

# ANNUAL REPORT 2012 | 13



IGB



60 YEARS  
Fraunhofer IGB



**ANNUAL REPORT**  
**2012 | 13**

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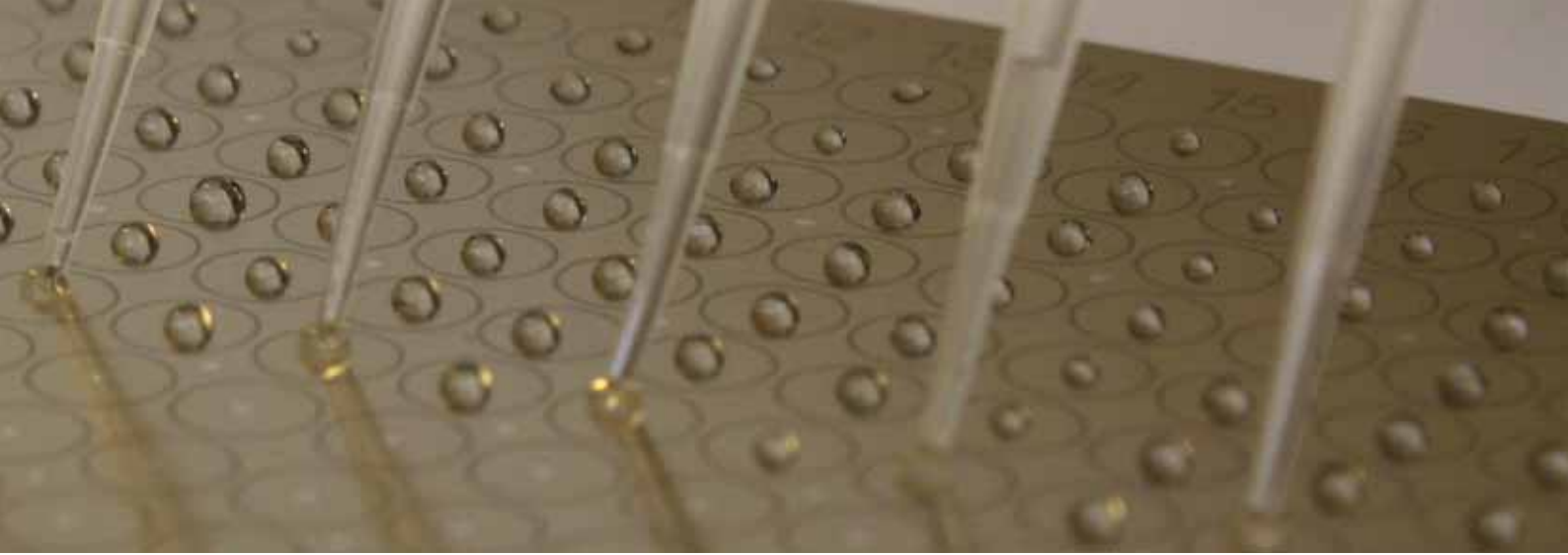
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## THE FRAUNHOFER IGB CELEBRATES 60 YEARS OF INNOVATIONS FOR THE “MARKETS BEYOND TOMORROW”

This year the Fraunhofer IGB turns 60 and – as at its inception in 1953 – still bears “interfaces” in its name. Interfaces give rise to new phenomena, and 60 years mean six decades of innovations and contributions to the sustainable development of industry and society. Thanks to its employees, the Fraunhofer IGB has evolved over the last 60 years into an innovative institute at the forefront of interfacial R&D, shaped by its respective directors.

Today, the institute serves the five business areas medicine, pharmacy, chemistry, environment and energy with its core competences in interfacial engineering and biotechnology. The success of our work was confirmed to us last year in a strategy audit involving 18 auditors. The experts were particularly impressed by the growth of the institute and its “markets beyond tomorrow” approach. This result is simultaneously an incentive and an obligation. Through its memberships in the Fraunhofer Life Sciences and MATERIALS groups as well as eight Fraunhofer alliances, the Fraunhofer IGB is firmly rooted in the Fraunhofer-Gesellschaft. Over and above this, the institute benefits from its close association with the universities of Stuttgart, Tübingen, Würzburg and Munich and impulses from basic research that filter into the translation of applied research results into industrial practice.

The reduction of global CO<sub>2</sub> emissions, combating disease and hunger, and securing a global supply of water, raw materials and energy are the major challenges of the 21<sup>st</sup> century facing humanity. Against this backdrop, the development and implementation of sustainable processes and products is becoming ever more significant. The Science Year 2012 “Project Earth: Our Future” underlined how important it is for us to base our behavior on the concept of sustainability. We thus endeavor to adopt an integrated, holistic approach to our activities and to constantly optimize not only our main research, but also our actions. The five Fraunhofer Institutes at the Stuttgart site last year published the first cross-institute sustainability report

within the Fraunhofer-Gesellschaft. In it they commit themselves to continual improvement, including meeting objectives they have set themselves. In this context, I would like to mention the Sustainability Action Day on June 29, 2012 and the Fraunhofer joint “House of Sustainability” booth at the 2012 Hanover Fair as positive examples. Sustainability requires continuity, and for this reason last year we began a project on sustainability reporting guidelines together with the headquarters of the Fraunhofer-Gesellschaft and the Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT.

The sustainable use of natural resources and the development of efficient value chains, processes and products are central bioeconomical research priorities. Here we made considerable progress last year with our work on the sustainable material and energetic utilization of renewable raw materials. Of significant note are the success of our Central German BioEconomy cluster in the German Federal Ministry of Education and Research’s (BMBF) Leading-Edge Cluster Competition and the opening of the Fraunhofer Center for Chemical-Biotechnological Processes CBP. The goal of the leading-edge BioEconomy cluster, in which some 80 companies and research establishments from Saxony and Saxony-Anhalt are active, is the integrated material and energetic use of non-food-use biomass for the production of innovative materials, chemicals, and energy carriers. A sustainable supply of raw materials and energy on the basis of renewable resources is critically determined by the speed at which innovative processes can be translated from research into industrial scale. With the inauguration of the new building for the Fraunhofer CBP on October 2, 2012, in the presence of Federal Chancellor Dr. Angela Merkel and 350 invited guests from industry, academia and politics, we have closed this gap between lab and practice.

An important bioeconomy topic is bio- and chemical catalysis. Our Fraunhofer BioCat Project Group is working on

developing and establishing a “catalyst and process screening” technology platform which harnesses naturally occurring synthesis activities. On October 11, 2012 we celebrated the inauguration of the new lab building with 200 guests drawn from industry, academia and politics. In addition, the State of Bavaria made further funding available, which is being used to develop expertise in chemical energy storage. Particular importance is attached to both the material and the energetic use of residual biomass in raw material and energy conversion. In this context, in October 2012 our BMBF-funded two-stage multi-substrate demonstration plant EtaMax was taken into operation on the premises of the EnBW combined heat and power plant in Stuttgart-Gaisburg.

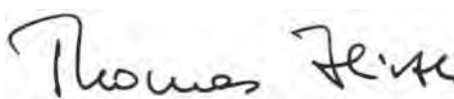
The business areas medicine and pharmacy were also significantly expanded last year. In December 2012 the Bavarian State approved the funding of a “translational center for medical products and cell-based regenerative therapies” in Würzburg. Lead-managed by Fraunhofer Oncology Project Group in Würzburg, this center is to be grown in the next five years with the aim of achieving quicker conversion of findings from materials research and regenerative medicine into clinical application. A second highlight was the launch of a co-operation with the Hebrew University in Jerusalem. In the next three years joint research projects will be funded with the Jerusalem University School of Pharmacy, investigating the experimental validation of active agents and drug delivery.

With the integration of the IPF in the IGVT – approved by the governing bodies of the University of Stuttgart in January 2013 – we have significantly extended our basic research capabilities in plasma physics, which is now combined with and complemented by plasma chemistry and plasma process engineering. The new Institute of Interfacial Process Engineering and Plasma Technology IGVP is part of the Faculty of Energy, Process Engineering and Biotechnology (Faculty 4) at the University of Stuttgart and has a staff of around 100.

While the main focus was on progressing our R&D activities, a continued major issue last year was sustainable personnel development, for our scientific and commercial success is substantially dependent on the employees of the Fraunhofer IGB and their colleagues at the Stuttgart University institute IGVP. Building on the results of the Fraunhofer-wide employee survey, we have started internal projects to improve leadership, communication, and knowledge management, as well as to optimize the interfaces between the departments on the one hand and the departments and administration on the other.

In 2012, we acquired further customers from industry, as well as attracting additional public funding for R&D projects. I would be delighted if this report piques your interest in our R&D activities: together with our customers and partners we aim to shape the future of the region, of Germany and of Europe through innovative, sustainable developments and to open up “markets beyond tomorrow”.

I hope you enjoy and are inspired by the new annual report, and look forward to suggestions and productive collaboration.



Best regards  
Thomas Hirth

# PROFILE

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## BRIEF PROFILE

The Fraunhofer IGB develops and optimizes processes and products for the business areas of medicine, pharmacy, chemistry, the environment and energy. In addition to contract R&D we offer our clients services in analytics and advise on the introduction of novel technologies. Our customers come from various industries as well as municipal, state (Länder) and federal authorities.

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### Application-oriented and interdisciplinary

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

More than ever, the success of new products and processes is dependent on interdisciplinary and constructive cooperation between science and engineering. Some 300 experts in the fields of chemistry, physics, biology and engineering work effectively together at Fraunhofer IGB and IGVP. Customers benefit from the synergies and multidisciplinary potential at our institute, which facilitate novel approaches and innovative solutions in areas such as medical engineering, nanobiotechnology, industrial biotechnology and environmental technology.

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### Competences

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#### Departments

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

#### Project groups

- Fraunhofer Center for Chemical-Biotechnological Processes CBP, Leuna
- Project Group BioCat, Straubing
- Project Group Oncology, Würzburg

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### Guiding principles: mission statement and vision

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“At the Fraunhofer IGB we carry out application-oriented research according to the principles of good scientific practice and on the basis of our competences and guiding principles in the areas of medicine, pharmacy, chemistry, the environment and energy. With our innovations we contribute to a sustainable development of the economy, society and the environment.”

EVER BETTER TOGETHER.



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# ADVISORY BOARD OF THE FRAUNHOFER IGB

The individual Fraunhofer Institutes are advised by Advisory Boards whose members are drawn from industry, public authorities, and the scientific community.

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## Members

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### Dr. Gerd Esswein

Freudenberg Forschungsdienste KG

### Ltd. Ministerialrätin

#### Dr. Renate Fischer

Ministry of Science, Research and the Arts of the State of Baden-Württemberg

### RegDir Dr. Hans-Jürgen Froese

Federal Ministry of Food, Agriculture and Consumer Protection (BMELV)

### MinDirig Dipl.-Ing. Peter Fuhrmann

Ministry of the Environment, Climate Protection and the Energy Sector of the State of Baden-Württemberg

### MinDirig Dr. Fritz Holzwarth

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU)

### Prof. Dr. Dieter Jahn (Chair)

BASF SE

### Dr.-Ing. Bernd Krause

Gambro Dialysatoren GmbH

### Dr. Henk van Liempt

Federal Ministry of Education and Research (BMBF)

### Dr. Gerd Maaß

Roche Diagnostics GmbH

### Dr. Christian Naydowski

VOITH Paper

### Prof. Dr. Klaus Pfizenmaier

Institute for Cell Biology and Immunology, University of Stuttgart

### Prof. Dr. Dr. h. c. Ralf Riedel

Faculty of Materials- and Geo-Sciences, TU Darmstadt

### Prof. Dr. techn. Günter Scheffknecht

Institute of Combustion and Power Plant Technology, University of Stuttgart

### Dipl.-Ing. Otmar Schön

HYDAC Technology GmbH

### 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

Linde Engineering Dresden GmbH

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## Permanent guests

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### Prof. Dr. Herwig Brunner

Former Director of Fraunhofer IGB



## SERVICES AND INFRASTRUCTURE

Our contract R&D services range from basic research – scientific and technological – to the development of new applications, from laboratory up to pilot plant scale including the design, construction, and testing of pilot plants. We also offer patent and market surveys, feasibility studies and comprehensive consultancy in our specialist areas of expertise. We can train your executives and introduce young people at school or studying to the fascinating world of science and technology.

### Infrastructure and laboratory equipment

The Fraunhofer IGB has at its disposal modern laboratories equipped with the latest technology. Our central storage facilities for chemicals and hazardous substances are shared with the other institutes on the Stuttgart Fraunhofer campus.

### Analytics: quality management and accreditation

The Fraunhofer IGB has established a quality management system for the analytics carried out in its reference laboratories, ensuring the highest standards. Accreditation guarantees that our proprietary, in-house test methods are sufficiently validated and that the quality of our tests is assured even where no standardized methods are available. The following analytical methods and test procedures are accredited according to DIN EN ISO/IEC 17025:

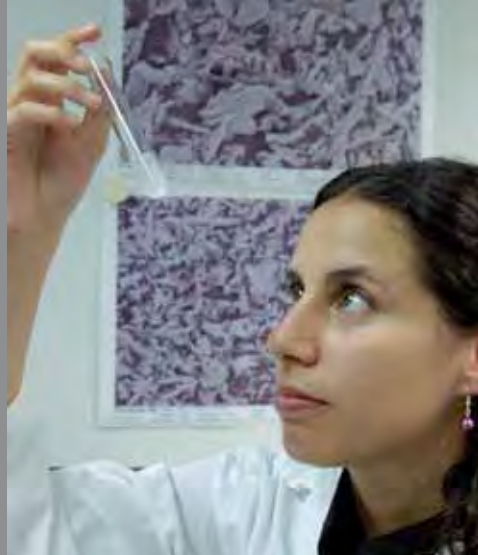
- High-performance liquid chromatography (HPLC)
- Ion chromatography (IC)
- Size exclusion chromatography (SEC)
- Gas chromatography (GC, GC/MS)
- Atomic emission spectrometry (ICP-OES)
- Electron spectroscopy for chemical analysis (ESCA/XPS)

### Accredited biocompatibility and bioavailability testing

Our biocompatibility testing using cell lines and our 3D skin equivalent are accredited according to DIN EN ISO 10993-5. In December 2009, our two-dimensional intestinal assay (Caco2) was included in the accreditation audit report. It was certified by the competent body, the Deutsche Gesellschaft für Akkreditierung (DGA), as an in-house method for the classification of substances by their transport characteristics at the intestinal barrier, which enables us, in turn, to certify analysis results.

### GMP unit and authorization for the manufacturing of cell-based products

The Fraunhofer IGB has a good manufacturing practice unit for collaborative development and manufacturing of clinical test material for cell and tissue engineering products (e.g. advanced therapy medicinal products, ATMPs).



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#### **Good laboratory practice (GLP) test facility**

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Our test category 9 GLP test facility ("Cell-based test systems for the determination of biological parameters") is used in research and development projects such as the investigation of the biological activity of type 1 interferons using the antiviral assay (AVA) or the detection of pyrogens.

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#### **Special services**

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##### **Physico-chemical analytics**

quality control, food analysis, trace analysis, analysis of residues, environmental analytics, water analysis

##### **High resolution 400 MHz NMR analytics**

molecular structure elucidation, reaction monitoring, development of novel experimental NMR methods, low temperature analytics

##### **Surface and particle analytics**

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

##### **Biochemical and molecular biological analytics**

diagnostic biochips, RNA and protein expression profiles, protein analysis using MALDI-TOF/TOF mass spectrometry (also quantitative)

##### **Cell biology analysis**

cell sorting and characterization, single cell preparation/microdissection, quality and sterility control of tissue engineering products

##### **REACH**

evaluation and testing of chemicals

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**For detailed information, please order our special brochures or visit: [www.igb.fraunhofer.de](http://www.igb.fraunhofer.de)**

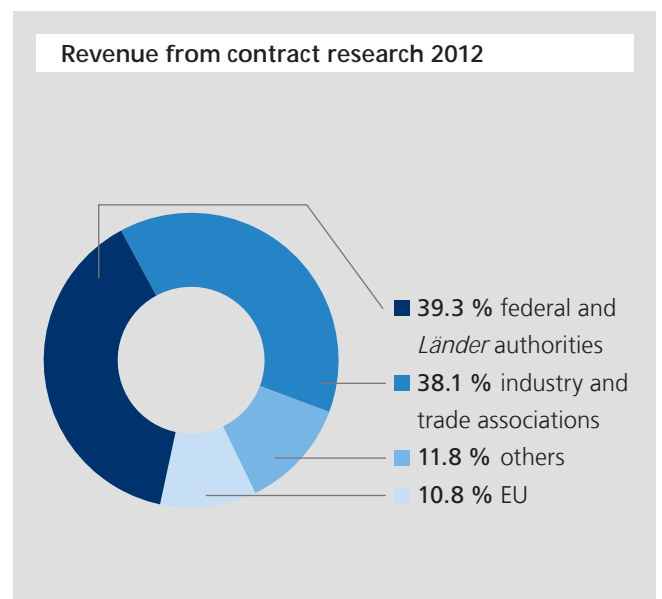
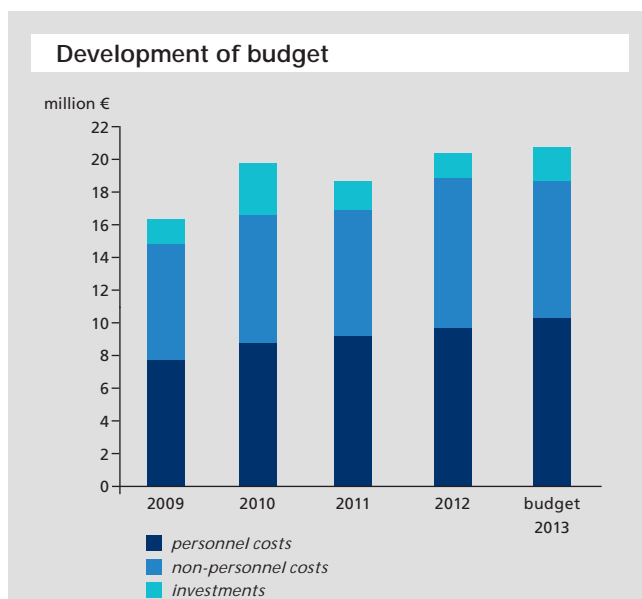
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## KEY FIGURES

### Budget

The total budget for 2012 amounted to 20.3 million euros, of which 18.7 million euros was allocated to the operational budget (personnel costs: 9.7 million euros; non-personnel costs: 9.0 million euros). A total of 1.6 million euros was spent on investments.

69 percent of the operational budget was financed from Fraunhofer IGB's own revenues generated from contract research projects, while governmental funding covered the remaining 31 percent. 38 percent of the Institute's revenues came directly from industry.



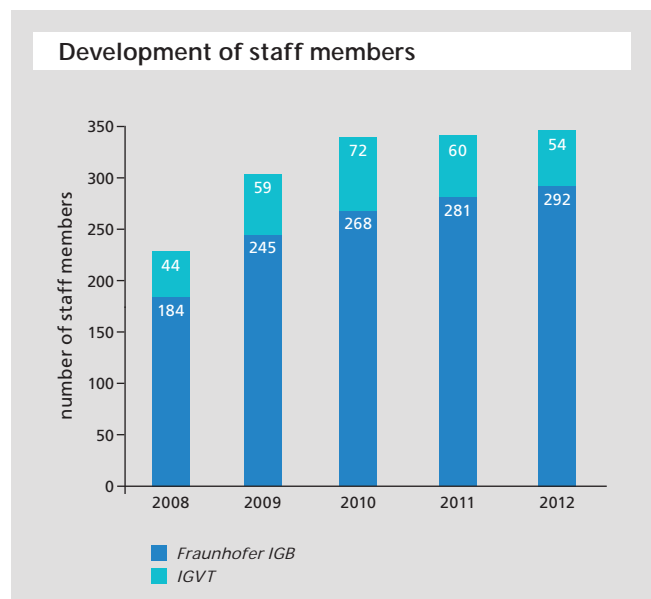
## Personnel

At the end of 2012, the Fraunhofer IGB had a staff of 292 of which some 90 percent were scientific or technical employees. Women made up 58 percent of the total. The Project Group at the Fraunhofer CBP in Leuna was able to expand its staff once more, giving a year-end headcount of 21.

The Institute for Interfacial Engineering IGVT at the University of Stuttgart (as of January 2013 the joint Institute of Interfacial Process Engineering and Plasma Technology IGVP) counted a staff of 54 as at December 31, 2012, predominantly scientists and Ph.D. students as well as technical staff and student research assistants. Women constituted 53 percent of the total.

The Fraunhofer IGB and IGVT employees work closely together and have remarkably culturally diverse backgrounds, with 46 members of staff coming from 26 different nations outside Germany.

Stuttgart University's Institute for Plasma Research IPF, where Professor Hirth was acting head from July to December 2012, and which was integrated into the IGVT in January 2013, employed a total of 30 staff as at December 31, 2012.



Staff composition as at December 31, 2012	Fraunhofer IGB	Fraunhofer CBP	IGVT	IPF
Scientists	75	4	45 <sup>1</sup>	16 <sup>1</sup>
Technical staff	65	13	5	11
Work students/masters students/student apprentices	17		4	
Student research assistants	99	3		1
Administrative and secretarial staff	28	1		2
Apprentices	8			
	<b>292</b>	<b>21</b>	<b>54</b>	<b>30</b>

<sup>1</sup> incl. Ph.D. students

## ORGANIZATION CHART



**Director**

Prof. Dr. Thomas Hirth  
Phone +49 711 970-4400  
thomas.hirth@igb.fraunhofer.de



**Assistant to Director**

Christine Demmler  
Phone +49 711 970-4401  
christine.demmler@igb.fraunhofer.de



**Head of Administration**

Ass. Ulrich Laitenberger  
Phone +49 711 970-4004  
ulrich.laitenberger@igb.fraunhofer.de



**Controlling**

Dipl.-Kfm. Michael Bangert  
Phone +49 711 970-4019  
michael.bangert@igb.fraunhofer.de



**Human Resources**

Katja Rösslein M.A.  
Phone +49 711 970-4009  
katja.roesslein@igb.fraunhofer.de



**Controlling**

Dipl.-Kfm. Brigitte Steinmetz  
Phone +49 711 970-4018  
brigitte.steinmetz@igb.fraunhofer.de

### INTERFACIAL ENGINEERING AND MATERIALS SCIENCE



**Dr. Christian Oehr**

Phone +49 711 970-4137  
christian.oehr@igb.fraunhofer.de



**Dr. Achim Weber**

Phone +49 711 970-4022  
achim.weber@igb.fraunhofer.de

- Inorganic interfaces and membranes
- Particle-based systems and formulations
- Plasma technology and thin films
- Polymeric interfaces, biomaterials and biopolymers

### MOLECULAR BIOTECHNOLOGY



**Priv.-Doz. Dr. Steffen Rupp**

Phone +49 711 970-4045  
steffen.rupp@igb.fraunhofer.de



**Dr. Kai Sohn**

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

- Infection biology and array technology
- Functional genomics
- Molecular cell technology
- Enzyme, strain and process development for biotechnology
- Analytics

### PHYSICAL PROCESS TECHNOLOGY



**Dipl.-Ing. Siegfried Egner**

Phone +49 711 970-3643  
siegfried.egner@igb.fraunhofer.de



**Dipl.-Ing. Mike Blicher**

Phone +49 711 970-3539  
mike.blicher@igb.fraunhofer.de

- Heat and sorption systems
- Drying
- Nutrients management
- Electro-physical processes
- Oxidative water treatment
- Aseptic systems
- Design and system integration



**Business Development**  
Dipl.-Agr.-Biol. Sabine Krieg  
Phone +49 711 970-4003  
sabine.krieg@igb.fraunhofer.de



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



**Press and Public Relations**  
Dr. Claudia Vorbeck  
Phone +49 711 970-4031  
claudia.vorbeck@igb.fraunhofer.de



**Business Development**  
Dr. Uwe Vohrer  
Phone +49 711 970-4134  
uwe.vohrer@igb.fraunhofer.de



**European Business Development**  
Ina Andrees-Ostovan M.A.  
Phone +49 711 970-3621  
ina.andrees@igb.fraunhofer.de

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## ENVIRONMENTAL BIOTECHNOLOGY AND BIOPROCESS ENGINEERING



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



**Dr. Iris Trick**  
Phone +49 711 970-4217  
iris.trick@igb.fraunhofer.de

- Water management
- Biobased raw materials
- Bioenergy
- Interfacial biology

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## CELL AND TISSUE ENGINEERING



**Prof. Dr. Heike Walles**  
Phone +49 711 970-4117  
heike.walles@igb.fraunhofer.de



**Prof. Dr. Katja Schenke-Layland**  
Phone +49 711 970-4082  
katja.schenke-layland@  
igb.fraunhofer.de



**Dr.-Ing. Jan Hansmann**  
Phone +49 711 970-4084  
jan.hansmann@igb.fraunhofer.de

- Avascular test systems
- Vascularized test systems
- Cells and biomaterials
- Bioreactors for tissue engineering
- GMP-production of cell-based products
- Attract Group Cardiovascular Tissue Engineering, leader Prof. Dr. Katja Schenke-Layland

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## PROJECT GROUPS



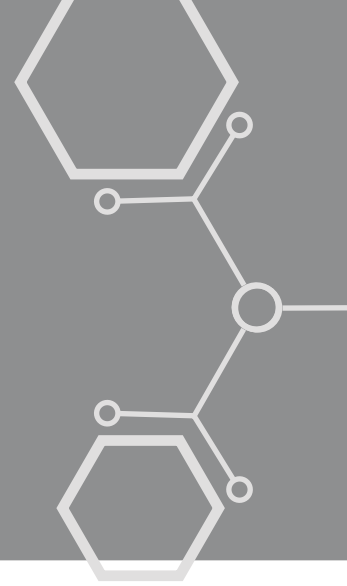
**Fraunhofer CBP, Leuna**  
Dipl.-Chem. (FH) Gerd Unkelbach  
Phone +49 3461 43-9101  
gerd.unkelbach@cbp.fraunhofer.de



**BioCat Project Group,  
Straubing**  
Prof. Dr. Volker Sieber  
Phone +49 9421 187-300  
volker.sieber@igb.fraunhofer.de



**Oncology Project Group,  
Würzburg**  
Prof. Dr. Heike Walles  
Phone +49 931 31-88828  
heike.walles@uni-wuerzburg.de



## THE FRAUNHOFER IGB'S NETWORKING ACTIVITIES

The 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 competences and enable us to exploit synergies in developing new solutions for the needs of industry. We are also actively engaged in shaping research policy through championing strategic, economic and sustainable standpoints.


