Fraunhofer
IGB

FRAUNHOFER INSTITUTE FOR INTERFACIAL ENGINEERING AND BIOTECHNOLOGY IGB

ANNUAL REPORT
2017 | 18

In the “Water Technology Center” commissioned in 2017, the institute develops and optimizes processes for the treatment of process water up to pilot scale. The demonstration plants or prototype facilities are also available for investigations in contract for customers.

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CONTENTS

DEAR READERS,

2017 was a year of major changes for Fraunhofer IGB. It had already been shown before that our Würzburg branch of the institute was able to make more and more use of the synergies with Fraunhofer ISC. In the first quarter we therefore decided to transfer the administrative part of the business to our sister institute, thus significantly optimizing the working methods in Stuttgart and Würzburg. In this regard, it was of course necessary to clarify which tissue engineering activities will remain in Stuttgart and which ones will be expanded in Würzburg. This process has been carried out and the integration of the Würzburg branch of the institute was successfully completed by the middle of the year.

At the same time, the appointment procedure for the management of our institute and the university institute was pushed ahead. It was initially unclear on the basis of the candidates whether we would focus more on the pharmaceutical or general engineering field. In October, it was decided that Dr. Wolperdinger would become director of Fraunhofer IGB from March 2018, thus strengthening the activities in the field of general process technology and bioeconomics. This development is also very well prepared with the commissioning of our technical center plants at the Stuttgart location in the first quarter of 2017. With these pilot plants, we were able to close a gap in our approaches to scaling processes, so that we now also offer process development up to pilot scale in Stuttgart. In particular, our "Water Technology Center" is gaining in importance here and is contributing to our ability to expand our activities in regions where water problems are already much more urgent than for us today. We are therefore negotiating with corresponding partners in India and South Africa; a joint project is already underway in Chile in this topic area.

Also in the autumn of 2017, Professor Schenke-Layland decided to run for head of the Natural and Medical Sciences Institute (NMI) in Reutlingen. As expected, she was selected immediately and will start there in April 2018. The question now was to what extent these developments, the handover of our Würzburg office and the departure of Prof. Schenke-Layland, influence the Tissue Engineering Department at IGB. We address this question by focusing on our topics in Stuttgart. Certainly some activities will be eliminated, but the three essential and particularly promising activities are not affected by this, and we will continue to expand them even further. These are firstly the activities with the organ-on-a-chip topic, i.e. effective cell-based test systems for investigating the effect of chemical substances from pharmaceuticals, cosmetics, the food industry and the environment on organ-like structures. Secondly, the development of further test systems based on cell compartments, such as our receptor-based pyrogen test assay.

The third activity is bioprinting in the field of biomaterials. In this context, three-dimensional structures are generated by printing processes, which enable the cells to settle in an optimized manner, since the biomaterial structures correspond to the extracellular matrix to a large degree. In individual cases, this matrix can be printed directly as "ink" with the cells.

In general, the interaction of material and cells is also a crucial aspect for the development of further medical devices, which we pursue in our Mass Personalization High Performance Center in Stuttgart. In the High Performance Center, which we started in October 2017, procedures and processes are being investigated for the mass production of personalized products. Various Stuttgart university institutes and the other Fraunhofer Institutes at the Stuttgart campus are involved. In terms of content, the focus is on products for the areas of mobility, residential sector and medical technology.

I would now like to thank you, our customers and partners, for the confidence you have placed in us and I am looking forward to working with you on projects that have already been started and, of course, to working together with you on new projects. I hope that this annual report will provide new impetus for further cooperation.

I look forward to working with you and to a lively exchange of ideas.

Christian Oehr
(Director (acting) from January 1, 2016 to March 31, 2018)

INTERVIEW WITH MARKUS WOLPERDINGER

With the appointment of Dr. Markus Wolperdinger as director of the institute, a two-year transition phase at Fraunhofer IGB comes to an end. He holds a PhD in chemistry and has many years of industrial experience. He is already very familiar with IGB being a member of the Board of Trustees since 2011 and its chair since 2014. Markus Wolperdinger will assume responsibility as director of the institute on March 1, 2018. In the interview he explains his motivation and goals.

Dr. Wolperdinger, you've known the institute for a long time. What connections to IGB did you have in the past?
I have many relationships to Fraunhofer IGB, which go back well before my time on the Board of Trustees. I still remember my first contact with IGB more than 15 years ago during discussions on patents that my company licensed from IGB at the time.

In 2006, I met Prof. Hirth at a conference in Munich, who was still working at Fraunhofer ICT in Pfinztal at the time. Then, I was responsible at InfraLeuna GmbH for the development of the industrial biotechnology at the chemical site in Leuna. I was looking for a partner for a new "process center" that I wanted to establish in Leuna. These discussions led to an intensive and very fruitful cooperation with IGB, which I continued when I moved to the Engineering Division of Linde AG in Dresden in 2011. There, I was initially responsible for business development of the Biotechnology Plant, and shortly afterwards I took over the management of the product line worldwide.

The cooperation with IGB resulted in several publicly funded projects and ultimately in the undertaking of the state of Saxony-Anhalt, several Federal Ministries and the Fraunhofer-Gesellschaft to establish and finance a center for "chemical-biotechnological processes" – today's Fraunhofer CBP in Leuna. Together with Linde, I was able to accompany the construction of CBP as general engineering contractor.

What motivated you to take over the management of the institute?
An essential aspect is that I already know IGB well from the joint activities in the past, my work on the institute's Board of Trustees and as a member of the Appointment Committee for the succession of the institute's management. I therefore know what the institute's potential is and how urgently a new leadership is needed. In addition, over the past few years I have already met and appreciated many of the employees of IGB and its branches. I am very much looking forward to shaping the future of the institute together with them.

Additionally, the field of industrial biotechnology, which plays an important role at IGB, is very close to my heart. Based on my professional experience, I am able to bring with me broad knowledge and, above all, an extensive industrial network. The other business areas of IGB, e.g. health as well as environment and energy are also highly exciting and have great potential, which needs to be leveraged.

After all, the management of a Fraunhofer Institute is a step that opens up new perspectives for me at the interface between applied research and industrial implementation of the results, which I did not have in industry. I am therefore looking forward to these new design possibilities and to the scientific challenge associated with establishing links with the university.

What are your priorities in terms of content?
I see it as an advantage that IGB has a broad technical and thematically diversified structure. In terms of content, I don't want to anticipate anything, because in the next few weeks I want to consult with the employees in order to identify the most promising areas.

It is very important to me that we set up the diverse range of applications integrally and interlink them with each other. This means that I want to define a concrete division of labor with the departments and parts of the institute so that the institute can offer the different dimensions of technological scale-up – from the laboratory to pre-industrial dimension. To this end, I would like to clearly define the institute's range of services in value-added chains and the resulting added value for industry. My goal is to achieve a unique selling proposition in the development and implementation of processes that competitors cannot offer in this way.

Which future topics bring new perspectives?
I see it as an important task to reconcile the global challenges and technological future trends with the thematic structure of IGB. One keyword here is digitization and what contribution the institute can make in this respect. Besides, I am addressing the following questions: How can we provide the growing world population with sufficient food and raw materials? How to ensure access to clean water? How to produce sustainably? At IGB, we are already very well positioned to make contributions here. In the field of medicine and health, it is essential to be able to manufacture individualized products at the cost of a mass product. The "Mass Personalization" initiative, which we are pursuing in the High Performance Center, is an important step towards achieving this goal.

Vita

Professional career
2012–2018 Head of Biotechnology Plants Division and Senior Manager Public Funding, Linde AG, Engineering Division & Linde Gas – Dresden, Pullach
2011–2012 Head of Business Development Biotechnology Plants, Linde Engineering Dresden GmbH – Dresden
2006–2010 Head of Relocation Management and Strategic Development Industrial Biotechnology, InfraLeuna GmbH – Leuna
2000–2006 Managing Director Munich Innovative Biomaterials GmbH – Marburg, Leuna
1998–2000 Director of Product Development, Innovative Lasers Corporation – Tucson, USA
1995–1998 Senior Research Scientist, Innovative Lasers Corporation – Tucson, USA

Education and academic background
1991–1995 PhD in the field of Physical Chemistry at the Ludwig-Maximilians-University of Munich
1985–1991 Study of chemistry at the Ludwig-Maximilians-University of Munich
1979–1982 Training as a state-certified chemical laboratory assistant

Where do you see challenges?
It is important to me that we as an institute have a clear idea of what concrete goals we want to achieve, in which areas of activity we pursue these goals and what we must do to achieve them. I want our employees to internalize the idea that we all pull together, and that we move in the same direction together and with each other. For me, the basis for this is an institutional culture based on mutual trust. I would like to achieve this.

FRAUNHOFER IGB IN PROFILE 2017

44 Doctoral students

19 Apprentices

14 BoGy high school students

120 Students

47% Proportion of women

417 Employees

76 University employees

25 Nationalities

3 Prizes and awards

8 Associate lecturers

341 Fraunhofer employees

62.4% Own revenues

€26.8 million Total budget

€2.3 million Investments

€13.6 million Personnel costs

€10.9 million Non-personnel costs

2 Branches of the institute

5 Departments

2 Fraunhofer Groups

10 Fraunhofer Alliances

21 Members of Advisory Board

PROFILE

INNOVATIONS AT INTERFACES

The Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB develops and optimizes processes, plants, products, and technologies for the business areas of health, chemistry and process industry as well as environment and energy. We offer our customers research and development (R&D) along the entire material value chain, complemented by a broad range of analysis and testing services. As a result, we are a strong partner for industrial enterprises and small or medium-sized companies in a wide range of industries, as well as for municipalities and special-purpose associations and for the EU, federal and state contract research.

Application-oriented and interdisciplinary

Our overriding goal is the translation of scientific and engineering research results into similarly economically efficient and sustainable processes and products for industrial application. Our strength lies in offering complete solutions from laboratory to pilot plant scale.

More than ever, the success of new products and processes depends on interdisciplinary and constructive cooperation between natural sciences and engineering. Experts in the fields of chemistry, physics, biology, and engineering work together effectively at Fraunhofer IGB, its branches at Leuna and Straubing and our partner institute at the University of Stuttgart, the Institute of Interfacial Process Engineering and Plasma Technology IGVP. Customers benefit from the synergistic and multidisciplinary potential at our institute, which facilitates novel approaches and innovative solutions in areas such as medical engineering, nanotechnology, downstream processing and environmental technology.

Competences

Departments in Stuttgart

- Interfacial Engineering and Materials Science
- Molecular Biotechnology
- Physical Process Technology
- Environmental Biotechnology and Bioprocess Engineering
- Cell and Tissue Engineering

Branches of the institute

- Fraunhofer Center for Chemical-Biotechnological Processes CBP, Leuna branch
- Bio, Electro, and Chemocatalysis BioCat, Straubing branch

Motivation

Through our research, we want to help find solutions for the pressing challenges of our society such as to provide a growing world population with food, water, raw materials and energy, as well as to improve medical care by patient-tailored approaches. Resource-efficient and sustainable processes, bioeconomy and biologization are the strategies we rely on.

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, 2017)

Dr. Susanne Arbogast

Dr. Gerd Eßwein
Freudenberg New Technologies SE & Co. KG

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

Prof. Dr. Matthias Frosch
Faculty of Medicine, University of Würzburg

MinDirig Dipl.-Ing. Peter Fuhrmann
Ministry of the Environment, Climate Protection and the Energy Sector of the State of Baden-Württemberg

Dr. Jürgen Gross
(since July 1, 2017)
Robert Bosch GmbH

Prof. Dr. Elke Guenther
(since July 1, 2017)
AIT Austrian Institute of Technology GmbH

Dr.-Ing. Bernd Krause
Gambro Dialysatoren 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. Michael Resch
Institute of High Performance Computing, University of Stuttgart

Prof. Dr. Dr. h.c. Ralf Riedel
Dispersive Solid Group, TU Darmstadt

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

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

MinR Dr. Joachim Wekerle
Ministry of Finance and Economics of the State of Baden-Württemberg

Dr. Günter Wich
Wacker Chemie AG

Prof. Dr. Karl-Heinz Wiesmüller
EMC microcollections GmbH

Dr. Wieland Wolf
ProBioGen AG

Dr. Markus Wolperdinger
(Chair)
Linde AG

Permament guests

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

Prof. Dr. Dieter Jahn
(Chair 1999–2013)

SERVICES AND INFRASTRUCTURE

Fraunhofer IGB is a research and development partner for customers from the business and public sector. In our business areas, we develop, implement and optimize processes, products and systems as well as new technologies – from feasibility studies and initial laboratory tests to technical and pilot plant scale, including deployment. Our R&D is accompanied by a broad range of analysis and testing services.

Quality management and assurance systems

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 standard. Our quality assurance system ensures that the statutory guidelines of Good Laboratory Practice (GLP) are complied with.

Accredited testing

The accreditation of reference laboratories and test procedures of our analytics according to DIN EN ISO/IEC 17025 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.

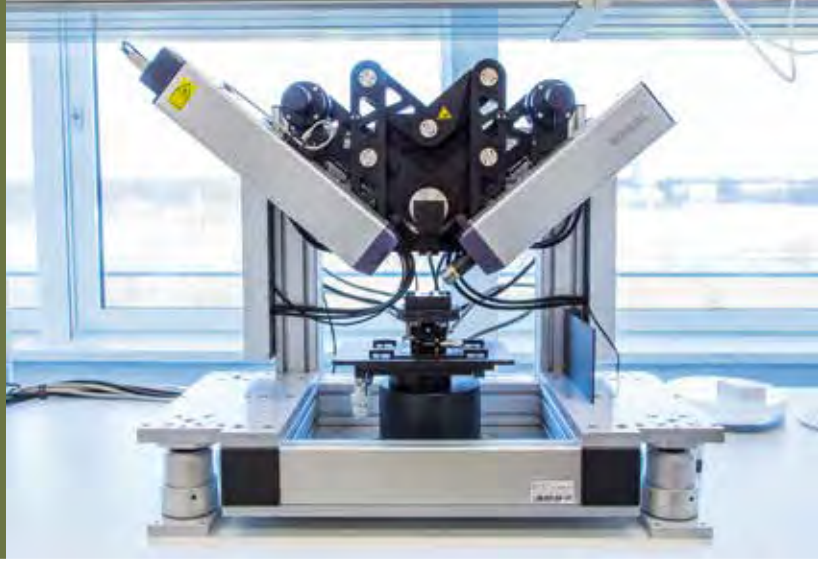
Accredited analytical methods and test procedures:

- High-performance liquid chromatography (HPLC)
- Ion chromatography (IC)
- Gas chromatography (GC, GC/MS)
- Atomic emission spectrometry (ICP-OES)
- Electron spectroscopy for chemical analysis (ESCA/XPS)
- *In vitro* cytotoxicity testing (DIN EN ISO 10993-5)
- *In vitro* phototoxicity testing

With our in-house method for *in vitro* testing of phototoxicity, we can investigate solutions and substances with respect to their phototoxic potential on our in-house designed three-dimensional skin model. The test method is in accordance with the OECD Guideline 432 and the INVITTOX Protocol no. 121.

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 the 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, as well as detection of pyrogens and microbial residues (pathogen-associated microbial patterns, PAMPs).



Infrastructure and laboratory equipment

Cutting-edge technologies and 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.

Spectrum of services

Process, technology and product development

- From laboratory to technical and pilot scale
- Design, construction and demonstration of pilot plants and prototypes
- Implementation of new technologies
- Licensing of technologies and processes

Studies and consultancy

- Feasibility studies and technology analyses
- Profitability studies and life cycle assessment

Analysis and testing services

Our broad range of biological and physical/chemical examination methods makes the institute a versatile partner in the fields of medicine and pharmacy, food production and chemistry as well as environmental and water analysis.

Physico-chemical analysis

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

High-resolution 400 MHz NMR analysis

Molecular structure elucidation, reaction monitoring, low-temperature analysis

Surface and particle analysis

Characterization of chemical, physical and morphological properties of surfaces, thin layers, powders, and particles

Microbial evaluation

Testing of antimicrobial effects and photocatalytic properties of surfaces

Biochemical and biomolecular analysis

Diagnostic microarrays, protein expression profiles, protein analysis using MALDI-TOF/TOF mass spectrometry (also quantitative)

Next-generation sequencing

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

Cell biology analysis

Cell characterization, flow cytometry, laser scanning microscopy

Cell-material interactions

Testing of cytotoxicity/biocompatibility of R&D materials and industrial products, assessment of phototoxicity of substances and solutions

For detailed information on our analysis and testing services:

www.igb.fraunhofer.de/analytics

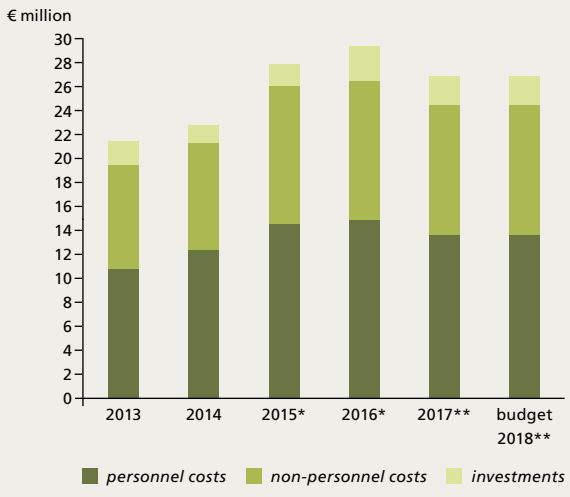
KEY FIGURES

Budget of Fraunhofer IGB

The total budget for 2017 amounted to €26.8 million, of which €24.5 million were allocated to the operational budget (personnel costs: €13.6 million; non-personnel costs: €10.9 million). A total of €2.3 million was spent on investments.

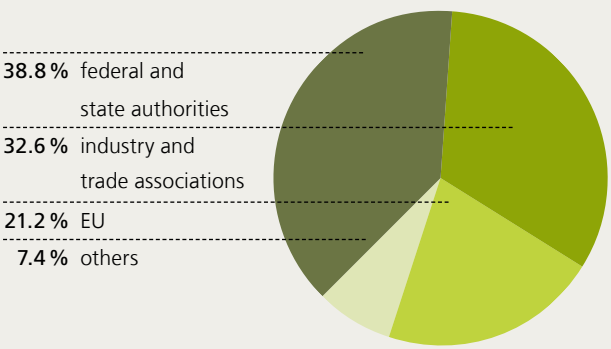
62.4 percent of the operational budget was financed from Fraunhofer IGB's own revenues generated from contract research projects. 32.6 percent of the institute's revenues came directly from industry.

Development of budget



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

Revenue from contract research 2017



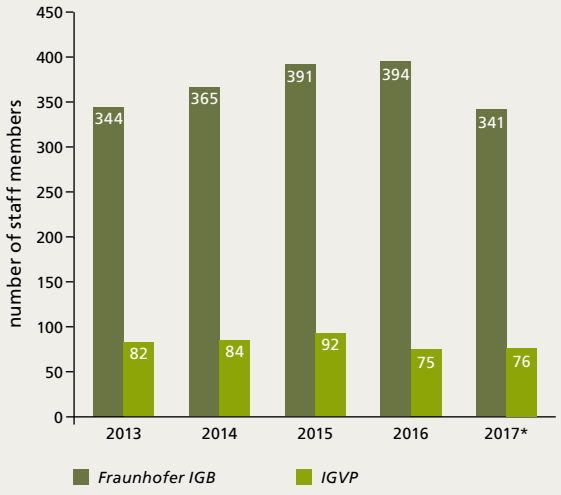
Personnel

At the end of 2017, Fraunhofer IGB (in Stuttgart and its branches in Straubing, and Leuna) had a staff of 341 of which some 90 percent were scientific or technical employees. Women made up 50 percent of the total.

The Institute of Interfacial Process Engineering and Plasma Technology IGVP at the University of Stuttgart counted a staff of 76 as of December 31, 2017, predominantly scientists and doctoral students as well as technical staff and student research assistants. Women constituted 32 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 26 staff members coming from 25 different countries outside Germany.

