cell lines, for example to establish assays, the production of biologicals or the handling of (pathogenic) microorganisms. In addition, there is the interdisciplinary expertise and infrastructure for developing microphysiological organ-on-chip systems. Here, a wide variety of microstructuring approaches are combined with tissue engineering methods (based on stem and primary cells) to create physiologically relevant human tissue in microfluidic systems. An overarching focus is the integration of immune components into microphysiological tissues or reporter cell lines and the use of cell systems as biosensors.

Fields of activity and technologies

- Organ-on-chip models
- 3D skin models
- 2D cell assay and cell line development
- Customized microfluidic platforms
- Biosensors
- *In vitro* active substance and toxicity testing (GLP)

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In-vitro diagnostics

This innovation field of focuses on the establishment, development and exploitation of diagnostic procedures for biological and medical applications. Here, innovative methods of molecular biology, biochemistry and bioinformatics are developed, combined and applied.

The technology of high-throughput sequencing of nucleic acids (Next-Generation Sequencing, NGS) is one of the core technology platforms within this field of innovation. State of the art hardware infrastructure for automated sample processing, high-throughput sequencing and bioinformatic analysis of complex data is available. This enables the innovation field to offer complete workflows from sample (clinical, environmental, biotechnology, etc.) to molecular biological analysis (high-throughput sequencing) and bioinformatic evaluation from a single source.

Fields of activity and technologies

- NGS-based diagnostics
- Precision diagnostics and biomarkers
- Microbiomics
- Environmental genomics
- Bioinformatics

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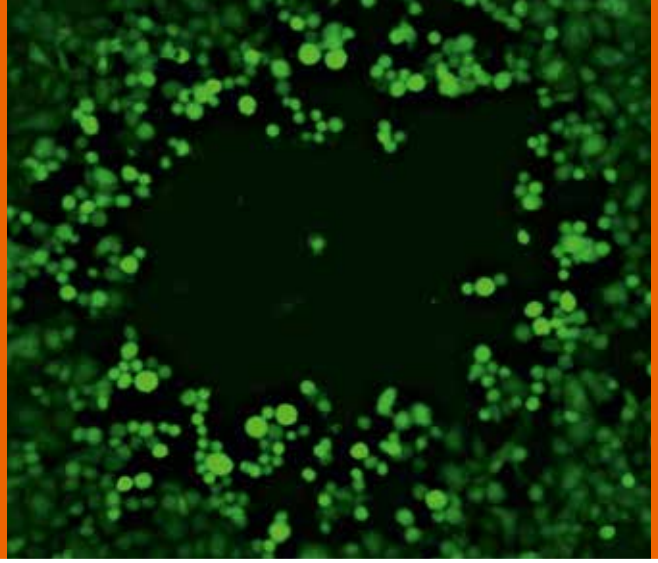

Virus-based technologies

The focus of this innovation field is on concepts and solutions for the use of viruses and phages for the targeted medical (prevention, therapy, diagnostics) or biotechnological application and biointelligent use. The services offered range from genome engineering to process development for the production of viral agents in lab-scale.

One focus is the development of viruses into therapeutic agents. Oncolytic viruses, for example, represent promising and innovative cancer therapies. In the innovation field, a viral platform based on Herpes Simplex Virus 1 (HSV-1) has already been developed. The ability of viruses/viral vectors to transport genetic information into cells and anchor it there can be used in diverse ways, e.g. for cell and gene therapy.

Bacteriophages are attractive alternatives for combating antibiotic-resistant bacteria and can be used in a variety of technological ways, for example for the production of antibodies, as biointelligent actuators and sensors in fermentation or for the degradation of biofilms. In addition, within the innovation field we are developing virus-like particles as vaccines and for targeted drug delivery.

Fields of activity and technologies

- Engineering of therapeutic viruses
- Oncolytic viruses
- Viral vectors (Cell and gene therapy)
- Phage technology
- Virus-like particles

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Functional ingredients

The innovation field focuses on the customized production and processing of functional ingredients from microalgae and bacteria for the production of food and feed, cosmetics, biostimulants and biobased polymers. Processes based on CO_2, methane and renewable resources are being developed for this purpose. By means of targeted process management, these processes can be transferred to pilot scale. For faster process development, new online analysis methods (real-time MS) and predictive models for control systems are used.

Furthermore, the focus is on processing technologies, such as the efficient extraction of carotenoids and omega-3 fatty acids with subcritical solvents and recovery of the individual components. New non-thermal processing methods (pasteurization and cell disruption) are used to obtain high-quality ingredients in food and contribute to a healthy diet. Thermal treatment (drying/torrefaction) of material flows with superheated steam and integration into a value-added chain will allow them to be processed more efficiently. Energy-efficient processes for the extraction of drinking and process water from air are designed for technical implementation.