### Networking with universities

Basic research is a must for the applications of tomorrow. Thus the Fraunhofer IGB maintains close contacts with neighboring universities, both through scientific cooperation and through the professorial and other teaching commitments of Fraunhofer employees. Our project groups and the Attract group in particular have enabled us to extend our scientific network to locations outside of Stuttgart and as far away as the USA.

The Fraunhofer IGB is also particularly closely allied to the Institute of Interfacial Process Engineering and Plasma Technology IGVP at the University of Stuttgart, which is headed by IGB director Prof. Hirth. Here Ph.D. students carry out research that will form the basis of future projects and IGB staff are actively involved in teaching. The IGVP was renamed as a result of the integration, in January 2013, of the Institute for Plasma Research IPF into the Institute for Interfacial Engineering IGVT (pages 58 and 59).

- **Prof. Dr. Dieter Bryniok**  
Professor of Environmental Biotechnology at Hamm-Lippstadt University of Applied Sciences
- **Prof. Dr. Thomas Hirth**  
Professor, chair and director of the Institute of Interfacial Process Engineering and Plasma Technology IGVP at the University of Stuttgart
- **Dr. Petra Kluger**  
Associate lecturer in the Faculty of Energy Technology, Process Engineering and Biological Engineering at the University of Stuttgart
- **Dr. Christian Oehr**  
Associate lecturer in the Faculty of Energy Technology, Process Engineering and Biological Engineering at the University of Stuttgart
- **Priv.-Doz. Dr. Steffen Rupp**  
Private lecturer in the Faculty of Chemistry and in the Faculty of Energy Technology, Process Engineering and Biological Engineering at the University of Stuttgart
- **Prof. Dr. Katja Schenke-Layland**  
Professor of Biomaterials in Cardiovascular Regenerative Medicine at the University Hospital of the Eberhard Karls University, Tübingen, and Visiting Assistant Professor at the Medical Faculty/Department of Cardiology at the University of California, Los Angeles (UCLA), USA





■ **Dr.-Ing. Ursula Schließmann**

Associate lecturer in the Faculty of Energy Technology, Process Engineering and Biological Engineering at the University of Stuttgart

■ **Prof. Dr. Volker Sieber**

Professor and chair of Chemistry of Biogenic Resources at the Technische Universität München

■ **Prof. Dr. Günter Tovar**

Professor in the Faculty of Energy Technology, Process Engineering and Biological Engineering at the University of Stuttgart; Vice Director of the Institute of Interfacial Process Engineering and Plasma Technology IGVP at the University of Stuttgart

■ **Prof. Dr. Heike Walles**

Professor and chair of Tissue Engineering and Regenerative Medicine at the University of Würzburg

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**Fraunhofer Sustainability Network**

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Sustainable development is arguably the key political objective of our time. What sustainability means in concrete terms for the Fraunhofer-Gesellschaft was defined in a project carried out by the society's Sustainability Network and financed by the Fraunhofer-Gesellschaft Executive Board. The Sustainability Network has more than 20 member institutes and is chaired by Professor Thomas Hirth. The Fraunhofer IGB was involved in all three sub-projects. As a result of the project, the Executive Board decided to adopt the internationally recognized Global Reporting Initiative (GRI) standard to further sustainability reporting within the Fraunhofer-Gesellschaft. [www.nachhaltigkeit.fraunhofer.de](http://www.nachhaltigkeit.fraunhofer.de)

**Fraunhofer International Business Development (IBD) Network**

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International cooperations and joint development activities between globally active partners are of strategic importance for Fraunhofer. The Fraunhofer IGB is an active member of the Fraunhofer-Gesellschaft's International Business Development Network where it coordinates the International Position Task Force. This working group examines aspects for internationalization strategy from the perspective of the individual institutes.

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**Fraunhofer EU Network**

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The EU Network constitutes a common platform for all Fraunhofer colleagues involved in promotion of European research. The spirit and purpose of the network is the exchange of information and experience regarding both strategic aspects of funding and how to handle application and tendering procedures effectively, as well as how to ensure the smooth implementation of EU financed projects. The EU Network is coordinated by Maximilian Steiert from Fraunhofer-Gesellschaft headquarters and Ina Andrees-Ostovan of the Fraunhofer IGB.

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**EU Working Group for Research and Technological Development Organizations in Baden-Württemberg**

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The Fraunhofer IGB is a member of the EU Working Group for Research and Technological Development Organizations (RTOs) in Baden-Württemberg, which aims to promote the regional exchange of information on the topic of EU grants for non-university research establishments.

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## FRAUNHOFER GROUPS AND ALLIANCES

Fraunhofer Institutes working in related subject areas cooperate as groups, foster a joint presence on the R&D market and help define the Fraunhofer-Gesellschaft's business policy. Institutes or departments of institutes with complementary competences collaborate in the form of Fraunhofer "alliances" to develop business areas together and offer and market solutions along the entire value chain. The Fraunhofer IGB has recently joined the Food Chain Management Alliance. In addition, Fraunhofer Institutes carry out joint activities within Fraunhofer internal research programs. Examples of IGB involvement are systems research into cell-free biotechnology and the Beyond Tomorrow projects "Molecular sorting" and "SKIN HEAL".

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### Fraunhofer Group for Life Sciences

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The Group for Life Sciences is a key R&D partner to the pharmaceutical and medical engineering industries and to the biotech industry. By pooling complementary areas of expertise, the group is able to offer a broad spectrum of technologies and services. The group has an international outlook that reflects the globalized nature of this scientific field and the related commercial market. The Life Sciences Group is active in business areas such as medical translational research and biomedical technology, regenerative medicine, healthy foods, industrial biotechnology, and process, chemical, and herbicide safety, thus including numerous Fraunhofer IGB key competences. Professor Hirth was appointed Group Chairman at the beginning of 2012.

[www.lifesciences.fraunhofer.de](http://www.lifesciences.fraunhofer.de)

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### Fraunhofer Group for Materials and Components – MATERIALS

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Materials research covers the entire value chain, from the development of new materials and the enhancement of existing ones, to industrial-scale manufacturing technology, characterization of material properties and evaluation of service behavior. The same research scope applies to the components made from these materials and the way they function in systems. The Fraunhofer Group for Materials and Components addresses the entire range of materials and their composites, including metallic, inorganic/non-metallic, polymeric and renewable materials. The Fraunhofer IGB's strong competence in materials science qualified it to become a guest member of the Group in 2008.

[www.vwb.fraunhofer.de](http://www.vwb.fraunhofer.de)



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### **Fraunhofer Building Innovation Alliance**

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The Building Innovation Alliance offers single-source construction expertise in the form of integrated systems solutions. It has particular know-how in the systematic assessment of buildings – from construction materials to structural elements, from rooms and buildings to complete residential estates. The alliance's portfolio also includes the chronological assessment of a building in terms of its entire life cycle from drawing board to recycling. The Fraunhofer IGB participates here with its innovative infrastructure concepts for semi-decentralized energy and water management as well as with its competence in the microbiological aspects of construction.

*[www.bau.fraunhofer.de](http://www.bau.fraunhofer.de)*

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### **Fraunhofer Energy Alliance**

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The Fraunhofer Energy Alliance is a gateway to R&D services in energy technology and economics. Above all small and medium-sized companies, but policy makers, too, benefit from Germany's technology leadership in energy efficiency and the development of renewables. The Fraunhofer IGB contributes its knowledge in the exploitation of energy resources contained in raw, residual and waste organic materials (e.g. for biogas production) as well as in membrane technology, particularly for gas purification/reforming and fuel-cell applications. Additionally, the Fraunhofer IGB carries out research into concepts and technologies for the storage and use of energy in the form of heat.

*[www.energie.fraunhofer.de](http://www.energie.fraunhofer.de)*

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### **Fraunhofer Food Chain Management Alliance**

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The Fraunhofer Food Chain Management Alliance is focused on new approaches in food safety, microelectronics and logistics that can be easily integrated in the entire food chain and are characterized by highest possible added value at low cost. The Fraunhofer IGB's specialization here is superheated steam for drying processes and the development of new physical methods for the hygienization and stabilization of food.

*[www.fcm.fraunhofer.de](http://www.fcm.fraunhofer.de)*

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### **Fraunhofer Nanotechnology Alliance**

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The Fraunhofer Nanotechnology Alliance bundles the nanotechnological expertise that is spread across nearly a third of the Fraunhofer Institutes. The alliance's activities cover all aspects of nanotechnology, such as multifunctional layers for automotive applications, the design of special nanoparticles as carrier substances for biotechnology and medical applications, and the use of carbon nanotubes in actuators. Professor Günter Tovar is the Alliance's spokesperson.

*[www.nano.fraunhofer.de](http://www.nano.fraunhofer.de)*

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### Fraunhofer Photocatalysis Alliance

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Nine Fraunhofer Institutes are involved in this alliance, the aim of which is the development of more effective and higher-performance photocatalysts for application to various surfaces such as glass, ceramics, plastics or metals. Vacuum plasma processes, sol-gel techniques and water-based paints are used to develop self-cleaning layers that break down organic compounds and destroy microorganisms. In order to determine the photocatalytic activity of a layer quickly and reliably, the Fraunhofer Photocatalysis Alliance is engaged in developing analytical methods for both chemical-physical and microbiological evaluation – the latter being Fraunhofer IGB's remit within the alliance.

*[www.photokatalyse.fraunhofer.de](http://www.photokatalyse.fraunhofer.de)*

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### Fraunhofer Polymer Surfaces Alliance POLO®

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The Fraunhofer Polymer Surfaces Alliance POLO® pools the core competences of seven Fraunhofer Institutes in using functional surfaces, barrier layers or thin films to develop polymer products with new or improved properties. POLO® was one of the first Fraunhofer alliances, and products such as coatings on foils as a barrier against oxygen and humidity, as well as anti-microbial polymer surfaces, have already been successfully jointly developed and marketed. The Fraunhofer IGB's Dr. Christian Oehr has been a member of the alliance's board of directors since its inception, and has contributed significantly to its success.

*[www.polo.fraunhofer.de](http://www.polo.fraunhofer.de)*

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### Fraunhofer Cleaning Technology Alliance

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The alliance covers the entire spectrum of cleaning technology, including special cleaning technologies like laser, plasma or mechanical jets, specific-cleaning planning of plants including cleanroom technology, and the recycling of cleaning and process media, including the recovery of energy and material streams. The Fraunhofer IGB's expertise includes plasma cleaning and plasma coating, and assessment using surface analytical and microbiological methods. Further competences are the conditioning and recycling of cleaning and process media as well as cleaning and hygienic aspects in design.

*[www.allianz-reinigungstechnik.de](http://www.allianz-reinigungstechnik.de)*

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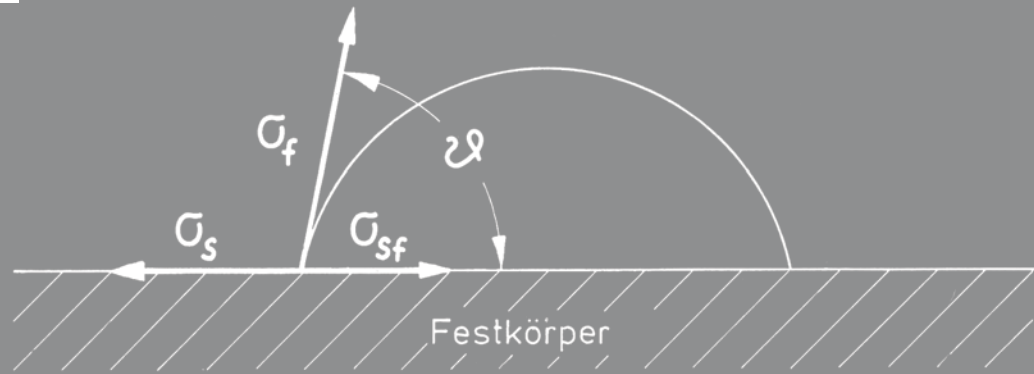
### Fraunhofer Water Systems Alliance (SysWasser)

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SysWasser's mission is to develop sustainable solutions for water and wastewater treatment, utilization, reuse, and management, as well as sustainable water infrastructure systems and adapt them for use in practical applications, taking into consideration relevant social, economic and environmental aspects. The participating institutes provide a wide range of expertise on water treatment technologies, water infrastructures, system control and measurement techniques, automation and resource management, which enables the alliance to develop and implement system solutions based on a variety of technologies. The alliance's spokesperson since December 2012 is Dr. Harald Hiesl of the Fraunhofer ISI and its managing director is Professor Dieter Bryniok of the Fraunhofer IGB, where the SysWater office is based.

*[www.syswasser.de](http://www.syswasser.de)*





## 60 YEARS FRAUNHOFER IGB – 60 YEARS INTERFACIAL RESEARCH

This year the Fraunhofer IGB celebrates its 60th anniversary. Since its foundation as “Institut für Physik und Chemie der Grenzflächen” (Institute for Interfacial Physics and Chemistry) in 1953, the institute has borne the term “interfaces” in its name. An interface is a surface that forms a common boundary between two non-miscible phases or two different substances. At these boundaries the phases “touch” – are effectively in contact with each other, yet the transition between their material characteristics is abrupt. An interface is thus above all a place where differences coincide and give rise to new phenomena, and for 60 years now, interfaces have been the focus of research at the IGB.

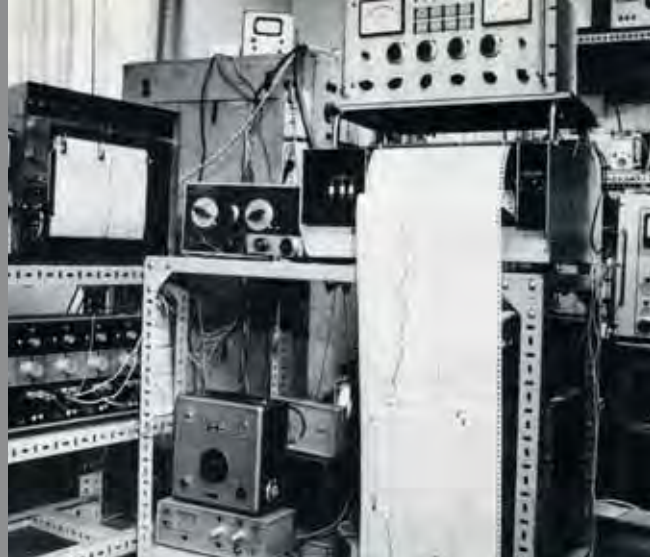
### 1953

The roots of the IGB lie in the village of Marienthal near Kirchheimbolanden in the Rhineland-Palatinate. Here, Prof. Karl Lothar Wolf, a physicist, founded the institute as a private initiative. In 1962, the Fraunhofer-Gesellschaft took over the institute, initially under its previous name. In the same year the “Fraunhofer Institute for Interfacial Physics and Chemistry IGF” moved to Stuttgart, where Prof. Karl Hamann, head of the Stuttgart Research Institute for Pigments and Coatings, took over as acting director. Even in those days, the focus was on interfaces – which continue to be important for industrial applications today. Now as then, the basis of all developments was the measurement of interfacial energy – surface tension, wetting tension, the work of adhesion. Thus the annual report of 1972 is almost topical 40 years on – including the development of measuring techniques to determine the wetting behavior of surfaces, glass fibers and pigment powders, the gravimetric investigation of the wetting kinetics of liquids penetrating into pore spaces, and the pretreatment of surfaces to be coated in order to improve the adhesive strengths of coatings.

### 1976

In 1975, Dr.-Ing. Horst Chmiel, then engaged in medical technology research at the Helmholtz Institute in Aachen, was

appointed successor to Prof. Hamann, who retired on age grounds. A process engineer by specialization, Prof. Chmiel took up post as institute director on January 1, 1976. His concern was to introduce bioengineering to the institute and to steer the existing “interfacial” orientation of its work more strongly toward process engineering and its applications. Thus research was thematically expanded, and the institute received its current name, “Institute for Interfacial Engineering and Biotechnology”, abbreviated in German to IGB. The “old” institute was retained as the Department for Interfacial Engineering, headed by Dr. Herbert Bauser. A new research focus was added: the “interfacial problems of medicine”, the interface between the “interfaces” and the new field of medical engineering. Soon a third field of work was planned, announced in the 1978 annual report as “Specific problems of biotechnology” – meaning biological treatment of exhaust air and wastewater, a topic dear to the heart of Dr. Walter Trösch, who joined the IGB in 1976. This work area spelled the arrival of the “microbiological interfaces”, i.e. the interactions of microorganisms. The move into the “new” building at today’s Institute Center site in Stuttgart-Vaihingen followed in 1981, with five departments covering the subject areas Technical Biochemistry, Technical Microbiology, Chemical Microbiology, Process Engineering and Interfacial Engineering. Dr.



Bauser recognized the huge potential of plasma technology as a tool to modify and engineer interfaces. Thus Dr. Christian Oehr, with a background in plasma chemistry, joined the IGB in 1989, and in 1992 was made departmental head, when Dr. Bauser took over as acting director of the institute.

## 1994

In 1994, Prof. Herwig Brunner came from Boehringer Mannheim to the Fraunhofer IGB as director. Intent on a solid scientific foundation for the application-oriented research at the IGB, Brunner instigated the creation of a chair for Interfacial Engineering at the University of Stuttgart, which after five years was elevated to institute status (IGVT). A highlight in 1996 was the opening of the Demonstration Center for Process Integrated Environmental Technology, in cooperation with the then Fraunhofer Institute for Food Technology and Packaging ILV. Parallel to these activities, Brunner added further molecular biological competences to the IGB. In 1998, the "Protein screening systems" junior research team headed by Dr. Steffen Rupp, moved into new, dedicated premises and went on to enjoy a success story: today the Department of Molecular Biotechnology is one of the largest at the IGB. At the same time, Brunner built a bridge from biotechnology to interfacial engineering: with a second junior research group "Biomimetic interfaces" under the direction of Dr. Günter Tovar, he secured the biofunctionalization of nanoparticulate surfaces and the nanobiotechnology at the IGB. Acting with foresight, Brunner also strengthened cell biology activities at the IGB, systematically developed them into cell system research – with the goal of tissue engineering. In 1994, Prof. Heike Walles became head of department for "human-cell interfaces", the basis for biologic medical products and regenerative medicine.

## 2007

In December 2007, Prof. Thomas Hirth took over as director of the IGB and created the business areas medicine, pharmacy, chemistry, environment, and energy. When the Fraunhofer-Gesellschaft discontinued the Technology Development Group (TEG) in 2009, the Department of Physical Process Engineering

under the direction of the process engineer Siegfried Egner was integrated into the IGB. This once again yielded new synergies and interactions, strengthening the business areas environment and energy, and also chemistry. The following years saw the institute continue to grow at the Stuttgart site and beyond. In July 2009, a joint Federal Government/Länder committee approved the setting up of a "Chemical Biotechnological Process Center" in Leuna, Saxony-Anhalt. On August 1 of the same year, the project groups BioCat (Prof. Volker Sieber) and Oncology (Prof. Heike Walles) commenced their activities in Straubing and Würzburg. Since then, building work has proceeded apace in Stuttgart, Straubing and Leuna. In 2012, the Federal Chancellor Dr. Angela Merkel inaugurated the CBP in Leuna, and the Straubing BioCat Project Group its new lab building. Prof. Hirth succeeded in achieving public awareness of the interfaces and their interactions that are at the heart of industrial biotechnology and the utilization of renewable resources. In 2011, Prof. Trösch handed over management of the Environmental Biotechnology and Bioprocess Engineering Department to Dr.-Ing. Ursula Schließmann, previously his deputy. At the University of Stuttgart, the Institute for Plasma Research was integrated into the former Institute for Interfacial Engineering IGVT at the turn of the year 2012/2013 to become the Institute of Interfacial Process Engineering and Plasma Technology IGVP. Thus plasma activities in Stuttgart are now bundled, strengthening the roots of the IGB, with which the IGVP is closely associated.

Today around 400 employees work at the Fraunhofer IGB, its project groups in Leuna, Straubing and Würzburg and at the associated IGVP researching interfaces to materials, (bio)molecules, microorganisms and algae, as well as to human cells. Thanks to the unique combination of interactions and the numerous interfaces and links between and among the individual disciplines, our staff help provide answers to the urgent issues of the millennium – climate change, resource scarcity, cancer and infectious diseases. In this anniversary year, we want to celebrate this success with new discoveries at the "inner" interfaces.

# HIGHLIGHTS 2012

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## PROJECTS AND PROJECT GROUPS

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### Central German BioEconomy cluster wins third Leading-Edge Cluster Competition

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Under the scientific direction of Professor Thomas Hirth, our Central German BioEconomy cluster beat fellow competitors to come out top in the third round of the German Federal Ministry of Education and Research's (BMBF) Leading-Edge Cluster Competition, whose winners were announced in January 2012. At the Cluster Conference held on February 23–24, 2012 in Berlin, state secretary Cornelia Quennet-Thielen honored the Central German BioEconomy cluster as one of the five winners. Federal Minister of Education and Research Professor Annette Schavan numbered among the first well-wishers.

The cluster's core objective is the sustainable creation of value from non-food biomass, focusing on the combined material and energetic utilization of biomass – in particular wood from native forests – to produce innovative materials, chemical products and energy sources. A further major focus is on scaling up and putting proven processes in labs and pilot plants into industrial application with a minimum of delay. The Fraunhofer Center for Chemical-Biotechnological Processes CBP plays a key role here.

The leading edge BioEconomy cluster is focused regionally in the German federal states Saxony-Anhalt and Saxony and the existing chemical sites there. The cluster also integrates successful existing cluster structures such as the Central German Chemistry/Plastics Cluster, the Rottleberode Wood cluster and the Leipzig Energy and Environmental Technology Cluster. Partners include both large companies and over 40 innovative SMEs. On the research side are partners such as the Fraunhofer-Gesellschaft with its CBP, PAZ and IWM establishments in Leuna, Schkopau and Halle as well as the Martin Luther University in Halle-Wittenberg, the German Biomass Research Centre, the Helmholtz Centre for Environmental Research and the Leipzig Graduate School of Management (HHL). Altogether, over 80 companies and research bodies from the region with total sales in excess of 21 billion euros and over 29,000 employees are involved in the BioEconomy cluster.

The extensive pool of expertise means that the cluster is in the position to offer a huge variety of biobased value chains. The cluster integrates seamlessly into the German Federal Government's High-Tech and BioEconomy Strategies and the EU's Europe 2020 strategy.





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## Federal Chancellor at opening of the Fraunhofer CBP in Leuna

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The Fraunhofer Center for Chemical-Biotechnological Processes CBP aims to close the gap between the lab and industrial-scale implementation of technologies for sustainable material utilization of renewable raw materials. After only 21 months of construction, the new Fraunhofer CBP complex was inaugurated on October 2, 2012 in the presence of 350 guests drawn from industry, science and politics. The guest of honor at the gala titled “Shaping the Future with Bioeconomics” was German Federal Chancellor Dr. Angela Merkel, who took the opportunity to visit the Central German BioEconomy cluster, where the Fraunhofer CBP is a center of innovation.

In her ceremonial address, the Chancellor stressed that the opening of the Fraunhofer CBP on the eve of the reunification celebrations was a sign of how a brilliant Leuna has emerged out of the drab chemistry site, offering good perspectives for the development of Central Germany. Besides host Professor Thomas Hirth, the speakers included Professor Reimund Neugebauer (who had assumed office as Fraunhofer president only the day before), the minister-president of Saxony-Anhalt, Dr. Reiner Haseloff, as well as Professor Aldo Belloni, executive board member at Linde AG. On the same day, at the press conference, Linde and Fraunhofer signed a framework agreement for a strategic partnership.

After her speech, Angela Merkel took a tour round the new process center and learned about the work of the Fraunhofer CBP and the leading-edge cluster. At the lignocellulose biorefinery module, project group manager Gerd Unkelbach explained how the valuable materials lignin, cellulose and hemicellulose – or rather the sugars glucose and xylose that they contain – can be derived from waste wood. At the technical enzymes module, CBP and IGB staff described how the sugars obtained can be used as a substrate for biotechnological fermentations for producing a variety of chemicals, such as surfactants and even enzymes.

After the two-year expansion phase, there are now 19 employees working at the Fraunhofer CBP. The new building with floor space of over 2000 square meters was planned by architects Scherr+Klimke of Ulm. It comprises a main building containing offices, labs, pilot plant and media facilities, and a separate building with storage rooms for raw materials, auxiliary materials and final products. Linde Engineering Dresden GmbH was general contractor with responsibility for the technical aspects of the process engineering units, including the requisite infrastructure and media. Using the biorefinery model, the various process plants are now available as modules that can be operated separately or easily combined as required for the development and scaling of biotechnological, chemical and combined processes.



### Commissioning ceremony for the high-load digester in Bad Dürrenberg

3

“As of today, the transition to renewable energy has become reality in Bad Dürrenberg, where we are now realizing the ambitious objective of obtaining energy from wastewater in future,” enthused Johanna Michaelis, executive secretary of the joint water supply and waste management authority (ZWA), at the commissioning ceremony held on June 14, 2012 for the high-load digester developed by the Fraunhofer IGB. The inauguration of the wastewater treatment plant in Bad Dürrenberg, Saxony-Anhalt, was attended by representatives from communal and regional politics and Stockleben GmbH (local consulting engineers involved in the project) as well as the IGB’s Professor Thomas Hirth, Dr.-Ing. Ursula Schließmann and Dr.-Ing. Werner Sternad (director, head of department and project manager, respectively).