Development of staff members



* since 2017, without Translational Center, Würzburg branch

Staff composition as of December 31, 2017

	Fraunhofer IGB	IGVP
Scientists	82	16
Technical staff	90	10
Doctoral students	3	27
Administrative and secretarial staff	31	5
Apprentices	11	8
Scholarship holders	8	6
Work students/Master students/student apprentices	48	–
Student research assistants	68	4
	341	**76**

ORGANIZATION CHART

Director (acting until March 31, 2018)

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Director (acting since March 1, 2018)

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Deputy Director

apl. Prof. Dr. Steffen Rupp
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- Particle-based Systems and Formulations
- Plasma Technology and Thin Films
- Polymeric Interfaces and Biomaterials

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Dr. Kai Sohn
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- Infection Biology and Array Technologies
- Functional Genomics
- Molecular Cell Technologies
- Industrial Biotechnology

FRAUNHOFER CENTER FOR CHEMICAL-BIOTECHNOLOGICAL PROCESSES CBP, Leuna branch

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Dr. Moritz Leschinsky
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Dr. Daniela Pufky-Heinrich
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- Biotechnological Processes
- Chemical Processes
- Pretreatment and Fractionation of Renewable Feedstocks

BIO, ELECTRO AND CHEMOCATALYSIS BIOCAT, Straubing branch

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Phone +49 9421 187-300
volker.sieber@igb.fraunhofer.de

Dr. Michael Hofer
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michael.hofer@igb.fraunhofer.de

- Biocatalysis – Catalyst Design and Process Development
- Chemical Catalysis and Electrochemistry – Catalyst Design and Process Development

PHYSICAL PROCESS TECHNOLOGY

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Dr. Ana Lucía Vásquez-Caicedo
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analucia.vasquez@igb.fraunhofer.de

- Heat and Sorption Systems
- Physico-chemical Water Technologies
- Nutrient Management
- Aseptic Technologies
- Prototype Development

ENVIRONMENTAL BIOTECHNOLOGY AND BIOPROCESS ENGINEERING

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Dr. Iris Trick
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- Technical Microbiology
- Bioprocess Engineering in the Water Sector and Circular Economy
- Accredited Analytics

CELL AND TISSUE ENGINEERING

In vitro Test Systems
Sibylle Thude
Phone +49 711 970-4152
sibylle.thude@igb.fraunhofer.de

Attract Group "Organ-on-a-Chip"
Jun. Prof. Peter Loskill.
Phone +49 711 970-3531
peter.loskill@igb.fraunhofer.de

- *In vitro* Test Systems and Implants
- Attract Group "Organ-on-a-Chip"

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. Hence, Fraunhofer IGB maintains close contacts with neighboring universities in Stuttgart and Tübingen, both through scientific cooperation and through professorial or other teaching commitments of Fraunhofer employees. In addition, our branches in Straubing and Leuna have enabled us to extend our scientific network to locations outside of Stuttgart.

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 joint operations.

We are also networked with numerous other universities, 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 2017, the research budget accounted for €2.64 million. At the end of that year, a staff of 76 scientific, technical and administrative employees, among them 27 doctoral students, worked at the institute. In addition, 40 students have completed their master or bachelor thesis at the IGVP.

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apl. Professor Dr. habil. Günter Tovar
Director (acting)
Phone +49 711 970-4109
guenter.tovar@igvp.uni-stuttgart.de

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, 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 Building Innovation Alliance
  www.bau.fraunhofer.de
- Fraunhofer Big Data Alliance
  www.bigdata.fraunhofer.de
- 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. Examples of IGB's involvement are the current Fraunhofer lighthouse projects "Critical Rare Earths" and "Electricity as a Raw Material" and those successfully completed in 2017 such as "Theranostic Implants" and "E^3-Production".

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 2017

PROJECTS

Stuttgart gets High Performance Center **1**
"Mass Personalization" –
Personalized products at an affordable price

In October, the Minister of Economic Affairs of Baden-Württemberg, Nicole Hoffmeister-Kraut, announced the launch of the High Performance Center as a joint initiative of the Fraunhofer Institutes IPA, IGB, IBP and IAO, the University of Stuttgart and numerous industrial partners in the region. The center investigates interdisciplinary and cross-sectoral methods, procedures, processes, product systems and business models for the manufacture of personalized products.

The concept of "Mass Personalization" describes a reorientation of product development, which leads from the development of a holistic user understanding to the seamless implementation in personalized product and service innovations – with costs that are hardly higher than those of mass-produced products. The project will run for 2.5 years with a total project volume of €12.5 million. In addition to the state of Baden-Württemberg, Fraunhofer also contributes €2.5 million.

The "Mass Personalization" process chain is being worked on in three pilot projects in each case with specific application scenarios from the areas of needs health, mobility and housing. Fraunhofer IGB and its partner institute IGVP at the university are involved in two of these pilot projects. In the field of "Personalized biomechanical assistance systems", IGVP and IGB research together to develop novel implant materials. Their surfaces are to be equipped with functional properties using additive manufacturing processes such as inkjet printing.

The pilot project "Personalized therapeutic products" deals with concepts and the implementation of quality assurance, logistics and production technologies in the "mass personalization" process chain. IGVP and IGB are working closely together to develop, for example, a novel detection system for microorganisms and their inflammatory components. The system is supposed to function on the basis of human immune receptors and without a time-consuming laboratory blood test. Further research work focuses on faster and quality assured medical sampling as well as faster diagnostics by organ-on-a-chip systems without animal testing.

ZIM cooperation network PerFluSan
Perfluorinated surfactants –
New remediation processes and alternatives

In November 2017, the ZIM cooperation network "PerFluSan", funded by the German Federal Ministry of Economics and Energy (BMWi) as part of the Central Innovation Program for SMEs, started. The network, which is coordinated by ifectis Innovationsförderung and currently consists of eight SMEs and six research institutions, has two central objectives: Firstly, new, effective remediation processes for soil and wastewater contaminated with perfluorinated surfactants (PFT) are to be developed. Secondly, alternatives to fire extinguishing agents containing PFT are to be investigated in order to prevent the introduction of pollutants into the environment. Because in firefighting, the use of fluorine-containing extinguishing agents is still relied upon today.

1

PEOPLE

Ivan Tolpe Award for Dr. Jennifer Bilbao

On February 9, 2017, Dr. Jennifer Bilbao received the Ivan Tolpe Award for her work within the framework of the EU joint research project BioEcoSIM. The award is presented every two years by the Flemish Coordination Centre for Manure Processing for pioneering innovations in manure processing. As BioEcoSIM project coordinator, the IGB scientist accepted the prize in Gent, Belgium. Within the scope of the project, 14 project partners from four European countries developed a novel process for the production of fertilizers and soil conditioner from manure.

Top young scientist: Awards for Dr. Svenja Hinderer

2017 was a very successful year for IGB scientist Dr. Svenja Hinderer: For her research on a novel artificial heart valve, the biomaterials expert was selected from two renowned lists of the best. In June, the innovator magazine "Technology Review" included her in their list of top ten "innovators under the age of 35". With this award, the journal honors outstanding young scientists in the fields of natural sciences, engineering and computer science. She won a second award in November: The Capital magazine voted Hinderer into this year's "Top 40 under the age of 40". This list of the best of the young elite in Germany includes particularly outstanding talents from the fields of business, research and society.

Dr. Susanne Bailer obtains Professorship at the University of Stuttgart

By appointing Dr. Susanne Bailer as an *außerplanmäßiger* professor, the University of Stuttgart honors the committed teaching and research work of Dr. Susanne Bailer. After her postdoctoral lecturing qualification at Saarland University in the faculty of biochemistry and molecular biology and after an intermediate position at the Ludwig-Maximilians-University of Munich, she joined Fraunhofer IGB in 2012 as a private lecturer at the University of Stuttgart. Since then, she has been working very successfully as a group manager at both institutes. At the University of Stuttgart, she teaches mainly in the fields of human and animal pathogenic viruses and infection biology. At Fraunhofer IGB, she is dedicated to the development and application of technologies for the diagnosis of infectious agents. Another focus is on the engineering of oncolytic viruses for the development of an immunotherapy of cancer.

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INTERNATIONAL

EU projects

Horizon 2020 is the European Union's eighth Framework Programme for Research and Innovation and, at the same time, the world's largest integrated research and innovation program with almost €80 billion in funding for the period 2014–2020. In 2017, Fraunhofer IGB received confirmation of its participation in three H2020-EU projects, including one coordination project. In addition, at the end of the year we received the good news that two further project proposals had been selected for funding. The results of other project proposals are still pending.

New projects in section I "Excellent Science"

ORCHID

For the first time, Fraunhofer IGB is participating in a FET Open project. ORCHID is a coordination and support action that is creating a roadmap for the further development of organ-on-a-chip technology. The six participating European research institutions are conducting research with the aim of establishing a European infrastructure to facilitate the coordinated development, production and implementation of organ-on-a-chip systems.

IBISBA 1.0

Since October 2017, Fraunhofer IGB and 15 other European partners have been developing a concept for a pan-European research infrastructure with the aim of accelerating future innovations in the field of Industrial Biotechnology and Synthetic Biology. The long-term goal is to define a European "Industrial Biotechnology Innovation and Synthetic Biology Accelerator" and to make it available for first use by selected industrial customers.

New projects in section II "Industrial Leadership" 1

CO_2EXIDE

The project "CO_2EXIDE – CO_2-based Electrosynthesis of Ethylene Oxide", coordinated by Fraunhofer IGB, was launched on January 1, 2018. Its aim is to develop a combined electrochemical-chemical technology for the production of ethylene oxide from biobased CO_2.

Completed projects from the 7th Research Framework Programme 2

In 2017, a number of projects from the 7th Research Framework Programme were successfully completed. These include the EnReMilk project coordinated by Fraunhofer IGB.

Outlook

Fraunhofer IGB is working intensively on project applications for the last work program of Horizon 2020 and will continue to be a reliable partner in a large number of EU projects. Our first Horizon 2020 project SteamBio will also be completed in 2018.

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

www.igb.fraunhofer.de/eu-projects

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Kiwi Cooperation with SCION in New Zealand

Together with the internationally renowned New Zealand Forest Research Institute, SCION for short, one of New Zealand's eight Crown Research Institutes, Fraunhofer IGB is looking into an innovative biobased future. Both research institutions share the goal of making research and science more effective and efficient for industry and society. With a start-up financing from the New Zealand Catalyst Fund, scientists of both institutes with a research focus on the forestry sector and wood processing industry want to develop new ideas for the utilization of tree bark in biorefineries and to plan joint research projects.

Prior to the signing of a cooperation agreement in spring 2017, several meetings were held in which the competencies of the partners involved were analyzed and initial concepts for ideas were formulated. Representatives of SCION were also able to present this promising recent cooperation to the German Federal President Frank-Walter Steinmeier who, at the beginning of November, made a state visit to New Zealand in the course of a trip to Asia.

India's focus on clean water 3

With its project "Smart Water Future India", Fraunhofer IGB intends to develop a sustainable and intelligent solution for the design of fast-growing cities using the southern Indian city of Coimbatore as an example. The complex challenges of urban development are to be dealt with as an overall concept, thus reducing competition for scarce resources at an early stage.

One aim of the project is to develop specific recommendations for action for urban decision-makers in order to improve the situation regarding water supply and wastewater disposal in a sustainable manner. A further goal is to enable German companies in the water sector to gain access to the Indian market for water and wastewater management, thereby paving the way for long-term partnerships between German and Indian companies. The sustainability of the project will be ensured by a Water Innovation Hub to be established in Coimbatore. The project has been funded by the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) since the beginning of October 2017.

Young scientists go Down Under

Science and research are international. No journey was too far for the young scientists Ilka Mühlemeier and Felix Derwenskus, who are both doing their doctorates at the IGVP at the University of Stuttgart. Both used their scholarships from the "BBW ForWerts" graduate program, part of the Bioeconomy Baden-Württemberg research program, for a five-week study stay at the University of Queensland in Australia. In line with their research priorities, they visited various research institutes, where they and local colleagues in their special field of work were able to explore ideas for future joint projects.

Mühlemeier was a guest at the School of Civil Engineering, where she deepened her expertise in technical microbiology by collaborating with Dr. James Strong, who also conducts research in the field of methanotrophic bacteria at the University of Queensland. Derwenskus studied at the School of Agriculture and Food Sciences in Brisbane. There he met with international colleagues in the working group for algae biotechnology headed by Prof. Peer Schenk to exchange views on the cultivation of microalgae, which can be used to produce chemical raw materials – among other things for the pharmaceutical, food, animal feed and cosmetics industries.

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TRADE FAIRS AND EVENTS

Fraunhofer IGB's research topics are as diverse as the trade fairs and events at which the institute presents itself in order to promote the process of technology transfer into practice. We present a selection of events organized by Fraunhofer IGB or in which the institute has participated.

Science and art in dialogue: Water – Resource of Life

The science year 2016/17 was themed "Our seas and oceans". The Fraunhofer-Gesellschaft also took up this guiding principle in the series of events "Science and Art in Dialogue". The participants of the event on March 13, 2017, for example, discussed the topic "Water – Resource of Life" at the Fraunhofer headquarters in Munich. Fraunhofer scientists, including IGB head of department Dr. Ursula Schließmann, and the artist Stefan Wischnewski talked about their views on ecological aspects in dealing with our oceans.

Business meets Science: Industrial process water treatment and wastewater treatment

Fraunhofer IGB offers a wide range of technologies for the treatment of chemically and biologically contaminated process wastewater from various industrial sectors. As part of the series of event "Potentials – Business meets Science" organized by the Stuttgart Chamber of Industry and Commerce (IHK), IGB experts showed on May 10, 2017 how biological and chemical-physical processes as well as adsorption and membrane processes are developed, optimized and combined for different applications. Using practical examples, they were able to demonstrate how water can be treated more efficiently and economically.

Inauguration of Technical Center: Room for scaling on an industrial scale 1 + 2

The scaling of processes is a central concern for a process-oriented institute such as IGB. After a construction period of several years, Fraunhofer IGB and Fraunhofer IPA were able to move into their new Technical Center at the beginning of the year. The modern new building now houses laboratories and technical centers, in which IGB conducts research and development work in the areas of food and medical technology, process water treatment, and sludge and wastewater treatment and is able to represent processes on an industrial scale. For the research location of Stuttgart, Fraunhofer therefore provides further important infrastructures to promote future innovations for the region, the state of Baden-Württemberg, Germany and Europe. After moving in, the building was officially inaugurated in the summer with a ceremony.

20th Colloquium on wastewater and waste treatment "Technology with a future"

In October 2017, Fraunhofer IGB hosted their colloquium on wastewater and waste treatment for the 20th time. Under the motto "Technology with a future", experts from IGB and research partners discussed the latest developments in wastewater technology, e.g. on aspects such as the energy efficiency of sewage treatment plants or new ways of using purified water and resulting biomethane. In particular, the focus was on the trend topic "Water 4.0", i.e. the potential of digitization in the water management sector.

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Open Day at Schwarzwaldmilch: Saving energy with microwaves

Together with partners from research and industry, Fraunhofer IGB has researched a new technology platform to preheat high-viscosity dairy products by using microwaves. In November 2017, the consortium was able to show the pilot plant developed in the project together with a live demonstration to interested parties from the food industry. Since the use of microwave technology significantly reduces fouling and cleaning costs in pasteurization systems, time, energy, water and costs can be saved. The presentation was held as part of an "Open Day" at the Offenburg plant of Schwarzwaldmilch GmbH, which was involved in the development as a project partner.

Phosphorus – A critical raw material with a future 3

The annual Phosphorus Congress of Baden-Württemberg deals with the technical possibilities and market mechanisms for the recycling of phosphorus from wastewater, sewage sludge and sewage sludge ash. In November 2017, the congress visitors were also able to take part in a field excursion to Fraunhofer IGB. After the presentation of various plants and concepts for wastewater treatment and nutrient recovery in Stuttgart, the participants visited the PhosKa pilot plant for the recovery of phosphorus from manure developed by IGB at the project partner in Kupferzell, a town in Franconia in Germany.

Current exhibitions

We look forward to seeing you at our stand.

Analytica
April 10 – 13, 2018, Munich

Leuna-Dialog
April 26, 2018, Leuna

IFAT
May 14 – 18, 2018, Munich

ACHEMA
June 11 – 15, 2018, Frankfurt am Main

PSE
September 17 – 21, 2018, Garmisch-Partenkirchen

parts2clean
October 23 – 25, 2018, Stuttgart

formnext
November 13 – 16, 2018, Stuttgart

International Green Week/nature.tec
January 18 – 27, 2019, Berlin

Energy Storage
March 12 – 14, 2019, Düsseldorf

For further information and current events see:

www.igb.fraunhofer.de/events

1

PROMOTION OF YOUNG TALENTS

Fraunhofer researches on behalf of the future. In order to achieve this goal, we want to ensure today that intelligent talents will continue to contribute their knowledge and skills to Fraunhofer in the future. Fraunhofer IGB and the Fraunhofer Institute Center Stuttgart are committed to promoting young talent and held numerous events in 2017 to inspire young people for a career at Fraunhofer. The aim is to spark pupils' interest in MINT subjects (mathematics, informatics, natural sciences and technology) at an early age and to open up career prospects for students in applied research.

Fraunhofer Talent School 1

In March 2017, Fraunhofer Talent School enabled students aged 15 and over to gain an in-depth insight into the working world of researchers at Fraunhofer. Within the framework of the Talent School, the Stuttgart institutes offer three-day workshops every year in which the guests can try their hand at various scientific papers. The main focus is always on practical relevance. Fraunhofer IGB participated with the workshop "CSI Stuttgart": In this context, the Functional Genomics working group of the Molecular Biotechnology Department presented students with the task of solving an exciting criminal case. Using saliva samples from the suspects, the 10 participants were allowed to carry out a molecular characterization to create a genetic fingerprint that would enable the conviction of the suspect.

www.stuttgart.fraunhofer.de/talents

Girls' Day

Girls' Day is a nationwide day of action to encourage young girls and women to pursue careers in MINT professions that were once considered classic male domains. The German Federal Ministry of Education and Research had launched Girls' Day back in 2001 to combat such prejudices and remove obstacles so that girls can recognize and fully develop their own potential. The Fraunhofer Institute Center in Stuttgart supported this initiative at an early stage and has been inviting schoolgirls between the ages of 10 and 16 to the Fraunhofer Campus in Stuttgart since 2003. Since then, the institutes have opened their laboratories and workrooms to visitors every year in order to give them an insight into the various research areas. This year, Fraunhofer IGB offered two guided tours on the topics "Plasma Technology" and "Tissue Engineering – Tailor-made Tissues from the Laboratory".

www.stuttgart.fraunhofer.de/girlsday

2

BOGY – Career and study orientation at the High School

Short internships as part of the "Career and Study Orientation at Grammar Schools", or BoGy for short, are intended to help pupils find a career path that is suitable for them. The institutes at the Fraunhofer Institute Center Stuttgart also take on several BoGy interns each year. The aim is to motivate young people early on for a career in science. Fraunhofer addresses pupils with a keen interest in scientific and technical topics. In 2017, a total of 14 pupils were guests at Fraunhofer IGB for one week each.
www.stuttgart.fraunhofer.de/bogy

Educational partnership with Hegel-Gymnasium

When it comes to getting young people enthusiastic about scientific careers at an early age, the Fraunhofer Institute Center in Stuttgart is also involved at a local level. For this reason, an educational partnership has existed since 2015 between the Institute Center and the Hegel-Gymnasium in Stuttgart-Vaihingen. Joint activities and visits to institutes are intended to familiarize pupils with professional and career prospects in application-oriented research. On July 19, 2017, eleven pupils of grade 10 visited Fraunhofer IGB and participated in a practice-oriented workshop on the topic of "Renewable Raw Materials".