Fields of activity and technologies

- Process development for customized algae ingredients
- Cell disruption and extraction with subcritical fluids
- Pressure change technology (PCT) for food
- Drying/torrefaction with superheated steam
- Sorptive water extraction from air
- Gas fermentation with methane
- Real-time fermentation analysis with MS

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Water technologies and resource recovery

This innovation field develops concepts, processes and technologies for purifying water and recovering valuable substances from water. Hygiene in drinking and process water and the associated water analysis play an important role in this. For water management, the innovation field develops comprehensive concepts, e.g. within the framework of the Morgenstadt City Lab. One focus is on international cooperation to develop and adapt solutions for emerging countries (e.g. South Africa, India, Brazil).

Our activities within this innovation field are not limited to the topic of water. As part of system solutions, we are developing technologies for the use of organic and recycling inorganic (waste) materials. We also use the electro-oxidative and reductive processes developed for water treatment in the electrochemical production of basic chemicals from aqueous solutions.

Fields of activity and technologies

- Water and wastewater treatment for municipalities and industry
- Recycling of waste and residual materials
  - Biogas
  - Nutrient recycling
- Digitization
- Electrochemical production of basic chemicals
- Interfacial biology

Membranes

Technical membranes can be used wherever mixtures of substances need to be separated. The core competences at Fraunhofer IGB are the shaping and the functional coating of membranes. In the innovation field Membranes, we develop both hollow-fiber and flat membranes using phase inversion processes, furthermore we are able to manufacture them from laboratory to pilot scale. In addition, we have established a wide range of roll-to-roll coating processes (wet chemical, plasma processes) to optimize the separation or fouling properties of membranes.

For the development of new membranes, we also have extensive know-how in material synthesis (polymers, ceramics) and the characterization of materials, surfaces and membranes. With the available test rigs we carry out application studies for our partners in the fields of activity listed below.

Fields of activity and technologies

- Humidifier membranes for fuel cells
- Hollow-fiber membranes made of mixed conducting ceramics
- Gas separation with mixed matrix membranes
- Osmosis membranes for FO, PRO, RO
- Filtration membranes (MF, UF, NF, membrane adsorbers)
- Ionomer membranes for electrolysis and fuel cells

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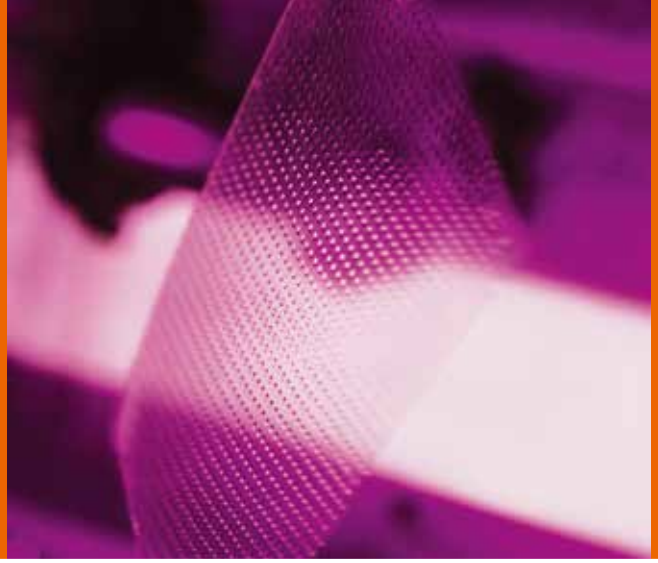

Functional surfaces and materials

The design of material and product surfaces to achieve defined target properties is in demand for many applications in the automotive industry, medical technology and diagnostics, textiles and packaging, etc. This innovation field gives surfaces of plastics, ceramics or metals new properties and offers solutions for applications that require a combination of different processes. In sensor coating, for example, the chemical modification of coating materials is combined with printing and plasma processes to apply functional layers.

In this innovation field, for the modification of surfaces we use and develop plasma processes from laboratory to roll-to-roll pilot scale, as well as coating processes from the gas and liquid phase. For material production, we have expertise in chemical synthesis and formulation. The innovation field has comprehensive analytical equipment for the characterization of surfaces, polymers and particles – for process control, quality assurance and damage analysis.