In the face of rising costs for energy and waste disposal, the ZWA had been investigating the options for forward-looking, economic and sustainable wastewater treatment. Using the high-load digestion process developed by the Fraunhofer IGB, it was possible to convert the existing wastewater treatment plant from an aerobic stabilization plant into an anaerobic sewage-sludge digestion facility. The high-load digester generates gas, which is fed to a micro-gas turbine where it is converted into energy and heat. As a result of this process, the sewage plant’s energy consumption will fall by over 50 percent, and a third less sludge that has to be disposed of will be produced – leading to a significant reduction in future operating costs.



### Inauguration of the EtaMax-demonstration plant in Stuttgart-Gaisburg

4

One of the key factors for the success of energy transition is an adequate supply of renewable energies. The EtaMax joint project, funded for five years by the German Federal Ministry of Education and Research (BMBF) as part of the “BioEnergie 2021” funding initiative, makes a small but important contribution here. It facilitates the decentralized generation of energy from local waste that is not yet being utilized energetically, the local utilization of biogas in e.g. mobility, and helps to reduce the emission of carbon dioxide.

On October 25, 2012 a two-stage multistage demonstration plant with two 3500-liter bioreactors was taken into operation on the premises of the EnBW combined heat and power plant in Stuttgart-Gaisburg. It has capacity to ferment an annual 160 metric tons of raw organic waste from the wholesale market in Stuttgart, which translates into 20 to 25 cubic meters of biogas produced daily, depending on the composition of the waste. After purification with membranes, there is a daily yield of just under 15 kilograms of biogas-methane available as a fuel for gas-powered vehicles used for test-driving or engine-testing.

After the welcome by the hosts EnBW and Fraunhofer IGB, which is also coordinating the project, Baden-Württemberg’s environment minister Franz Untersteller expressed his delight that the new process makes possible almost perfect biogas plant. Further words of greeting were offered by Dr. Hans-Josef Zimmer (Chief Technical Officer and Member of the Board of Management, EnBW Energie Baden-Württemberg AG), Dr. Christian Mohrdieck (Director of Fuel Cell & Battery Drive Development, Daimler AG Group Research and Advanced Engineering Division), as well as Ines Aufrecht (Business Development Director, Stuttgart Economic Development Department).



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## New lab building for the BioCat Project Group 5 in Straubing

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Dr.-Ing. Ursula Schließmann, departmental head at the Fraunhofer IGB, went on to present the project and the demonstration facility, designed as a flexible “multi-substrate plant”. The project involves taking watery biowaste with a low lignin content and extracting the maximum possible amount of biogas, which is then further processed as fuel for vehicles. The project consortium wants to use the concept implemented in Stuttgart to utilize all the materials streams arising – from biogas to liquid filtrate to the residues that cannot be further fermented – and so complete the cycle of materials.

First of all, the market waste is size reduced for fermentation in a plant developed by the Fraunhofer Institute for Process Engineering and Packaging IVV in Freising together with the machinery and instrumentation manufacturer NETZSCH. The comminution process is designed to require as little energy as possible. The size reduced waste is stored in various storage containers that feature automated measurement of parameters such as the pH value. A management system uses these data to calculate how many liters of the waste and from which containers are to be mixed and fed into the bioreactors. Here, microorganisms degrade up to 90 percent of the waste, producing the desired biogas in only a few days.

This is then collected outside in a gas tank. Membrane technology is used to remove carbon dioxide from the biogas, and its methane concentration increased to 80–95 volume percent. The treated biogas is compressed under high pressure and stored in a gas station. In the end it was possible to refuel two of the test vehicles with biogas.

Fraunhofer IGB’s BioCat Project Group in Straubing, set up in 2009 and funded by the Bavarian State, develops new chemical and biocatalytic methods for the material utilization of renewable raw materials. Construction of a new lab building commenced with a groundbreaking ceremony on July 22, 2010, and on October 11, 2012 the project group and 200 invited guests representing industry, science and politics inaugurated the finished complex at Straubinger Schulgasse 11a – in the direct vicinity of the Straubing Science Center, which had made labs and offices available to the project group for its research activities for two years. The new building currently houses 15 members of staff.

It is imperative to develop the next generation of catalysts and processes as soon as possible, so that biomass and carbon dioxide can be used as sources of raw materials for chemicals and energy carriers in the place of fossil oil, said Professor Volker Sieber, head of the project group, at the inauguration ceremony. The senior mayor of Straubing, Markus Pannermayr, made a short welcoming speech in which he was pleased to point out that the inauguration of the building coincided with the 225<sup>th</sup> birthday of Straubing-born Joseph von Fraunhofer. Undersecretary Dr. Georg Ried passed on congratulations from the Bavarian Secretary of Commerce, Martin Zeil, who was unable to attend due to illness. Dr. Alexander Kurz, Senior Vice President Personnel and Legal Affairs at the Fraunhofer-Gesellschaft, also said some words of greeting.

After the speeches, Hans-Peter Gartner of the architectural office Gartner, handed over the keys to the new landlord Professor Sieber, and pastors Erna Meiser and Franz Alzinger blessed the new lab building. Afterwards, many guests took the opportunity for a tour. Only recently the project group received an undertaking of further funding from the Bavarian State for the topic “chemical energy storage”.



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### **New Fraunhofer Translational Center for Medical Products and Cell-based Regenerative Therapies in Würzburg**

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In December 2012 the Bavarian Ministry of Economic Affairs approved the funding of a “Translational Center for Medical Products and Cell-based Regenerative Therapies” in Würzburg under the direction of Professor Heike Walles, who heads the Cell and Tissue Engineering department at the Fraunhofer IGB in Stuttgart and the IGB’s Oncology Project Group in Würzburg. Over the next five years, the Bavarian State will fund the planned center with an annual grant of 3.5 million euros. The objective is to get findings from materials research and regenerative medicine flowing more quickly into clinical practice. This process will also involve the University Clinic in Würzburg, where Walles has been Chair of Tissue Engineering and Regenerative Medicine since 2009.

The goal of the center will be to cover the entire value of innovative medical products and regenerative therapies – from the development of substances in an early experimental developmental phase, via the pre-clinical phase up to clinical studies required for regulatory approval. The aim is to promote collaboration between scientists engaged in fundamental research, pre-clinical researchers, clinicians and materials researchers, and to pool these activities. Thus biologic medical products and cell-based, regenerative therapies could soon become a substantial component of medical care. Biologic implants are based on medical products whose surfaces or substances are modified with active agents or cells in order to trigger or accelerate regenerative processes following implantation. Ideally, the human cells used for biologic medical products as well as for regenerative therapies will come from the patients requiring treatment themselves. Thus it will be possible to replace damaged cells or injured tissue without the risk of rejection and act directly on the cause of the disease.



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## FRAUNHOFER IGB INTERNATIONAL

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### New EU projects

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The EU's Seventh Framework Programme for Research and Technological Development constitutes the main instrument of European research funding, and supports the European Union in its aim of becoming the "most dynamic and competitive economic region in the world". Of interest to the Fraunhofer IGB are not only FP7 calls for research proposals in the thematic programs Health, Environment, Energy, NMP (Nanotech, Materials, Processes) and the Knowledge Based Bio-Economy (KBBE), but also the calls specifically targeted at small and medium-sized enterprises. The Fraunhofer IGB also welcomed its first Marie-Curie scholarship holder in 2012.

#### REWAGEN

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In the REWAGEN project (Electrochemical WATER treatment system in the dairy industry with hydroGEN REcovery and electricity production), a European project consortium consisting of partners from research and industry and led by the Fraunhofer IGB is developing a multistage process for the efficient electrochemical treatment of effluents from the dairy industry. The aim is to combine and integrate the individual process steps to form a closed system where each step delivers a stream of materials that can be further processed, recycled or reintroduced into the system. Thus the electrolytic treatment of water will yield hydrogen, which can be used to provide parts of the installation with electrical energy. The treated water can be reused directly as required. A modular construction allows the system to be adapted flexibly to the quantities of effluent at smaller dairies and milk-processing operations.

[www.rewagen.eu](http://www.rewagen.eu)

#### NAWADES

The objective of the NAWADES project is to study, design, produce, and test a new membrane system for the desalination of seawater. The technical concept is based on four developments:

1. The ultra-membrane filtration that usually precedes an osmosis membrane stage can be integrated directly and compactly in a multi-layer membrane filter.
2. Formation of deposits (scaling and fouling) can be reduced by using plasma technology to treat the surfaces of the membranes.
3. Fouling through microbial growth can be prevented by integrating titanium dioxide nanofibers into the membrane in conjunction with the radiation of UV light through a glass fabric into the space between the membrane layers.
4. The state of the membranes can be monitored by applying a double-sided coating which functions capacitively. This is then analyzed.

The new filter is designed to provide a self-cleaning, low-maintenance membrane filtration system to be used in seawater desalination processes. It is characterized by higher efficiency and longer lifetime, as well as reduced energy consumption as a result of reduced fouling leading to lower pressure.

[www.nawades.eu](http://www.nawades.eu)



### ECOWAMA

The effluents from the metal and plastic surface processing industry, particularly from galvanization, are rich in organic loading, salts, and heavy but valuable metals like nickel, copper and zinc. Led by the Fraunhofer IGB, the ECOWAMA project ("ECO-efficient management of WAter in the MAnufacturing industry") seeks to develop an efficient and cost-effective method for electrochemical treatment of the effluents of the project partners from France, Spain, the Netherlands and Germany. The goal is to recover valuable materials and reuse them in the production process. In times of rising prices on the global market, metals are particularly valuable. At the same time the hydrogen arising from the electrolytic treatment of water is to be recovered as electrical energy to improve energy efficiency.

[www.ecowama.eu](http://www.ecowama.eu)

### BioEcoSIM

2

In the EU-funded project BioEcoSIM, involving 15 partners from five European countries, pig manure is used as a valuable source of raw material. Coordinated by the Fraunhofer IGB, the project aims to convert the constituents of the slurry into various fertilizers: biochar as a phosphorous-rich organic soil improver as well as mineral fertilizers such as ammonium sulphate, calcium phosphate and magnesium ammonium phosphate (struvite). The products can be mixed to a nutrient composition depending on the plant species and soil conditions, and used as easy-to-dose fertilizers for agricultural purposes. This not only prevents overfertilization but also reduces the need for synthetic nitrogen fertilizers, the production of which is highly energy-intensive. The overall process makes use of energy-efficient technologies and works on the principle of circular economy.

[www.bioecosim.eu](http://www.bioecosim.eu)

### ProEcoWine

Fungi like downy mildew reduce wine yield and impair wine quality. In conventional as well as organic viticulture, grape growers usually apply copper to prevent these fungal diseases. Copper accumulates in the soil and is toxic to soil organisms. In the ProEcoWine project being conducted on behalf of five SMEs, the Fraunhofer IGB is collaborating with the University of West Hungary and Laboratoire PHENOBIO to develop an eco-friendly plant protection product suitable for bio viticulture to replace copper salts. It will be available as a combined preparation enriched with micronutrients.

[www.proecowine.eu](http://www.proecowine.eu)

### L4CW-Demo

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Many industrial processes produce toxic wastewater that, in the interest of sustainable manufacturing, must be treated and purified before being reintroduced into the process or released into the environment. This approach is reflected extensively in the legislation, including the EU Water Framework Directive and the IPPC [Integrated Pollution Prevention and Control] Directive. The Light4CleanWater project (FP7-SME-2008-01-232073) developed a pilot system that is able to safely and cheaply treat toxic, persistently organically polluted, waste streams without generating any secondary toxic by-products. The follow-up project, L4CW-Demo, focuses on industrial production of the system and its long-term demonstration at customers' premises, with a view to market launch by the consortium.

[www.l4cw.eu](http://www.l4cw.eu)

### **HeatSaver-Demo**

In the EU HeatSaver project (FP7-SME-2007-1-222116), we succeeded in developing a novel heat storage technology based on a closed adsorptive heat storage process and which could be realized on a scale ranging from 1.5 to 750 liters. In the follow-up HeatSaver Demo project, in which the Fraunhofer IGB is acting as scientific partner to the industrial consortium, the focus now lies on technology transfer and demonstrating the technology in various industrial test scenarios. [www.heat-saver.eu](http://www.heat-saver.eu)

### **AquaCat**

The Fraunhofer IGB Project Group BioCat in Straubing is being internationally enriched for two years with the presence of the Thai researcher Dr. Pranee Inprakhon. Most recently lecturer at Mahidol University in Bangkok, Dr. Inprakhon has been awarded a Marie-Curie EU scholarship which she will use to carry out research at the BioCat Project Group into sustainable and environmentally synthesis paths for manufacturing polylactone nanoparticles and sugar esters for the chemical industry from renewable raw materials.

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## **BRAZIL**

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### **Official visit to São Paulo, Rio de Janeiro and Brasília**

August 20–25, 2012

Delegates from the Fraunhofer IGB took part in a fact-finding mission to Brazil in August. The purpose of the trip was to visit renowned research institutions such as the CNPEM and the IPT and to hold discussions with representatives of the key Brazilian research sponsors. The discussions centered on the topic of bioeconomy and were attended by representatives of the German Federal Ministry of Education and Research (BMBF) and important research facilities. The delegation stay resulted in an agreement to hold a workshop to discuss ideas for bilateral projects.

### **German-Brazilian Partnering Event**

November 26–27, 2012, São Paulo

The Fraunhofer IGB participated in this event with scientific contributions on topics such as biogas production from residues from sugar and ethanol production, the recovery of valuable materials from waste streams in the cosmetics industry, and biorefinery concepts. The projects that arose from the ideas developed together with Brazilian partners projects were defined in the framework of the “Bioökonomie International – Bioeconomy International” funding initiative, and are now under application for bilateral funding.




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**CHINA**


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**Modern decentralized wastewater treatment for Guangzhou** 4

Without doubt, China is one of Germany's most important trading partners. China's massive industrialization has led to a huge rise in its energy consumption, while at the same time the water pollution is one of the nation's greatest environmental challenges. Germany on the other hand is a world leader in the export of environmental protection products and water technology.

In the spirit of the Fraunhofer mission to carry out applied research for the benefit of industry and society, a bilateral cooperation agreement was concluded between the Fraunhofer IGB and its Chinese Partner China National Electric Apparatus Research Institute (CEI), headquartered in the city of Guangzhou in Guangdong province.

Back in 2011, Professor Walter Trösch initiated a first project, which is currently proceeding under the leadership of Dr. Tosca Zech of the Environmental Biotechnology and Bioprocess Engineering Department at the Fraunhofer IGB. The "Advanced wastewater treatment in Guangzhou" project involves developing a strategy for effluent disposal at the KINTE industrial park in Guangzhou. The project is focused on the adaptation of the DEUS technology developed at the Fraunhofer IGB to the Chinese circumstances. The objective is the transfer of knowledge of this key IGB technology to the Chinese project partner CEI, and thus to open up the market for water and wastewater technologies "made by Fraunhofer". The cooperation was intensified in 2012 by further high-ranking visits from the CEI to the Fraunhofer IGB and is intended to be extended to further topics such as the development of energy-efficient systems and bioenergy.




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**FRANCE**


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**Les Rendez-vous CARNOT**

October 3–4, 2012, Lyon

In October, a Fraunhofer IGB business development officer traveled to Lyon to take part in the Les Rendez-vous CARNOT meeting, France's largest science forum where some 6000 exhibitors from science and research meet annually. Intensive discussions with representatives of Carnot institutes and the research funding organization ANR (Agence National de la Recherche) ensued. Attendance of the event had the aim of intensifying strategic cooperations with French partners and initiating further bilateral projects against the background of 50 years of the Elysée Treaty.

**Fraunhofer-Carnot cooperation** 5

Thanks to funding by the BMBF and the ANR, a very successful cooperation has evolved between the Carnot-Institut CIRIMAT in Toulouse and the Fraunhofer IGB. It started with the BioCapabili project (page 62), in which the partners developed biomimetic bone substitute material with antimicrobial properties. The desire of the sponsors was not only to promote German-French cooperation, but first and foremost to align research to the current needs and applications of industry. The project was concluded with very good results and received top marks from the experts drawn from science and industry to evaluate it. In order to continue successful, application-oriented collaboration in the future, the CIRIMAT and Fraunhofer IGB scientists launched the BIOCAPABILI Engineering Cluster, a research alliance which has already attracted concrete queries and expressions of interest from various companies.

[www.biocapabili.com](http://www.biocapabili.com)






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## ISRAEL

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### Cooperation on drug delivery with the Hebrew University 6

During initial exploratory discussions between Professor Shai Arkin, vice president of the Hebrew University, and Fraunhofer head of research Professor Ulrich Buller, Life Sciences crystallized as a strategic area for a collaborative research venture between the two institutions. The School of Pharmacy is one of the Jerusalem-based university's strongest areas and is embedded in a lively Israeli pharmaceuticals sector characterized by young, innovative companies. During the visit of a Fraunhofer delegation to Israel in January 2012, including Prof. Ulrich Buller, representatives of the Fraunhofer ITEM and IAP Institutes and a strong contingent from the Fraunhofer IGB, the prerequisites were created for the signing of a strategic cooperation on the topic of drug discovery and delivery. Drug delivery is understood as the path and release of a medication to its target location in the patient's body.

This agreement resulted in a call for joint project proposals, which was taken up by the scientific coordinators Prof. Gershon Golomb (Hebrew University) and Dr. Steffen Rupp (Fraunhofer IGB). The Fraunhofer-Gesellschaft is making a total 1.4 million euros available for the funding of the cooperation from its internal ICON program for financing international activities. Following evaluation by external experts, two projects were authorized for the Fraunhofer IGB and its Hebrew University partners, to the tune of some 900,000 euros – and the active phase of the cooperation commenced in November 2012. Here the expertise of the Fraunhofer IGB is asked for, particularly with regard to the experimental validation of active agents using easy-to-handle model systems. A third project will be identified from additional applications in early 2013.

## Contacts



**Ina Andrees-Ostovan M.A.**  
 European Business Development  
 Phone +49 711 970-3621  
[ina.andrees@igb.fraunhofer.de](mailto:ina.andrees@igb.fraunhofer.de)



**Dipl.-Agr.-Biol. Sabine Krieg**  
 Business Development  
 Phone +49 711 970-4003  
[sabine.krieg@igb.fraunhofer.de](mailto:sabine.krieg@igb.fraunhofer.de)



## STRATEGY PROCESS AT THE FRAUNHOFER IGB

Strategy is looking at today's markets and thus at the goals and successes of tomorrow: accordingly, strategic orientation is the key to long-term commercial and scientific success of an institute. At the Fraunhofer IGB we therefore monitor the focus of our core competences and business areas through an ongoing strategy process.

When Professor Hirth took over the helm of the Fraunhofer IGB at the end of 2007/beginning of 2008 one of his first acts was to initiate a process to develop a joint mission and vision for the institute based on its guiding principles. In parallel, Professor Hirth reorganized the institute into the five business areas medicine, pharmacy, chemistry, environment, and energy. As early as 2011, the Fraunhofer IGB adopted the strategy process established in the Fraunhofer-Gesellschaft, which serves as a planning and appraisal tool for constant strategic orientation and innovative development. In November 2012 we concluded this intensive strategy process with a strategy report for the period 2013–2017 and a technology audit. External auditors from industry and science evaluated the institute's eight core competences and five business areas and gave them a preliminary rating of very good. The auditors' final report is expected in spring 2013.

The strategy plan, which is structured according to core competences and business areas, reveals how the core competences of the Fraunhofer IGB serve as a broad base for pursuing market-oriented technology developments in the business areas. It also gives details of the themes that have been identified and prioritized for the next five years. To this end, SWOT

analyses and technology roadmaps were drawn up for all core competences and business areas. A further focus here was the potential for product or process developments that extend across core competences and disciplines, which in many cases the Fraunhofer IGB can realize – from planning to design/construction to process optimization up to pilot-scale phase. As a consequence, a priority was to identify the relevance of the core competences for the business areas: it was shown that all core competences make a contribution in at least three of the five business areas. The synergistic linking of core competences and the associated diversification of R&D that can be offered makes it hugely easier to react flexibly to rapidly changing markets, and ensures the success of the institute in times of crisis. The ability to offer expertise in diverse sectors and business areas also increases innovation potential. Thus an IGB-internal "open innovation process" effectively takes place, which makes it possible to continually tap into new markets.

Finally, we identified ten strategic topics, based in part on the criterion that each of them must contribute significantly to at least two of the business areas. Apart from these thematic focuses, we have set ourselves four goals that encompass our clients and customers from industry, politics and science as well as our social responsibilities. We are convinced that in this way we can make a sustainable and remarkable contribution to tackling the major challenges of the 21<sup>st</sup> century.



## APPOINTMENTS AND PRIZES

### Professorship for Günter Tovar

On October 17, 2012 Priv.-Doz. Dr. Günter Tovar was appointed Professor at the University of Stuttgart. Professor Tovar is Vice Director of the Institute of Interfacial Process Engineering and Plasma Technology IGVP at the University of Stuttgart, with teaching commitments on the study programs Process Engineering, Technical Biology, Chemistry and Medical Technology. At the Fraunhofer IGB he is responsible for the Fraunhofer IGB's university relations as part of the institute's business development activities. Tovar is also spokesperson for the Fraunhofer Nanotechnology Alliance.

### VDI Ring of Honor for Dr. Petra Kluger

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Dr. Petra Kluger, Group Manager Cells and Biomaterials in the Fraunhofer IGB's Cell and Tissue Engineering Department, was awarded the VDI (Association of German Engineers) Ring of Honor on November 21, 2012 for her interdisciplinary research into the development of biomaterials for regenerative medicine. Her work provides new and deeper insight into specific cell-material interactions which are needed to design novel medical devices as well as tailor-made scaffolds or tissue engineering. She also received recognition for her commitment to organizing lectures and internships for up-and-coming scientists and schoolchildren. The VDI found that Kluger inspired her bachelor, masters and Ph.D. tutees through highly structured supervision of their practical work and outstandingly good communication of scientific content.

### Poster award for Petra Keller

Petra Keller from the Fraunhofer IGB's Molecular Biotechnology Department was awarded one of six prizes at the 11<sup>th</sup> European Conference on Fungal Genetics from March 30 to April 2, 2012 in Marburg for her poster "Identification and characterization of novel antifungal compounds against fungal human pathogens". The poster, which was presented in the Biotechnology category, was rewarded with 150 euros. The co-authors were colleagues at the Institute for Interfacial Engineering IGVT at the University of Stuttgart and the Fraunhofer IGB as well as members of two further university groups and an SME: Anke Burger-Kentscher, Karl-Heinz Wiesmüller, Karin Lemuth, Ekkehard Hiller, Isabel Engelhardt, Christoph Müller, Klaus Schröppel, Franz Bracher and Steffen Rupp. Over 400 posters were submitted and evaluated according to scientific quality, presentation and design.

### Poster award for Silke Palzer

At the 18<sup>th</sup> Conference of the International Society for Human and Animal Mycology ISHAM from June 11-15, 2012 in Berlin, Silke Palzer from the Fraunhofer IGB's Molecular Biotechnology Department received one of ten prizes awarded with 300 euros for her poster "An expanded genetic code in *C. albicans* to study molecular interactions in vivo". The co-authors of the poster, submitted in the Basic Mycology category, were Yannick Bantel, Franziska Kazenwadel, Michael Berg, Steffen Rupp and Kai Sohn. The winning criteria in the evaluation of the over 800 posters submitted were scientific quality and presentation of the content.



## PROMOTING YOUNG TALENTS – EXHIBITIONS

The Fraunhofer-Gesellschaft is keen to make early contact with the researchers of tomorrow and give them exciting insights into research opportunities. Thus the Fraunhofer IGB is active in both promoting young talents and getting young people interested in research and technology. We do this through events at the Fraunhofer campus in Stuttgart, as well as exhibits at various exhibitions.

### Girls' Day at the Fraunhofer campus in Stuttgart 1

In Germany we currently have the best educated cohort of young women of all times, with girls making up 55.2 percent of high-school graduates alone. Despite this, girls still tend to opt disproportionately in favor of typical female jobs or courses when choosing an apprenticeship or higher studies. Girls' Day – a nationwide event initiated by the German Federal Ministry of Education and Research (BMBF) – at the Fraunhofer campus in Stuttgart gives young women an insight into the Fraunhofer Institutes and the careers available in engineering, IT and the natural sciences. The researchers open the doors to laboratories and test areas, offices and workshops, where they use practical examples to demonstrate how interesting their work is. For girls, this is a good chance to find out more about what scientists do through talking to the scientists in real life, on a one-to-one basis. 2012 saw once again well over 100 interested participants in Stuttgart, some of whom visited the "Magic liquids and fascinating surfaces" and "Making DNA visible" information stations at the Fraunhofer IGB. The next Girls' Day will take place on April 25, 2013.  
[www.stuttgart.fraunhofer.de/girls-day](http://www.stuttgart.fraunhofer.de/girls-day)

### BOGY – vocational and academic career orientation at academic high schools

16 high-school students completed their "BOGY" internships at the Fraunhofer IGB in 2012. They gained insights into the work of scientists and graduate students in different disciplines (engineers, biologists, chemists and physicists) as well as finding out about typical "recognized" (i.e. requiring formal training) vocational occupations in a research institute, such as technical assistant or laboratory technician. The students were introduced to various working groups in the respective departments and their laboratories, assisted on real projects, became acquainted with methods for identifying particular substances and helped out with the planning and performing of experiments as well as the documentation of the test results. The internship gives the youngsters a detailed picture of the work that goes on in a research institute and helps them to make better-informed career choices.