Fraunhofer Science Campus Stuttgart **2**

The Fraunhofer Science Campus is an information event lasting for several days for students and graduates in MINT subjects, which takes place annually at different Fraunhofer locations. In September 2017 it was Stuttgart's turn. The science campus is aimed specifically at female junior researchers in scientific and technical subjects. Participants gain deep insights into research work and valuable offers to improve their personal and professional skills. In addition to lectures and discussions, the program also included workshops related to practice. At Fraunhofer IGB, 12 female students completed a one-day workshop on the topic of "Health Research Field".
www.fraunhofer.de/wissenschaftscampus

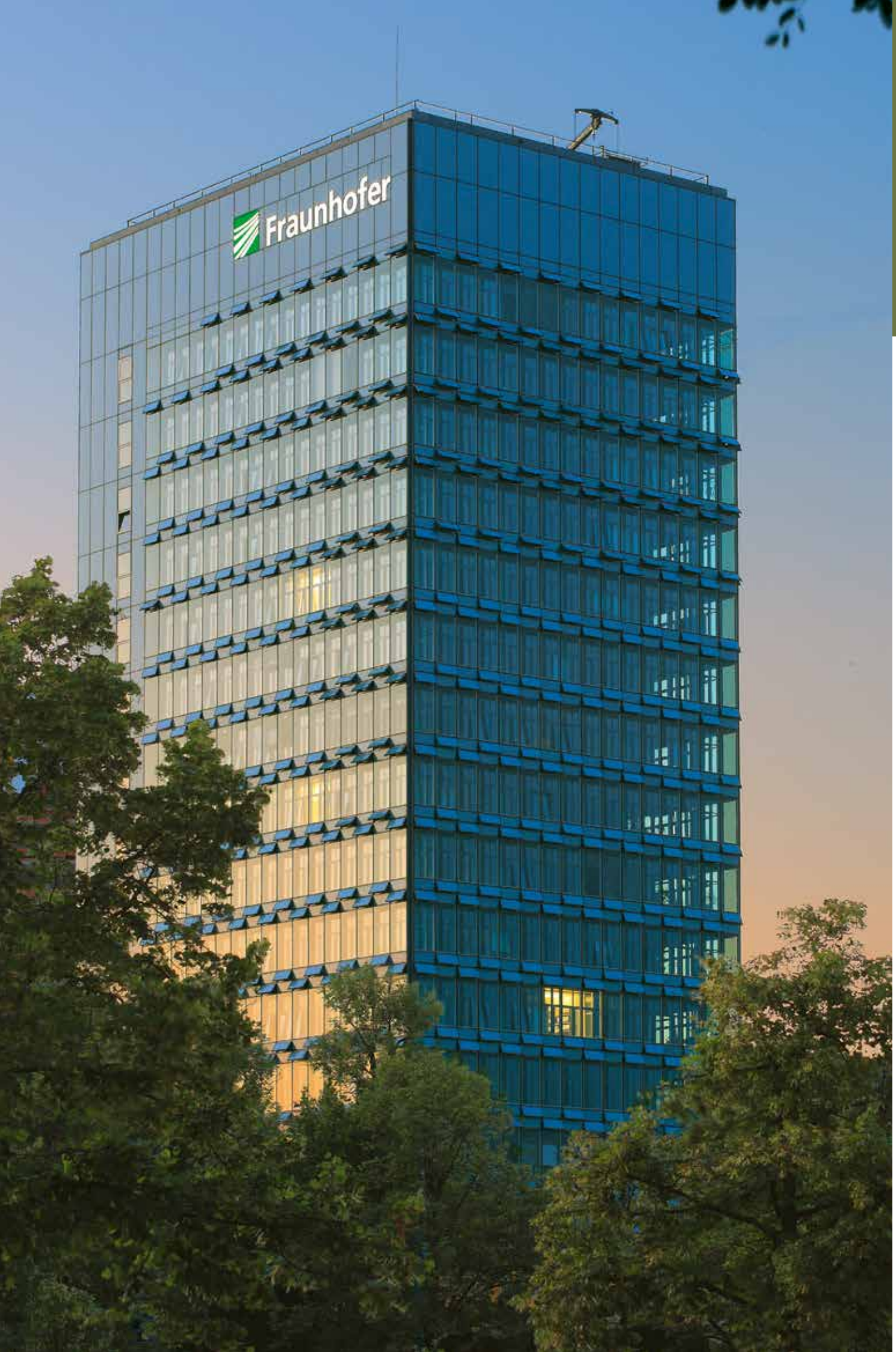
Dual Training at Fraunhofer IGB

In addition to supporting young scientists, Fraunhofer is also committed to non-university education to a large degree. Therefore, Fraunhofer IGB trains young women and men in various jobs requiring formal training. At the end of 2017, a total of 19 trainees were employed at Fraunhofer IGB and its partner institute at the University of Stuttgart, the Institute for Interfacial Process Engineering and Plasma Technology IGVP. In the scientific field, they work as biology and chemistry laboratory assistants, in administration either as IT specialists or as office management clerks.

As part of their dual training, these junior employees go through several stations at the institute in addition to vocational school, so that they can get to know the different work areas of a research institution. In this way, they acquire the necessary qualifications for a future career in research or the industrial sector. Even if the trainees decide to study after completing their training, they are supported by the institute.
www.igb.fraunhofer.de/ausbildung

For further information on promotion of young scientists and training:

www.igb.fraunhofer.de/career


Fraunhofer

COMPETENCES

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 72 institutes and research units. The majority of the more than 25 000 staff are qualified scientists and engineers, who work with an annual research budget of €2.3 billion. Of this sum, almost €2 billion 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 2018.

www.fraunhofer.de

Fraunhofer headquarters in Munich, Germany.

Interfacial Engineering and Materials Science

Material surface requirements are often very different from the properties intrinsic to the bulk of the material concerned. The department offers a variety of processes for film deposition from either the gas or liquid phase. We also develop polymeric and inorganic material systems with large surface areas such as particles, porous membranes, non-woven materials and foams as well as biomaterials, especially hydrogels. A multitude of analytical tools are available for the monitoring of processes (process diagnostics) and the characterization of the generated material surfaces. Apart from the quality of the products, the material and energy efficiency of processes is of foremost concern.

Technology and expertise

- Deposition of thin monolayers or multiple films from the gas phase (e.g. plasma)
- Chemical modification of surfaces (dip coating, doctor-blading, printing etc.)
- Generation and loading of functional nanoparticles using polymerization methods or spray drying
- Production of polymeric and ceramic separation membranes by phase inversion processes
- Synthesis of biocompatible polymers, chemical modification of biomolecules, development of biomaterials
- Determination of interfacial energy, topography, adsorption, and chemical composition of surfaces
- Plasma process diagnostics: probe measurements, optical and mass spectrometric methods

Molecular Biotechnology

The biologization of industrial processes is one of the most important issues of the 21st century. New sequencing technologies and proteome analyses, the targeted modification of organisms of all species and the development of enzymatic or fermentative production processes provide new ways for the production of fine and bulk chemicals as well as for the development of diagnostics and therapeutics. We apply these new technologies for the development of diagnostics in infection research and in personalized medicine as well as in the development of antimicrobial drugs and for the production of therapeutic proteins. In the field of industrial biotechnology, we convert renewable raw materials to new products for the chemical industry using biotechnological processes.

Technology and expertise

- Molecular-biological workflows for clinical samples
- Diagnostic microarrays
- Next-generation sequencing (NGS)
- Bioinformatic workflows for NGS data
- Development of stable cell lines and production strains
- Cell-based assays, e.g. antiviral and pyrogen detection assays (GLP), and complex 3D infection models
- Virus-like particles and therapeutic viruses
- Protein purification and characterization
- Strain and enzyme screening
- Development and scale-up of bioprocesses

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Physical Process Technology

The department is involved in developing processes and process components based on physical and physico-chemical principles. A hallmark of our R&D activities is improving economic efficiency and sustainability of production processes at the same time – by minimizing material consumption, recovery of high-value substances in a quality equal to primary raw materials, and saving and reuse of energy. Our customers are either manufacturers of process components, contractors, and process system suppliers, or industrial companies from sectors such as metal processing, the food industry, biotechnology and the water sector with a specific problem to be solved.

Technology and expertise

- Thermo-chemical heat-storage (adsorptive and absorptive)
- Evaporation and drying with superheated steam combined with winning of volatile fractions
- Cell-desintegration and extraction with high-pressure technique
- Chemo-physical water treatment (mechanical, electrolytic, photolytic)
- Electrolytic and photolytic synthesis
- Electrophoretic separation of substances
- Primary/secondary winning of materials
- Processes and techniques to recycle organic and inorganic products for agricultural applications
- Stabilization of liquid food and biogenic products
- Integration of the technologies into customized processes
- Design, construction and operation of demonstrators

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Environmental Biotechnology and Bioprocess Engineering

The core areas of the department are the development of (bio)engineering processes along the value chains in the fields of water management, wastewater treatment, bioenergy, environmental technology, algal technology, product recovery from organic raw/waste materials and interfacial biology. Based on these processes, we are following new approaches to the development of system concepts for energy, waste and water management in industry and for municipalities. The aspects of resource and energy efficiency as well as biorefinery concepts as defined by bioeconomy are important to us when designing industrial processes.

Technology and expertise

- Process development in bioreactors from laboratory to pilot and technical scale
- Development and operation of demonstration plants for aerobic and anaerobic wastewater treatment, high-load digestion, bioenergy, algal technology
- Analysis of substrates and fermentation products, protein analysis
- Real-time mass spectrometry
- Isolation and downstream processing of bioproducts (membrane-based filtration processes, process chromatography, liquid-liquid extraction, extraction with supercritical CO_2)
- Development and operation of apparatuses for testing antimicrobially finished materials
- Evaluation of microbial contaminations
- Process simulation and automation (Mat-Lab, Siemens)

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Cell and Tissue Engineering

The department creates biomedical solutions using principles from tissue engineering and regenerative medicine. A focus is on the development of human test systems as alternative to animal experiments. Here, we use human isolated primary cells and induced pluripotent stem (iPS) cells to establish 2D/3D *in vitro* tissue models. In addition, we leverage microfluidic technology to develop and validate organ-on-a-chip systems as high-throughput screening tests for drug candidates.

Technology and expertise

- Tissue engineering using tissue-specific human primary cells as well as adult and induced-pluripotent stem cells (iPS cells) for development of 3D tissue models
- Patented 3D human skin equivalent
- Microfluidic organ-on-a-chip systems
- Accredited *in vitro* testing of cytotoxicity (DIN ISO 10993-5)
- Accredited phototoxicity testing of cosmetics
- Development and modification of biomaterials (together with Interfacial Engineering and Materials Science Department)

Bio, Electro and Chemocatalysis BioCat, Straubing branch

The focus of BioCat, the Straubing branch of the institute, is on the development of new chemical catalysts and biocatalysts and their application in technically relevant synthetic and electrochemical processes. Based on substrates such as biomass, CO_2, organic and inorganic waste streams, the entire spectrum of catalysis is used to develop new sustainable and resource-efficient chemical products. BioCat is also developing new catalytic methods of managing electrical energy by binding and converting CO_2 to produce long-chain hydrocarbons, making it possible to store electricity from regenerative power generation in the form of chemical energy for later use.

Technology and expertise

- Chemical (homogenous and heterogeneous) catalysis, biocatalysis (enzymes, whole cells), electrocatalysis, screening for catalysts, organic synthesis
- Molecular-biological and technical optimization of enzymes and enzyme reactions
- Analyses of natural materials and chemical reactions (e.g. high-resolution NMR analytics, high-throughput LC-MS and GC-MS)

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Fraunhofer Center for Chemical-Biotechnological Processes CBP, Leuna branch

The Fraunhofer CBP in Leuna develops and scales up chemical and biotechnological processes for the utilization of renewable and petrochemical raw materials – from upstream processing of raw materials and several conversion processes to separation and downstream processing of products. By making infrastructure and plants available and by providing high-qualified personnel, Fraunhofer CBP closes the gap between the lab and industrial implementation and makes it possible for partners from research and industry to scale up processes right up to production-relevant dimensions and thus to accelerate process developments.

Technology and expertise

- Processing of raw materials – integrated pilot plant for pulping and fractionation of lignocellulose
- Biotechnological processes – modular process units up to 10 m^3 reactor volume for fermentations
- Cultivation of microalgae in automated greenhouse and outdoor pilot plants, with a total volume of photobioreactors of 11.7 m^3
- Chemical processes – various process units for chemical reactions under ATEX conditions (continuous up to 20 kg/h or batch up to 100 liters)
- Downstream processing for separation, purification and reconditioning of products, e.g. by distillation or extraction

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SELECTED R&D RESULTS 2017

26 Fraunhofer internal projects

4 Fraunhofer lighthouse projects

55 Projects funded by German federal ministries

11 Projects funded by German states

201 Projects

10 Projects with universities, municipalities or funded by foundations

26 EU projects

69 Industrial projects

HEALTH

A faster and more precise diagnoses using molecular biological approaches or new opportunities for recovery through individualized therapy approaches – one example is the coordinated interplay between a ("biologized") implant and its physiological environment – are scientific trends that are becoming more important because of the increase in life expectancy. Hence, drug efficacy has to be improved, for example by optimizing formulations and targeted release of active ingredients at the sites where they are needed.

Fraunhofer IGB is developing solutions in these research areas. The aim is to improve medical care for patients and simultaneously reduce healthcare costs. One focus is on the development of three-dimensional organoid *in vitro* models from human tissues, which already in preclinical research allow conclusions about effects and side effects of potential drug candidates and thus can replace animal experiments.

We take increased health awareness into account by using new extraction, preparation and stabilization processes that minimize damage to food products and can also be used for cosmetics. We also provide algae ingredients with antioxidant or anti-inflammatory properties.

Technology platform

Formulations and release systems

Transport of a substance to their destination – e.g. a tissue or cell – is a key factor in the development of functional ingredients or active compounds. At Fraunhofer IGB, we are developing structures that transport substances to their site of action in a targeted manner (drug delivery) and release them there in a controlled manner (drug release). For example, we are formulating active compounds in a matrix consisting of biobased, polymer or siliceous material in the form of (nano-) particles or layers. To achieve this, we are using various techniques such as spray technologies, solvent evaporation, emulsions or dispersions. Using virus-like particles as vehicles, we are persuing a new approach to packaging and targeted transport of active compounds.

Networking and cooperation

With our expertise, we contribute to the offerings of the Fraunhofer Group for Life Sciences, facilitating a scope of activity ranging from the development of medicines to screening for active agents to the production of test samples. As a partner of the Fraunhofer Food Chain Management Alliance, we make a contribution to healthcare through the development of physical hygienization processes that protect the properties of products. In addition, we are networked in the Fraunhofer Big Data and Generative Manufacturing Alliances.

Food and cosmetics

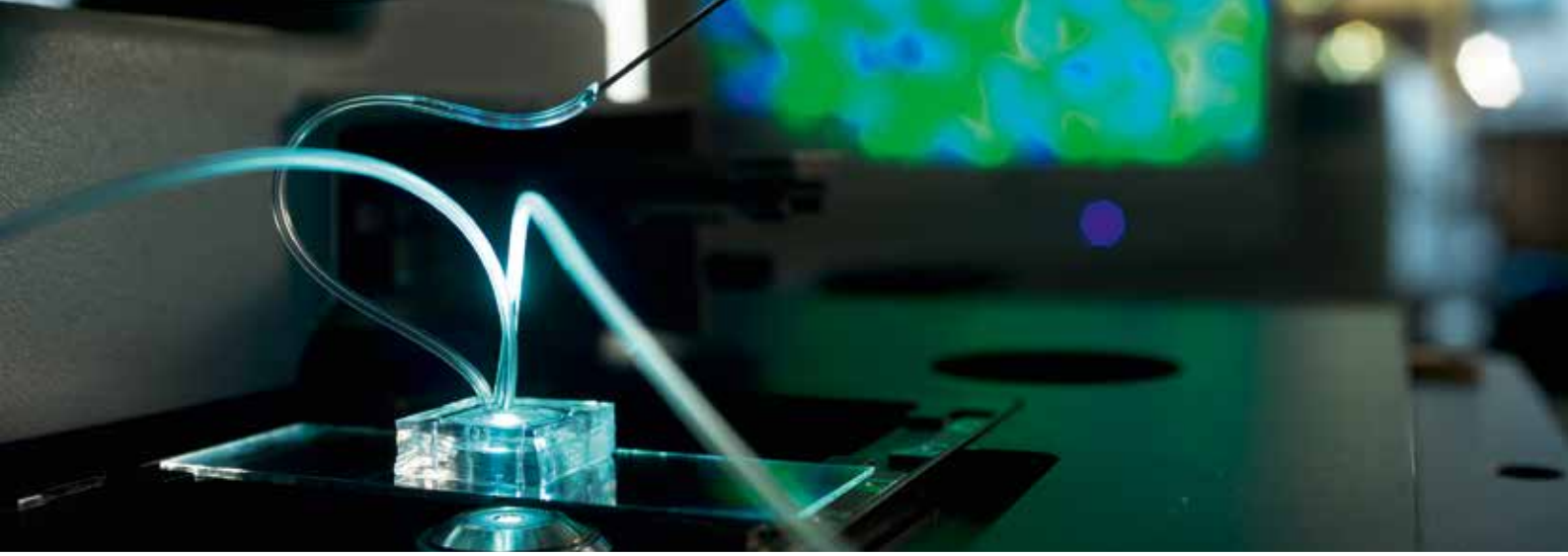
Our aim in this topic area is the extraction of functional ingredients from biogenic raw or residual materials, from intermediate products in agricultural and food production. For this purpose, we are developing processes for extraction and fractionation using high-pressure technology in combination with pressure change technology (PCT) and the application of electrophoretic and mechanic separation processes to purify the ingredients. For the production of valuable compounds from microalgae – e.g. omega-3 fatty acids (EPA) and carotenoids such as fucoxanthin, lutein or astaxanthin – we are developing efficient extraction procedures using supercritical fluids and pressurized liquid extraction (PLE).

In addition, we are developing new physical processes such as pressure change technology to stabilize and conserve food, cosmetics, drug substances and plant extracts. Since these procedures are carried out at low temperatures below 50°C, the biological function of valuable ingredients, such as vitamins, is not affected during the treatment. For the energy-efficient drying of foodstuffs, we optimize superheated steam drying procesess in our demonstration plants.

Drug development

Diseases are often caused by faulty interactions among endogenous molecules – for example, due to modified receptors or enzymes playing a decisive role in cellular signal chains and metabolic pathways. Fraunhofer IGB has developed various screening systems – from simple cell-based assays to complex human tissue models with immune system components. These systems support the analysis of the interactions of different cell types associated with autoimmune diseases such as psoriasis or dermatitis, for example, or host-pathogen interactions on molecular level. As a result, we are able to identify new target structures for the development of antibiotics or for the modulation of a patient's own immune system.

To analyze the effects and side effects of potential active compounds, we are developing three-dimensional *in vitro* tissue models and organ-on-a-chip systems based on human primary or iPS cells. These systems help to replace animal tests and to increase the information value of preclinical results. In addition, we are developing processes to produce pharmaceutical proteins: from the establishment of new expression vectors to strain development and purification of the pharmaceuticals.



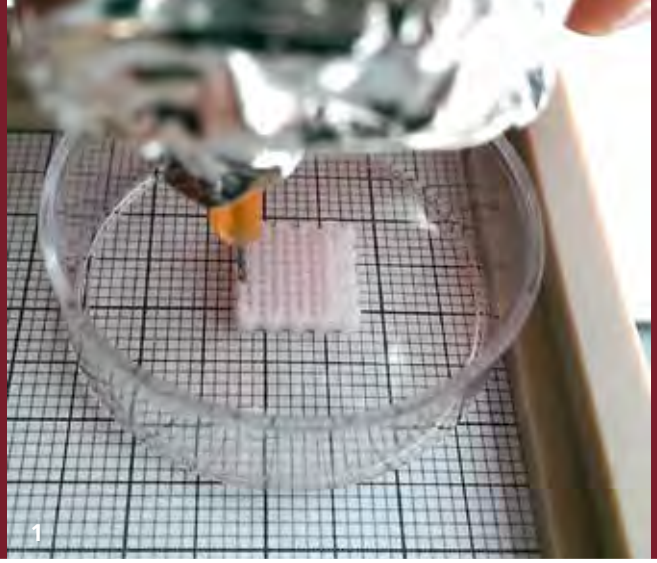
OUR OFFER FOR PERSONALIZED MEDICINE

Coatings and biomaterials for medical technology and regenerative medicine

Properties of the materials and interactions between the material and the biological system are key factors in the manufacture of implants and medical devices. Fraunhofer IGB is developing bioactive, biocompatible or bioinert materials for use in medicine and medical technology, e.g. for stents, catheters and implants. We are testing biocompatibility of the materials using an accredited testing method according to DIN EN ISO 10993-5. For implants, we are investigating cell-material interactions and developing materials such as electrospun, biodegradable fibers or hydrogels that are developed further to bioinks for additive manufacturing of tissue models. In addition to biological carriers, Fraunhofer IGB is also developing miniaturized tubes as supply systems for larger tissue models.

Molecular diagnostics

Precise diagnosis of a disease is a fundamental prerequisite for any therapy and the basis for personalized medicine. Fraunhofer IGB is developing novel molecular biology technologies based on nucleic acids (microarrays, high-throughput DNA sequencing) or using cellular reporter systems (pyrogen assay system) that can be used for clear and unambiguous diagnoses. This information helps to initiate measures for specific treatments or develop personalized medicines for different population groups. In particular for combating infectious diseases, the combination of methods of functional genome analysis with our expertise in cell culture technology and infection biology results in a unique position for developing infection models and diagnostics.



BIOPRINTING – PRINTED BIOMATERIALS FABRICATE FUNCTIONAL BONES AND VESSELS

Medicine of the future is biological. In order to turn the concept of biological implants and personalized therapies into tangible reality, scientists at Fraunhofer IGB are optimizing biological materials for processing with 3D printing techniques.

Like classical tissue engineering, the so-called bioprinting pursues the goal of producing biological or biologically functional tissue in the laboratory. The printed *in vitro* tissues will serve as test systems to answer questions about the efficacy of active substance candidates and thus help replace animal testing. In the future, as biological implants, they may also act to stimulate damaged tissue to regenerate, or substitute them.

"We must create an environment where body cells isolated from tissues and multiplied in the laboratory can fulfill their specific functions over a longer period of time," says Dr. Kirsten Borchers about one of the challenges facing the scientists. The best artificial environment for the cells is one that mimics the natural conditions in the body as closely as possible: "In our printed tissues, the role of the tissue matrix is thus taken over by biomaterials that we generate from molecules of the natural tissue matrix," explains the scientist.