Fields of activity and technologies

- Materials and formulations
  - Modification of biopolymers/hydrogels
  - Encapsulation/particulate systems
  - Ink formulation for bioprinting
  - Formulation of coating dispersions
- Functional surfaces
  - (Bio)sensor surfaces
  - Anti-ice/anti-adhesion coating
  - Coatings for medical technology
  - Barrier coatings

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Regenerative resources

The innovation field of regenerative resources in the two working groups Biomass Fractionation and Chemical Processes deals with the development of innovative procedures and processes for the material use of regenerative resources (lignocelluloses, carbohydrates, oilseed, protein fractions, CO_2) for the production of renewable chemicals. Biogas and syngas also play an increasingly important role. With the existing know-how, a wide range of process steps for the development of processes from the laboratory (TRL 3–4) to the pilot plant scale (TRL 6) can be covered. This combines processes to investigate complete value chains from raw material supply and conditioning to the isolation of material flows and its chemical transformation as well as implemented processes for effective product separation and purification. Sample quantities from kilogram to ton scale can be provided. The techno-economic evaluation of the processes plays a decisive role in the implementation in biorefinery concepts. Together with partners, we conduct assessments that serve as the basis for further process and plant design on a demonstration or industrial scale.

Fields of activity and technologies

- Biomass fractionation
  - Oilseed biorefinery
  - Lignocellulose biorefinery
- Chemical processes
  - Biogenic epoxy resins
  - Added value of lignin
  - Electricity-based fuels and chemicals – Leuna electrolysis platform
  - Product separation and processing
  - Process and plant design

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Industrial biotechnology

The aim is to develop biotechnological processes for the production of biobased fine and platform chemicals for further processing in the chemical industry and in branches such as cosmetics, cleaning agents and plastics or adhesives. We primarily use monosaccharides, vegetable oils or other biobased extracts as raw materials for biotechnological conversion.

In this innovation field, we are concerned with screening for new, industrially usable enzymes and the optimized recombinant production of these enzymes. In addition, we use novel microorganisms as biocatalysts. Processes are optimized with regard to influencing factors of substrates and culture media components and adapted for scale-up. Thus, in addition to the development of processes, the transfer of the new process concepts from laboratory to pilot plant scale (10,000 liters fermentation capacity) can be optimized.

The fermentative production and liquefaction of gaseous products in an ATEX-compliant demonstration plant with over 1,500 measuring points is also possible. Due to the wide range of equipment, up- and downstream processes can be carried out promptly. The similarly constructed and well-characterized bioreactors allow the scaling of processes according to various criteria up to readiness for industrial use.

Fields of activity and technologies

- Bioprocess engineering
- Bioprocess scale-up
- Process demonstration isobutene

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Catalysts

Catalysts are indispensable and omnipresent in chemical industry and industrial biotechnology. They accelerate chemical reactions by reducing the activation energy, thus enabling the selective and efficient synthesis of products. The innovation field "Catalysts" is working on the development of chemical, electrochemical and biotechnological catalysts for the sustainable production of chemicals and fuels from renewable resources.

In so-called CCU processes (Carbon Capture and Utilization), carbon dioxide (CO_2) is converted by means of heterogeneous catalysis and electrocatalysis into C_1 intermediates, ethene and higher hydrocarbons. Furthermore, catalysts are developed for ammonia synthesis, reforming processes and the oxidative conversion of organic educts. The C_1 intermediates obtained, such as methanol or formate, are used as substrates in whole-cell catalytic processes for the fermentative synthesis of value-added products.

Fields of activity and technologies

- Catalysts for heterogeneous gas phase reactions
- High-throughput screening of catalysts
- Electrocatalysts and electrodes for cathodic and anodic reactions
- Coupling of chemo-, electro- and biocatalytic reactions in process cascades
- Metabolic engineering of microbial production strains
- Process development
- Feasibility studies for industrial process implementation

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Bioinspired chemistry

This innovation field researches sustainable conversion processes and is particularly concerned with the development of new synthesis and production methods for fine and specialty chemicals and for functional materials of the future. In doing so, we use biomolecular structures and synthesis principles to create new material properties.

The innovation field focuses on interdisciplinary approaches to synthetic and retrosynthetic strategies that combine chemical and biological aspects and thus lead to innovative manufacturing processes. The functionality of the products is evaluated on the basis of application requirements and optimized with regard to industrial use.

The aim of our activities is to expand the toolbox for sustainable synthesis by synopsis of raw materials, conversion methods and desired product properties. Thereby we want to achieve technological leaps towards "green" chemicals and novel functional materials.

Fields of activity and technologies

- Development of bioinspired synthesis routes
- Chemo-enzymatic synthesis
- Organic synthesis
- Biobased monomer and polymer synthesis
- Production and processing of biobased materials
- Transient, responsive, switchable materials
- Biodegradation of specialty chemicals
- Chemical analysis, material characterization and material testing

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