[www.stuttgart.fraunhofer.de/schuelerpraktika](http://www.stuttgart.fraunhofer.de/schuelerpraktika)

### Open day for university students

In February 2013, 94 science and engineering students from various universities and universities of applied sciences visited the Fraunhofer campus in Stuttgart. Through presentations, interviews and tours they had the chance to find out about



the institutes' highly varied fields of work as well as opportunities for starting their careers at the Fraunhofer-Gesellschaft – in particular at the Stuttgart institutes. Answering the question “Why not go into industry straight away?” the participants were shown the various career paths at the Fraunhofer-Gesellschaft. Extremely positive feedback and rising numbers of participants, especially of female students, reflect the success of the event, which has taken place once a year since 2007.

[www.stuttgart.fraunhofer.de/studierende](http://www.stuttgart.fraunhofer.de/studierende)

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### Training at the Fraunhofer IGB

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The IGB is not only dedicated to the training of young people pursuing academic studies; we are also expressly committed to enabling young people of all backgrounds to train at Fraunhofer. For over ten years we have been providing youngsters with apprenticeships in the recognized (requiring formal training) vocational occupations of office administrator, chemical lab technician and biology lab technician. When not attending vocational training college, the apprentices have the opportunity to work alongside more experienced colleagues in the many diverse fields of activity of a research institute, and so learn the handiwork for a career in research or industry. Many of our apprentices choose to go on to study or to participate in an advanced occupational training course designed for full-time employees and sponsored by the institute.

[www.igb.fraunhofer.de/ausbildung](http://www.igb.fraunhofer.de/ausbildung)

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### MS Wissenschaft 2012 – “Project Earth: Our Future”

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2 + 3

On October 15, 2012 Würzburg was the final stop in MS Wissenschaft's tour, which had featured two Fraunhofer IGB exhibits. During the trip, covering 4270 km of waterways, some 90,000 people visited the exhibition and discovered about the research being done on sustainable development topics.

Following its launch on May 30, 2012 in Berlin, the ship visited a total 36 cities and towns in Germany and Austria. 480 school classes came on board to experience the exhibition, which was themed on a typical town, where each of the municipal facilities represented a topic area.

### Wastewater as a raw material – intelligent water management

For the “public utilities” in the exhibition the Fraunhofer IGB presented the DEUS 21 (“DEcentralized Urban Infrastructure System”) project in the form of a planning board. The DEUS system is used to reduce the drinking water consumption of a settlement, a housing complex or a neighborhood, treat rain-water and at the same time harness wastewater as a source of recyclable material. To this end, the wastewater is treated anaerobically in dedicated bioreactors where the organic components are converted into biogas, which can then be used as a source of electricity and heat. Inorganic nutrients can be reclaimed from the wastewater in the form of fertilizing salts.

### Eco-friendly cleaning and washing – bio-surfactants from renewable raw materials

The “house” was home to sustainable solutions and the topic “everyday life”. Fraunhofer IGB presented a washing machine that shows how bio-surfactants can be made from renewable raw materials using fungi. Washing powder, household detergents, shower gels or shampoos all contain surfactants that enable the washing agents to foam and dirt and fat to dissolve. Up till now, most surfactants have been produced from crude oil. With the aid of fungi and bacteria, the Fraunhofer IGB aims to manufacture eco-friendly and effective grease and dirt removers using renewable raw materials as feedstock. For the production process the microorganisms require sugar, which can also be generated from second generation feedstock like straw and plant oils. Properly cultivated in the bioreactor, the microorganisms form a large number of surface-active substances which can be isolated and used as detergents.



## PURSUING SUSTAINABLE GOALS – “FUTURE PROJECT EARTH” AT THE FRAUNHOFER IGB

Sustainable development of society that will give it the ongoing capacity to endure can only be achieved through safeguarding and reconciling its ecological, economic and social potentials. Not only politics and industry, but also science and research make an essential contribution here. To serve the goal of increasing the sustainability of Fraunhofer research and its application, Fraunhofer IGB employees maintain close exchange with the other institutes at the Stuttgart campus as well as within the Fraunhofer “Sustainability Network” that links more than 20 institutes. In the previous year, an executive-board-level project headed by Professor Thomas Hirth at the Network set the course for the strategic implementation of a sustainability policy for the entire research organization.

The policy focuses on a holistic approach and continual optimization of the research carried out both in terms of themes addressed and operative aspects. It is being piloted by the five Fraunhofer Institutes based at the Stuttgart site, who are collaborating on a common vision for sustainable development. In order to visibly profile this process, they published the first cross-institute sustainability report within the Fraunhofer-Gesellschaft in March 2012. In the publication, the institutes report on the sustainable development aspects of their activities at the Stuttgart research campus and commit themselves to continual improvement through goals and measures they have set themselves.

The main challenge faced was to take into account the commercial and organizational independence of the institutes. The involvement of employees from all the institutes, from different fields of activity and hierarchical levels in the development

of guiding principles, goals and activities was the prerequisite for a vigorous process that is hoped will continue to characterize the institutional culture.

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### Sustainability Action Day

1 + 2 + 3

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One of the measures announced in the Sustainability Report was the Sustainability Action Day on June 29, 2012 – the Stuttgart Fraunhofer Institutes’ own response to the nationwide “National Sustainability Action Day” appeal. In the run-up to this date, the Sustainability work group at the Fraunhofer Institute Center Stuttgart IZS, coordinated by Ina Andrees-Ostovan from the Fraunhofer IGB, announced an idea competition. Of the nearly 50 ideas submitted by the employees a large number were realized on the Action Day and beyond:

In a campaign aimed at motivating people to think and act long-term as individuals, Fraunhofer experts advised their colleagues how everyone can reduce CO<sub>2</sub> emissions through prudent behavior at the workplace and on the commute. The first “brown bag lunch” provided a forum for short talks presenting current research topics and ideas. This type of scientific dialog is intended to stimulate networking beyond the walls of the institutes and will be continued at regular intervals. The opportunity to test drive electric vehicles from the Fraunhofer IAO e-mobility test fleet met with keen interest as did the e-waste collection campaign where the employees had the chance to dispose their private electric and electronic appliances to the charitable company Neue Arbeit GmbH to be



professionally dismantled and recycled. A certain measure of “compensation” for the green spaces lost to the new buildings on the campus was the setting up of nesting and wintering aids for insects, to be followed by the sowing of meadow flowers in spring 2013. The institutes’ efforts to operate in a more healthy and resource-saving fashion were rounded off by a “regional week” in the Piccante staff restaurant. A jury made up of institute management representatives and the sustainability workgroup awarded prizes to the submitters of the best ideas on the Action Day.

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### **Fraunhofer “House of Sustainability”**

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In the 2012 Science Year “Project Earth: Our Future”, the German Federal Government called for society to debate our communal life, our economic activities and environmental protection. A graphic illustration of this was provided by the Fraunhofer IGB together with 22 other Fraunhofer facilities at their joint booth “House of Sustainability” at the Hanover Fair in April 2012. Whether the innovative water infrastructure concept DEUS 21, a skin model for testing cosmetics as an alternative to animal testing or photocatalytic surfaces for chemical degradation – these constitute only a few of the current research activities that are paving the way for a more sustainable form of living. Further exhibits, such as the recovery of nutrients from wastewater, the conversion of organic residues into fertilizer and the energetic utilization of waste biomass, demonstrated the spectrum of sustainability-oriented technologies developed at the Fraunhofer IGB.

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### **The story continues**

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The many impulses from our employees, coupled with the Sustainability Network project to publish guidelines on sustainability reporting that was launched in June 2012, inspire us to take our work ever further. Under the aegis of Fraunhofer headquarters and Fraunhofer UMSICHT, the Fraunhofer IGB is using its experiences with the first sustainability report at the Fraunhofer IZS to produce a code of practice plus a training concept for Fraunhofer-wide sustainability reporting, based on the internationally recognized Global Reporting Initiative (GRI) standard.

[www.nachhaltigkeit.fraunhofer.de](http://www.nachhaltigkeit.fraunhofer.de)

[www.stuttgart.fraunhofer.de](http://www.stuttgart.fraunhofer.de)





# COMPETENCES

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## 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 66 institutes and independent research units. The majority of the more than 22,000 staff are qualified scientists and engineers, who work with an annual research budget of 1.9 billion euros. Of this sum, more than 1.6 billion euros is generated through contract research. More than 70 percent of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Almost 30 percent is contributed by the German federal and *Länder* 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.

Affiliated international research centers and representative offices provide contact with the regions of 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.

*[www.fraunhofer.de](http://www.fraunhofer.de)*

<sup>1</sup> *Joseph von Fraunhofer (1787–1826).*



## INTERFACIAL ENGINEERING AND MATERIALS SCIENCE

Interfaces play a key role in many technical areas such as the automotive sector, technical textiles and in medical technology. For many surfaces, properties are required that are very different from those intrinsic to the bulk of the material concerned. Besides these material surfaces, inner interfaces in composite materials are becoming increasingly important. Examples are membranes used in separation technology as well as materials for energy conversion, such as separators in fuel cells or thin films in photovoltaics. Another instance of the growing significance of interfaces is as barriers in packaging materials.

Finally, in response to the growing complexity of demand, we combine various technical processes under the aspects of material and energy efficiency. With regard to technical realization, we have established a large variety of methods which involve either films being deposited from the gas phase or the precipitation of thin films or particles from the liquid phase.

### Established preparation methods

- Deposition of thin films by chemical and physical means, i.e. chemical or physical vapor deposition
- Deposition of nanoparticles using various polymerization methods
- Production of separation membranes by sol-gel processes and consecutive annealing
- Deposition of thin layers by layer-by-layer (LbL) techniques as well as by self-assembly monolayers (SAM)
- Deposition of thin films via spin-coating
- Generation of nanofibers by electrospinning

To achieve reliable processes, all steps of the process development have to be controlled. In addition, the products have to be characterized in detail. For this purpose a multitude of analytical tools is available and can partly also be used for in situ monitoring of processes (process diagnostics). Due to the fact that the majority of our products are characterized by nanometer dimensions (ultra-thin films and nanoparticles), we use several methods to deliver information which is space-resolved on the nanometer scale. Application-relevant properties such as the separation and permeation properties of films (membranes, barriers and corrosion protection) as well as the specific separation capabilities of molecularly imprinted nanoparticles or the dispersibility of modified carbon nanotubes are examined in customized experimental set-ups.

### Established characterization and diagnostic processes

- Determination of interfacial energy with different types of tensiometers
- Logging of the topography and geometric patterning of surfaces on the nanometer scale using a variety of AFM probe modes as well as scanning electron microscopy
- Determination of adsorption properties either by means of microcaloric measurements at the liquid phase (measurement of adsorption enthalpy) or by means of gas adsorption with simultaneous measurements of specific surface area (BET)
- Determination of film thicknesses using ellipsometry or microscopic techniques



- Qualitative and quantitative estimation of the chemical functions at surfaces and in thin films using IR spectroscopy in ATR mode, IR microscopy, confocal Raman and fluorescence spectroscopy as well as MALDI-TOF-MS (matrix-assisted laser desorption-ionization time-of-flight mass spectroscopy)
- Determination of elemental composition, using electron spectroscopy for chemical analysis (ESCA) and energy dispersive X-Ray analysis (EDX)
- Plasma process diagnostics: probe measurements, optical and mass spectrometric methods

Apart from the quality of the products, the material and energy efficiency of processes is of foremost concern. One way of tackling this is to miniaturize entire functional units which are manufactured as a combination of several thin films. The internal structure and the chemical composition of these layers are significant for the role of the films in modulating the transport of materials (membranes), of electrons (conductors and semi-conductors) or photons (fiber optics). This also opens up applications for thin-film components in photovoltaics, in batteries and in organic electronics. The challenge and objective of our process engineering development work is to find the best ways of combining thin films using a variety of specialized techniques.

Thanks to our combination of preparation methods and analytical tools, we are well prepared to successfully handle the development challenges of our clients across the Fraunhofer IGB portfolio – whether in the medicine, pharmacy, chemistry, the environment or energy business area.

#### Range of services

- Development of processes for the plasma modification of surfaces
- Thin films as protective layers (scratch and corrosion protection), barriers against permeation, and for use as reservoirs for the targeted release of substances (formulations)

#### Contact



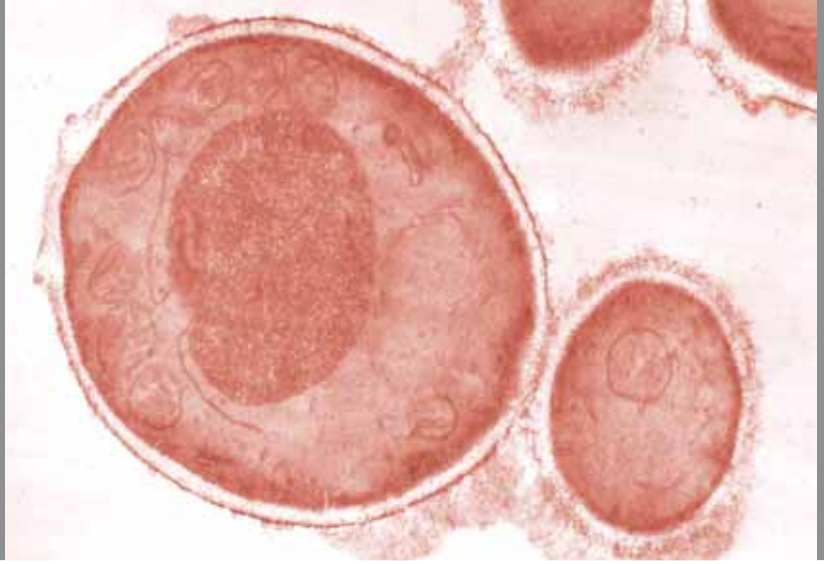
#### Dr. Christian Oehr

Head of Department of Interfacial Engineering and Materials Science  
 Phone +49 711 970-4137  
[christian.oehr@igb.fraunhofer.de](mailto:christian.oehr@igb.fraunhofer.de)

- Functionalization of surfaces (chemical and biochemical)
- Development of plasma-cleaning and plasma-sterilization processes
- Synthesis and preparation of nanostructured materials with tailored surfaces
- Novel formulations using core-shell particles
- Characterization of nanoparticles, measurement of the particle sizes and particle size distribution by optical methods or in an electrical field
- Development of membranes and membrane modules
- Manufacturing and testing of membranes in pilot scale
- Surface and layer characterization
- Development of methods and plants
- Scaling up of laboratory processes to produce thin films on large format surfaces and scaling of nanoparticle production for greater volumes

#### Infrastructure and technical equipment

- Plasma reactors for cleaning, sterilization, coating and functionalization
- Equipment for sputtering and parylene coating
- Electron (SEM) and probe (AFM) microscopes
- Equipment for the analysis of surfaces and thin films
- Chemical-nanotechnical laboratories for the synthesis and preparation of nanostructured (bio)materials and surfaces
- Pilot plants for the manufacturing and testing of membranes



## MOLECULAR BIOTECHNOLOGY

The Molecular Biotechnology Department focuses on work in the fields of pharmaceutical biotechnology, diagnostics and chemistry. Thus, for instance, we use our know-how for the functional genome analysis of pathogens (infection biology) in order to develop new approaches for the screening of anti-infectives. We develop new diagnostic methods based on nucleic acid technologies (diagnostic microarrays) or by means of cell-based assays, e.g. for a cell-based pyrogen assay. A further focus is the development of production strains or cell lines for industrial and pharmaceutical biotechnology. In the past, we have developed production processes for pharmaceutical proteins such as interferons (e.g. cinnovex, soluferon) as well as for chemical products such as biosurfactants and dicarboxylic acids. Our work extends from the metabolic engineering of production strains to the development of integrated bioprocesses for effective downstream processing. In addition to microorganisms, we also focus on enzymes as a key to render sustainable raw materials available for biotechnological processes as well as for the enzymatic synthesis of chemicals (e.g. epoxides from fatty acids).

The core competences of the department lie in the application of molecular-biological and biotechnological methods for genomics, transcriptomics and proteomics. A further asset is our accredited analytics, which can also be used for metabolome analyses. Metabolic engineering for strain development, integrated in a bioprocess and focused on simplified product purification, is a central competence for both microbial production processes and for the production of pharmaceutical proteins from mammalian cell lines. In infection biology, the combination of methods of functional genome analysis with our expertise in cell culture technology gives us a unique selling point in the development of infection models and diagnostics.

Our goal is to use nature's toolbox to create biotechnological value chains and to develop new diagnostics and therapeutics. The new technologies in genome and proteome analysis, for example, allow comprehensive analysis of entire microbial communities or of the interaction between microorganisms and the human individual in the shortest of times. This enables the identification of the impact of microbiota on human health – both via host-pathogen interactions and in synergistic form (probiotics). The malignant transformation of the body's normal cells can also be investigated. Using this information, measures for specific treatments for individual groups of the population can be applied. Thus personalized medicine may become reality. In industrial biotechnology, too, the quick availability of genomes and the analysis of cellular circuits make it possible to identify and optimize new metabolic pathways, which can then be ideally exploited for the production of chemicals or proteins.

Using these competences, the Molecular Biotechnology Department in cooperation with other departments of the Fraunhofer IGB, is active in the business areas of medicine, pharmacy, chemistry and the environment. In the field of biocatalysis we work closely with the BioCat Project Group based in Straubing, while we collaborate with the project group at the Fraunhofer CBP in Leuna to develop our laboratory-scale bioprocesses up to 10 m<sup>3</sup> scale. We also cooperate with the Fraunhofer Institute for Toxicology and Experimental Medicine ITEM on developing processes for manufacturing pharmaceutical proteins, up to GMP-compliant production of biologicals for clinical phases of pharmaceutical development.



### Range of services

- Screening of targets and active compounds for anti-infectives (2D and LC proteomics, DNA microarrays, parallel sequencing, infection models, screening assays)
- Gene expression analyses and genome sequencing for customers
- Development of DNA microarrays: design of probes, production of PCR fragments, contact printing, and hybridization
- Cell-based assays: antiviral assays (GLP), pyrogen detection, mutagenicity, toxicity
- Development of production cell lines and processes for recombinant production of proteins (biosimilars), protein purification and characterization
- Development of high-throughput enzyme assays and screening
- Strain and parameter screening in multi-fermenter systems
- Development of integrated fermentation processes for industrial biotechnology with a focus on downstream processing of raw materials and products
- Chemical-physical and biochemical analysis

### Infrastructure and technical equipment

- Molecular-biological laboratories conforming to safety levels L2, S1 and S2 of the German GenTSV (genetic engineering safety regulations)
- Microarray facility, universal microarray platform
- Quantitative real time PCR (qRT-PCR LightCycler 480)
- Parallel sequencing facility (Illumina HiSeq GAIIX)
- Proteomics facility using high-resolution MS techniques (2D gel electrophoresis, nano-LC-MALDI-TOF/TOF, HPLC-ESI-MS/MS)
- Fermentation plant for suspension and adherent mammalian cell culture up to 10 L (non-GMP)

### Contact



#### **Priv.-Doz. Dr. Steffen Rupp**

Head of Department of  
Molecular Biotechnology  
Phone +49 711 970-4045  
steffen.rupp@igb.fraunhofer.de

- Protein purification equipment
- Pulping machines (ball mills, etc.), multi-fermentation bioreactors for bioprocess development, and small bioreactors (up to 30 L) S2
- Picking robot for the systematic storage of DNA- and microbial libraries
- Accredited analytical lab: GC-MS/MS, LC-MS/MS, GPC, IC, ICP-AES and ICP-MS

## PHYSICAL PROCESS TECHNOLOGY

The Physical Process Technology Department is involved in developing processes and process components based on physical and physical chemical principles. Our customers come from sectors such as pulp and paper, metal processing or food industries, and our work for them ranges from the supply of drinking water or energy to integrated treatment, processing and recycling in industrial production.

### The current main themes

- Heat storage using thermo-chemical processes
- Use of sorption systems to remove moisture from gases
- Drying with integrated recovery of volatile materials
- Recycling and management of inorganic nutrients
- Soil-improving substrates by treatment and processing of organic residuals
- Electrophysical processes and oxidative water treatment
- Technical design combined with numeric simulation
- System integration of aseptic processes in the food industry and biotechnology
- Use of electric fields in process engineering applications

The main quality criteria in our R&D activity is sustainability. We define this principally in terms of the minimization or substitution of material consumption – above all of non-renewable sources – and the energy efficiency of processes, but also in terms of the efficient use of regenerative energy and the materials made available from recycling processes. Recycling and energy saving result directly in improved economic efficiency of processes, meaning that our approach satisfies both ecological and economic demands. One example of this is the development of a process to store thermal energy from waste heat or solar thermics. The intention is to enable availability of

heat energy for municipal or industrial use, decoupled in time and space from its source. Potential applications are drying processes in production, the temporary heat supply of buildings, or the treatment of highly contaminated process wastewater with vacuum vaporization.

Our development work on processes and process components extends from initial laboratory-scale characterization and analytics via simulation and software modeling to design and system integration in industrial applications. For developing and designing our technical solutions, we use the latest 3D CAD design software, which is directly linked by data interface to various numerical simulation programs. For standard modeling we use COMSOL Multiphysics® for theoretical pre-studies of multi-phase processes such as the behavior of solid particles in a fluid flow, and CST Microwave Studio® for the calculation of high frequency electromagnetic fields in cavities and the design of antennas for the production of the corresponding electromagnetic waves. From the knowledge thus gained we can proceed to realize demonstration prototypes using the many resources at our disposal – workshops, laboratories and pilot plant facilities, as well as a network of industrial partners.

The Physical Process Technology department is staffed by scientists from various disciplines – such as process engineering, chemical engineering, food chemistry, mechanical and electrical engineering – who work together in multi-disciplinary project teams. Projects may also involve collaboration with specialists from other Fraunhofer IGB departments, such as microbiologists and bioengineers, or from other Fraunhofer institutes, leveraging synergies in expertise to address specific issues.



### Range of services

- Process development carried out by an interdisciplinary team drawn from the fields of process engineering, mechanical and chemical engineering
- Engineering specification including characterization of automation algorithms, up to industrial prototypes
- Feasibility studies and preliminary investigations in laboratory and pilot-plant scale

### Infrastructure and technical equipment

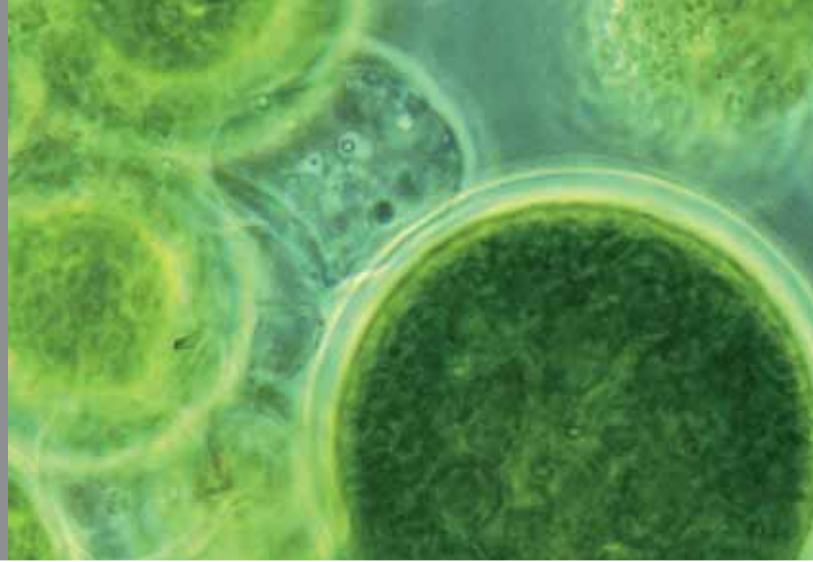
- Laboratory systems for investigating the floccing and oxidation properties of water
- Pilot plants for advanced oxidation processes (AOP) such as electrophysical precipitation, ozone, hydrogen peroxide, UV radiation, ultrasound, anodal oxidation (direct/indirect), and cathode reactions
- Mobile pilot plants for on-site feasibility investigations and demonstrations, for example for drying with superheated steam or for water treatment
- Design and simulation software (SolidWorks, CST Microwave Studio®, COMSOL MultiPhysics®, Design-Expert Workstation)

### Contact



**Dipl.-Ing. Siegfried Egner**

Head of Department of  
Physical Process Technology  
Phone +49 711 970-3643  
siegfried.egner@igb.fraunhofer.de



## ENVIRONMENTAL BIOTECHNOLOGY AND BIOPROCESS ENGINEERING

The activities of the Environmental Biotechnology and Bioprocess Engineering Department are focused on the development of processes to convert organic raw materials, residuals and waste products into bulk chemicals, valuable compounds and sources of energy. These processes are often coupled with the recovery of inorganic substances for reuse as fertilizers and the treatment of the water arising from bioconversion, where it serves as a solvent. We generally use anaerobic methods to treat organic residuals such as biodegradable waste or sewage sludge, as these allow commercially viable generation of biogas as a regenerative source of energy. The use of specific anaerobic microorganisms also enables new approaches in communal and industrial wastewater purification, as well as the realization of innovative semi-decentralized prototype wastewater treatment plants. The retention or immobilization of biocatalysts plays a key role here, and we leverage our expertise in this area extensively – both in researching biological surface reactions (biocorrosion, biofilm formation, biomineralization, biofouling, biosensors, and bioleaching) and in the testing of antimicrobial technical equipment. An additional – aquatic – source of raw material we use is microalgae. Natural and sustainable, algae provide a large number of basic chemical materials and an easily digestible biomass.

The core competence of the department is developing robust biotechnological processes for the production of basic chemicals, which may either be used as raw materials or as sources of energy (methane, ethanol and methanol). In this context “robust” means processes that are resistant to contamination and thus can be operated continuously under aseptic (non-sterile) conditions. Processes are designed exclusively on the basis of microbiological parameters, such as the growth and

degradation kinetics of the different organisms concerned. Our engineering activities extend from the planning, commissioning and optimization of laboratory and pilot plants to the planning, construction, commissioning and optimization of innovative demonstration plants in cooperation with our industrial partners. Intelligent combination of the unit operations of mechanical and chemical process engineering (including downstream processing) with bioprocesses using modeling and simulation methods gives us a unique selling proposition, as does our expertise in the targeted colonization and depletion of microorganisms on surfaces.