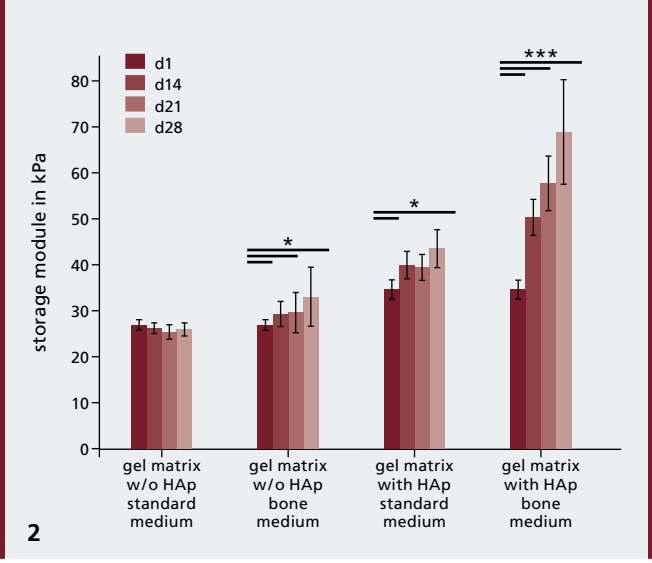
In order for the biomaterials to be brought into shape by means of 3D printing, their flow properties must be adapted to the printing technique used in each case. After the printing process, the structure thus generated is then additionally stabilized by a cell-compatible crosslinking reaction. Dr. Borchers and her colleagues, Prof. Dr. Günter Tovar and Dr. Achim Weber and her team, set out to meet these challenges.

Flexible shapes and standardized conditions through additive manufacturing

"In order to build tissues in the lab that work just as well as their natural counterparts, we need not only the best possible biomaterials, but also production processes that limit us as little as possible in terms of shaping," explains Borchers.

"Additive methods offer great flexibility in this respect. With their help, three-dimensional objects that were previously designed on the computer can now be fabricated layer by layer," says Weber. Flexible shaping is particularly important in terms of the vision of generating personalized printed biological implants. Because modern diagnostic imaging modalities, which are currently already frequently used in daily medical practice, can provide the very digital 3D data required for customized implants.

"The additive processing of tissue matrix and cells into tissue models offers yet another advantage – automation and digital control could in the future guarantee that production can take place under controlled and standardized conditions," adds Borchers.



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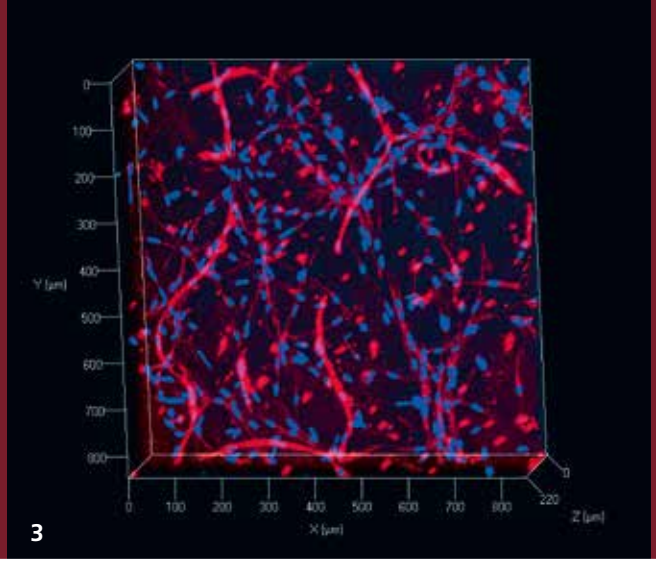

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In the current state of the art, 3D printing methods are used to combine different cells and biomaterials as well as structures such as perfusion channels for suppling the cells in simply constructed tissue models. The branch of research that deals with the fabrication of biological structures using additive manufacturing processes is known as bioprinting.

A material kit with natural biopolymers

Typically, the tissue matrix has the texture of a highly hydrous gel. In bones, mineral components are embedded as well. In this way, the extracellular matrix (ECM) ensures the mechanical stability of tissues. In addition, the tissue matrix is also involved in intercellular communication. It is not easy to simulate these comprehensive functions with synthetic materials.

"Our approach is therefore to optimize biopolymers recruited from the natural portfolio for technical processing," says Borchers. Natural, biofunctional molecules of the tissue matrix such as gelatin, heparin, hyaluronic acid and chondroitin sulfate are chemically furnished with additional functions at IGB: "As an example, by ´masking´ certain side chains of biomolecules, we can reduce intermolecular interactions and thereby influence the viscosity and gelling behavior of gelatin solutions," explains the scientist. On the other hand, reactive groups can be introduced in order to chemically crosslink biomolecules to generate hydrogels, for example by means of a light stimulus. The ratio of the introduced masking acetyl and the reactive methacrylic groups enables both the flow behavior of the solutions and the swelling properties of the crosslinked hydrogels to be adjusted.

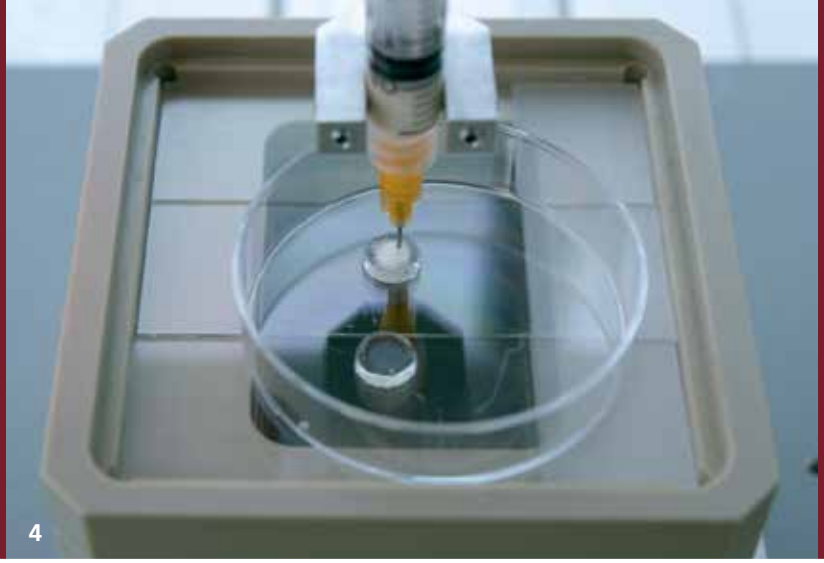
Optimized bioinks for biologically functional tissues

"Bioink" is a biomaterial in its uncrosslinked, printable form. By deliberately varying the composition, bioinks are optimized for the printing process and at the same time for the stimulation of tissue-specific functions. Borchers and her colleagues were already able to successfully produce "bone inks" and "vascularization inks" on the basis of the available material kit. Both bioinks are dispersions of biomolecules and tissue-typical cells that can be stably converted into a 3D structure via dispensing processes.

1 *3D printing of a bone ink.*

2 *The addition of hydroxylapatite (HAp) to bone ink increases remodeling of the matrix during the culture of osteogenically differentiated mesenchymal stem cells.*

3 *Capillary formation in a vascularization ink.*



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Bone ink

Bone ink contains a mass fraction of 13 percent of crosslinkable biopolymers and a mass fraction of 5 percent hydroxylapatite (HAp) as a tissue-specific mineral additive. The proportion of HAp is adjusted in such a way that the vitality of the mesenchymal stem cells used and the crosslinking reaction of the hydrogels are not impaired. The increase in the viscosity of the ink due to the addition of the HAp is very desirable: By choosing a suitable ratio of the available gelatin derivatives with different gelling abilities, a gelling temperature of, say, 21.5°C can then be set. Bone ink thus has excellent extrudability at room temperature (Fig. 1).

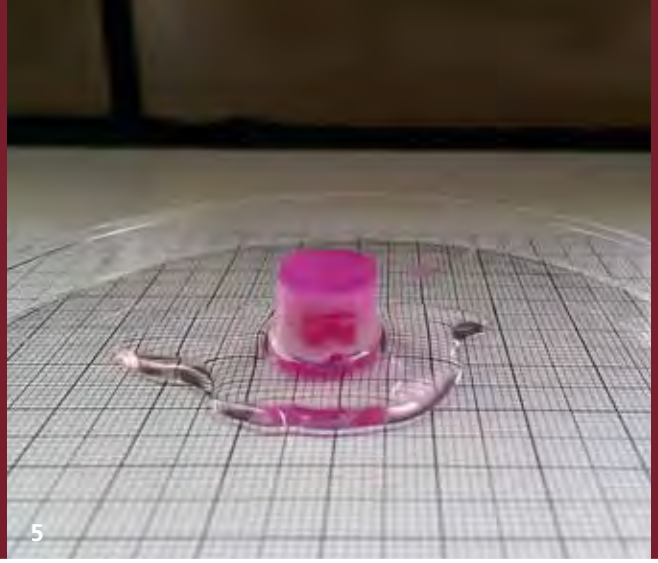
Research has shown that after the ink has been crosslinked to hydrogel, the mineral component promoted the remodeling of the matrix by the cells contained therein: The mechanical strength of the gels increased more markedly during the four-week cultivation when HAp was contained in the matrix than in carrier gels without HAp (Fig. 2). Raman spectroscopy suggests that the observed effect is mainly due to increasing mineralization of the matrix. In addition, bone-typical marker proteins indicate that the mesenchymal stem cells differentiated into bone cells in the printed matrices.

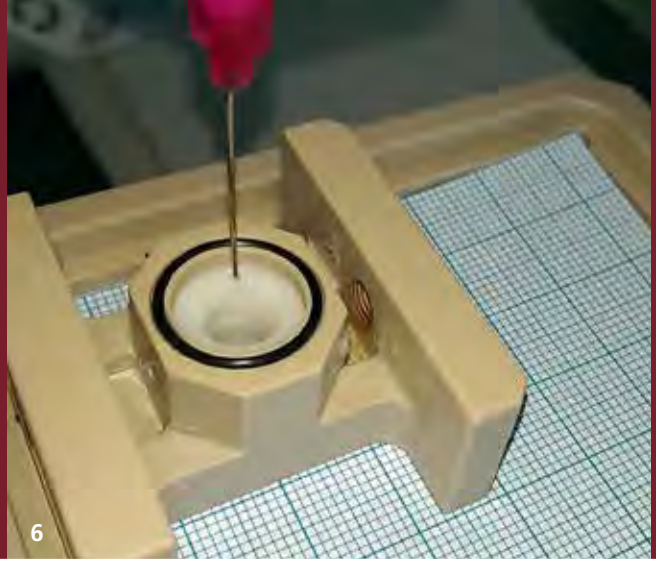
Vascularization ink

The supply of nutrients and oxygen via vascular structures is particularly important for extensive *in vitro* tissues, as diffusion takes too long. The endothelial cells that line the vessels from the inside play an important role in the formation and growth of new vessels.

Vascularization matrix must have different properties than bone matrix: First and foremost, it must be soft and less strongly cross-linked, so that the endothelial cells can migrate and form capillaries. The vascularization ink developed at IGB therefore contains only 5.75 percent by weight of crosslinkable biopolymers. These also have a low degree of methacrylate and thus crosslink less strongly than bone ink. By the addition of gelatin derivatives with masking, IGB succeeded in manufacturing soft vascularization gels (storage modulus of 2.7 kPa ± 0.31 kPa) with a high water absorption capacity (degree of swelling in equilibrium > 2000 percent). By varying the share of unmodified gelatin (which gels already at room temperature), it was possible to produce a bioink that can be stably printed at room temperature. When microvascular endothelial cells are introduced into these gels, the formation of capillary-like structures takes place (Fig. 3).

Individually or in combination, bioinks can be used to construct vascularized tissue models (Fig. 4, 5 and 6).





OUR OFFER

Printing devices
- Inkjet printing
- Pneumatic and extrusion-based dispensing

Biomaterials with adjustable properties, e.g.
- Gelatin, collagen
- Hyaluronic acid, chondroitin sulfate, heparin

Chemical modifications
- For crosslinking e.g. with methacrylate functions, thiol functions, benzophenone
- For reducing intermolecular interactions e.g. with acetyl groups (DE 10 2012 219 691 B4 2015)

Features and applications
- Control of viscosity and gelling behavior
- Crosslinked hydrogels with adjusted stiffness, swelling
- API storage with controlled release
- Biobased fluids with adjusted flow characterics
- Cytocompatible or tissue-specific 3D matrices

Analysis, e.g.
- NMR
- Rheology
- Compression testing at physiological conditions
- Cytocompatibility (according to DIN ISO)
- Pyrogen detection (cell-based assay)

Cells and tissues
- Primary cells isolated from human or mammalian biopsies, e.g. mesenchymal stem cells, chondrocytes, endothelial cells, skin cells, mature fat cells
- Expansion, 2D and 3D culture
- (Immuno)histological methods and cell culture assays
- Flow cytometry for characterization of cells and cytokines

ECM biomolecules are also used in pharmaceutical and cosmetic formulations. As an animal by-product, gelatin has multiple technical applications as well. Fraunhofer IGB offers services in development, consulting and technology transfer.

www.igb.fraunhofer.de/en/bioprinting

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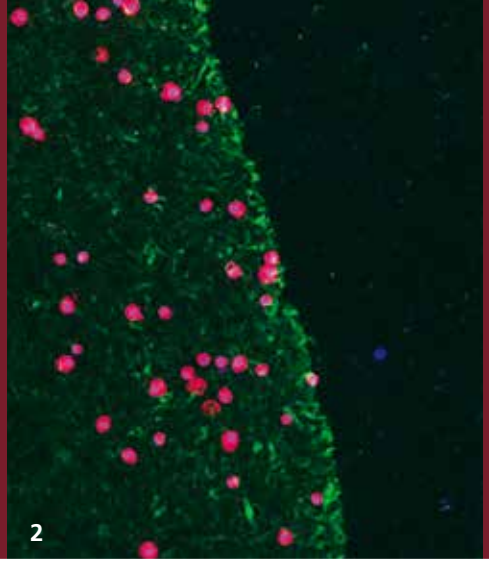
Collaboration and partners

This scientifically demanding and challenging field of research implicitly requires the investigation of fundamental issues. IGB therefore works closely with its partner institute at the University of Stuttgart, the Institute of Interfacial Process Engineering and Plasma Technology (IGVP). Here, Dr. Kirsten Borchers, along with Prof. Dr. Günter Tovar (and until 2017 also with Prof. Dr. Petra Kluger), supervise doctorate students and student graduation theses in the field of biomaterial development.

The presented results are part of Annika Wenz's PhD thesis (scholarship by Carl Zeiss Foundation) and Julia Rogal's Master's thesis.

4 *3D printing of various bioinks.*
5 *Tissue model for vascularized bone.*
6 *3D printing of bone ink in a bioreactor.*

1



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Albumin-based coating accelerates stem cell proliferation on titanium implants

It is known that albumin coatings greatly reduce the adhesion of bacteria to plastic or metal surfaces. Fraunhofer IGB has now shown that cross-linked albumin coatings also accelerate the adhesion of stem cells to Ti6Al4V surfaces, a titanium alloy commonly used in medical engineering. After just one minute, first mesenchymal stem cells (MSC, from bone marrow aspirates) adhered to the coated surfaces (Fig. 2). On the uncoated Ti6Al4V, no adherent cells were detected at this early stage. After 30 minutes, the number of cells on both surfaces was similar, although a much greater spread of the cells and thus a higher surface coverage was frequently observed on the cross-linked albumin. The effect was robust and it was demonstrated on Ti6Al4V with different surface coarseness as well as on substrates produced by laser melting using Ti6Al4V powders of different qualities. The cross-linked albumin layer could be sterilized with standard sterilization methods (gamma irradiation, electron beam) without any loss of function.

Severe infections can occur in succession to implantation of prostheses into bone tissue. These are caused by bacteria that reach the implant surface already during implantation.

The functionalization of the surface of Ti6Al4V alloys with cross-linked albumin can substantially shift the often cited "race to the surface" (i.e. the competition of microorganisms and tissue cells for the colonization of surfaces) greatly in favor of MSC. We are happy to introduce the developed coatings into advanced studies for medical device companies.

The work was carried out as part of the Fraunhofer lighthouse project "Theranostic Implants".

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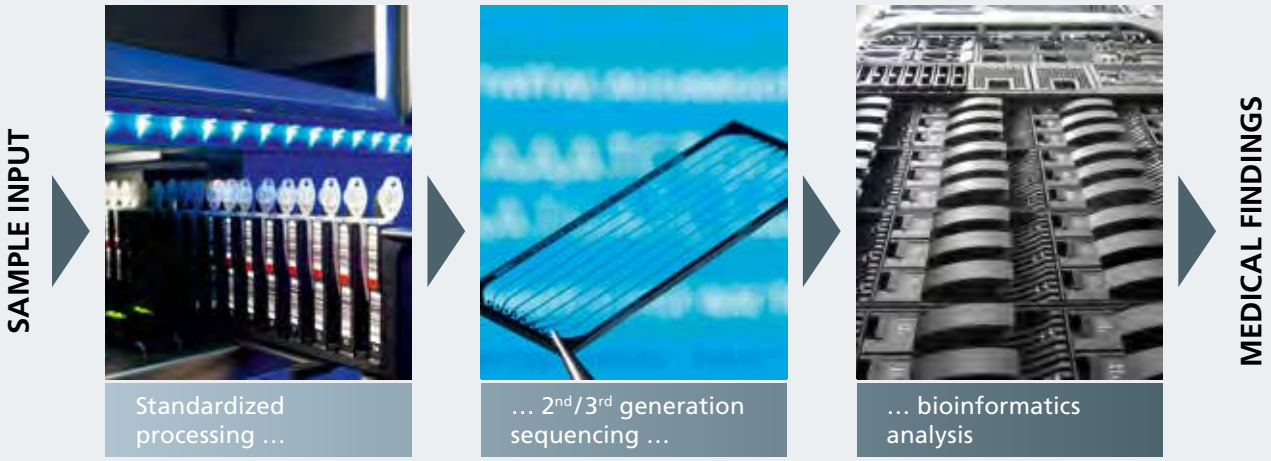
Novel biodegradable bone replacement materials for regenerative medicine

In our ageing society, an increasing number of patients suffer from skeletal defects caused, for example, by accidental injuries or cancer diseases. Thus, there is great interest in developing novel bone replacement materials. However, although it is already possible to reproduce the complex structure of bone using additive methods, to date it has not been possible to modify implant materials made of metal or polymers in such a way that they promote the growth of bone cells.

The international BMBF-funded Intelbiocomp project therefore developed a novel 3D polymer bone replacement material on the basis of polycaprolactone (PCL), which can accelerate integration into bone. This type of carrier material with different orientation of the polycaprolactone fibers was fabricated at the Polytechnic University in Tomsk, Russia, in order to reproduce the extracellular matrix that corresponds to *in vivo* structure. Additional modification of the surface with silicon hydroxylapatite should also improve bioactivity and bone growth of the novel hybrid material.



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Analysis of the cell adhesive and osteoinductive properties of the novel materials in human mesenchymal stem cells (hMSC) at Fraunhofer IGB showed that adhesion and proliferation could be improved significantly with the novel design of the developed hybrid material.

With the new fabrication methods, bioactive replacement materials that promote the growth of bone cells was fabricated for the first time and moreover the costs for individual bone replacement were reduced significantly. The cell-based test methods to determine cell adhesion and osteoinduction developed in the project are now available for testing with different bone replacement materials at Fraunhofer IGB.

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Next-generation molecular diagnostics

The diagnosis of infectious diseases is based mainly on microbiological techniques that have been used for more than 100 years: the cultivation of pathogens, combined with their characterization and identification. The disadvantage here is that the growth of pathogens is a time-consuming process and some pathogens cannot be cultivated at all or only under special conditions. In addition, the result is often negative even though the disease is actually caused by an infection.

For this reason, the research group Functional Genomics develops innovative molecular methods for pathogen diagnostics on behalf of and in cooperation with customers and partners from industry and hospitals. These new methods are based on molecular analyses of the genetic information of pathogens. The three-stage process comprises optimal sample preparation, high-throughput sequencing (Next-Generation Sequencing, NGS) and bioinformatics analysis using proprietary diagnostic algorithms.

The new technology avoids time-consuming cultivation procedures and makes possible the detection of all pathogens: viruses, parasites and bacteria that do not grow on the culture media used. This not only makes the diagnosis faster, but also significantly more reliable. The NGS data can also be used for pathogen diagnostics, or for the identification of new biomarkers. The Functional Genomics group at Fraunhofer IGB has extensive experience in the indications of sepsis, endocarditis, amniotic fluid infections, as well as in biomarker screening, the genome characterization of pathogens and microbial studies (e.g. on the skin).

1 *Titanium hip implant.*
2 *Early stem cell (red) adhesion on albumin coating (green) after one minute.*
3 *Three-stage process for molecular infection diagnostics using NGS.*

1

Thanks to its comprehensive, open platform character, this type of infection diagnostics already holds the potential for universal use in hospitals. With third-generation sequencers, immediate point-of-care diagnosis is also within reach, as we have been able to show in successful pilot studies.

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Identification of pathogens of sexually transmitted diseases with highly parallel diagnostics using DNA microarray

Sexually transmitted diseases (STDs) such as gonorrhea, syphilis, chlamydia and trichomonads are of increasing global importance for individual and reproductive health. The development of specific STD diagnostics is an integral part of the strategy to combat these diseases developed by the World Health Organization (WHO). Development of point-of-care tests (POCTs) that enable diagnostics independent of central laboratories and within close proximity of the affected persons has strategic importance for therapy and monitoring.