- Both classic and “continuous” high-throughput screening methods for autochthonic production strains as high potentials for robust processes or new product lines
- Batch, fed-batch, and continuous fermentation processes, including those involving partial or total cell retention
- Cultivation of microalgae in flat-panel airlift photobioreactors
- Microbiological characterization of surfaces using standard processes and application-oriented processes, including development of test procedures
- Psychrophilic, mesophilic, and thermophilic bioprocesses
- Development of real-time processes for monitoring water systems for contamination
- Modeling of processes and simulation of process lines
- Scale-up processes and scale-down of unstable process states to solve problems during technical operation
- Downstream processing technologies such as membrane-based filtration processes, liquid-liquid extraction, and extraction with supercritical media
- Integrated models for management of energy, waste, and water





The use of anaerobic biocatalysts to produce bulk chemicals or energy carriers has the advantage of a 90 percent carbon-source-to-product yield. The use of rapidly growing photoautotrophic cells (microalgae) also leads to comparatively higher productivities than is achievable with terrestrial plants. Further benefits are reduced water requirements and the feasibility of water-based production of algae.

The Environmental Biotechnology and Bioprocess Engineering Department is thus in a position to take part in solving socio-political challenges such as the greenhouse effect, energy supply and freshwater shortage. By offering sustainable technology options, the department can help industry, communities and policymakers design a balanced future. Combining our competences with those of other Fraunhofer IGB departments, we serve the needs of the chemical, energy and environmental business areas.

#### Range of services

- New wastewater and water purification methods
- Biotechnological purification processes and hybrid processes for industrial wastewater
- Development of utilization concepts for both inorganic and organic residual materials
- Development of regional-level system concepts for energy and water management
- Digestion processes to produce biogas from a range of organic substrates
- Development of photoautotrophic processes for microalgae and cyanobacteria in flat-panel airlift reactors
- Biotransformation of renewable raw materials and industrial waste materials into basic chemicals
- Development of processes for the isolation, separation and purification of biotechnically manufactured products
- Analysis of microbial contamination on surfaces and in processing media

#### Contact



#### Dr.-Ing. Ursula Schließmann

Head of Department of  
Environmental Biotechnology and  
Bioprocess Engineering  
Phone +49 711 970-4222  
[ursula.schliessmann@igb.fraunhofer.de](mailto:ursula.schliessmann@igb.fraunhofer.de)

#### Infrastructure and technical equipment

- Pilot plant for environmental and bioprocess engineering applications
- Bioreactors of various sizes (laboratory, pilot and technical scale)
- Analytics for substrates and fermentation products, protein analytics
- Mobile membrane bioreactors for wastewater treatment
- Mobile pilot plants in m<sup>3</sup>-scale to generate basic engineering data in situ for the planning of innovative demonstration plants
- Demonstration sites Knittlingen (DEUS 21), Stuttgart-Gaisburg (bioenergy), Reutlingen and Fraunhofer IGB (cultivation of algae), Franca, SP, Brazil (bioenergy)
- Photobioreactors of various sizes for lab, outdoor and greenhouse applications
- Test facilities for different membrane processes (e.g. rotating disk filtration)
- Official approvals for handling pathogenic organisms
- Special apparatuses for testing antimicrobially finished materials
- Test facilities for cell disruption and extraction with supercritical fluids
- GIS applications using the ESRI ARC-INFO software; process simulation and automation (MATLAB, Siemens programming)



## CELL AND TISSUE ENGINEERING

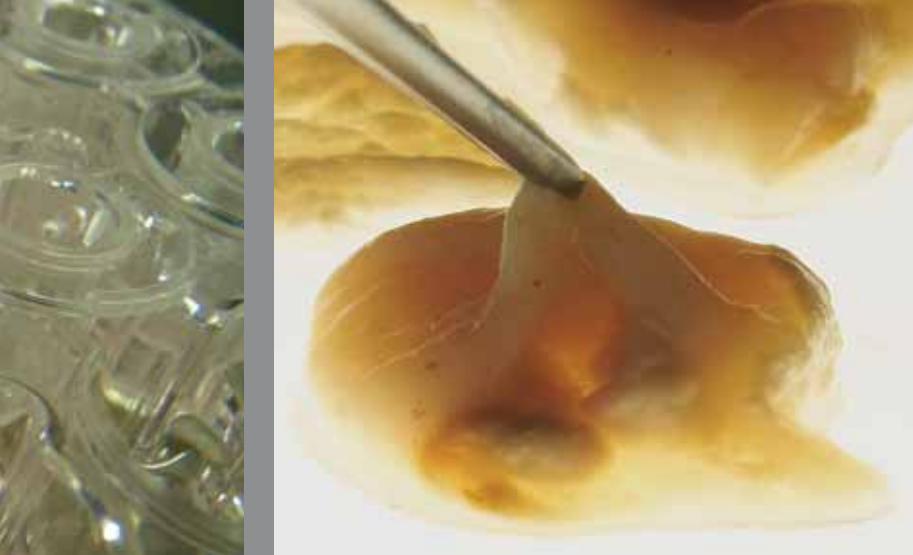
The core competence of the Cell and Tissue Engineering Department is the development of functional 3D tissue models in vitro from isolated primary human cells. With these tissue models, we help solve complex challenges in the areas of regenerative medicine, tissue engineering and the development of medicinal products and cell-based assays for toxicology. We develop biocompatible micro- and nano-structured material surfaces for the effective isolation and culture of primary cells and for optimal cell type-specific cultivation, in particular of adult stem cells. The physiological cultivation of our 3D tissue models is made possible by computer-controlled bioreactor systems designed specifically for the cell type in question. Sterility testing and quality control of cell-based transplants is a laborious process, which always requires two graft samples – one for testing and one for transplantation. We are therefore establishing a non-invasive reference method based on Raman spectroscopy.

A two-layered human 3D skin equivalent has been patented (EP 1 290 145B1) and accredited for the testing of the biocompatibility of medicinal devices (DIN ISO 10993-5). The skin model can be extended by further cell types such as melanocytes or tumor cells. It is also suitable – as a preliminary stage to animal testing – in investigations of the penetration and the distribution of test substances, as required by the EU chemicals regulation REACH. The model's scope extends to investigation of differentiation, apoptosis, and also of tumor initiation and graduation. We have recently succeeded in integrating vascular structures (blood vessel equivalents) into the skin model. In addition, we were able to automate the complete process for manufacturing the avascular skin models.

A further focus is the miniaturization and the characterization of our 3D intestinal testing system. Our accredited two-dimensional intestinal assay based on colon carcinoma cells (2D Caco-2 model) allows validated permeability and transport studies of potential candidate drugs and other substances at the intestinal barrier. We have also been able to establish GMP conditions for the cultivation of our vascularized matrix (BioVaSc) in specific bioreactors. This matrix is used to generate complex organ structures. As part of a project funded by the German Federal Ministry of Education and Research (BMBF) we are currently preparing the first clinical study of a trachea transplant based on the BioVaSc.

- Isolation and culture of primary cells from different tissues and species according to GLP or GMP regulations
  - Micro- or nanostructured (bio)material surfaces
  - Skin including skin tumor, liver, intestine, trachea, cardiovascular tissue
- Establishing processes to develop three-dimensional organotypical cell cultures as testing model or for tissue reconstruction
  - BioVaSc (biological vascularized scaffold)
  - Tissue-specific computer-controlled bioreactors
  - Vascularized human liver, intestine and trachea model
- Establishing methods for non-destructive cell and tissue characterization by means of Raman spectroscopy

With the help of these vascularized human test systems, the absorption, distribution, metabolism, excretion and toxicity (ADMET) of substances or medicinal products can be investigated. These parameters are critical in the characterization of the pharmacokinetic and toxicological properties of active substances. Our findings can be extrapolated directly to the



human organism, with the consequence that a large number of animal experiments could be replaced.

Another goal is the use of our complex tissues as transplants in regenerative medicine. In our GMP manufacturing unit, we offer process development and manufacturing of autologous transplants (advanced therapy medicinal products, ATMPs) as investigational medicinal products (IMPs). The first step involves establishing and verifying the specific manufacturing process for a particular ATMP, which is then adapted to regulatory demands. The final step is applying for the manufacturing authorization for investigational medicinal products. At present, we possess manufacturing authorization for an autologous cartilage transplant, an autologous stem cell transplant and an autologous blood vessel transplant for bypass surgery.

#### Range of services

- Cell culture technology of primary human cells and of specific cell culture media
  - In vitro testing of biocompatibility according to DIN ISO 10993-5
- Cell biology analysis
  - Molecular-biological, histological and immunohistological methods
  - Flow cytometry (FACS), including cell sorting
  - Modern digital image processing techniques such as microdissection and Raman spectroscopy
- Establishing of various 3D tissue models
  - Accredited for REACH testing
  - Alternatives to animal testing in cosmetics R&D
  - ADMET testing in substance and drug screening
  - Target screening for new therapeutics and infection biology

#### Contact



#### Prof. Dr. Heike Walles

Head of Department of  
Cell and Tissue Engineering  
Phone +49 711 970-4117  
heike.walles@igb.fraunhofer.de

- Development of specific computer-controlled bioreactor systems for the cultivation of vascularized tissue models
- Process development, manufacturing and testing of cell and gene therapeutics as investigational medicinal products or ATMPs (phase I/II clinical studies)

#### Infrastructure and technical equipment

- Cell culture laboratories conforming to safety levels S1 and S2 of the German GenTSV (genetic engineering safety regulations)
- State-of-the-art equipment like inverse fluorescence microscope, FACS, and microdissection instrumentation
- GMP production unit (cleanrooms, separate quality control area, storage facilities)



## FRAUNHOFER CENTER FOR CHEMICAL-BIOTECHNOLOGICAL PROCESSES CBP

The Fraunhofer Center for Chemical-Biotechnological Processes CBP in Leuna, central Germany, closes the gap between the lab and industrial implementation. By making infrastructure and plant (pilot scale and miniplant) available, the center makes it possible for cooperation partners from research and industry to develop and scale up biotechnological and chemical processes for the utilization of renewable raw materials up to an industrial scale.

The CBP building, with over 2000 m<sup>2</sup> floor space for pilot plants, labs, offices and storage facilities was completed in September 2012 and inaugurated on October 2, 2012 in the presence of the German Federal Chancellor Dr. Angela Merkel. The Fraunhofer CBP, which is run jointly by the Fraunhofer IGB und ICT institutes, represents a hitherto unique platform for developing new processes up to commercially relevant scale, with a direct link to the chemical industry on the one hand, and to Fraunhofer research on the other.

Joint projects involve partners from industry, academia and non-university research establishments, and currently focus on the following specializations:

- Functionalization of vegetable oils, e.g. biotechnological epoxidation and  $\omega$ -functionalization
- Pulping of lignocellulose and separation of its components
- Fermentative production of platform chemicals
- Manufacturing of biobased alcohols and olefins
- Development of new technical enzymes
- Production of high quality extractives from biogenic raw and residual materials

The core focus of the Fraunhofer CBP's activities is the sustainability of processes along the entire value chain involved in generating products based on renewable resources. The goal is to achieve a cascading material-energetic utilization of as many biomass plant components as possible, on the lines of a biorefinery.

Process development will thus concentrate on the following aspects:

- Exploiting the carbon synthesis potential provided by nature
- The energy and resource efficiency of the processes developed
- Minimizing waste streams
- Reducing CO<sub>2</sub> emissions
- Utilizing plants that are not suited as either human food or animal feed
- Integration of the processes developed into existing systems, e.g. to obtain biogas from residual biomass

Small and medium-sized enterprises frequently do not have the resources of their own to realize the transfer of these new technologies from the laboratory to industrially relevant orders of magnitude. The center's pilot scale and miniplant facilities offer an excellent platform for process development.



### Range of services

The Fraunhofer CBP provides modular process capacities of up to 10 m<sup>3</sup> fermentation volume and continuous plants capable of high-pressure processing up to 10 kg per hour, plus a wide range of processing, treatment and reconditioning techniques and methods. This versatile “flexible biorefinery” facilitates the conversion of raw materials such as vegetable oils, cellulose, lignocellulose, starch and sugar into chemical products.

### Infrastructure and technical equipment

- Fermentation capacities of 10 / 100 / 1000 and 10,000 L, including downstream processing for fermentation products
- Continuous gas phase reactions of up to 10 L/h
- Chemical liquid phase reactions of up to 100 L at up to 70 bar
- Mechanical and thermal separation processes (including extraction with propane and sc-CO<sub>2</sub>)
- Pulping and component separation of lignocellulose using organic solvents, with a capacity of 1 metric ton of biomass per week
- Stirred tank reactors for the enzymatic hydrolysis of polysaccharides

## Contacts

### Fraunhofer Center for

### Chemical-Biotechnological Processes CBP

Am Haupttor | Tor 12, Bau 1251

06237 Leuna | Germany

Fax +49 3461 43-9199 | [www.cbp.fraunhofer.de](http://www.cbp.fraunhofer.de)



#### Dipl.-Chem. (FH) Gerd Unkelbach

Head of CBP Project Group

Phone +49 3461 43-9101

[gerd.unkelbach@cbp.fraunhofer.de](mailto:gerd.unkelbach@cbp.fraunhofer.de)



#### Dr.-Ing. Katja Patzsch

Group Manager

Biotechnological Processes

Phone +49 3461 43-9104

[katja.patzsch@cbp.fraunhofer.de](mailto:katja.patzsch@cbp.fraunhofer.de)



#### Dr. Moritz Leschinsky

Group Manager

Pre-Treatment and Fractioning of

Renewable Raw Materials

Phone +49 3461 43-9102

[moritz.leschinsky@cbp.fraunhofer.de](mailto:moritz.leschinsky@cbp.fraunhofer.de)



#### Dr. Daniela Pufky-Heinrich

Group Manager Chemical Processes

Phone +49 3461 43-9103

[daniela.pufky-heinrich@cbp.fraunhofer.de](mailto:daniela.pufky-heinrich@cbp.fraunhofer.de)



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## FRAUNHOFER PROJECT GROUP BIOCAT

The focus of the Project Group BioCat is on developing catalytic processes and new, renewables-based products to enable a sustainable future supply of raw materials and energy to industry and society. In researching the utilization of biomass and CO<sub>2</sub>, the project group employs key technologies from the fields of chemical catalysis and white biotechnology, as well as a combination of chemical and bio-catalysis. As part of these activities, the group also establishes and implements new methods for creating and optimizing (bio)catalysts. These catalysts can be used, for instance, for the conversion of terpenes – obtained from plants and residual materials in wood processing – into epoxides and monomers for the polymer industry. Further examples are the use of the biopolymer lignin, found in the secondary cell walls of plants, to produce monomers for conductive polymers, and synthesizing functionalized carboxylic acids and biobased surfactants from plant oils and fatty acids. The group's goal is to achieve optimum added value in transforming biomass raw material into biobased end products. Additionally, the group is involved in developing new methods for using and storing surplus electric energy, for instance by binding CO<sub>2</sub> and converting it into fuels.

It is vital that we turn our efforts today, and no later, to developing the next generation of catalysts and processes that will enable us to replace crude oil with biomass and CO<sub>2</sub> as key sources of raw materials. BioCat aims to accelerate this trend in "sustainable" chemistry and make a decisive contribution to

the field. Its approach is to develop new chemical and biocatalytic processes for the material utilization of renewable raw materials, focusing on identifying ways of combining chemical and biotechnological methods that can optimally exploit the material diversity of biomass.

Besides wide-ranging expertise in biotechnology (enzyme technology, fermentations, screening of biocatalysts) and chemistry (organic synthesis, analytics, homogeneous and heterogeneous catalysis), the BioCat Project Group, which is composed of biotechnologists, molecular biologists and chemists specialized in catalysis and synthesis, can offer in-depth knowledge in the field of biogenic raw materials and natural materials. By pooling these interdisciplinary specializations, we are able not only to provide scientific and technical consulting services, but also to carry out work in the analytics, research and development of new materials, new reactions and new catalysts as well as the optimization of existing catalysts and processes, offering close cooperation with our customers.

Combining bio- and chemical catalysis is carried out in close cooperation with the TU München, the Fraunhofer IGB departments and with the Fraunhofer Institute for Chemical Technology ICT in Pfinztal. Collaborative projects offer an opportunity to address the conversion of renewables and thus, for instance, set new impulses for the biopolymer industry.



#### Range of services

- High-resolution NMR spectroscopy (400 MHz) for determining molecular structure, reaction kinetics, deep temperature analytics, e.g. 1D  $^1\text{H}$ -/ $^{19}\text{F}$ -/ $^{13}\text{C}$ -/ $^{31}\text{P}$ -/ $^{15}\text{N}$  measurements and 2D applications including development of methods
- Screening of bio- and chemical catalysts
- Optimization of enzymes by enzyme engineering and enzyme immobilization
- Custom synthesis of fine chemicals
- Design of processes for utilizing waste material
- Design of processes to integrate renewable feedstock into existing processes
- Carrying out of studies in the field of renewable resources

#### Infrastructure and technical equipment

- Autoclave unit with several laboratory-scale parallel reactors (material: Hastelloy C22; volume: 100 ml/reactor; pressure: up to 300 bar; temperature: up to 400 °C)
- Various bioreactors up to 40 liters
- Automation platform for high throughput applications
- Analytics: GC-MS, LC-MS, HPLC and FT-IR with online probe
- 400 MHz NMR spectrometer

#### Contact

##### Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB

##### Project Group BioCat

Schulgasse 11a | 94315 Straubing | Germany

Fax +49 9421 187-310 | [www.biocat.fraunhofer.de](http://www.biocat.fraunhofer.de)



##### Prof. Dr. Volker Sieber

Head of Project Group BioCat

Phone +49 9421 187-301

[volker.sieber@igb.fraunhofer.de](mailto:volker.sieber@igb.fraunhofer.de)



##### Dr. Harald Strittmatter

Laboratory Manager

Phone +49 9421 187-350

[harald.strittmatter@igb.fraunhofer.de](mailto:harald.strittmatter@igb.fraunhofer.de)



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## FRAUNHOFER PROJECT GROUP ONCOLOGY

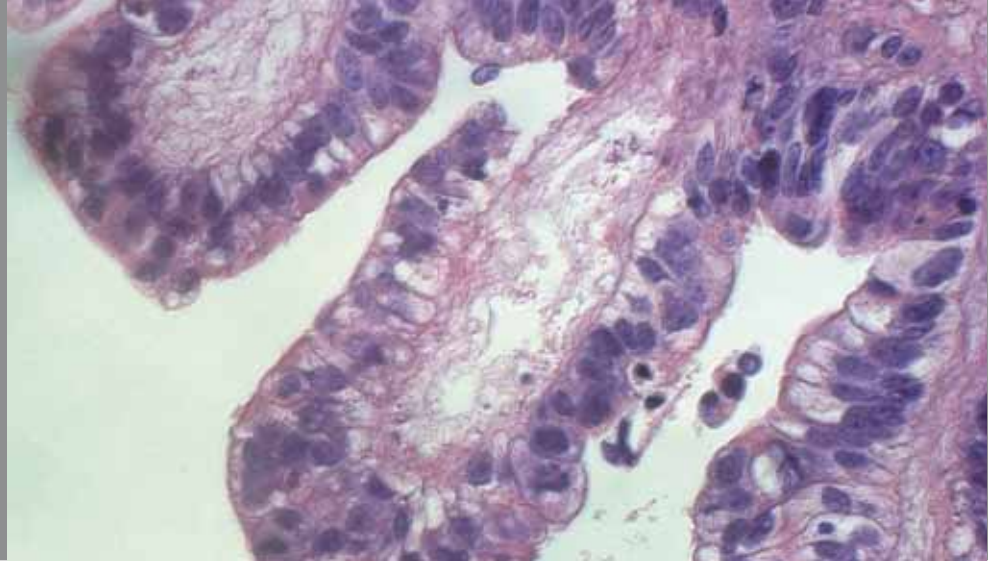
The project group “Regenerative Technologies for Oncology” of the Fraunhofer IGB was created in 2009 to coincide with the establishment of the Chair of Tissue Engineering and Regenerative Medicine at the University of Würzburg. The project group benefits from the synergy of leveraging the research of the Fraunhofer IGB and the Medical Faculty of the University of Würzburg.

The focus of the project group is the development of human 3D test systems for the development of cancer drugs. With primary tumor cells, tissue-specific, vascularized in vitro tumor models are established as a test system. The project group will produce human vascularized tumors utilizing the Fraunhofer IGB Cell and Tissue Engineering Department’s methodology of growing human tissue with a functional blood vessel equivalent in vitro. A bioreactor system will support the artificial tumor tissue through blood vessels as in the human body, which will enable the in vitro examination of the molecular mechanisms of angiogenesis (the formation of new blood vessels) and other relevant mechanisms of tumor formation and metastasis. Similarly, by using such tumor models, we can study how new drugs are distributed within the tumor and how they reach their target destination. With the help of these tumor models, we are able to create new cancer diagnostics and therapeutics that will circumvent the need for animal tests and result in validated findings that are directly comparable to human tumors in vitro.

Another focus is the development of 3D in vitro generated tumor stem cell niches. Tumor stem cells are now seen as the cause for the emergence and growth of cancer. Because healthy tissue stem cells divide infrequently, they are resistant to conventional treatments with chemotherapy or radiation. This resistance complicates the treatment of cancer and can lead to relapse, a recurrence of the tumor, or give rise to metastases. There is evidence that tumor stem cells are protected from therapeutic attacks in their specific microenvironments, known as niches. If we can replicate this niche in vitro, targeted therapies could be discovered, which act directly on tumor stem cells.

In Germany, 450,000 people suffer and 216,000 people die from cancer each year. After cardiovascular diseases, cancer is the second leading cause of death. Cancer cells grow uncontrollably and form their own nutrient-supplying blood vessels. Many tumors move through the blood or lymphatic system cells to distant organs and form metastases, which can often lead to incurable cancer. An important goal of our work is to therefore discover the mechanisms of cancer growth, metastasis, and their distribution in the human body.





#### Range of services

- Production and biochemical modification of tissue engineered electrospun 3D scaffolds
- Isolation of primary human stem and tumor cells
- Establishment of co-cultures for the generation of human solid tumors in vitro and tumor test systems
- Development of specific bioreactors for various tumor models
- Development of human vascularized tumor tissue for the establishment of individual diagnostics and personalized treatments
- Biological cell analysis of tumor tissue: molecular-biological, histological and immunohistochemical methods, flow cytometry (FACS), including sorting
- Target screening for new cancer therapeutics

Our research services can be used for the entire value-added chain in the development of cancer therapies:

- Investigation of the active principle and/or the side effects of new drug candidates utilizing vascularized human tumor test systems
- Use of the tumor model in the process development of optimizing drugs or diagnostics
- Implementation and validation of in vitro tests as alternatives to animal testing at the end of the preclinical development phase
- Efficacy experiments of new drugs that are currently undergoing evaluation for clinical use
- Cooperation with the medical faculty of Würzburg for the organization of the clinical phases I–III

#### Contact

##### Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB

##### Project Group Oncology

c / o University of Würzburg

Chair of Tissue Engineering and Regenerative Medicine

Röntgenring 11 | 97070 Würzburg | Germany



##### Prof. Dr. Heike Walles

Phone +49 931 31-88828

Fax +49 931 31-81068

heike.walles@igb.fraunhofer.de

#### Infrastructure and technical equipment

- Cell culture laboratories for work on safety levels S1 and S2 GenTSV
- Cell analysis: Fluorescence microscope, FACS, microdissection system, Raman spectroscopy



## INSTITUTE OF INTERFACIAL PROCESS ENGINEERING AND PLASMA TECHNOLOGY IGVP

The former Institute for Interfacial Engineering IGVT was re-named in January 2013: the new Institute of Interfacial Process Engineering and Plasma Technology IGVP is headed by Professor Thomas Hirth and remains part of the University of Stuttgart's Faculty of Energy Technology, Process Engineering and Biological Engineering (Faculty 4). The IGVP integrates the Institute for Plasma Research IPF, previously part of the University of Stuttgart's Faculty 8 Physics Department, where Prof. Hirth took over as acting director on July 1, 2012. At year-end 2012, the IGVT had a staff of 54 and a research budget of around 2.5 million euros. The IPF employed 30 staff (page 13). Most of the restructured institute's activities will be carried out as before on the premises of the Fraunhofer IGB, which is a close cooperation partner. The IGVP will also continue to use the laboratories, pilot plant facilities and offices at the Allmandring 5b multipurpose facility belonging to the university, but now has additional premises and resources at the former IPF site at Pfaffenwaldring 31. The institute's working groups, now numbering eight, have at their disposal sophisticated equipment for research into and using interfaces and plasmas, using a whole spectrum of biological, chemical, physical and process-engineering methods.

Close cooperation with the various Fraunhofer IGB departments makes it possible to pursue projects from basic research to application. This integrated approach is also reflected in the variety of sources of research funding received by the IGVP, including the German Federal Ministry of Education and Research (BMBF), the German Federal Foundation for the Environment (DBU), the German Research Foundation (DFG), the European Union, the *Land* of Baden-Württemberg, various foundations, and industry. At the IGVT, and now the IGVP,

our guiding principle is to combine fundamental academic research with application-oriented approaches, including incorporating ideas from practice.

### Research and teaching

In 2012, the IGVT focused on the design, functionalization and characterization of surfaces of inorganic, biological and organic origin as well as of bio-, nano- and hybrid materials and their interactions. Further activities included the simulation and development of interfacially driven processes, e.g. in membrane technology and biotechnology, as well as research into the underlying biochemical, cell-biological, chemical, molecular-biological and physical-chemical phenomena.