On behalf of Immundiagnostik AG Bensheim, the Infection Biology and Array Technologies Group of the Molecular Biology Department is developing DNA-based microarrays for highly parallel diagnostics of STDs. The test being developed helps to differentiate diseases caused by fungi, bacteria, viruses or protozoa using highly sensitive and molecular procedures, allowing them to be treated quickly and adequately. For the diagnostics of STDs, we first identify suitable target regions of the pathogen, then develop pathogen-specific primers and simultaneously amplify the pathogen targets using multiplex PCR (Polymerase Chain Reaction). After immobilizing the primers on carriers (glass carrier or 8-strip tube or microtiter plate), highly parallel and highly sensitive DNA microarrays are available for detecting pathogen targets. The aim is to achieve semi- or fully-automated processing of samples – preferably integrated into a POCT in order to enable simplified and cost-effective diagnostics.

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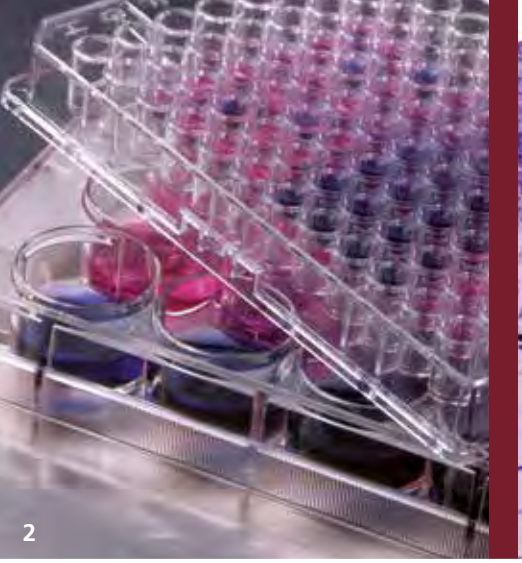
1 *Parallel diagnosis of infectious pathogens.*
2 *Cell-based reporter gene assay in cell culture plates.*
3 *Infection of skin models with C. albicans in the presence (right) and absence (left) of immune cells.*



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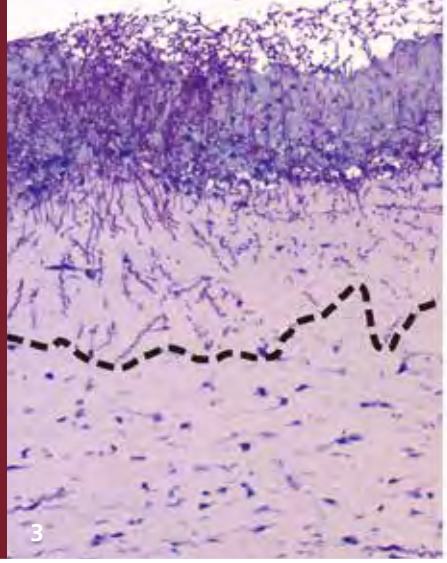

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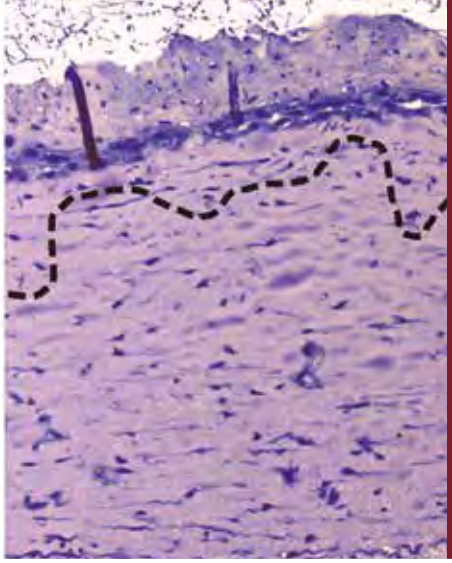

Control of the innate immune system as therapeutic option

Receptors of the innate immune system such as toll-like receptors (TLR) play a key role in the development of acute and chronic inflammatory diseases in humans. The indication spectrum ranges from allergies and tumors to autoimmune diseases. Our aim is to develop new active substances that modulate the mechanisms of innate immunity in order to use them for the therapy of inflammatory processes and dermatological diseases such as lupus, atopic dermatitis or psoriasis.

In a joint project with the Hebrew University (HU), promising initial findings have already been obtained on the use of immunomodulatory substances in the treatment of inflammatory diseases. Using computer-based methods, our partner HU identified new agonists and antagonists of innate human immune receptors that are relevant for the above indications.

Patented cell-based assays and 3D tissue models are being used at Fraunhofer IGB for validating receptor modulating features of the identified active substances. The best compounds will be further validated in animal models by partners. Ten TLR9 antagonists effective in nanomolar concentrations have already been verified e.g. out of millions of compounds.

The complementary competences of the partners – the procedure for molecular modeling at the HU and cell-based TLR screening assays and 3D tissue models developed and patented at IGB – provide crucial added value with regard to the prospects of the ambitious goal to detect new TLR-based immunomodulators for therapy and prophylaxis of inflammatory diseases.

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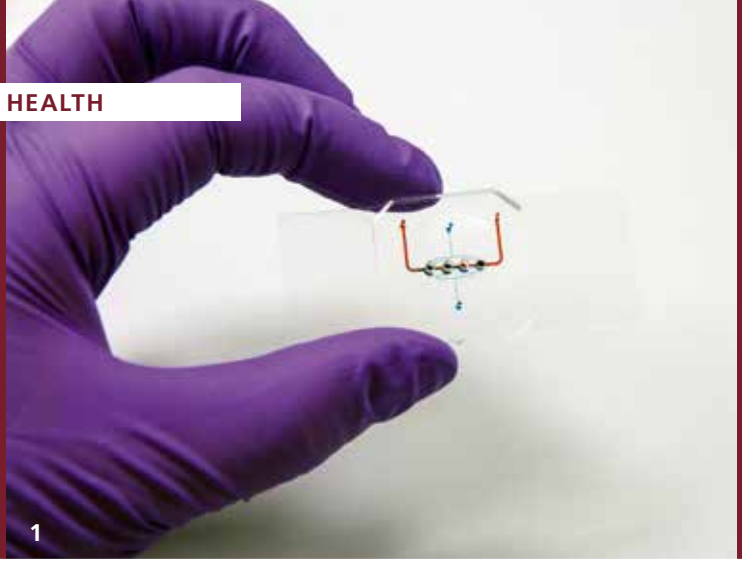
Identification of protective mechanisms of the skin using immunological 3D tissue models

The human skin forms an important barrier against microorganisms such as the human pathogenic fungal yeast *Candida albicans*. 3D tissue models offer significant advantages in the analysis of mechanisms of host-pathogen interactions, which are important during adhesion and invasion of the pathogen. They reflect the natural infection environment much better than classical 2D cell cultures.

By integrating human immune cells into a 3D skin model, we developed a test system that allows the analysis of defense mechanisms against invading pathogens. With this tissue model and using gene expression analyses of individual cell types via next-generation sequencing, we have already identified dermal fibroblasts as a cell type that plays a significant role in the protection of the skin against *C. albicans* invasion.

Due to its properties, the skin model allows comprehensive, cell-type-specific molecular and functional analyses. These showed that in particular the innate immune receptor TLR2 and the messenger substance Interleukin-1β play a crucial role in putting fibroblasts into an antimicrobial status or triggering an antimicrobial response, depending on the presence of an acute fungal infection and of CD4 T-cells.



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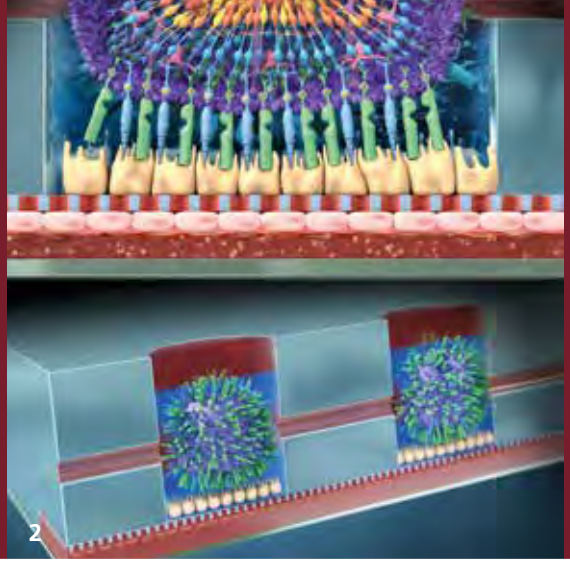

2

In future, we will expand these studies to other pathogens and epithelia in order to obtain comprehensive information on epithelial barrier functions. This will open up new possibilities for the treatment of infectious and immune diseases by targeted manipulation of specific signaling pathways using immune modulators.

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Retina-on-a-chip – A physiological 3D model of the human retina

Degenerative diseases of the retina such as age-related macular degeneration or retinitis pigmentosa are the most common causes for loss of vision. Existing *in vitro* or *in vivo* model systems for the testing of new pharmaceutical compounds as well as for mechanistic research recapitulate the structure and complexity of the human retina only to a very limited extent. New achievements in the field of stem cell biology, in particular the induced pluripotent stem cells (iPSC), enable the generation of complex 3D tissue structures: Stem cell-based retinal organoids (RO) feature multiple layers of a variety of different cell types representing parts of the structure of retinal tissue. However, even ROs are still limited, especially with regard to the interaction of the photoreceptors with the surrounding tissue, their maturation and the vascularization.

Microphysiological *in vitro* models or organ-on-a-chip systems (OoC systems) represent a new technology that can revolutionize the development of pharmaceuticals. By integrating physiologically relevant human tissue into a microfluidic environment, OoCs offer many advantages, such as a tissue-like microenvironment and vascularization. The retina-on-a-chip system developed in this project (Fig. 1) integrates human iPSC-based ROs in an OoC to enable a physiological interaction between photoreceptors and the surrounding retinal pigment epithelium (Fig. 2). This interaction is crucial for the functionality of the retina, and has previously not been recapitulated *in vitro*. The developed retina-on-a-chip has great potential as a physiologically relevant model system for the development and testing of new pharmaceutical agents as well as for the investigation of disease mechanisms.

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3

4

Recovery of eicosapentaenoic acid (EPA) and fucoxanthin from microalgae

Tailored production of the diatom *Phaeodactylum tricornutum* results in algae biomass with a high content of polyunsaturated fatty acids such as eicosapentaenoic acid (EPA, 20:5 ω-3) and accessory pigments such as fucoxanthin. These ingredients have various health-promoting and anti-oxidative properties, which is why the recovery of the relevant extracts is of great interest to the food, feed and cosmetics industries.

As part of the Bioeconomy Baden-Württemberg project, the diatom *P. tricornutum* was cultivated in flat-panel airlift reactors (FPA reactors) in semi-continuous operation at different light intensities. The influence of light availability on the composition of biomass with regard to EPA and fucoxanthin content was investigated. In particular, the fucoxanthin content showed a significant dependence on the relative light availability, i.e. the ratio of photon flux (on the reactor surface) to total biomass in the reactor and time (in µmol photons g^{-1} of dry mass s^{-1}). In combination with an optimized and controlled supply of nutrients, we were able to achieve fucoxanthin contents of more than 2 percent (w/w) in terms of dry weight using the FPA photobioreactor. After mechanical cell disruption, both EPA and fucoxanthin can be recovered by means of pressurized liquid extraction (PLE) using suitable organic extraction solvents with yields of over 90 percent (Fig. 4). At the Institute of Clinical Nutrition at the University of Hohenheim the extracts were investigated with regard to their nutritional properties: they have a high anti-oxidative and anti-inflammatory capacity.

The extracts obtained provide the food, feed and cosmetics industries with natural extracts that have health-promoting and coloring properties, which can then be converted into the corresponding products.

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1 *Retina-on-a-chip.*
2 *Interaction of photoreceptors of retinal organoids with the retinal pigment epithelium.*
3 *Microscope image of the diatom Phaeodactylum tricornutum.*
4 *Purified fucoxanthin powder.*

CHEMISTRY AND PROCESS INDUSTRY

The chemical industry is one of the most important and research-intensive economic sectors in Germany. Many innovations in the automotive, electrical and electronic, construction and packaging industries would not be possible without the contributions of chemistry. More than all other sectors, the chemical industry is characterized by resource- and energy-intensive processes.

The dependence on the import of raw materials, the limited availability of fossil resources worldwide – even in competition with energy use – and the need to consider the impacts on both climate and the environment mean that our research also emphasizes initiatives to make the use of fossil resources more efficient or to create substitutes for them.

Technology platform

Purification technologies

A key task in many processes in chemistry and biotechnology is the separation of molecules from mixtures. Fraunhofer IGB has established a wide range of different separation techniques and has corresponding facilities both in terms of laboratory and pilot scale. Membrane and adsorption processes, electrophysical and thermal processes, as well as crystallization, extraction and chromatography processes are constantly being further developed within the scope of our own research and optimized for various applications. A unique selling proposition is to freely combine the processes and integrate them into process chains for optimal resource efficiency.

Networking and Cooperation

Our distinctive networking collaborations with other institutes of the Fraunhofer Groups for Life Sciences and for Materials and Components – MATERIALS, or the Fraunhofer Nanotechnology, Technical Textiles, Polymer Surfaces POLO® and Cleaning Technology Alliances, as well as with universities and other research institutions, guarantee competent approaches even to interdisciplinary tasks.

OUR OFFER FOR BIOECONOMY

Fermentation and biocatalysis

The goal of our work is to develop and optimize biotechnological (fermentative or biocatalytic) processes for the production of chemicals from renewable raw materials or biogenic residuals. In addition to mild reaction conditions and high specificity, these offer a virtually inexhaustible product diversity. We are also able to achieve optimized transformation processes through coupling with chemical processes. Our range of services includes screening for new chemical catalysts, industrially useful enzymes and microorganisms (bacteria, fungi) as well as the development of production processes for fine and basic chemicals including scale-up and product processing.

Biobased chemicals

We investigate the production of drop-in and basic chemicals as intermediates from various raw materials, as well as of fine chemicals and specialties. Fraunhofer IGB has successfully developed fermentation and purification processes, for example, for C2 compounds (ethylene, acetic acid, ethanol) and C3 compounds (propylene, propanol, propanediol, propionic acid, lactic acid) as well as for dicarboxylic acids (malic acid, itaconic acid, furan dicarboxylic acid), amino acids and proteins such as thaumatin or bacteriorhodopsin. Based on renewable resources, algal lipids or biogenic residuals, we have successfully demonstrated new ways to produce basic materials (long-chain dicarboxylic acids, fatty acid epoxides, lactams) for plastics production. Further examples are aromatics, lignins, phenols and furans as well as extractives and their derivatives (terpenes, phytosterols, camphor), and gaseous and liquid hydrocarbons such as methane, olefins and long-chain alkanes. We have acknowledged expertise in the microbial production of biosurfactants for use as emulsifiers or detergents.

Biorefinery concepts

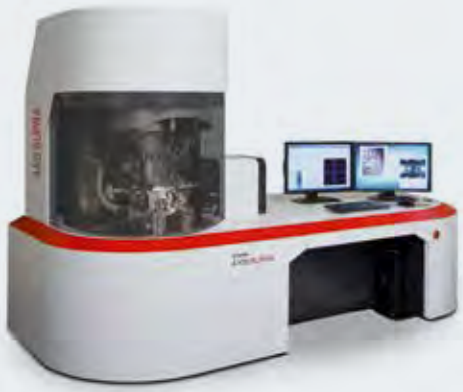
One sustainable approach to the production of chemical products involves the most complete possible use of biomass according to the principle of a biorefinery. We have already successfully made use of different agricultural and forestry residuals (straw, wood waste) and organic residuals from a variety of industries (whey, crab shells and insect carapaces, terpenes) as a source of raw material and successfully convert them in fermentative or biocatalytic and combined chemical processes into basic chemicals that are subsequently purified into fine chemicals or biopolymers. Parallel or subsequent use of the residual biomass closes the cycle and increases the overall efficiency.

Functional surfaces and materials

For the surfaces of many materials e.g. industrial components or technical textiles, the desired properties are often different from those that are intrinsic for the bulk material. Fraunhofer IGB is decoupling volume and surface properties by interfacial process engineering. We give surfaces of polymers, ceramics or metals new properties by applying thin layers or creating defined functions on surfaces. For this purpose, we use gas phase processes (CVD, PVD, PECVD), wet-chemical processes or combined processes. For open-pored polymeric foams with functional groups, we developed a single-stage synthesis strategy.

Electrochemical conversion

With the energy revolution and the expansion of regenerative decentralized power generation, cheaper power will be available – weather-dependent – in the future. If this excess electricity accruing in intervals is used flexibly for electrochemical reactions, basic chemicals can be produced sustainably. For this purpose, we are developing catalysts and suitable electrodes, electrolysis processes and equipment. In the Fraunhofer lighthouse project "Electricity as a Raw Material", for example, Fraunhofer IGB is developing an electrochemical procedure to produce ethylene in a single process step. An electrochemical cell in which hydrogen peroxide can be produced from just water and air is already available as a prototype at the institute. In various other projects, we use renewable electricity to bind atmospheric CO_2 and convert it into chemicals.



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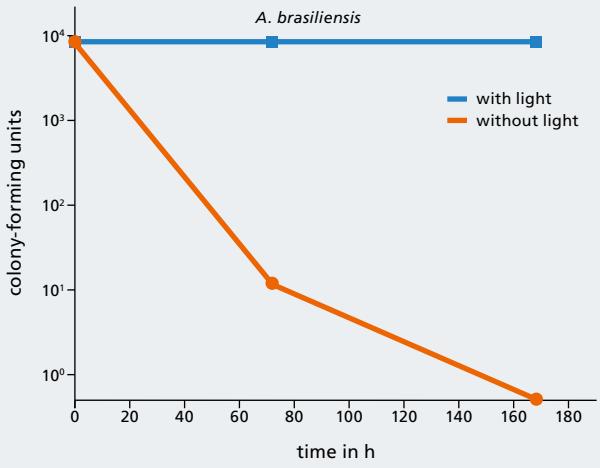

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Combined surface analysis

The control of surface properties is of utmost importance in almost all applications. Even with purely mechanical functional components, the question arises of how they can be glued, protected against corrosion or decoratively coated. This usually requires several process steps for surface finishing. A frequent pressing issue is that all manufacturing steps of the component leave marks on the surface – for example, residues of parting agents may cover localized spots or even more extensive areas. Already the search for suitable finishing processes often requires surface analysis to determine the status quo. But even with established methods, surface analysis is time and again resorted to when problems such as failing bonds, peeling coatings, and lack of electrical conductivity suddenly occur. Here is where root cause analysis comes in to eliminate the source(s) of error.

When examining a surface, we often realize that the selected analytical method provides only part of the information required and that another method of measurement would be expedient. By default, the sample would now have to be removed and fed to the other measuring method – and thereby the previously examined measuring point recovered again.

At Fraunhofer IGB, a new ESCA device (electron spectroscopy for chemical analysis with Kratos Axis Supra, also XPS) is now available, which allows us to circumvent this problem since a sample can be analyzed with several integrated devices. This device was individually upgraded to include a scanning electron microscope (SEM-EDX) and an Auger electron spectroscope (AES) in addition to a latest-generation X-ray photoelectron spectroscope (XPS). Ion scattering spectroscopy (ISS) for hydrogen detection is also available. It provides important information on the hydrogen content at the surface, which is especially useful in the case of polymer surfaces.

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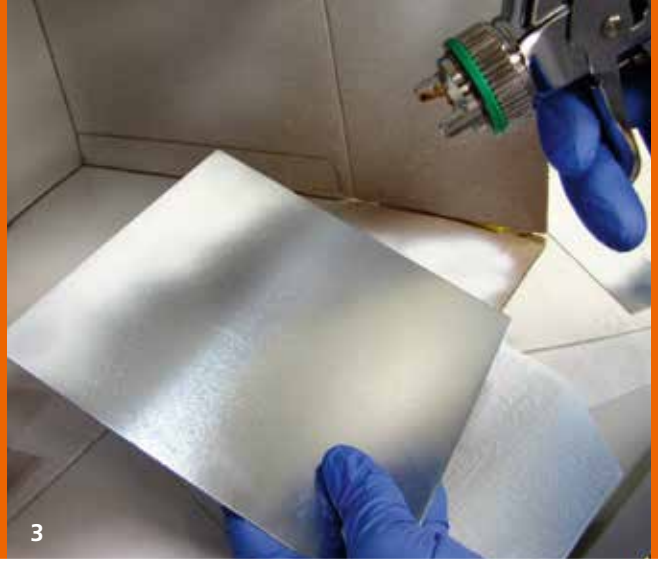
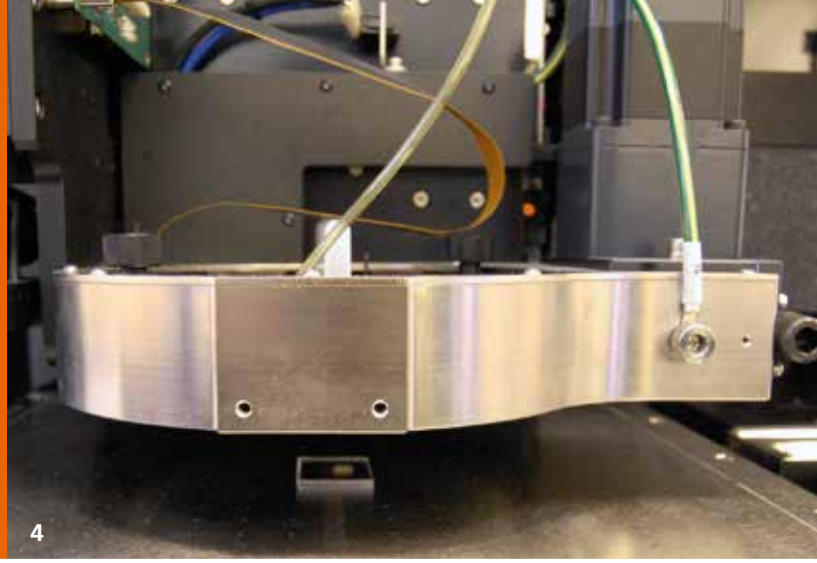
Improved indoor air quality through photocatalytically active coatings

Our health and well-being are negatively affected by harmful substances indoors. Such harmful substances are, for example, outgassing compounds from furniture and carpets or contamination of the breathing air with spores from any mold that is present. De-polluting paints for outdoor applications have already been established with titanium dioxide as the active material, although the challenge is to achieve this effect even with normal room lighting.