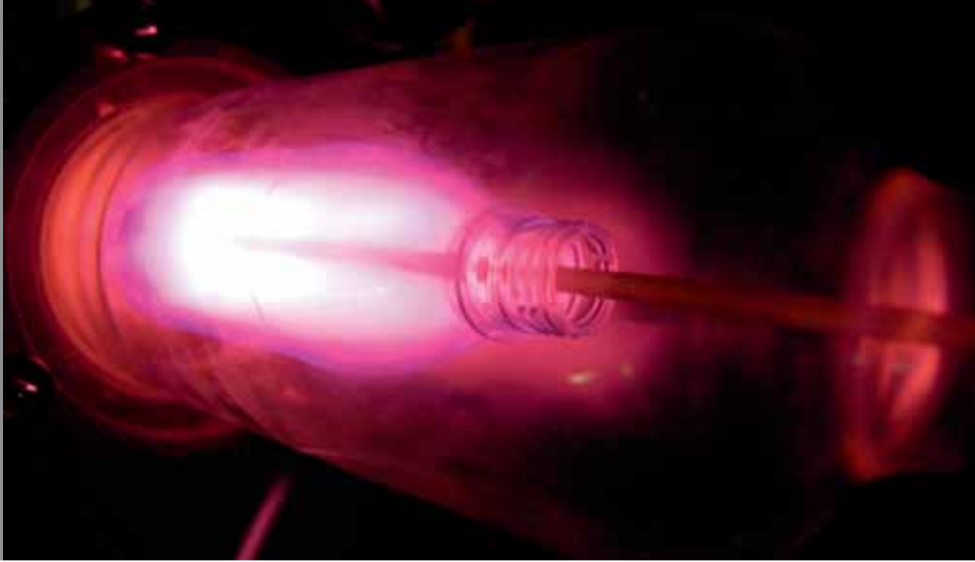
Teaching activities at the institute centered on the subject areas biomaterials, industrial biotechnology, interfacial process engineering and nanotechnology. Credited instruction is also offered in further interdisciplinary fields. Students mostly come from courses in applied materials science, chemistry, mechanical engineering, medical engineering, process engineering, technical biology, technical cybernetics, and the WASTE master study program.

### Biological Interfacial Engineering

- Host-pathogen interactions
- Interactions between microorganisms and surfaces
- Microarray technologies for diagnostics and biomedicine
- Process development for industrial biotechnology
- Screening for enzymes and microorganisms

### Chemical Interfacial Engineering

- Biomaterials and nanobiomaterials



- Biomimetic functional layers
- Composite materials, hybrid materials, ionic liquids
- Core-shell nano- and microparticles
- Nano- and microstructured (bio)functional surfaces
- Surfaces for molecular recognition

#### Medical Interfacial Engineering

- 3D tissue engineering
- Cells and biomaterials
- Development of tissue-specific bioreactors
- Generation of vascularized tissue
- Organoid human test systems as a substitute for animal experiments
- Toxicity studies using organoid tissue models

#### Physical Interfacial Engineering

- Chemical vapor deposition (CVD)
- Development of plasma processes
- Interface characterization
- Microplasmas
- Nanoscopic surface functionalization
- Plasma diagnostics and physical-chemical modeling
- Plasma-enhanced chemical vapor deposition (PECVD)
- Processes for the dispersion of nanomaterials

#### Environmental Interfacial Engineering

- Adsorption/desorption processes for heat storage and dehumidification
- Development of processes for the energetic and material use of biomass
- Drying processes using superheated steam
- Electrochemically stimulated crystallization and recovery of inorganic nutrients
- Membrane processes for water treatment, cell retention and water hygienization
- Membranes for gas separation and fuel cells
- Particle suspensions and emulsions in electric fields
- Production processes with microalgae in photobioreactors

#### Contacts

##### Institute of Interfacial Process Engineering and Plasma Technology IGVP

University of Stuttgart  
 c/o Fraunhofer IGB, Nobelstrasse 12, 70569 Stuttgart  
 Fax +49 711 970-4006  
[www.igvp.uni-stuttgart.de](http://www.igvp.uni-stuttgart.de)



**Prof. Dr. Thomas Hirth**  
 Director  
 Phone +49 711 970-4400  
[thomas.hirth@igvp.uni-stuttgart.de](mailto:thomas.hirth@igvp.uni-stuttgart.de)



**Prof. Dr. Günter Tovar**  
 Vice Director  
 Phone +49 711 970-4109  
[guenter.tovar@igvp.uni-stuttgart.de](mailto:guenter.tovar@igvp.uni-stuttgart.de)

#### IPF working groups

As of 2013, the three research areas Microwave Technology, Plasma Dynamics and Diagnostics, and Plasma Technology of the former Institute of Plasma Research IPF will augment the five existing IGVT areas named above in the new IGVP.



# MEDICINE

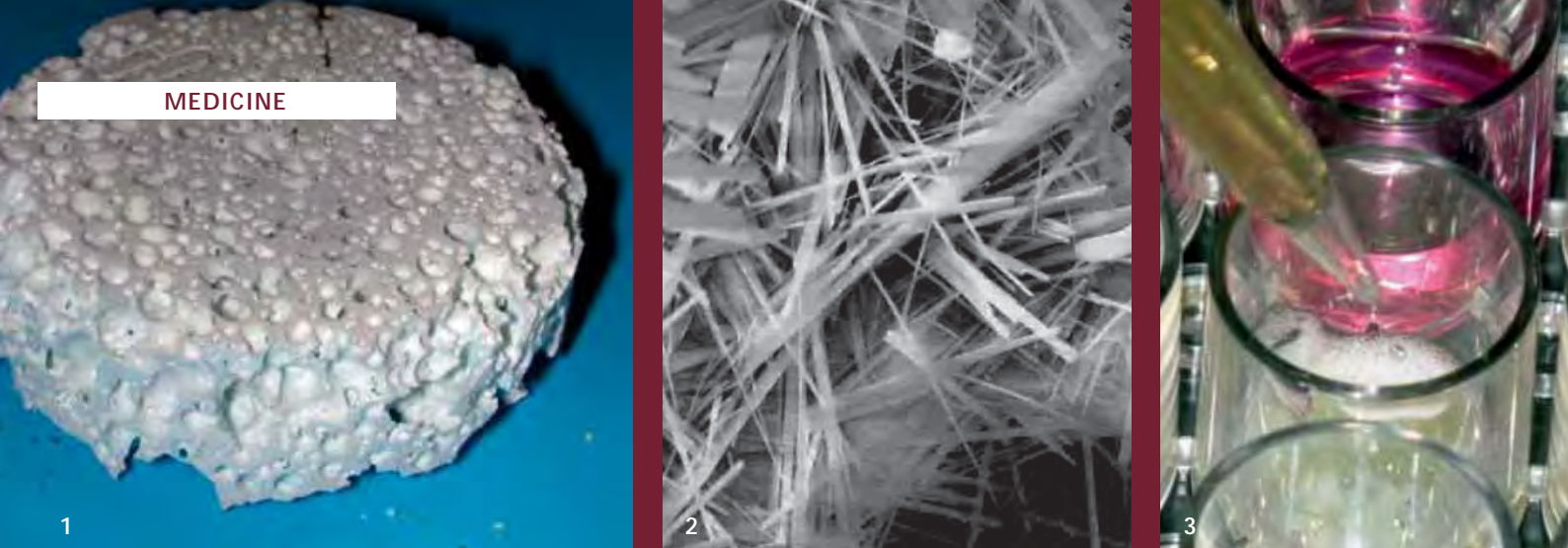
Prof. Dr. Heike Walles

Better cure rates offered by regenerative medicine, quicker and more accurate diagnostics using molecular-biological approaches, and coordinated interaction between medical implants and their physiological environment are scientific trends which improve healthcare provision and at the same time can reduce costs. In the medicine business area at the Fraunhofer IGB we frequently work together with medical specialists on interdisciplinary projects, addressing topics in the areas of tissue engineering, regenerative medicine, immunology, infection biology, diagnostics, and the “biologization” of established medical products. The quality of the food we eat is also critical to human health – which is why improving its production is also a subject of investigation at the Fraunhofer IGB.

The focus of regenerative therapies is on the development of autologous transplants, known as ATMPs (advanced therapy medicinal products). The Fraunhofer IGB maps the complete value-added chain up to GMP-compliant manufacturing of ATMPs. In the last year we started to launch two phase I clinical studies for European registration, together with our network of physicians. The Fraunhofer IGB will make the experience and competence gained through these studies available to small and medium-size enterprises, assuming the role of the mediator from the fundamentals up to the preclinical stage. To promote the role of tissue engineering products in healthcare, we are developing a GMP-conform plant for the standardized, fully automated in-vitro manufacture of skin models through a joint Fraunhofer research project financed by the Fraunhofer-Zukunftsstiftung (Fraunhofer Future Foundation).

Both bacterial and fungal infectious diseases are again on the increase in industrial nations, making new scientific strategies to combat infection or avoid sepsis a priority. Thanks to the various array technologies and transcriptome analysis methods, as well as human tissue models it has developed on the basis of its own patents, the Fraunhofer IGB is in a position to elucidate host-pathogen interaction and make targets available for new anti-infectives. Using this know-how, we aim to develop new diagnostics as well as active agents and treatment strategies.

A further focal point, enabled by the interdisciplinary mode of operation of the Fraunhofer IGB, is the optimization of surface properties of established medical devices such as tracheal stents and contact lenses. This is carried out primarily by means of plasma processes to generate bioactive or antibacterial surfaces; we then proceed to test the effectiveness and biocompatibility of these surfaces on in-vitro tissue models. We also make a contribution to preventive healthcare through the development of processing techniques and methods for hygienization and pasteurization that are gentle on the product and thus preserve the product’s original properties.



## BIOMIMETIC, ANTIBACTERIAL BONE IMPLANTS FOR THE PREVENTION OF LOCAL INFECTIONS

Dr. rer. nat. Iris Trick, Prof. Dr. Christophe Drouet\*

### Prevention of bone infections by antibacterial implants

Hospital-acquired bone infections, for example, as a result of surgery, are a serious and costly problem, making the prevention of such infection a matter of the highest priority. Calcium phosphate (CaP) apatites are highly suitable candidates for the preparation of biomaterials for bone repair. However, although CaP compounds have been the subject of the extensive industrial research and development, there are still no technological concepts for equipping calcium phosphates with antibacterial properties. Since the use of antibiotics is problematic, due to the development of bacterial resistance, other strategies must be found, compared and developed.

### French-German research alliance BioCapabili

The binational BioCapabili project involves the collaboration between the Fraunhofer IGB and the CIRIMAT Carnot Institute in France, in order to equip bioactive, biomimetic CaP apatite with various antimicrobial compounds and fully investigate them. Antibiotics were not used. CaP apatites were developed in the CIRIMAT "Phosphates, Pharmacotechnics and Biomaterials" working group, with a focus on their synthesis, characterization and surface reactivity. Alternative surface modifications as well as biological characterization were carried out at the Fraunhofer IGB.

### Methods

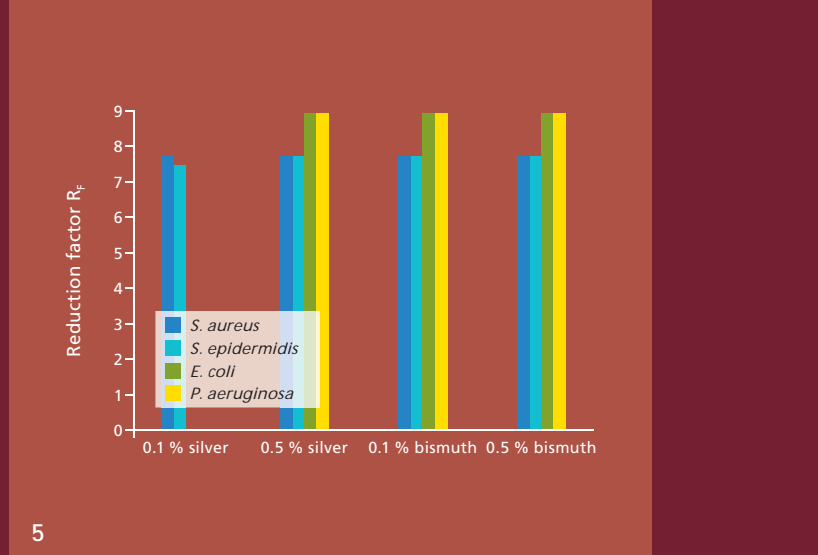
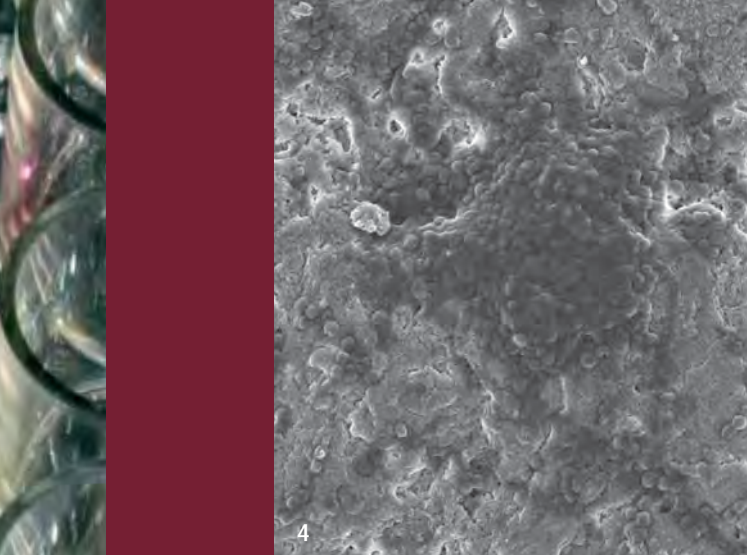
Calcium phosphates crystallized in the apatite structure have a similar construction to the mineral content of bone. In order to produce new formulations of nanocrystalline biomimetic apatites with antibacterial properties we modified the composition of the apatite. A second approach was to functionalize the hydrated surface layer of nanoscale CaP apatite with

active agents. Various methods were employed to modify preferably the surface of the nanocrystals (e.g. using a dialysis membrane), or the entire crystal. The surface adsorption of organic or organic-inorganic compounds on the surface of the CaP crystals was also investigated. We were able to show antibacterial effects for various different pathogens and with various test parameters. We compared the concentration-dependency of the antibacterial effect with regard to cytotoxicity and antibacterial properties. The best formulations were subsequently tested in vivo for osteoconduction.

### Results

Several new formulations of chemically-modified (with or without surface modifications) nanocrystalline apatites were synthesized and fully characterized. The conditions enabling us to obtain single-phased apatite systems were retained and tests for antibacterial effects and cytotoxicity were carried out. Non-doped systems served as a reference. The apatite nanocrystals obtained showed high surface reactivity, especially through a hydrated surface layer. The influence of synthesis parameters, particularly the amount of antibacterial agent used per formulation and subsequent treatments was thoroughly investigated, especially in view of future possible areas of application.

All the systems developed in the project were screened for antibacterial properties and cytotoxicity and the results were compared to determine the most promising formulations for future development to an industrial level. Fig. 5 shows several selected screening results. The figure shows the reduction factor  $R_r$ , which is calculated from the starting cell count used and the re-cultivable cells ( $R_r = \log(\text{starting cell count}) - \log$



(number of re-cultivable cells)). A high starting cell count of between  $10^7$  cells/ml for Staphylococci and  $10^9$  cells/ml for *E. coli* and *P. aeruginosa* was reached on silver and bismuth-doped CaP apatite in high-concentration screening. The reduction factor  $R_f$  shown in the diagram specifies the reduction in viable and reproductive cells in logarithm form. The maximum possible value corresponds to the number of starting cells used and therefore the total inactivation of the cells was accomplished. It was possible to fully inactivate the Staphylococci with the levels of doping shown. *E. coli* and *P. aeruginosa* show no impairment at 0.1 percent silver ( $R_f=0$ ), while at only 0.5 percent silver both bismuth concentrations were equally fully inactivated.

Preliminary in vivo implantation tests were launched at the end of the project to investigate the potential impact of the best formulations on osteogenesis.

### Outlook

With a view to future developments, we were able to establish contact with surgeons and industrial companies during the course of the project and a patent for one of the new formulations has been filed. A number of industrial companies have shown serious interest in this patent and in the French-German BioCapabili research alliance. Both institutes have identified several further novel applications for the antibacterial materials – as the foundation for long-term collaboration in the development of antibacterial materials in Europe.

### Contacts



#### Dr. Iris Trick

Phone +49 711 970-4217  
iris.trick@igb.fraunhofer.de



#### Dr. Michaela Müller

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

### Funding

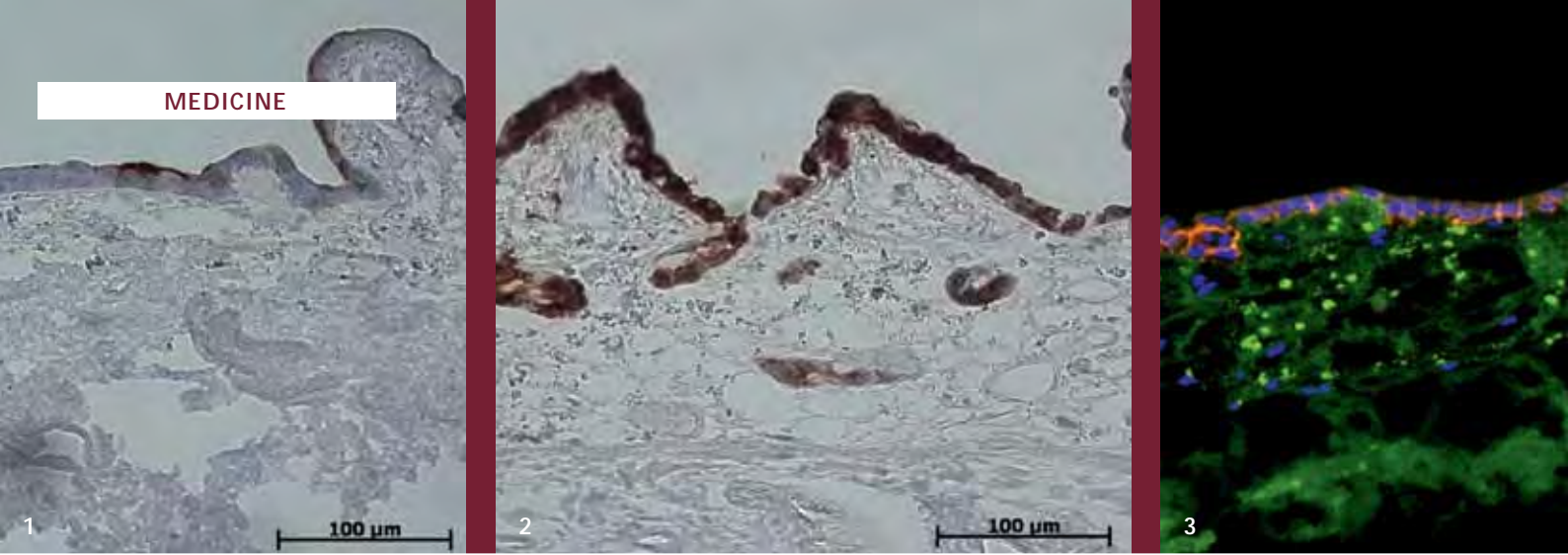
We would like to thank the German Federal Ministry of Education and Research (BMBF) and the French National Research Agency (ANR) for funding the project “BioCapabili” within the joint project “Inter Carnot Fraunhofer PICF 2009”.

### Project partner

CIRIMAT Carnot Institute | ENSIACET, 4 allée. Emile Monso, 31030 Toulouse cedex 4 France | \* Dr. Christophe Drouet, christophe.drouet@ensiacet.fr

- 1 Specimen of the biomimetic bone replacement material (source: CIRIMAT Carnot Institute).
- 2 Microscopy image of the apatite used (source: CIRIMAT Carnot Institute).
- 3 Screening to quantify the antimicrobial properties of the BioCapabili formulations.

- 4 Scanning electron microscope image of a biofilm of the species *Staphylococcus aureus* on the surface of nanocrystalline calcium phosphate apatite (without antimicrobial properties) from the CIRIMAT Institute.
- 5 Antibacterial effect of various BioCapabili formulations on relevant bacterial strains.



## HUMAN 3D LUNG TUMOR MODEL

David Fecher M.Sc.

### Lung tumors, a difficult to treat condition

Lung cancer is the most common cancer worldwide and is difficult to treat due to its heterogeneity. Of the numerous types of cancer, lung tumors are the most prevalent [1]. A realistic model, which enables the possibility to study and understand the development and treatment of these tumors, is urgently required.

Testing substances for drug development is a complicated and costly process. Of 250 potential compounds in preclinical studies, ultimately only one is made commercially available [2]. One reason for this is the absence of a suitable human test system. In pre-clinical studies and basic research on tumors, both cell lines and animals, especially immunosuppressed mice, are used. The small number of usable substances that eventually make their way into the clinical settings demonstrates that the currently used tumor models do not adequately represent the human tumor.

### Development of a lung cancer test system

In the Project Group Oncology, an acellular bowel segment called SIS (small intestinal submucosa) is used as the scaffold for the tumor models. This collagen structure is a derivative of the BioVaSc and can be statically cultured between two metal rings [3]. On this biological support structure, lung tumor cell lines with different genetic backgrounds may be applied to generate a three-dimensional human tumor model.

### Differentiated model for the clinical testing of therapeutic strategies

After 14 days of static culture, a polarized epithelial layer of the tumor cells forms on the three-dimensional matrix. In comparison to two-dimensional culture, the cells have a marked change in the expression of tumor-related proteins, which better reflect in vivo tumor conditions.

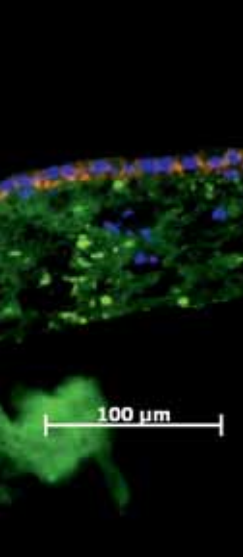
For the treatment of lung tumors which have a mutation of the EGF receptor (EGFR), the EGFR-inhibitor Gefitinib is used in the clinic. When applying the Gefitinib treatment on the tumor cell line in our model, which includes an active EGFR mutation, we get a similar response to what is seen in patients. The proliferation of the tumor cells is inhibited, while more tumor cells go through apoptosis.

### Co-culture with tumor-associated cell types increased complexity of the model

In addition to tumor cells, the tumor also has non-tumorous cells and connective tissue, which are referred to as tumor stroma. Tumor-associated fibroblasts are a major component of the tumor stroma and play a significant role in tumor development and progression.

To reflect this complexity in the in vitro tumor model, established tumor cell lines were co-cultured with tumor-associated fibroblasts, which were obtained from biopsies of lung cancer patients. Thus, the influence of these fibroblasts and their therapeutic potential can be examined as targets for new drugs.





### The development of an advanced, invasive tumor model

The leading cause of death from cancers are metastatic tumors elsewhere in the body. The so-called epithelial-mesenchymal transition plays an important role, in which the tumor cells acquire the ability to invade other tissues. This process can be induced in our system through the stimulation of tumor cells. The tumor cells lose the expression of epithelial markers and migrate deep into the matrix. Using this model, the process of invasion can be better understood, which will allow the development of targeted therapies.

### Outlook

With the developed human test system, new drugs for the treatment of lung adenocarcinomas can be tested and the effectiveness of targeted drugs and therapies can be predicted. The ease of use, rapid availability and low costs of the system makes it less time-consuming and more efficient than animal studies.

By the use of primary tumor cells from biopsies of the patient, a “personalized model” of the patient’s tumor can be generated, allowing a much better prediction of the patient’s reaction to a therapeutic approach.

To create a more realistic tissue model, we use an additional support structure based on decellularized lungs, which possesses the complex three-dimensional architecture of the lung. For culturing this tissue model, a bioreactor is designed so the negative pressure respiration of the lung can be simulated.

- 1 Apical mucin-1 expression of HCC-827 cell line.
- 2 Depolarized, increased expression of mucin-1 of the A549 cell line.
- 3 Co-culture with primary fibroblasts and tumor epithelial cells.
- 4 Matrix structure of an acellular lung.
- 5 The bioreactor for the culture of the lung matrix.

### Contacts



**David Fecher M.Sc.**

Phone +49 931 31-89034  
david.fecher@uni-wuerzburg.de



**Prof. Dr. Heike Walles**

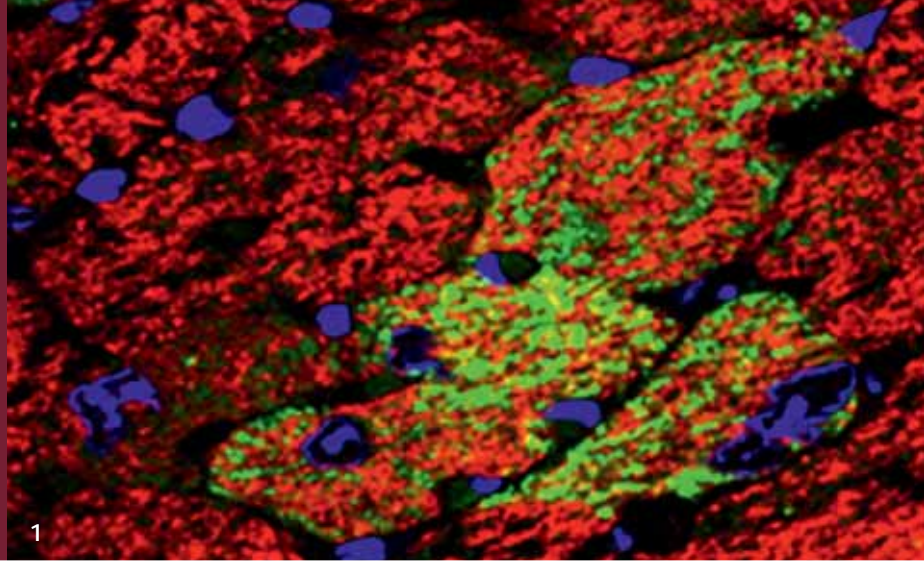
Phone +49 711 970-4117  
heike.walles@igb.fraunhofer.de

### References

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- [2] PhRMA industry profile (2012) <http://de.slideshare.net/PhRMA/2012-pharmaceutical-industry-profile-12691151>
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### Funding

We would like to thank the Bavarian State Ministry for Economic Affairs, Infrastructure, Transport and Technology and the Fraunhofer-Gesellschaft for funding of the Fraunhofer Project Group “Regenerative Technologies for Oncology” as part of the program Bavaria FIT.