Within the framework of the EU project OSIRYS, Fraunhofer IGB has developed a photocatalytically active interior paint in cooperation with SICC GmbH. The effect is based on the formation of active oxygen species when irradiated with light which chemically attack organic compounds. Fraunhofer IGB has investigated the photocatalytic activity of various commercially available materials under application-relevant conditions. This included the evaluation of the effect on organic compounds and microorganisms.





With the most active TiO_2 material, a paint has been developed by SICC. With standardized office lights, this coating for interiors shows high activity levels against microorganisms such as *Sarcina lutea* and *Aspergillus brasiliensis*, the cause of black mold. After 3 days of exposure to light, a reduction of the colony-forming units (CFU) from 10,000 to 10, and after 7 days to zero, was achieved for *Aspergillus brasiliensis*. No bacteria were reduced without light. Similar values were obtained for *Sarcina lutea*.

Commercial distribution is to be carried out via SICC GmbH.

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Formulation of reactive inks – Reactive inkjet printing of polyurethane foams

Novel additive manufacturing processes are currently being focused in a variety of research fields. Digital inkjet printing produces small, uniformly-sized droplets that can be used as micro building blocks. In this way, spatially resolved structures of new, as well as known materials can be generated in an innovative way. For this reason, Fraunhofer IGB focuses its research on inkjet printing as a production tool for the individualization of production processes.

The combination of inkjet printing and the well-known polyurethane chemistry has great potential for future production of functional materials. At present, we are focusing on the production of polyurethane foams using two-component reactive inkjet printing. Two inks (an isocyanate-functional and, for example, a hydroxy-functional ink), each containing a reactive component, are printed separately in layers. The hydroxy-functional ink contains a polyethylene glycol (PEG) as the main carrier, combined with a crosslinker and catalysts. The second ink contains the pure isocyanate compound hexamethylene diisocyanate to obtain the porous polyurethane structure via a chemical reaction. For the first time, we were able to produce polyurethane foams without further mechanical mixing of the two reactive inks. By varying the inks, it is conceivable that spatially resolved differently-defined surface properties can be achieved *in situ*.

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1 *Kratos Axis Supra allows for sample analysis simultaneously with chemical and imaging techniques.*
2 *Reduction of CFUs by exposure to light using the example of A. brasiliensis.*
3 *Application of the developed coating via spray gun.*
4 *Reactive printing using a Fujifilm Dimatix inkjet printer.*

Hydrophobic proteins for surface functionalization

Binding of functional proteins to membrane surfaces can provide them with new properties. Such biologization offers many advantages, has high industrial relevance and can be of great ecological and economical importance as a strategy for textile finishing. This applies in particular to the production of water-repellent textiles that until now have been mainly provided with environmentally unfriendly fluorinated hydrocarbons.

In the "Development of a natural fluorocarbon-free hydrophobing agent for textiles on the basis of proteins" project, we use hydrophobic proteins produced using recombinant techniques, known as hydrophobins, which are naturally produced by fungi, as well as natural cellulose anchor proteins as biological alternatives. Genes coding for the respective protein types are recombinantly assembled in modular designs such that the novel bi-functional fusion proteins can be produced in bacteria using established biotechnological methods from renewable resources. The anchor protein binds the fusion proteins to the surfaces; the hydrophobins provide the hybrid material with hydrophobic properties.

This work has resulted in an exclusive tool box of different proteins that can be applied functionally to material surfaces without any chemical or physical pre-functionalization. This leads to a changed surface energy and thus to strong hydrophobing of the surfaces. Currently, we are working to optimize purification and aqueous formulation of the fusion proteins for the application in order to make the process even more effective. Further projects with other cellulose-containing material surfaces used as substrate are planned.

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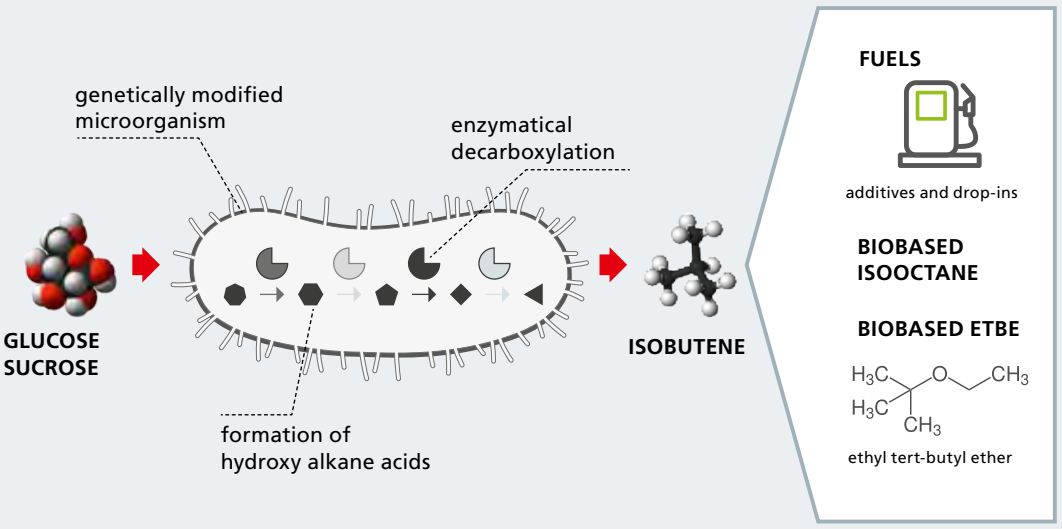
Demonstration workshop on fermentative carboxylic acid production

Fraunhofer IGB and Fraunhofer CBP together with the Association of German Engineers (VDI) held a demonstration workshop in Leuna that addressed representatives of industry and research, and students. The focus of the workshop was to present the European project Bio-QED, especially the itaconic acid value chain.

Highlights of the project results and the impact achieved included production of sugars from lignocellulosic material with the Organosolv process developed by Fraunhofer (Dr. Christine Rossberg, Fraunhofer CBP), using white biotechnology for the production of basic chemicals (Dr. Susanne Zibek, Fraunhofer IGB), scale-up of the fermentation process to produce itaconic acid using the filamentous fungi *Aspergillus terreus* as well as product recovery and purification by crystallization (Dr. Katja Patzsch, Fraunhofer CBP). Secondly, examples from research

1 *Textiles provided with fusion proteins show hydrophobic properties.*
2 *Guided tour through the fermentation facilities of Fraunhofer CBP.*
3 *Fuel additives from isobutene: from sugar to fuel.*



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and industry were presented – purification processes by membrane filtration technology (Prof. Gerd Braun, TH Cologne), fermentative production of carotenoids (Prof. Reinhard Pätz, HS Anhalt), scale-up of the process for the direct fermentation of isobutene from sugar and construction of a pilot plant (Tino Elter, Fraunhofer CBP) as well as the production of biosurfactants and epoxides from plant oils (Dr. Susanne Zibek, Fraunhofer IGB). The workshop was completed by a tour around the pilot facilities of Fraunhofer CBP and a get-together for discussion of current topics in the field of bioeconomy research and development.

The Bio-QED project was successfully completed in 2017 with the demonstration of an *Aspergillus* fermentation on the 10 m³ scale and downstream processing by continuous crystallization to produce several hundred kilograms of itaconic acid.

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Biobased fuel additives from sugar

The company Global Bioenergies and Fraunhofer CBP run a demonstration plant for the fermentative production of biobased isobutene from sugars. Isobutene is one of the key molecules of the petrochemical industry and is currently being produced commercially exclusively from fossil sources, mainly petroleum.

Transforming the biobased analogues to fuels and fuel additives is promising and has been explored and turned into reality in the project. The focus was on the conversion to isooctane and ethyl tert-butyl ether (ETBE). Established process concepts were adapted to the biogenic raw material source, and the feasibility of the CBP-operated integrated testing and pilot plants was successfully demonstrated. Finally, corresponding sample quantities of biogenic fuel additives were validated against the products available on the market. During the project, the world's first-ever production of fully renewable ETBE took place in February 2017.

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ChitoTex – Insect-based chitosan for coating textiles

Insect-based protein is currently used as pet food and was approved as fish feed for aquaculture in the summer of 2017. The side streams in protein production have a high content of chitin, a nitrogen-containing acetylated polysaccharide. At present, most of the production of chitosan, the deacetylated derivative of chitin, is obtained from crab and shrimp shells. The use of locally available insect-based chitosan for application as a textile coating is the focus of ChitoTex.

The identification of side streams with chitin content of more than 30 percent, based on specially developed analysis methods, laid the foundation for establishing purification processes for the polysaccharide. Together with its partners Fraunhofer IGB has identified and produced 15 chitin-degrading enzymes, paving the way for a purely biotechnological value-added chain for the production of chitosan. The chitosan produced showed similar properties to crab shell chitosan in physical-chemical studies and is therefore suitable for use as a sizing agent. In addition to characterization for the technical aspects of applications, unmodified chitosan has already been tested for textile coating purposes and initial investigations regarding the hydrophobic modification of chitosan have successfully been completed.

Insect-based chitosan has established itself in many ways as a local alternative to crab-based chitosan. Based on these results, a follow-up project for the application of hydrophobized chitosan for textile coating has already been initiated. In addition, research activities in cooperation with the protein producers are to be intensified and extended to other side streams.

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Piloting an innovative process for rapeseed processing

The kick-off meeting in September 2017 marked the start of the "EthaNa" project funded by the German Federal Ministry of Food and Agriculture (BMEL). Coordinated by Fraunhofer CBP, eleven partners from the industry and research are developing a novel process for the treatment of rapeseed.

In comparison to the established extraction process with hexane solvent, digestion and recovery of the material are carried out with ethanol in the EthaNa project. This makes it possible to significantly improve the quality of the rapeseed oil and rapeseed concentrate products. In addition, the project also aims to isolate novel recoverable substances that previously could not be obtained from rapeseed, such as secondary plant constituents or protein fractions.

1 *After the last molting of the pupa to the fly, chitin-containing exuviae remain.*
2 *Dehulled rapeseeds for the extraction of recyclable materials and new products.*
3 *Plant for the production of lignin fragments at Fraunhofer CBP.*

3

The aim of the three-year project is to set up a pilot plant at Fraunhofer CBP and to demonstrate the entire process from the peeling of rapeseed and the subsequent digestion to obtaining the oil from the rapeseed kernels. The first process units are scheduled to start operating in autumn 2018. The generation of product samples of rapeseed oil and rapeseed concentrate is planned for the end of 2019. Sample quantities (of 100 kilograms to tons) will initially be used for further investigations and the assessment of the product share in the food and feed industry.

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Lignin-based polyurethanes

Lignins, with a share of up to 30 percent in woody biomass, are among the most common organic compounds. However, due to the heterogeneity of their aromatic structures, they are difficult to turn into chemical applications.

Within the joint project "Lignoplast", a consortium – coordinated by Fraunhofer CBP – was working on new methods to be able to use different lignins, among others, in polyurethane systems. Depending on the pretreatment method, lignins have different properties that significantly influence further processing. It was necessary to process sulfur-containing lignins from pulp processes as well as sulfur-free lignins from biorefinery production (e.g. from the Organosolv process, which is also being intensively developed by Fraunhofer CBP).

The base-catalyzed cleavage proved to be a suitable method to break down all investigated lignin types into smaller phenol derivatives with a simpler structure. Based on preliminary investigations at Fraunhofer ICT, the multi-stage process consisting the continuous base-catalyzed cleavage and the subsequent separation and purification of the products, was successfully transferred to pilot scale at Fraunhofer CBP.

Consortium partners use the resulting lignin fragments for the production of high-quality polyurethane foams or as polyols for polyurethane coatings of long-term fertilizers. Application tests revealed positive properties, as well as some additional advantages such as biodegradability. Further work is needed before the products can be placed on the market. Continuous availability of raw materials, improved process stability as well as the economic considerations of the overall process will be aimed at in further activities.

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Torrefaction and transport conditioning of wood

Wood or lignocellulose is one of the most important renewable raw materials. In the EU SteamBio project, Fraunhofer IGB has developed a process for the pretreatment and torrefaction of raw materials and residues containing lignocellulose. This process is based on the principle of drying by means of superheated steam at atmospheric pressure. During torrefaction, the biomass is heated in an oxygen-free steam atmosphere for a certain process time. At approx. 220–250°C, the process temperature is below the value above which carbonization (pyrolysis) takes place. Water and hemicellulose are driven out together with other volatile substances and selectively condensed for use as platform chemicals. What remains is a hydrophobic material of high energy density that can easily be grinded into a highly reactive substrate.

To demonstrate the process on an industrial scale, a semi-mobile plant was built as part of the SteamBio project. The plant consists of a 20-foot container with a storage hopper and energy center as well as a 40-foot frame accommodating the reactors for drying and torrefaction, a device for solids discharge (with cooling) and condensers for the volatile fraction. The throughput of the plant can be adjusted flexibly depending on the substrate and is designed for 150 kg/h of raw material (freshly harvested wood chips). Agricultural waste such as vineyard pruning or press-cakes (olives, wine, fruit) can also be processed.

The system is designed for automated, continuous 24/7 operation and is controlled by software with integrated data acquisition developed at Fraunhofer IGB, which also allows remote control operation. A heating capacity of 155 kW using electrical elements is installed in order to permit compact construction, flexible operation and better measurement of the energy flows. A demonstration operation for the torrefaction of different substrates and the characterization of the products is planned for 2018 in Spain.

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Single-stage electrosynthesis of ethene from CO_2

The use of carbon dioxide (CO_2) for the production of carbon-based basic chemicals by using regenerative energy, in particular electricity generated from renewable sources, is increasingly gaining strategic importance. In addition to recycling CO_2, this avoids the use of fossil resources, which reduces economic dependence on oil and gas imports.

Within the framework of the Fraunhofer Lighthouse Project "Electricity as a raw material", the electrochemical synthesis of ethene, one of the most important raw materials in the petrochemical industry, from CO_2 and water will be demonstrated. Fraunhofer IGB is not only developing novel, efficient catalysts for the reduction of CO_2 to ethene as well as the necessary gas diffusion electrode, but has also designed and built a demonstrator with which reliable statements on scale-up design and efficiency with regard to the industrial use of the process can now be made.

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This demonstrator is equipped with a process control system for fully automatic operation (Fig. 2). The core component is an electrolytic cell (Fig. 3) with an integrated gas diffusion electrode (GDE). In the currently ungoing work, the demonstrator is used to validate the production of ethene on a membrane area of 130 cm^2 in continuous flow-through operation. The plant also allows the specific analysis of the products that are created in a gaseous or liquid form in each case. In addition to screenings of catalysts and electrode materials, further process parameters can be adjusted and monitored in order to optimize the technology and process and to be able to make statements about efficiency and long-term stability.

With the system, results achieved on a laboratory scale so far can now be transferred to a first industry-relevant scale. By adapting the electrolytic cell, the demonstrator can also be used for the synthesis of other basic chemicals in the future.

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Purification of monoclonal antibodies using a novel continuous chromatography method

"Intensification of purification of monoclonal antibodies" is a subproject processed in the framework of the "Industry on Campus" project "Raw material and energy efficiency by process innovations" funded by the state of Baden-Württemberg.

The objective of the project was to develop the basics for introducing continuous process steps in the production of biopharmaceutical compounds, which until now have been produced using traditional batch procedures. The focus is on the purification process for monoclonal antibodies. The key chromatographic capture step was successfully transferred from traditional batch-wise to a continuous process management. This change could significantly increase productivity and decreases operating costs by saving time and process chemicals. The chromatography steps of the batch procedure were transferred to ChromaConCube, a continuously working device at laboratory scale provided by partner LEWA, and optimized. At the end of the project term, a pilot/production plant was provided by LEWA and also put into operation as scheduled. For the initial tests with protein containing broths, chromatography materials from the partner Tosoh and Atoll were used.

With the project now complete, the pilot and production plant as well as the continuous working laboratory device (ChromaConCube) provided by LEWA are available for potential users from industry for tests at Fraunhofer IGB.

www.igb.fraunhofer.de/rawmaterial-energy-efficiency

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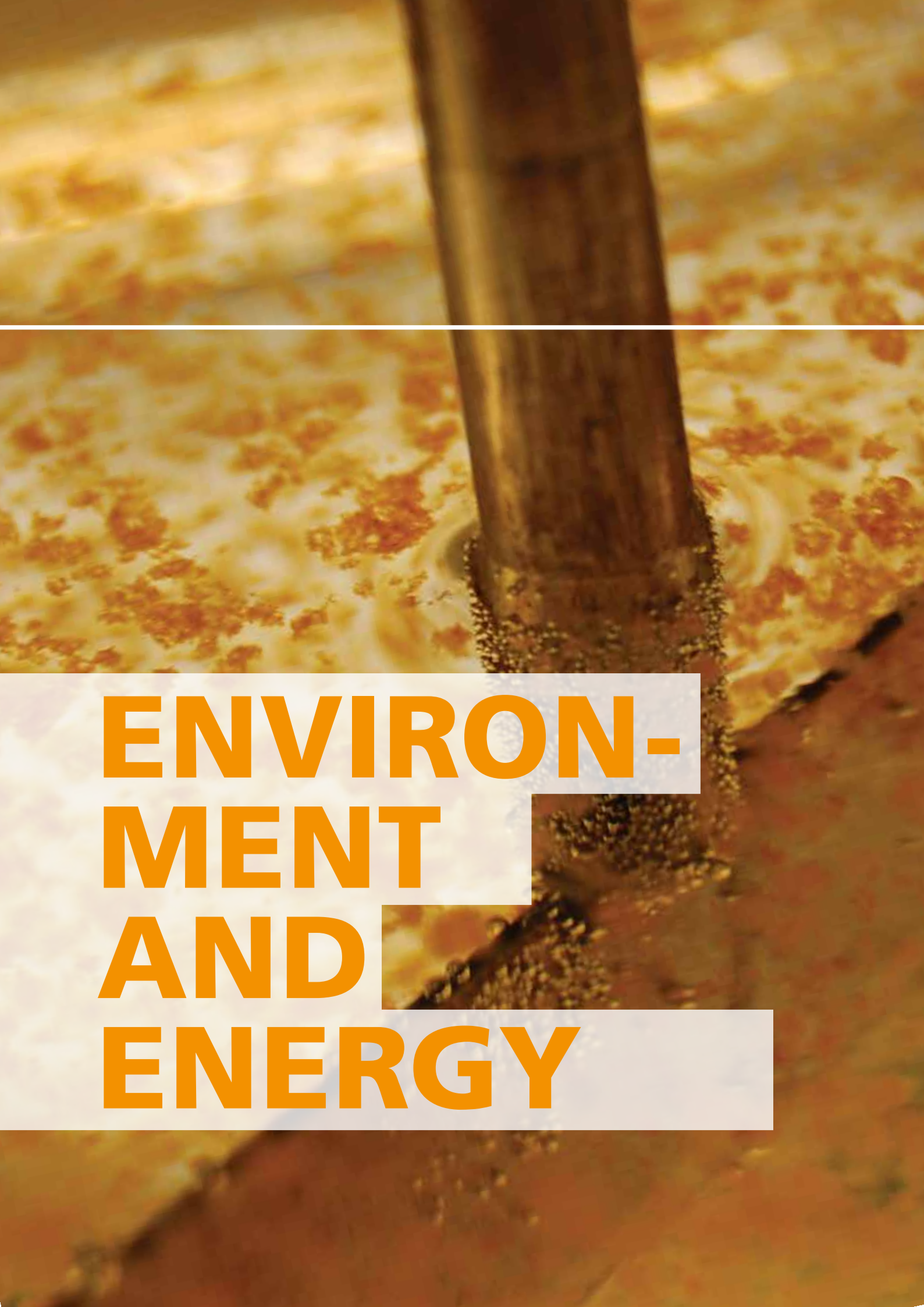
1 *Pilot plant for the torrefaction of lignocellulosic raw materials.*
2 *Demonstrator with the circuits to the electrolyte (left) and gas supply (right).*
3 *Electrochemical cell for CO_2 reduction.*
4 *LEWA Ecoprime Twin, pilot/production plant.*



ENVIRON-MENT AND ENERGY

Against the backdrop of the global debate on water shortage and pollution, resource scarcity and climate change, resource and environmentally friendly economies are becoming more and more important. The transition to sustainable, environmentally friendly yet reliable supplies of clean water, food, raw materials, and energy is therefore one of the major challenges of society today – also in view of the global climate protection targets.

In national and international projects with partners from research, industry and municipalities, Fraunhofer IGB is developing innovative processes, reactors and new technologies for a sustainable water supply and disposal system, especially for the treatment of industrial process water and municipal wastewater, for the reuse of residual and waste materials, and to improve energy efficiency by making use of waste heat and regenerative energy.

The business area "Environment and Energy" thus stands for a variety of advanced technological developments that help to prevent emissions being released into the environment, to recycle raw materials and to develop regenerative energy, thereby combining cost effectiveness with sustainability. Potential solutions are, in some cases, linked with major topics in the business area "Chemistry and Process Industry".

(Re)processing of raw and residual materials

Our primary raw materials are finite resources, yet in politically unstable regions they are frequently not exploited in a sustainable or socially acceptable way. To supply a growing world population with raw materials and to reduce the dependence on importing raw materials, we develop processes for recovering and recycling secondary raw materials from production and waste streams – in a quality equivalent to that of the primary raw materials and with comparable processing complexity and costs.

New techniques for example, enable us to selectively separate mixtures of inorganic raw materials (metals, rare earths) on a molecular or atomic level. Using new processes, important nutrients such as phosphorus and ammonium can be recovered from wastewater, sewage sludge, fermentation residues or liquid manure to be used as fertilizers. We process the residual low-nutrient organic fractions to obtain humus-forming soil conditioners.

Networking and cooperation

At Fraunhofer IGB we are developing integrated material flow and energy concepts for industry, municipalities and entire regions with the aim of replacing historically evolved infrastructures by system solutions using the latest technologies. We are therefore actively involved in the Fraunhofer Alliances Energy, Building Innovation, Water Systems, and the Morgenstadt Initiative. Also, Fraunhofer IGB is outstandingly networked in Germany through the national technology platforms SusChem Deutschland and German Water Partnership, and very well connected throughout Europe.

Water and wastewater technologies

Water is our most important food resource. To achieve a secure supply of water and efficient water purification, we develop innovative solutions for water extraction as well as water management concepts that are adapted to the geographical, demographic and regional conditions in each case. To ensure, as far as possible, the multiple use of industrial process water, we are working on technologies with which contaminations can be selectively removed and valuable substances can be recovered. We develop, optimize and combine aerobic and anaerobic biological processes with membrane and chemico-physical processes as required.

We employ various technologies, among them membrane adsorbers and electrooxidative processes, to prevent emissions of persistent substances into the environment. To purify water with persistent organic components, we develop technologies where treatment with electric current (electrolysis) or high-energy UV radiation (photolysis) result in reactive hydroxyl radicals that oxidize the organic molecules to recoverable compounds or completely to carbon dioxide, but without the addition of chemicals.

Water monitoring

Drinking water is subject to a wide range of hazards. For example, pesticides from agriculture or chemicals from industrial accidents can enter municipal supply systems via the groundwater. The release of toxic compounds brought about by criminal or terrorist attacks also represents a growing threat. To prevent the possibility of contaminated drinking water from reaching consumers, it must already be monitored in the supply network. Fraunhofer IGB develops biosensors based on living cells that are suitable as early warning systems for the municipal water supply or decentralized supply systems. We work together with other Fraunhofer Institutes on translating the cellular response into a physically measurable signal.

OUR OFFER FOR ENERGY REVOLUTION

Energy conversion and storage

To tap new regenerative energy sources, we develop innovative membrane technologies, for example for efficient ethanol fuel cells or economically viable osmotic power plants. For the energy system turnaround to succeed, storing excess power must be practicable. For this purpose, we develop catalytic processes to convert electrical energy – especially by binding and reducing CO_2 – to chemical energy reservoirs, for example longer-chained hydrocarbons.

In many cases, waste heat that results from power generation and many industrial processes remains unused. To make excess waste heat available for temporally and spatially decoupled heat requirements, Fraunhofer IGB is working on thermo-chemical sorption systems for the long-term storage of heat.

Bioenergy

The efficient generation of biogas from sewage sludge using anaerobic technologies is a key issue at IGB. We have already converted several sewage treatment plants of different sizes to our high-load digestion process, thus enabling them to generate their own electricity. We also use our know-how about the fermentation of organic substances for the reutilization of residual matter from the food industry and agriculture. Small mass flows are becoming increasingly interesting as the energy sector is decentralized.

However, biogas – a mixture of methane and carbon dioxide – is not just used to generate power and heat in combined heat and power (CHP) units. We therefore investigate absorption and membrane processes that bind CO_2 with high capacity to separate highly purified methane from biogas as a basic raw material or fuel.

OUR CONTRIBUTION TO THE NEXUS OF WATER – ENERGY – FOOD – RAW MATERIALS

More and more people are living on this planet, who need to be supplied with water, food, energy and consumer goods. Today, 780 million people have no access to clean water and more than one billion people worldwide suffer from hunger. Excessive consumption of resources and climate change mean that raw materials are running low, more and more soils are eroding and groundwater reserves are becoming scarcer. This will further intensify the competition for resources.

Sustainability through integrated resource management

Water is not only our most important foodstuff, it is also essential for agriculture, which uses up to 70 percent of the world's water requirements. The energy sector also needs water, for example for cooling, heating or the use of hydropower itself. Energy in turn is needed to treat, transport and purify water, to produce fertilizers for agriculture and to produce food products.

With integrated concepts, Fraunhofer IGB considers the Nexus of the resources water – energy – food – raw materials. The term "Nexus" is Latin and means link, connection, correlation. It expresses that resources cannot be considered independently of each other, even if they are managed in separate industries. The use of one resource always has an impact on the other.

New challenges require cross-sectoral action

This can be illustrated by the example of agriculture: For a long time now, the agricultural sector has not only been producing vital food products, but increasingly also energy carriers in the form of biofuels or biogas. On the positive side, this prevents the release of even more carbon dioxide from fossil fuels. However, competition for arable land and the additional consumption of water and nutrients may, under certain circumstances, affect the provision of food products.

Sustainable solutions can only be found if thinking in sectors is broken down and holistic action is taken. Fraunhofer IGB develops innovative integrated solutions for a sustainable interaction of the fields of water, energy, nutrition and raw materials for municipalities, agriculture and industry – and for the benefit of the environment.

In doing so, we also rely on the potential that results from the expansion of decentralized, renewable energies in the course of the energy revolution and develop technologies, for example, which compensate for the fluctuating generation of electricity from wind and solar by storing the electricity without loss or by directly linking it to industrial value creation.

1 *Sewage sludge can be efficiently digested into biogas and can therefore provide energy.*
2 *Anaerobic wastewater treatment in a closed bioreactor.*

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Sewage plants: Purifying wastewater while recovering energy

The central sewage treatment plants that are typical in industrialized countries are among the largest municipal energy consumers. For more than 20 years now, Fraunhofer IGB has been working on converting smaller sewage treatment plants from aerobic sludge stabilization to more efficient and flexible anaerobic high-load digestion producing biogas. "When sewage sludge, which consists primarily of organic carbon compounds, is treated in the absence of air in digesters with an efficient high-load process, anaerobic bacteria convert it – via acids and alcohols – into considerable amounts of biogas, a mixture of carbon dioxide and methane," explains Dr. Marius Mohr, who manages the "Bioprocess Engineering in Water Management and Circular Economy" group at Fraunhofer IGB. In combined heat and power plants, biogas supplies electricity and heat that significantly reduce or in some cases more than compensate for the net energy consumption of the sewage treatment plant.

In Brazil, on the other hand, where little additional heat is needed, biogas can be used in the mobility sector. Many vehicles are equipped with a Tetrafuel engine, which can run on gasoline and ethanol as well as compressed natural gas (methane). The vehicles only need to be equipped with an additional tank. The biogas produced at the wastewater treatment plant of the city of Franca in the state of São Paulo is therefore processed according to a concept developed by IGB and can be used as biomethane (see p. 76). In both cases, not only the operators of the wastewater treatment plant benefit, but also the climate, as fossil fuels are saved.

About 10 years ago, Fraunhofer IGB adapted the approach of producing biogas by digesting organic substances in municipal wastewater with high organic load." In the DEUS 21 project, we have successfully demonstrated that the organic substances in the wastewater supply biogas if they are treated semi-decentrally in anaerobic bioreactors," according to Mohr. The higher the concentration of organic load, the more efficiently the biogas can be produced. For this reason, biological waste generated in the household is at best "disposed of" with the wastewater.

Sustainable cities: Biowaste provides energy for cooking, wastewater nutrients for agriculture

Fraunhofer IGB and the Gesellschaft für Internationale Zusammenarbeit (GIZ) have taken up this approach in the project "The Urban Nexus". "For ten selected Asian cities in which the development of a suitable wastewater infrastructure could not keep up with the population growth, we have developed concepts for an integrated resource management," Mohr explains. One example is the city of Da Nang in Vietnam. 200,000 people live on the coastline, whose wastewater is currently seeping into pits unused.

According to Mohr's concept, household wastewater is discharged via a vacuum sewer system. Nearby hotels also dispose of their kitchen waste through these pipes to increase the content of organic carbon compounds. Together with the wastewater, they land in a tank that feeds a bioreactor. In the absence of air, the bacteria digest the organic cargo into biogas, which in turn nourishes the gas flames in the kitchen in hotels and households. The purified water is used (except during the rainy season) for soil irrigation of urban agriculture that is operated in an intensive manner. This preserves groundwater reserves and reduces the risk of groundwater salinization by subsequent seawater. As the wastewater purified in the anaerobic bioreactor still contains plenty of nutrients such as phosphorus and nitrogen, the plants on the field are fertilized at the same time. Farmers can dispense with the use of further fertilizers.

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After long and ultimately successful negotiations on financial support, the city of Da Nang wants to test the vacuum system on 110 plots of land. If the results are positive, it is planned to implement the overall concept by the end of 2018, which shows impressively how sustainable solutions will look when the areas of water, energy and food are considered together.

This is exactly what the "Smart Water Future India" project, in which Fraunhofer IGB is developing a concept for sustainable water and resource management in the city of Coimbatore in southern India, is all about. The challenges of urban development are not to be considered separately according to the traditional sectors, but solutions for water supply, energy supply and food are to be developed across the board and networked intelligently. For the requirements analysis, the project is based on the "Morgenstadt City Lab" methodology developed within the framework of the Fraunhofer City of the Future Initiative, which Mohr has already successfully applied in the Georgian capital of Tbilisi (see information box).

Regional competition for water – Fertilizing and irrigating vegetable plants with wastewater

Regional competition for the water resource exists in many places, including in the Mediterranean regions of Europe where vegetables are grown. Since agriculture is one of the largest water consumers, new concepts and processes for water reuse are in demand. As already mentioned above, anaerobically treated wastewater still contains plenty of inorganic phosphate and ammonium salts – nutrients that are urgently needed in agriculture after the decomposition of organic compounds. Why not use wastewater for irrigation and as a source of nutrients at the same time?

"In the research project HypoWave we are investigating whether anaerobically purified municipal wastewater can also be reused for hydroponic plant production due to its nutrient content," according to Marius Mohr. In the case of this cultivation of vegetable plants in the greenhouse, the seedlings do not need soil in their plant containers. As a result, no water seeps into the soil and it evaporates less. Initial results of a pilot experiment with lettuce plants show that only a small additional supply of nutrients is necessary for good growth – with the wastewater, the nutrients contained in it can be used again in a meaningful way.

Nutrient recovery for agriculture – Conservation of natural raw materials and fossil fuels

The reuse of nutrient-rich wastewater is limited to direct, regional local use. If this is not possible, also due to legal requirements, the nutrients phosphorus and nitrogen contained in the wastewater can be recovered in solid, transportable form as fertilizers – and create the basis for a cycle-oriented agriculture.

The harvesting of plants removes nutrients from the soil, which in today's modern agriculture are primarily balanced by synthetic fertilizers. However, deposits of raw phosphates are increasingly contaminated with heavy metals. And the industrial production of nitrogen fertilizers using the Haber-Bosch process consumes enormous amounts of energy: About two percent of the world's primary energy production and five percent of the world's natural gas consumption are caused by nitrogen fertilizer production alone.

5

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The nutrients stored in the plant are not really lost, but end up in biowaste, liquid manure and fermentation residues as well as in wastewater via the food chain. "If it is possible to close the nutrient cycle by recovering the nutrients from these waste streams and recycling them into fertilizers, natural raw material reserves and fossil energy sources can be protected," according to Dr. Iosif Mariakakis, Manager of the Nutrient Management Group at Fraunhofer IGB.

It is estimated that 4.3 million tonnes of phosphorus per year are lost worldwide through the sewage system alone. "With our ePhos® process, we have developed an electro-chemical process that allows nitrogen and phosphorus to be precipitated as Magnesium-Ammonium-Phosphate (struvite) from municipal wastewater without any addition of salts or alkalies," according to the IGB expert. The energy requirement is low and can be supplied entirely from renewable sources. Struvite is a high-quality long-term fertilizer for agriculture and can be directly absorbed by the plants.

Within the scope of various projects, IGB was also able to develop a concept for recovering phosphorus as fertilizer salt from liquid manure. In a mobile, fully automated pilot plant with a throughput of one cubic meter of raw slurry per hour, more than 90 percent of the phosphorus can be separated from slurry, precipitated and crystallized (see p. 75). The combination of the precipitation step with a low-energy solid-liquid separation also produces a nutrient-poor organic fraction, which can be used as a soil conditioner, in particular to increase the moisture capacity in the soil. The process can also be used for the recovery of phosphorus from fermentation residues produced in agricultural biogas plants.

Fraunhofer Morgenstadt Innovation Network – City of the Future

"Morgenstadt" (City of the Future) is the vision of a sustainable, liveable and sustainable city and its suburban surroundings. In the context of this, the challenge lies in the long-term consolidation of optimized technologies into a holistic system in the city of tomorrow.

Dr. Marius Mohr from Fraunhofer IGB is actively involved as an expert for water management in the Morgenstadt network. In the first phase of the project, he worked in an interdisciplinary team to identify relevant impact factors and together they developed an action-oriented model for sustainable urban development, which looks beyond the sector boundaries of the entire city. Within the framework of a Morgenstadt City Lab, he led a team of scientists to show the Georgian capital Tbilisi the way to a sustainable city, which is fit for the future with the help of the previously developed method.

3 *Agricultural land in the Vietnamese city of Da Nang: In the future, residents will be able to use purified wastewater to irrigate the beds.*

4 *Within the Hypowave project it is investigated how nutrient-rich municipal wastewater can be used for the irrigation of hydroponic cropping systems.*

5 *Organic soil conditioners, obtained from manure and fermentation residues, return organic matter to depleted soils and improve soil fertility.*

6 *Nearly 90 percent of the phosphorus in municipal wastewater is recovered as struvite fertilizer using the ePhos® process.*

7

8

Development of new water sources – cost-optimized and decentralized

In arid and semi-arid areas, drinking water supply can often only be ensured by desalination of seawater or groundwater. However, technologies such as reverse osmosis or conventional thermal processes are energy-intensive and currently still consume large quantities of fossil fuels. IGB is working on energy-efficient and at the same time robust alternatives, which are cost-optimized in terms of the materials used and which are also affordable for poorer countries. In the case of multi-stage vacuum evaporation, for example, solar thermal energy can be used for the desalination of salt water. In recent years, more and more electrophoretic processes for desalination have also been further developed. "Capacitive deionization (CDI) for example, requires significantly less energy than a reverse osmosis plant," according to Siegfried Egner, Head of the Department of Physical Process Technology at IGB. In a variant of vacuum evaporation, the underlying principle is used to open up air humidity as a water reservoir.

The Nexus approach in the process industry in times of energy turnaround

What is being implemented only slowly or only through the pressure of statutory regulations at local authority level has long since found its way into many production sites of process-oriented industries. Rising raw material prices and costs in wastewater disposal make the treatment and reuse of process water and process wastewater and the recovery of auxiliary and process materials an economically attractive challenge for companies.

In the wake of the energy revolution and the expansion of decentralized electricity production from renewable energies, the initial situation is changing: Whereas electrochemical processes – above all for the chemical synthesis of basic chemicals – were previously considered uneconomical because of their power requirements, they are gaining in importance in times when electricity from fluctuating sources (wind power and photovoltaics) which is not needed at the moment is driving down prices on the electricity exchanges.

It is crucial that electrochemical and electrophysical processes – just like the various energy storage systems – can contribute to grid stabilization as current collectors. "We therefore design our electrochemical and electrophysical cells to be as flexible as possible and implement them in a plant system in such a way that they can be operated as a function of the load on the power grid," according to Egner's explaination of the approach at IGB.

In addition to such flexible electricity utilization models (as well as batteries and pumped storages), sufficient long-term chemical storage facilities are required to balance the fluctuating generation of electricity from wind and solar energy. Biogas, purified into methane, can also play an important role in this context. It not only builds a bridge to the mobility sector but can also be fed into the natural gas grid as a long-term storage or converted into methanol as a material storage. Furthermore, new thermo-chemical sorption heat storage systems for the lossless long-term storage of heat developed at IGB make even the storage of electricity in this form efficient.

9

Resource efficiency through water reuse and resource recovery

In contrast to municipal wastewater treatment, pollution in industrial process and wastewater is largely determined by the industry and the specific manufacturing process. In order to reuse process water in the sense of recycling, the impurities must be removed with as little energy and material expenditure as possible. "In addition to mass flow management and the selective detection of contaminations, this requires a tailor-made integrated process technology for the specific treatment of waste," Egner explains.

For this purpose, Fraunhofer IGB has established various electrochemical and electrophoretic processes with which auxiliary material and resources contained in water can not only be removed, but also separated in a recyclable form. In this way, salts can be recovered by electrodialysis or capacitive deionization, and metal ions can be converted into high-purity fractions in the case of high yields using free-flow electrophoresis. The advantage of electrochemical and electrophoretic processes: They work without any additional chemicals.

Such production-integrated water recycling also makes it possible to achieve greater independence from natural water resources and therefore allows for production at locations with less water resources – right up to total independence from natural water resources through Zero Liquid Discharge.

Power-to-Chemicals – modular, flexible, energy-efficient

Fraunhofer IGB is developing catalysts and suitable membranes, processes and apparatus with current-controlled mode of operation for the electro-synthetic production of basic chemicals as an option for the direct compensation of an oversupply of electricity. In the Fraunhofer lighthouse project "Electricity as a raw material", for example, IGB is developing a single-stage process for the electrochemical production of ethene in just one process step. In the EU project Celbicon, methanol is produced from CO_2 by electrocatalysis, which is used as a substrate for fermentation. An electrolysis cell, in which hydrogen peroxide can be produced only from water and air using electrical energy, is already available as a prototype at IGB.

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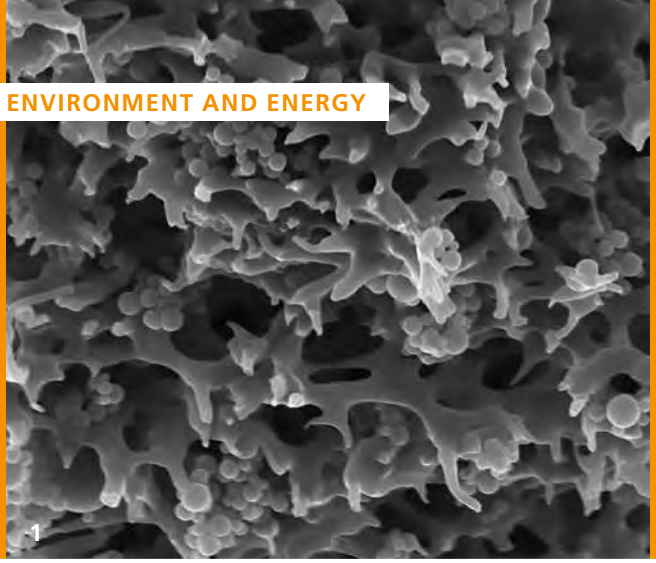
7 *By combining a multi-stage vacuum evaporation process with an adsorption step, water can be extracted from air humidity.*

8 *Metal ions are fractionated by free-flow electrophoresis.*

9 *Electro-synthetic processes combine the energy revolution with industrial value creation by enabling the flexible use of fluctuating electricity.*



Membrane adsorbers for the separation of micropollutants

Various types of membranes are already commercially available for water filtration. What these membranes have in common is that mainly different separation limits are used for size exclusion. In this project, we are developing mixed matrix membranes that, in addition to their filtration function, can adsorptively bind dissolved substances in water. Submicroparticles with different functional groups are produced and integrated into membranes using a phase inversion process. Hollow fiber membranes filled with particles can be manufactured by wet spinning. These membranes are used to separate micropollutants such as diclofenac or metoprolol from water. In the future, various particles will be incorporated into membranes in order to separate different micropollutants at the same time.