## DEVELOPING BIOLOGICALLY INSPIRED CARDIOVASCULAR REGENERATIVE TECHNOLOGIES

Prof. Dr. rer. nat. Katja Schenke-Layland, Shannon Lee Layland B.A.

Despite significant advances in cardiology and cardiac surgery, cardiovascular disease remains one of the leading causes of the death in the world. In Europe alone, an estimated 10 million people are affected each year. The most common cause of heart failure is either acute or chronic damage to the heart. The human heart possesses very little regenerative capacity. After a cardiac event, the loss of heart function cannot be naturally recovered, which permanently and drastically impairs the quality of life of patients. Therefore, restoration of normal heart function after the heart has been damaged is a driving goal for a variety of researchers worldwide.

### Deriving cardiomyocytes from cardiovascular progenitor cells

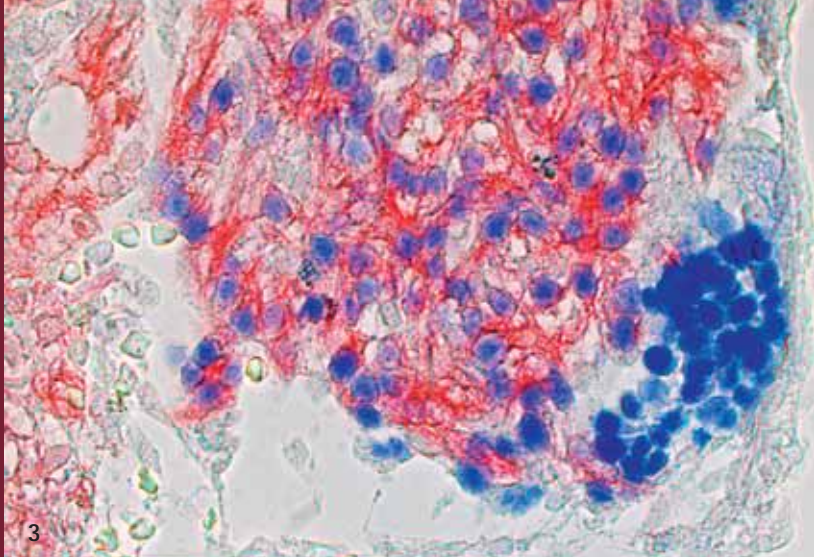
Cardiomyocytes as well as endothelial and smooth muscle cells evolve during the embryonic development of humans and other mammals from what are defined as cardiovascular progenitor cells (CPCs). CPCs have been of great interest in the field of biomedical research, but to date, have not been translated to clinical settings. CPCs can be identified using cell markers. Typical CPC markers, such as Nkx2.5, are located within cells. The use of such internal cell markers damages cells, leaving them therapeutically unusable. The lack of a cell marker that does not damage CPCs, such as a cell surface marker, has hindered the use of these potent cells in the clinic. Therefore, the search for CPC surface markers is of great research interest.

### Surface markers for identifying cardiovascular progenitor cells

Together with our partners, Professor Ali Nsair of the University of California Los Angeles (UCLA) and Professor W. Robb MacLellan of the University of Washington in Seattle, we are now able to identify surface markers for living and functional CPCs in the mouse that allow for their isolation and expansion [1]. Through gene expression analysis, the team identified the combination of receptors Flt1 (VEGFR1) and Flt4 (VEGFR3) as suitable surface markers for CPCs.

### Producing cardiovascular progenitor cells from induced-pluripotent stem cells

In further studies, we were able to produce the first Flt1-/Flt4-positive CPCs from clinically relevant, induced-pluripotent stem cells (iPSCs), which could develop into endothelial cells, smooth muscle cells and functional, beating cardiomyocytes. We used the iPSC method for which the Japanese scientist Shinya Yamanaka was awarded the 2012 Nobel Prize for Medicine. He published, just 6 years ago, that only four proteins are responsible for the pluripotency of mouse embryonic stem cells [2]. He brought the four genes into differentiated – mature and specialized – body cells, which then programmed the adult cells back to an embryonic state. From these cells, which he called iPSCs, specialized cells, such as liver and nerve cells or cardiomyocytes can be developed.



### iPSC-derived progenitor cells integrate into the living mouse heart

To answer the questions of how the iPSC-derived progenitor cells behave in vivo and whether they can really integrate into the cardiac tissue, we injected the cells into the heart of a living mouse. We could demonstrate that the progenitor cells developed into beating cardiomyocytes and fully integrated into the myocardial tissue of the mouse.

### Outlook

To stimulate the regeneration of heart muscle cells, adult stem cells have been injected directly into the heart. Although a majority of studies found a slight improvement in heart function, in most cases neither the long-term integration nor differentiation of the cells into functional heart muscle have been demonstrated. The result of our work provides the first opportunity to generate functional and mature heart muscle cells, which integrate into the heart muscle. We are currently focusing on the generation of human iPSC-derived progenitor cells for clinical trials and treatment of diseased heart muscle.

- 1 *iPSC-derived progenitor cells (green) that were injected into the heart of a living mouse become functional heart muscle (red). Cell nuclei are blue.*
- 2 *Bioinformatic analysis at Fraunhofer IGB.*
- 3 *Cardiovascular progenitor cells (blue) develop into cardiac muscle cells (red).*

### Contacts



**Prof. Dr. Katja Schenke-Layland**  
 Phone +49 711 970-4082  
 katja.schenke-layland@igb.fraunhofer.de



**Shannon Lee Layland B.A.**  
 Phone +49 711 970-4283  
 shannon.layland@igb.fraunhofer.de

### References

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### Project partners

University of California Los Angeles (UCLA), Los Angeles, CA, USA | University of Washington, Seattle, WA, USA | University Women's Hospital at the Eberhard Karls University Tübingen

### Funding

We would like to thank the Fraunhofer-Gesellschaft for the support of the Attract Group and the California Institute for Regenerative Medicine (CIRM) and the German Federal Ministry of Education and Research (BMBF) for funding the project "Characterization and Bioengineering of the cardiac stem cell niche", promotional reference 0316059.



# INNOVATIVE CELL AND TISSUE THERAPIES ON THE WAY INTO CLINICAL APPLICATION

Dr. rer. nat. Martin Funk, Dipl.-Biol. (t. o.) Iris Dally

## Process development for the production of “Advanced Therapy Medicinal Products” (ATMPs)

The advances in the development and wider use of novel cell therapies, tissue engineering and regenerative medicine have led in recent years to an extension of the term “medicinal”, which has equated to a modification of the legal regulation of these products. Cells or tissues that are used to treat people were placed in a new product group that is summarized by EU Regulation EC No. 1394/2007 for advanced therapy medicinal products (ATMP).

The GMP (good manufacturing practice) unit at the Fraunhofer IGB develops and validates new and sometimes complex production processes for innovative cell therapies and tissue-engineered products to gain regulatory approval for the production of clinical trial material as well as the production of sufficient ATMP material to allow our partners to employ their therapies in a clinical setting.

## Bioartificial tissue reconstruction for tracheal surgery

The aim of this project, funded by the Federal Ministry of Education and Research (BMBF), is to develop a manufacturing process and the clinical testing of a novel implant for the reconstruction of rare respiratory defects. The implant consists of a vascularized porcine support scaffold (BioVaSc, biological vascularized scaffold) and the patient’s own (autologous) cells.

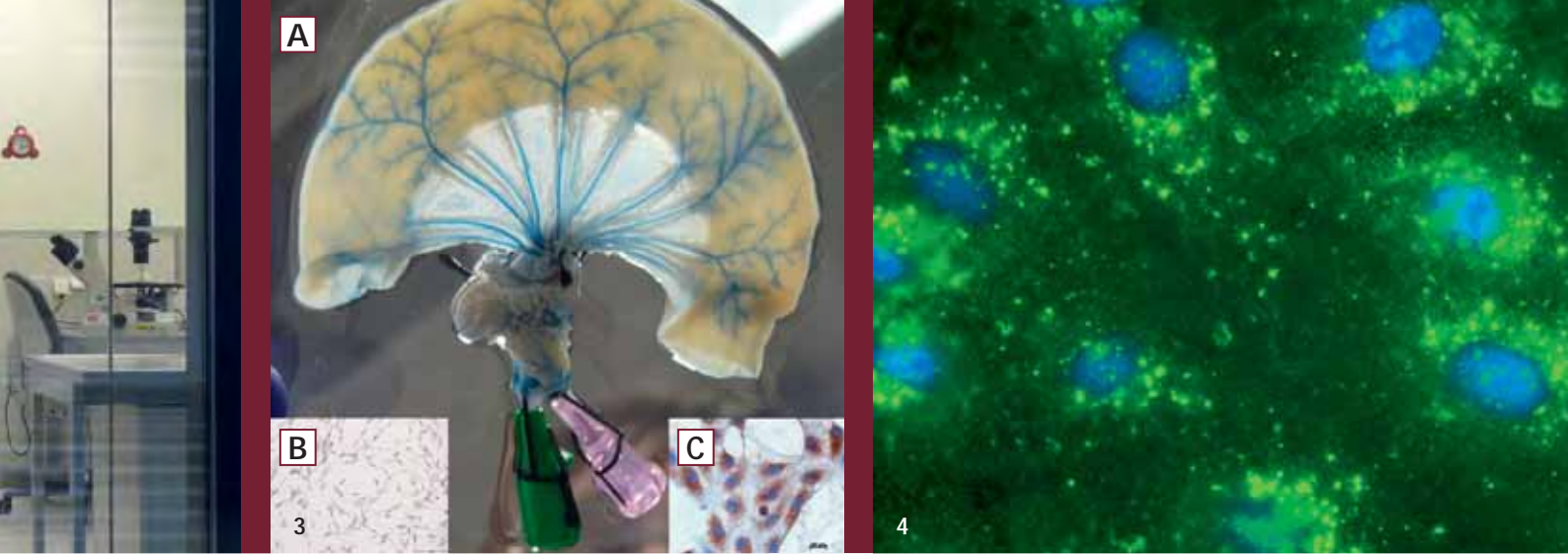
For the development of a GMP process, the preparation method of the BioVaSc was optimized. To ensure product quality, in particular the viral safety of the animal starter material, suitable methods for the analysis of the cell, DNA and endotoxins

were established. For the colonization of the BioVaSc with autologous fibroblasts, endothelial and muscle cells, we developed GMP-compliant protocols. After a four-week period of cell expansion, the cells are introduced into the matrix of the BioVaSc. The microvascular endothelial cells colonize the vascular structures, while the skeletal muscle cells and fibroblasts grow in the intestinal lumen of the BioVaSc. The subsequent two-week aging of the scaffold takes place in a specially designed bioreactor system, which allows the culture and particularly the maturation of the blood vessels under physiological conditions. Following issuance of manufacturing license for such implants by the competent authority, the BioVaSc should be tested in a clinical phase I study.

## Insulin-producing cells for the treatment of type 1 diabetes

The Fraunhofer IGB is developing a GMP-compliant process for the production of insulin-producing cells from the patient’s own liver cells for the US company Orgenesis. Before these cells can be tested in an initial clinical trial as a treatment for type 1 diabetes, the manufacturing process based on the official regulations for ATMPs and cell transplants must be standardized to ensure safety and reproducibility.

The cause of type 1 diabetes is the gradual loss of all the beta cells of the “islets of Langerhans”, which produce insulin in the pancreas. A possible cure for diabetes could be the replacement of the diseased beta cells with healthy pancreatic tissue. Such transplants of pancreas or islet cells are currently being investigated in clinical trials. In order to avoid the rejection of the transplant by the immune system of the recipient,



patients must take years of immunosuppressive drugs. In addition, the first clinical trial data have shown that such transplants are only functional for 3–5 years.

Orgenesis has established a technology that allows the development of the patient’s own liver cells into functional insulin-producing cells. In the process, a biopsy of liver cells are taken from the patient, expanded in the laboratory, and then genetically programmed so that they are of a similar phenotype of the cells from the islets of Langerhans, which produce insulin. Such a transplant would not be attacked by the patient’s immune system.

### Contacts



**Dr. Martin Funk**  
 Phone +49 711 970-4093  
 martin.funk@igb.fraunhofer.de



**Prof. Dr. Heike Walles**  
 Phone +49 711 970-4117  
 heike.walles@igb.fraunhofer.de

### Funding

We would like to thank the German Federal Ministry of Education and Research (BMBF) for funding the project “Reconstruction of bioartificial tissue for tracheal surgery”, promotional reference FKZ0315575.

### Project partners

Robert Bosch Hospital Schillerhöhe, Gerlingen | Orgenesis Inc., White Plains, NY, USA

- 1 *Incubator wagon and bioreactors for producing implants.*
- 2 *C-area of the GMP unit at the Fraunhofer IGB.*
- 3 *(A) BioVaSc, (B) muscle cells (C) endothelial cells.*
- 4 *Microvascular endothelial cells imaged by fluorescent LDL.*



# DEVELOPMENT AND VALIDATION OF A NOVEL SYSTEM FOR MILK PASTEURIZATION

Dr. rer. nat. Ana Lucía Vásquez-Caicedo, Ali Imran Javaid M.Sc., Dipl.-Ing. (FH) Alexander Lohner, Sildarista Fukohani-Lohner M.Sc.

## Initial situation

The preservation of milk products requires microorganisms contained in the milk to be completely or partially eliminated by increasing the product temperature. Different processes such as pasteurization, thermization or sterilization (UHT) are differentiated according to their temperature/time profiles. The most common technique for applying heat is indirect heating using plate heat exchangers. This has the disadvantage that, due to the temperature gradient between the exchanger surface and the product, deposits can form on the surfaces of the heat exchanger (fouling). The heat exchangers must therefore be regularly cleaned, leading to considerable costs due to downtimes and the use of energy and cleaning agents. It is therefore the goal of the milk industry to minimize the plant cleaning times, maximize the production times and simultaneously save operational costs, water and energy.

## Project MicroMilk – microwave pasteurization

Within the EU-funded project MicroMilk a Pan-European consortium of small and medium-sized dairy equipment, microwave technology and automation technology companies, two research institutes and one university have developed promising technology for the heating of milk by microwaves. Because of the volumetric energy charge, the MicroMilk technology operates very efficiently. As there is no heat exchanger interface in this direct heating process, the formation of deposits is minimized.

## Process development and test facility

After an analysis of current heating processes, various concepts for the microwave heating of milk were developed, tested and optimized using numeric simulations. The primary criterion for development was fast and regular heating. A test facility was designed, developed and constructed and initial test runs were carried out at a laboratory dairy in the University of Hohenheim, in order to validate principles of the process and determine data on the process parameters.

## Industrial prototype

Based on the results of the test facility, an industrial prototype for microwave pasteurization was designed, in cooperation with the project partners from industry and using the QFD methodology. Aside from aspects of production and materials technology, the HACCP and GMP Directives for food technology devices were considered as decisive criteria, in order to enable instant integration into a production. The central task for the product “Milk” was to maintain the microbiological, nutritional and organoleptic quality while still improving the shelf-life of the milk. The system has a modular construction so that it can be both retrofitted in existing systems, as well as being applied as a stand-alone system.

## Quality features and advantages

We were able to examine relevant quality characteristics by benchmark comparisons between conventional indirect heating and microwave heating using analytical reference methods. To this end, microwave test facility was integrated into an existing pasteurization system at the research dairy at the



University of Hohenheim (Fig. 1), including the newly developed automation feature (Fig. 2).

The integrated test facility was used to investigate the effects of the gradients of the temperature increase ( $dT/dt$ ) on the heating of the milk components. Microwave heating enabled a 3-fold faster temperature rise in comparison to conventional indirect heating using heat exchangers to be achieved (under comparable flow and holding time conditions). There were no significant differences in the physico-chemical (e.g. furosine and HMF formation), microbiological, nutritional (e.g. vitamin B1) and organoleptic characteristics (color and taste) of the milk between both processes. The product quality achieved using microwave pasteurization is thus comparable to that of conventional pasteurization.

The absence of the heat exchanger surface enables the operating time between cleaning cycles to be increased. This saves water and energy and increases operating efficiency.

### Outlook

To date, development has focused on the pasteurization of milk, the most commonly used process for the preservation of milk on the Central European market. However, the advantages of microwave heating regarding milk quality and the reduced formation of deposits are even more significant in UHT heating. We are aiming for an extension of the MicroMilk-technique to UHT and other thermal applications in food industry, especially for highly viscous milk products with low pH values. Furthermore, the MicroMilk system can be transferred to many other food and drink products.

- 1 *The test facility, integrated into an existing pasteurization system at the University of Hohenheim.*
- 2 *MicroMilk control system.*
- 3 *Process validation in the laboratory.*

### Contacts



**Dr. Ana Lucía Vásquez-Caicedo**  
Phone +49 711 970-3669  
analucia.vasquez@igb.fraunhofer.de



**Dipl.-Ing. Siegfried Egner**  
Phone +49 711 970-3643  
siegfried.egner@igb.fraunhofer.de

### Funding

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### Project partners

C. Van’t Riet Dairy Technology B. V., Nieukoop, Netherlands | Danthech UK LTD, Lancashire, UK | Rorosmeieriet, Roros, Norway | Malthe Winje Automasjon AS, Oppegård, Norway | Schwarzwaldmilch GmbH, Freiburg | University of Hohenheim, Stuttgart

### Further information

[www.micromilk.eu](http://www.micromilk.eu)

### Abbreviations

- UHT* ultra high temperature  
*HACCP* hazard analysis and critical control points  
*HMF* hydroxy methyl furfural  
*GMP* good manufacturing practice  
*QFD* quality function deployment





# PHARMACY

Priv.-Doz. Dr. Steffen Rupp

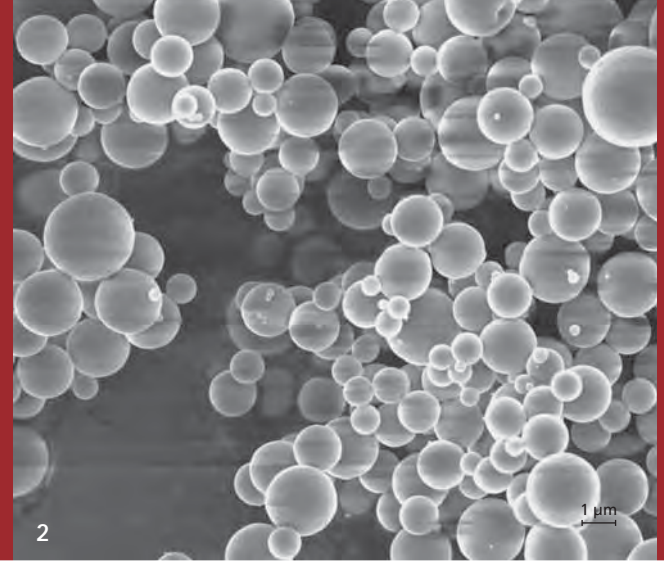
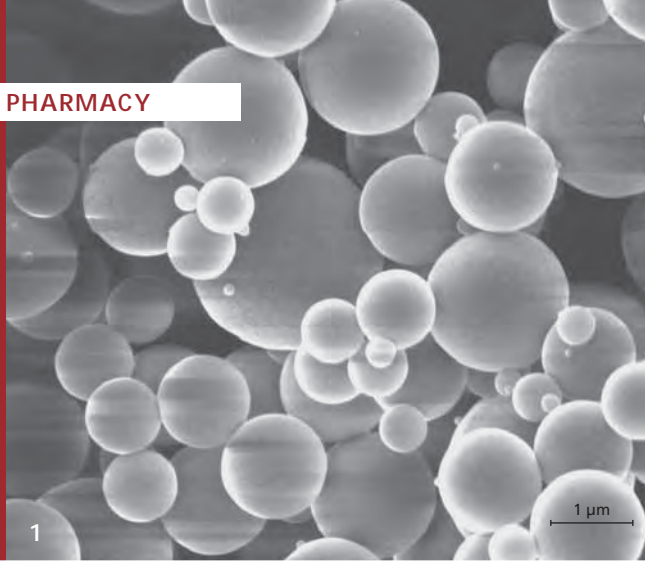
The current challenges faced by the pharmaceutical industry include the accurate diagnosis of diseases and their personalized therapy, the development of new active agents and the enhancement of the effectiveness of new drugs through improved formulations. The pharmacy business area at the Fraunhofer IGB is involved in developing solutions for drug screening, pharmaceutical biotechnology, pharmaceutical chemistry and drug release and formulation.

We identify new drugs by means of the targeted use of cell-based assays, for instance for immunomodulatory substances or anti-infectives. Structure-activity correlations are performed on active hits. Potential active compounds are characterized in vitro by using complex organotypic 3D primary cell models (skin, intestine, lungs, liver) for effectiveness, absorption, distribution in the organ model, metabolization and toxicity. These investigations – corresponding to phase I clinical studies – are complemented by molecular methods such as gene expression and proteome analysis as well as by histology and confocal Raman spectroscopy. The aim is to identify toxic side-effects of potential active agents and their metabolites at an early, pre-clinical stage.

In the field of pharmaceutical biotechnology we are developing processes to manufacture pharmaceutical proteins. These extend from the development of expression vectors and strain development in microorganisms and mammalian cells to the optimization of fermentation processes and the purification of the pharmaceuticals – including by means of molecularly imprinted nanoparticles (NanoMIPs). Cooperation within the Fraunhofer network enables us to supply customers with proteins produced in compliance with GMP (good manufacturing practice) for clinical testing. For the formulation of active agents we develop nanoparticle-based structures which deliver drugs directly to the target location and then release them in a controlled manner.

In addition, we develop cell-based therapeutics and produce samples for clinical trials according to GMP guidelines. Our quality control systems identify potential contaminants (microorganisms, viruses) in a non-destructive way using spectroscopic, cell-based or molecular methods according to the guidelines of GLP (good laboratory practice) or GMP.

Our work in the pharmacy business area is enriched in many ways by the collaboration of different departments at the Fraunhofer IGB. We also contribute to the activities of the Fraunhofer Group for Life Sciences, which cover the development of medicines from screening for active agents to the production of test samples for clinical trials.



# SKIN HEAL – A PARTICLE-BASED FORMULATION FOR IMPROVED WOUND HEALING

Dr. rer. nat. Carmen Gruber-Traub, Dr. rer. nat. Achim Weber

## The challenge of chronic wounds

The effective and cost-efficient treatment of chronic wounds is a great challenge in healthcare. Demographic changes have resulted in a constant increase in chronic wounds – above all, diabetic ulcers. Previously, the amputation of extremities and the associated loss in quality of life have often been unavoidable. The development and evaluation of new forms of treatment for chronic skin disorders are therefore extremely important in regard to reducing costs and improving care. For the individual treatment of these chronic wounds we are developing particle-based formulations within the Fraunhofer “Beyond Tomorrow” project “SKIN HEAL”. The particles loaded with active agents can be integrated into commercial wound dressings or directly applied during treatment as pharmaceutical formulations.

## Chitosan particles loaded with active agents by spray drying

Various particle technologies were used at the Fraunhofer IGB to formulate micro- and nanoparticles loaded with active agents. We use small molecules or proteins as active pharmaceutical ingredients (APIs). Chitosan, as well as its derivative chitosan hydrochloride, was chosen as the base material for the particles. Chitosan is a biobased, biocompatible polymer obtained from crustacean shells, which has antimicrobial properties. We have been able to successfully develop spray-drying procedures for the formulation of active agents that are implemented in wound healing, such as e.g., dexpanthenol or TGF- $\beta$  (transforming growth factor). The Fraunhofer

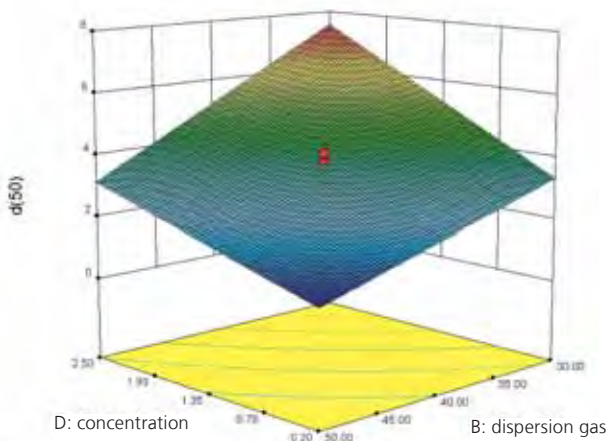
IGB has the Büchi Mini Spray Dryer B-290 and the Nano Spray Dryer B-90 available for this. The process parameters for spray drying using the Mini Spray Dryer were verified by design of experiments (DoE). This assures simple upscaling of the process parameters for the transmission of the spray drying process to the large-scale production process.