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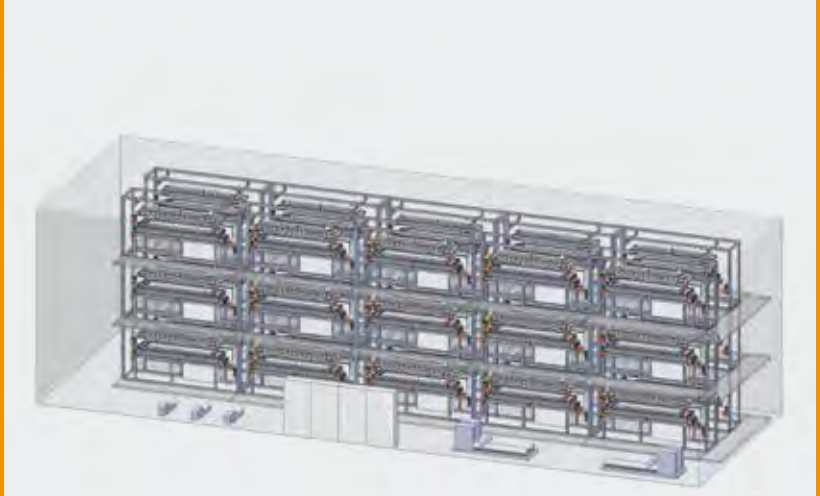
Mobile modular pilot plant for biological purification of industrial wastewater

When introduced into municipal sewage treatment plants, wastewater flows from industry often result in problems from persistent substances or high COD loads (chemical oxygen demand). For logical reasons, industrial wastewater should preferably be cleaned in undiluted concentrations at the place of origin in order to prevent extraordinary burdens on sewage treatment plants and, where appropriate, to allow water to be recirculated within the plant. Wastewater resulting from industrial production processes is mostly unique and variable in composition depending on the production cycle.

It is therefore advisable to carry out pilot tests before designing a wastewater treatment plant. Depending on the composition of the wastewater, it may be reasonable to use anaerobic and/or aerobic processes. In the framework of the "Raw material and energy efficiency by process innovations" (Rohstoff- und Energieeffizienz durch verfahrenstechnische Innovationen) project funded by the Baden-Württemberg Ministry of Science, Research and the Arts, an anaerobic membrane bioreactor was operated with brewery wastewater in the Fraunhofer IGB technical center and a mobile pilot plant was constructed.

The pilot plant includes an anaerobic EGSB (Expanded Granular Sludge Bed) reactor with a volume of 370 liters and an aerobic Sequencing Batch Reactor (SBR) with a volume of 250 liters. For flexible use, the modules were designed so that both the aerobic and the anaerobic plant components can be used individually or in combination. Depending on properties of the inflow and the purification targets, the part of the inflow that is lead past the EGSB reactor in bypass can be adjusted. The plant has been automated to the extent that staff is needed only for filling the feed tank.

1 *Electron microscope image of a mixed matrix membrane.*
2 *Mobile pilot plant at the new Fraunhofer IGB technical center.*
3 *Design of an installation plan for a wastewater treatment plant with 500,000 PE.*



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In mid 2018, the mobile pilot plant will have its first deployment at a pharmaceutical company. Subsequently, the plant will be available for tests by interested companies from various industries. In addition, Fraunhofer IGB assists in the decision about which wastewater flows can be brought together, which can be processed separately and which can be reused after treatment.

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ePhos® – Electrochemical phosphorus recovery

The need for phosphorous fertilizers is growing with the increasing global demand for foodstuffs. The ePhos® process developed by Fraunhofer IGB is used for the recovery of phosphate (PO_4^{3-}) and ammonium (NH_4^+) from municipal wastewater treatment plants. The substances are precipitated in an electrochemical process as a magnesium-ammonium phosphate $MgNH_4PO_4*6H_2O$ (MAP or struvite) which is a high-quality slow-release fertilizer and can be used directly in agriculture as a fertilizer. The main advantage of the ePhos® process is that no chemicals are added at all. The magnesium required for struvite formation is added by means of a sacrificial anode in an electrolysis cell.

The continuous operation of a pilot plant was successfully tested under real-life conditions last year on the premises of a municipal wastewater treatment plant, with a flow rate of up to 3 m³/h. An average elimination rate of more than 80 percent was achieved over the one-year operating period. The average energy requirement for the treatment of one cubic meter of filtrate water from dewatering waste sludge was just under 0.5 kWh. The technology is further optimized with the know-how gained from the pilot test phase. A first industrial-scale implementation is in preparation at a North German wastewater treatment plant with a population equivalent (PE) of 70,000. It is used there to recover phosphate from filtrate water produced in dewatering sludge after digestion.

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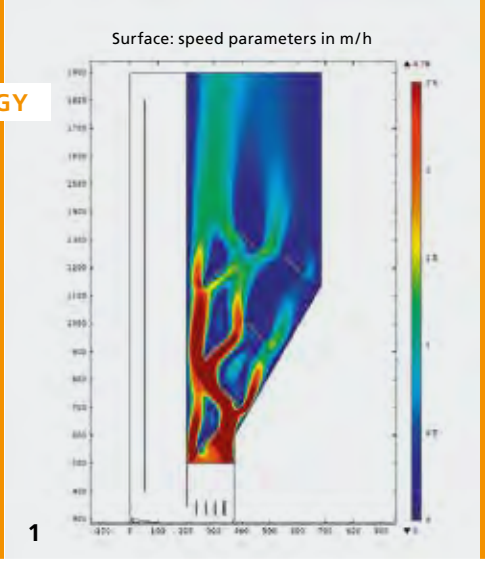
Liquid manure treatment and phosphorus recovery

In the EU-funded BioEcoSIM project, a concept was developed and verified in which a fertilizer containing phosphorus and potassium is recovered from manure by means of precipitation, which demonstrably enhances the properties of plants. The technology that the scientists developed was realized in a semi-technical installation. As part of the "PhosKa-Demo" project funded by the German Federal Ministry for Education and Research (BMBF), the process has now been further scaled up and tested in continuous operation.

A mobile, fully automated plant with a throughput of 1 m³/h raw liquid manure has been designed, constructed and installed. The core of the newly developed plant is a crystallization reactor which promotes the growth of the crystalline fertilizer for improved separation or formulation. The plant consists of a conditioning stage, a two-stage solid/liquid separation and downstream crystallization or precipitation.



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After commissioning, the system was tested and further optimized in continuous operation on the premises of a potential user, an agricultural farm with livestock farming.

With this process, more than 90 percent of the phosphorus contained in the liquid manure can be recovered as fertilizer salt. In addition, the combination with low-energy and robust solid-liquid separation produces an organic fraction low in nutrients that can be used as a soil conditioner.

In this project, the quality and effectiveness of fertilization by the recovered fertilizer salts – compared to mineral phosphorous fertilizers with similar phosphorus content – was also confirmed by greenhouse and field trials.

In another project, the plant will be followed by a stage for nitrogen recovery as ammonium sulfate. This makes the process suitable for the complete and efficient treatment of liquid manure.

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1 *CFD simulation of the newly developed crystallization reactor.*
2 *IGB scientist Barbara Waelkens at the first refueling with biomethane.*
3 *View of the sludge gas upgrading plant in Franca from one of the digester towers.*
4 *Test reactor at the Fraunhofer IGB technical center.*

Climate-friendly biogas upgrading plant opened in Brazil

In December 2017, the Brazilian municipality of Franca started operations of a new sludge gas treatment plant. This concludes the project "Use of sludge gases from a municipal sewage treatment plant for transport purposes" funded by the International Climate Initiative (IKI) from the German Federal Ministry for the Environment. In order to reduce greenhouse gas emissions, the demonstration project was carried out in cooperation with the Brazilian sanitation company SABESP and Fraunhofer IGB. The aim of the project launched in 2009 was to upgrade the sludge gas to natural gas quality. The produced biomethane now can be used to fuel the company's vehicle fleet.

The cooperation within the project covered the complete project chain, from preliminary evaluation and planning to construction and commissioning of the sludge gas treatment facility, which was integrated into the Franca sewage treatment plant (Fig. 3). Training courses for the proper technical operation of the plant were also planned. For this purpose, eight Brazilian delegates traveled to Germany in October 2017. In the cities of Heidelberg and Edenkoben, they visited sewage treatment plants with gas use facilities and took part in training courses dealing with biogas treatment and use.

The biogas upgrading plant in Franca was successfully commissioned at the beginning of December. It has the capacity to process 120 Nm^3/h of raw sludge gas and produces up to 2000 Nm^3/d of biomethane. The first service vehicle has already been fueled with the produced biomethane (Fig. 2). With a concentration of 98 percent methane, the upgrading plant is able to produce very high-quality biofuel. The upgrading plant now serves as a best-practice project with the potential to inspire other similar projects in the future. A great deal of interest in the upgrading system was expressed in Brazil even before commissioning. An inauguration ceremony is planned for March 2018.

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Increasing flexibility of high-load digestion against the background of the energy revolution

In the course of the German energy revolution, the share of wind and solar energy in power supply is steadily increasing. Since these energy sources are not available on a continuous basis, in addition to energy efficiency, increasing importance is being placed on the flexibility of electricity consumption and production from decentralized sources. Decentralized renewable energy sources also include biogas, one source of which is high-load digestion of sludge in sewage treatment plants.

In the framework of the ESiTI joint research project (Wastewater treatment plant of the future: energy storage in interaction with technical infrastructure as a trade-off between energy production and consumption) funded by the Federal Ministry of Education and Research (BMBF), Fraunhofer IGB researchers dealt with the question as to what an extent high-load digestion with and without microfiltration can be operated flexibly, when needed, without affecting the actual function.

The impact loads and temperature changes (minimum 32°C, maximum 43°C) applied in the tests at a lab scale plant at the IGB technical center resulted in only slight reduction of digestion rate and digester gas production but not a failure of the digestion process. Adding a large quantity of co-substrates finally led to acidification. For all applied disturbances, it was observed that with the same volumetric load, digestion with integrated microfiltration is more stable.

In addition to energy efficiency, it can be assumed that the flexible consumption and production of energy will become increasingly important for sewage treatment plants over the next years. Fraunhofer IGB can use its experience to help find the best solutions.

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High-load digestion in Erbach (Danube) inaugurated

Mayor Achim Gaus officially inaugurated the newly built high-load digestion unit on May 20, 2017 with an open day at the Erbach sewage treatment plant. High-load digestion is a process developed by Fraunhofer IGB for the anaerobic digestion and stabilization of sewage sludge. This technology was implemented at the Erbach wastewater treatment plant.

The first step included preliminary investigations on the digestion of the raw sludge from the treatment plant under high-load conditions. For the following steps, a planning team was employed with scientific support from Fraunhofer IGB. This support ranged from the first appointment with the approval authorities, to assistance with the tender documents, accompaniment through the construction phase, cold commissioning and subsequent inoculation with digested sludge from a neighboring wastewater treatment plant, as well as performance testing. In mid-December 2016, this was followed by inspection and approval with the executing companies and final acceptance by the district office. The fully functional plant was handed over to the city of Erbach.

The percentage of sewage sludge to be disposed of was reduced by more than 25 percent. In this process, a large part of the organic material is converted to digester gas by anaerobic microorganisms. After purification steps, a combined heat and power plant utilizes the produced biogas to generate electricity and heat. These are then used at the wastewater treatment plant and in the adjoining municipal building yard.

The high-load digestion ensures that a large part of the energy required to operate the sewage treatment plant is supplied by the sludge digestion. Both electricity and heat are used effectively, achieving a high level of overall efficiency. The next high-load digestion unit is already under construction.

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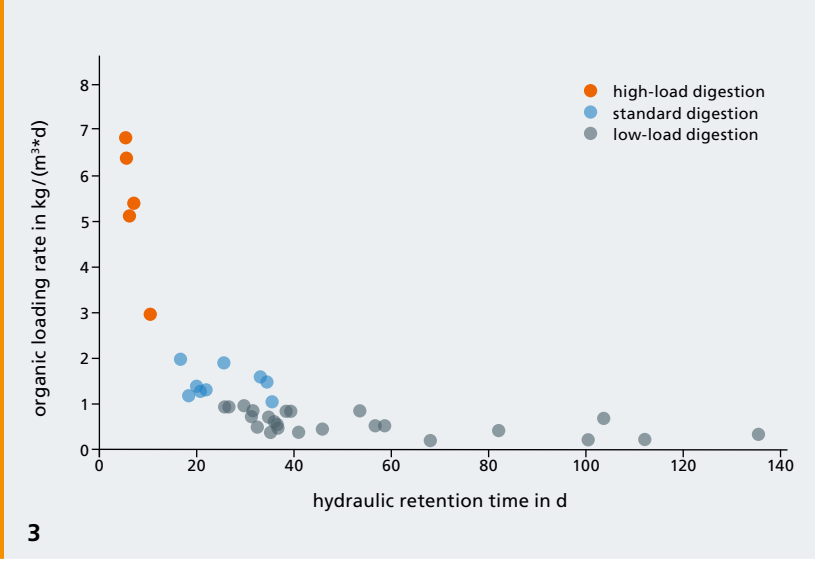
1 *High-load digestion under construction with emergency flare in the foreground.*
2 *Digested sludge from a neighboring wastewater treatment plant (WWTP) is delivered for inoculation.*
3 *Organic loading rate as a function of hydraulic retention time.*
4 *Biogas experiments at Fraunhofer IGB.*

Analysis of the biogas production potential in sewage sludge digestion plants

Within the scope of the Bioeconomy Baden-Württemberg program, an assessment was carried out to determine the potential of the waste material sewage sludge for the production of biogas in the state of Baden-Württemberg. The study demonstrated the further potential of the existing sewage treatment plants of size class 4 for extended biogas production. The conversion of sewage treatment plants of this size class from aerobic to anaerobic sludge stabilization, as well as an optimized digester operation through higher loads, allows an increase in biogas production.

Our analysis shows that the current biogas production in sewage treatment plants could be increased to produce another 40 to 52 GWh/a of electricity and 60 to 80 GWh/a of heat. The conversion of a sewage treatment plant from aerobic to anaerobic sludge stabilization enables the sewage treatment plant to produce its own electricity and heat. Especially the more than 60 municipalities without digestion would benefit from this. The conversion to anaerobic sludge stabilization alone could achieve about 40 percent of the total additional biogas potential. The optimization of the almost 220 existing digesters by means of higher load and improved operation would contribute to the remaining 60 percent increase in biogas potential.

In addition to the biogas potential, specific challenges of sewage treatment plants were identified by visits and discussions with operators, operational log books were evaluated, and "best practices" for optimizing energy efficiency at treatment plants were identified. Sludge management, its quality and an efficient digestion process are decisive for effective solids degradation and biogas production. For example, several wastewater treatment plants operate an activated sludge process with an unnecessarily high sludge age. A number of the evaluated digesters are operated under particularly low loads (Fig. 3). Fraunhofer IGB was able to demonstrate



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how to increase biogas production from sewage sludge, reduce sludge volumes and minimize disposal costs through systematic analysis and concrete measures at selected sewage treatment plants.

www.igb.fraunhofer.de/bioeconomy-biogas

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Integrated optimization of the biogas process chain – GOBi

In a joint project with the University of Hohenheim and various industrial partners, Fraunhofer IGB is working on a sustainable biogas process chain in which all process steps from plant cultivation to the recycling of residual materials were investigated. Scientists of Fraunhofer IGB characterized the fermentation behavior and the biogas production of various renewable raw materials, after modifications during ensilage.

For maize, amaranth, grass and rye whole-crop silage, various silage conditions were assessed with regard to the biogas yield of the pressed silage residues from which previously organic acids were extracted as recyclable substances. The tests were carried out in 1-liter fed batch operations under standardized conditions (Fig. 4). The resulting biogas yield from the silage solids and the acids obtained by ensilage made it possible to evaluate the cascade utilization from acid production and subsequent biogas production of the various silages.

In a two-stage pilot plant (each 130 liters, with each of the stages being operated as a methane reactor) we used amaranth and grass silage consecutively as monosubstrates for biogas production. They were examined with regard to improving productivity, biogas yield and organic degradation. The objective of obtaining stable, continuous long-term operation for continuous biogas production with the respective monosubstrate and a retention time of 25 days was achieved. For amaranth silage, a biogas yield of 451 L/g TVS_{input} (standard conditions) was achieved in the two-stage process with a retention time of 25 days per stage (TVS = total volatile solids). The major part of the biogas was produced in stage 1. With a retention time of 20 days per stage the biogas productivity increased from 561 L/m³/d to 638 L/m³/d, but at the same time the substrate-specific biogas yield decreased: in stage 1 from 369 L/kg TVS_{input} to 326 L/kg TVS_{input}. This means that with a retention time of 20 days, productivity can be enhanced, but not without losses on the substrate-specific biogas yield. With a slightly raised retention time this could be avoided: the greatest possible biogas productivity as well as a constant biogas yield thus can be achieved.

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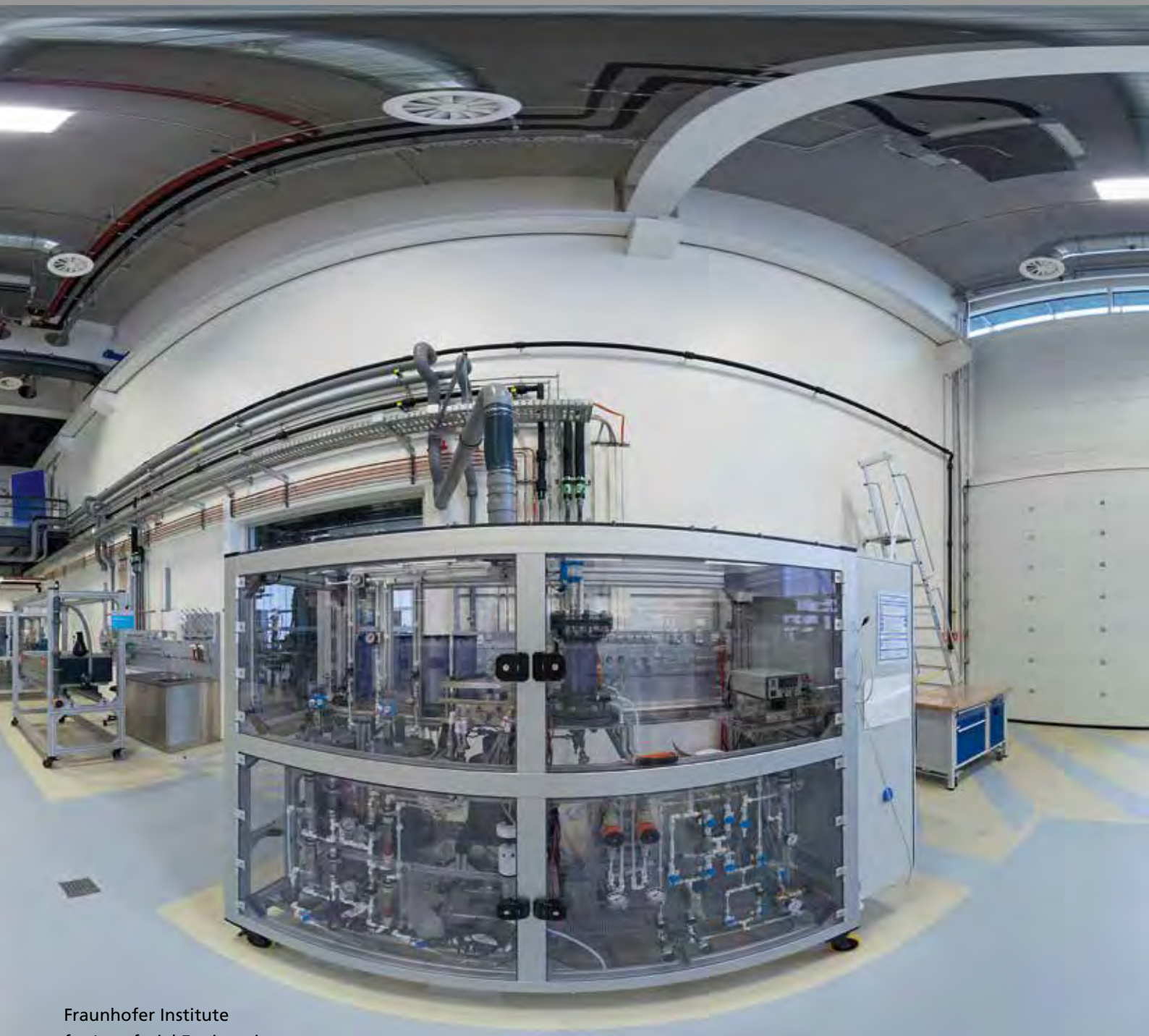
In the research field of "Industrial Biotechnology" we focus on establishing and optimizing processes using enzymes or microorganisms. The scalability of the conversion processes and downstream processing of the products are already taken into account during process development on laboratory scale.



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