## Optimized particle size for optimal integration into the wound dressing

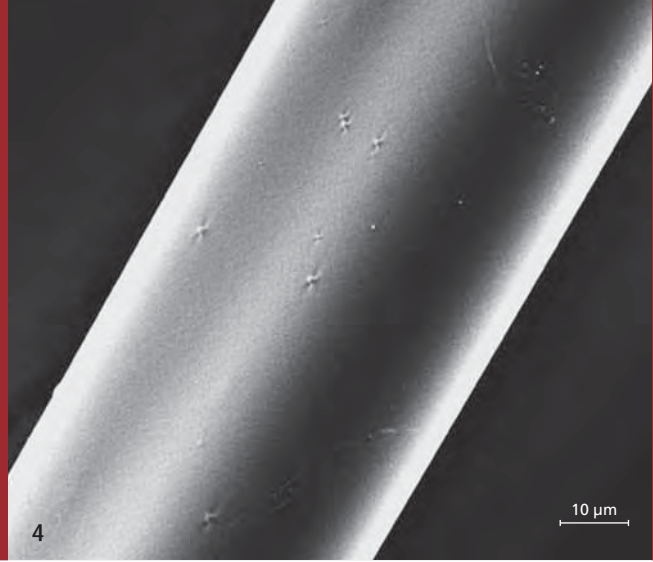
Dexpanthenol and TGF- $\beta$ -loaded chitosan and chitosan hydrochloride particles can be produced using both the Mini and Nano Spray Dryer (Figs. 1 and 2). Design of experiments is, among other things, suitable for the optimization of the process parameters with regard to particle size. This process helped us to create a model that enables the targeted setting of the particle size ( $d_{50}$ ) during particle production in the Mini Spray Dryer. This allowed us to produce chitosan particles with defined particle sizes of 2  $\mu\text{m}$ , 5  $\mu\text{m}$  and 10  $\mu\text{m}$ . The particles were integrated into fibers of the CE certified silica fiber wound dressing (Fig. 4) at the Fraunhofer ISC. Chitosan particles with a diameter smaller than 5  $\mu\text{m}$  were most suitable for this.

## Crosslinking for controlled active agent release

For the controlled release of the active agents, the chitosan and chitosan hydrochloride particles were crosslinked using ionic gelation with tripolyphosphate (TPP), and subsequent spray drying. The concentration of tripolyphosphate was varied and proportions of 0, 4, 7, 10 and 12 percent crosslinker



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were employed. The release rate of the active agent can effectively be controlled by the additional crosslinking of the matrix and the chosen level of crosslinking.

### Conclusions and outlook

Spray drying is suitable as a process for the production of particle-based formulations for improved wound healing. The particles were successfully integrated into the wound dressing. The release properties of the active agents and particles can further be optimized by the variation of the capsule material or the additional coating of the particles. Various crosslinkers (covalent and non-covalent) in the production of the chitosan particles are currently being tested for this.

The particle systems developed here could be transferred to the most varying problems in the area of formulation, as well as small molecule agents and biopharmaceuticals. This has already enabled interferon to be encapsulated while retaining full bioactivity [1].

### Contacts



**Dr. Carmen Gruber-Traub**

Phone +49 711 970-4034

carmen.gruber-traub@

igb.fraunhofer.de



**Dr. Achim Weber**

Phone +49 711 970-4022

achim.weber@igb.fraunhofer.de

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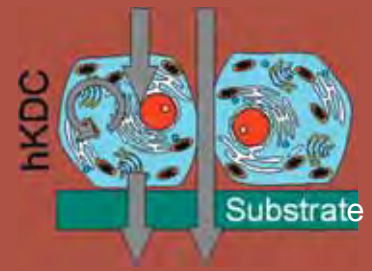
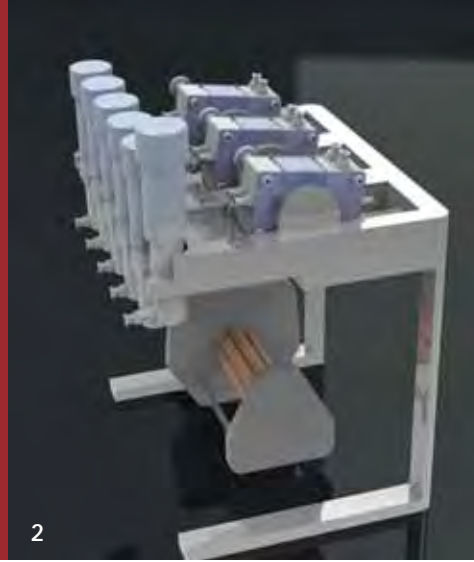
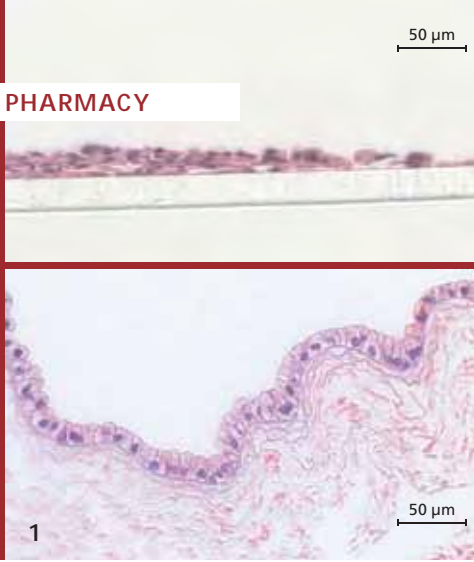
### Funding

We would like to thank the Fraunhofer-Gesellschaft for funding the project "SKIN HEAL", within the "Markets Beyond Tomorrow" program.

### Project partner

Fraunhofer ISC, Würzburg

- 1 Scanning electron microscope image of the particles loaded with dexpanthenol.
- 2 Scanning electron microscope image of the particles loaded with TGF- $\beta$ .
- 3 3D representation of the interaction of the significant parameters during statistical study planning.
- 4 Scanning electron microscope image of chitosan particles that were introduced into the fibers of the silica fiber wound dressing (source: Fraunhofer ISC).



## BIOARTIFICIAL PROXIMAL TUBULE DEVICE

Anke Hoppensack M.Sc., Dr.-Ing. Jan Hansmann

### Background and challenge

The kidney has several vitally important functions such as blood homeostasis, blood pressure regulation and the removal of endogenous and exogenous toxic waste products from the blood. Therefore, kidney failure can rapidly lead to severe, life-threatening clinical outcomes. Current standard therapies are dialysis and donor organ transplantation. However, a constant shortage of donor organs exists and dialysis still has several drawbacks [1]. For instance, the body loses valuable substances such as amino acids or glucose with the filtrate that is generated and subsequently withdrawn during dialysis. In the body, a structure which is called the renal proximal tubule recovers the majority of these molecules after endogenous filtration. The complexity of this functional unit cannot be mimicked by a technical device at the moment. Therefore, one strategy to improve dialysis is to include cellular components into an extracorporeal filter system [2].

Our project partner, *Advanced Technologies and Regenerative Medicine (ATRM), LLC*, a *Johnson & Johnson* company, established a source of highly proliferative and functional cells from human kidney tissue [3]. Our part of the project was to develop techniques for the kidney-specific culture of these human kidney-derived cells (hKDCs) and to enable their usage in a bioartificial proximal tubule device.

### Influence of culture substrate

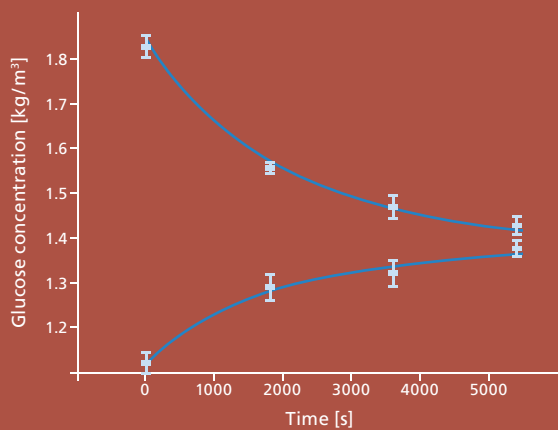
In a first approach, hKDCs were cultured on commercially available synthetic membranes under standard cell culture conditions. However, cells are exposed to a variety of biological and physical cues in vivo. These cell-specific conditions

guide cell differentiation and maintain cellular functionality. For the imitation of a natural microenvironment, biologically-derived scaffolds with a complex composition were used.

Cell culture experiments under static conditions revealed a strong influence of the used substrate on the cells. Human KDCs that were cultured on a synthetic membrane grew in an unphysiological multilayered formation and exhibited a flat morphology. In contrast, the biological matrix promoted the formation of a monolayered epithelium, which is characteristic for the proximal tubule (Fig. 1).

### Derivative of culture conditions and model for glucose transport

Culture conditions were derived from a finite element model of the proximal tubule. In a tailor-made compartmental bio-reactor system (Fig. 2), the cell-scaffold-constructs were cultured dynamically. A mathematical model for the concentration of glucose was developed to investigate the glucose mass transport activity of the hKDCs. The model incorporates passive and active transport (Figs. 3 and 4). Transport through a cell was differentiated into influx and efflux and the barrier of the substrate was considered. Furthermore, the glucose consumption by the cells was implemented. The model parameters for glucose diffusion, consumption and transport could be calculated on the basis of experimental data. Therefore, hKDCs were cultured at the interface between a donor and acceptor compartment and the glucose concentration was measured over time in both compartments. Finally, model validation was performed.



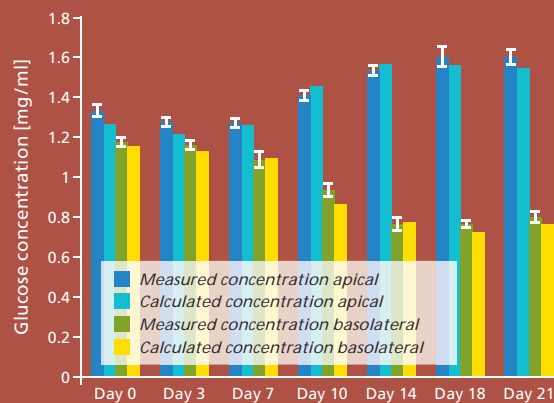
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The investigation of cell functionality showed that after 3 days in culture, hKDCs started to generate a glucose concentration gradient (Fig. 5). Even after impressed equilibration of the concentrations, hKDCs restored the initial concentration difference within 5–6 hours. hKDCs glucose transport functionality was tested over 3 weeks. The simulations demonstrated a high consistency in the measured values and calculated results. The mathematical model allowed deriving the magnitude of active glucose mass transport of hKDCs in culture. Furthermore, a first draft for a proximal tubule system could be developed

### Perspective

With the generated data, bioreactor and extracorporeal proximal tubule device design, crucial fundamentals for the development of novel bioartificial kidney assist devices were set. Employing standard filter technology, the generated filtrate could be fed into the bioartificial proximal tubule to recover molecules back into the patient's blood. In further studies, the system needs to be experimentally validated and further characterized to facilitate the translation of the results into a clinical system.

- 1 hKDCs cultured on a synthetic membrane (top) and on a biological matrix (bottom).
- 2 Bioreactor system for proximal tubule specific cell culture.
- 3 Mass transport pathways.
- 4 Parameter estimation.
- 5 Apical and basolateral glucose concentrations during hKDC culture.



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### Contacts



**Anke Hoppensack M.Sc.**

Phone +49 711 970-4073

anke.hoppensack@igb.fraunhofer.de



**Dr.-Ing. Jan Hansmann**

Phone +49 711 970-4084

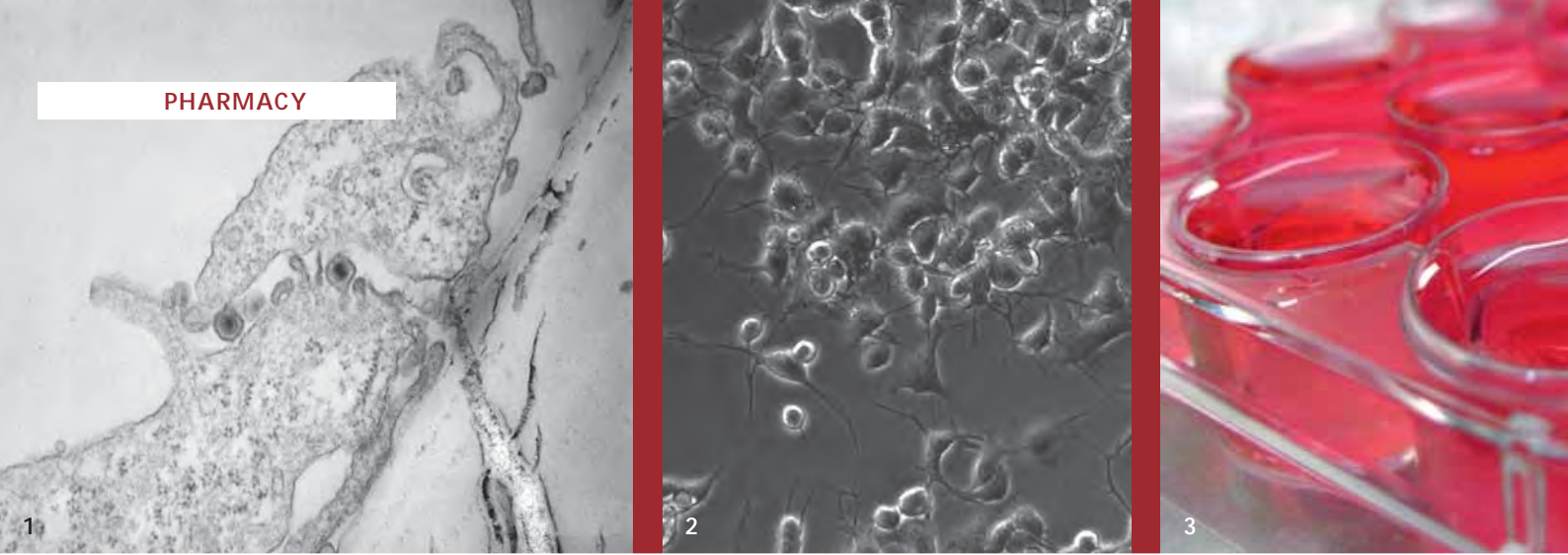
jan.hansmann@igb.fraunhofer.de

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### Project partner

The presented results were generated in cooperation of the Fraunhofer IGB together with the company *Advanced Technologies and Regenerative Medicine (ATRM), LLC, a Johnson & Johnson company*, Somerville, NJ, USA. Moreover, Jan Hansmann had the possibility to do research studies in the laboratories of the project partner. We thank ATRM for the support and cooperation in this project.



# TARGETED DRUG DELIVERY – RNA-MEDIATED TREATMENT OF HSV-1 INFECTIONS

Dipl.-Biol. (t. o.) Ina Hogk, Dr. rer. nat. Anke Burger-Kentischer

## Initial situation

Herpes simplex virus infections are among the most common skin diseases. More than 90 percent of the world's population is infected with Type 1 Herpes simplex (HSV-1). Aside from the characteristic skin lesions, HS viruses can also cause serious conditions involving other organs (ocular herpes), as well as the central nervous system (herpes encephalitis, herpes meningitis), which may prove fatal. Until now, there is still no effective treatment for herpes infections available. HSV infections have been exclusively treated with antivirals so far, mainly nucleoside analogues. These are merely able to alleviate the symptoms and to shorten the duration of the infection but cannot prevent reactivation of the virus. One aim is therefore to develop an alternative therapy approach for the treatment of HSV-1 infection.

## RNA interference-mediated therapy approach

RNA-based drugs represent a possible alternative to the antiviral drugs used to date. The use of RNA interference (RNAi) enables the targeted knockdown of individual genes, for example, those involved in the proliferation of HSV-1. For this purpose, small ribonucleic acid (RNA) molecules (siRNA or miRNA) are introduced into the cells, allowing the targeted inhibition of the key proteins decisive for viral reactivation, proliferation or replication, thereby achieving long-term inhibition of the outbreak of a latent herpes infection.

## Nanotechnology for targeted drug administration

One of the main problems in the application of the RNAi method is the targeted transport of the RNA molecules into the cells and the form of administration. RNA is a naturally unstable molecule, which is rapidly degraded by the body's

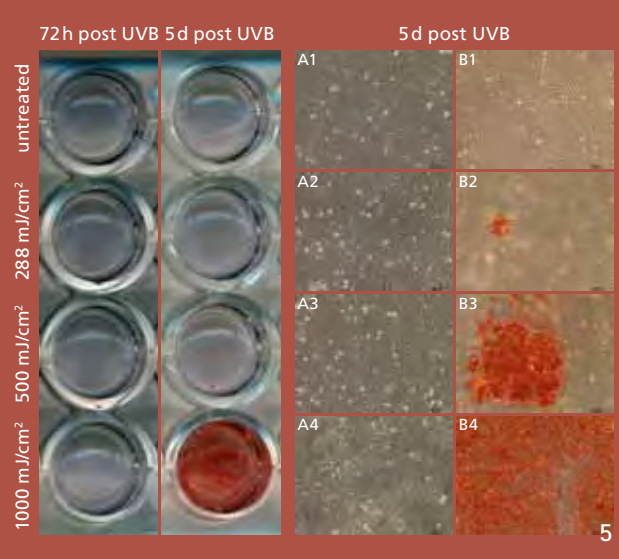
enzymes. Furthermore, the negative charge of RNA molecules results in an extremely limited membrane permeability. In order to overcome these problems and enable the use of RNA molecules as active agents in herpes treatment, we, in cooperation with the Hebrew University of Jerusalem, are developing a formulation of specific RNAs and a biodegradable polymer with nanometer-scale dimensions – also referred to as RNA nano-carrier system. Such a formulation can protect the non-membrane permeable, unstable RNA molecules against degradation from the immune system and enable their absorption through the skin. This targeted drug delivery is to be achieved by coupling the nanoparticles to viral envelope protein fragments or specific antibody fragments, which are targeted to a specific epitope of neural cells. Thus, the nanoparticles are specifically targeted to neural cells, which are potentially infected with HSV-1. Whereas, the coupling of viral envelope protein fragments to nanoparticles enables targeted delivery for all cell types.

## Competencies and technology

Complex, cell-based test systems have been developed at the Fraunhofer IGB for many years. This expertise will be employed to prove the effectiveness and compatibility of the oligonucleotide-based drug and its formulation. The Activity-Selectivity (AS) assay allows the effectiveness and simultaneously the compatibility of the RNA nano-carrier formulation to be examined [1]. Accompanying examinations of the immunomodulatory effects of the carrier are performed with the cell-based pyrogen assay developed and patented at the IGB [2]. Cell or membrane permeability, as well as continuing efficacy studies of the nano-carriers loaded with specific miRNA are carried out in an established co-culture system.



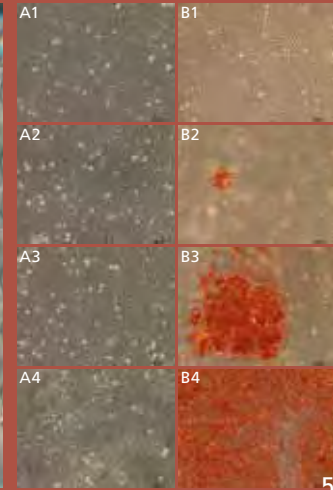
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untreated  
1000 mJ/cm<sup>2</sup>  
500 mJ/cm<sup>2</sup>  
288 mJ/cm<sup>2</sup>

72h post UVB 5d post UVB

5 d post UVB



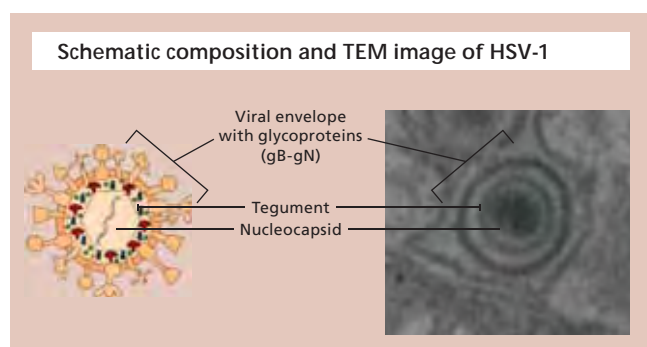
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The equally patented in-vitro HSV-1 infection model can subsequently be used to examine the skin permeability, targeted transport and specific inhibition of viral reactivation by the RNA nano-carriers in a complex test system [3, 4].

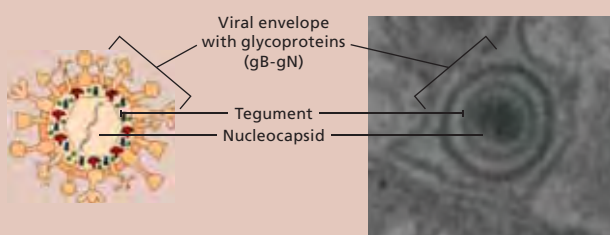
### Outlook

The use of RNAi technology is intended to achieve a targeted preferably long-term prevention of HSV-1 outbreaks and thereby significantly reduce the suffering of many affected patients. It is likely that this new technology can also be adapted for other virus infections and therefore present great potential in antiviral therapy.

- 1 TEM image of a cell infected with HSV-1 on a co-culture carrier.
- 2 Neural cell line (PC12).
- 3 Cultivation of the HSV-1 infection model.
- 4 Composition of the co-culture test system.
- 5 Reactivation of HSV-1 in the co-culture test system.



Schematic composition and TEM image of HSV-1



### Contacts



**Dipl.-Biol. (t. o.) Ina Hogk**  
Phone +49 711 970-4036  
ina.hogk@igb.fraunhofer.de



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

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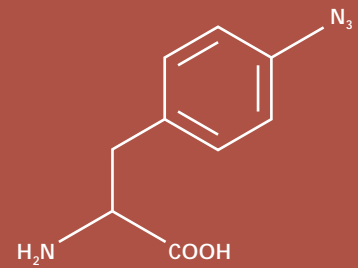
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### Funding

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### Project partner

Hebrew University of Jerusalem, Institute for Drug Research (IDR), Jerusalem, Israel



## SYNTHETIC PROTEINS IN HUMAN PATHOGENIC YEASTS

Dipl.-Biol. Silke Palzer, Dr. rer. nat. Kai Sohn

### Virulence factors determine pathogenicity

The numbers of infectious diseases caused by human pathogenic yeasts have been continuously increasing over recent years. Their high morbidity and mortality have turned them into a serious public health problem. An efficient treatment is particularly complicated by systemic mycoses, which spread throughout the whole body, or emerging resistance to antibiotics. The most prevalent causative of systemic mycoses in humans is the pathogenic yeast *Candida albicans*, which can elicit severe infections if the immune system of its host is suppressed by, for example, operations, chemotherapy or diseases. *Candida albicans* features a multitude of mechanisms which lead to pathogenicity. These mechanisms are mediated by virulence factors, proteins with various functions in the cell. Virulence factors are essential for pathogenicity and therefore appear to be a promising target for the development of therapeutics. However, this requires profound knowledge of the molecular characteristics and physiological interaction networks of cell proteins. As techniques to study protein interaction networks in vivo are scarce, especially for *C. albicans*, scientists at the Fraunhofer IGB developed a new method to analyze protein-protein interactions with artificial amino acids.

### Analysis of protein-protein interactions with synthetic proteins

The protein of interest is modified in only one building block, which is one amino acid that is replaced by an artificial amino acid. This artificial amino acid confers new physicochemical properties to the protein of interest. Artificial amino acids belong to the scientific area of synthetic biology and there are currently over 300 artificial amino acids available. These synthetic amino acids offer scientists a variety of applications for proteins, for example, to facilitate analyses or add entirely new properties. The artificial amino acid *p*-azidophenylalanine (Fig. 2), a derivative of the natural amino acid phenylalanine, is particularly suitable for the study of molecular interactions. The azido-group does not occur naturally in proteins and can be activated by UV light to form a stable covalent bond with molecules in close vicinity. If the modified, synthetic protein interacts with another protein in the cell, the interaction can be captured by UV photo crosslinking under physiological conditions and is stable for further purification or identification of the interacting partner.

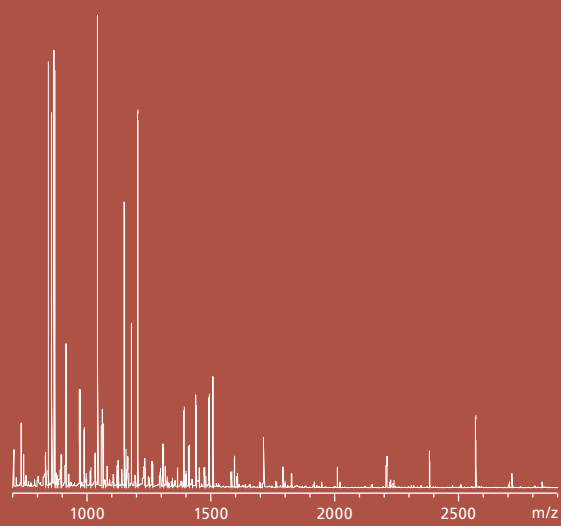
### An expanded genetic code

In order to conduct in vivo interaction studies, the synthetic amino acid must be incorporated into proteins. A synthetic biology method, the so-called expanded genetic code, can be used to achieve this. The artificial amino acid is incorporated during cellular protein synthesis specifically and with unrivalled efficiency into the protein of interest, at the desired position, mediated by special biomolecules, tRNAs and tRNA synthetases.





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### Successful position-specific incorporation into *C. albicans* virulence factors

After extensive basic research at the Fraunhofer IGB, we were able to successfully apply the expanded genetic code methodology to the human pathogenic yeast *Candida albicans*. The necessary tRNA and tRNA synthetases were specifically modeled for the incorporation of artificial amino acids in *C. albicans*. Moreover, we were not only able to demonstrate the general applicability of the method with a model protein, but also with the central virulence factor Tup1 (Fig. 3). Therefore, the position-specific incorporation of an artificial amino acid into a eukaryotic pathogen has been achieved for the first time. Furthermore, we could for the first time characterize a physiological interaction of the virulence factor Tup1 by means of the synthetic label. The thus modified *C. albicans* strains can now be applied to extensive interaction studies, such as in virulence factors. The investigation of host-pathogen interactions is also possible.

The system developed here is additionally suitable for protein-DNA or protein-metabolite interactions. After having demonstrated its general applicability, it is likewise conceivable to expand the genetic code of *Candida albicans* with other artificial amino acids and thereby further extend the range of molecular tools for the investigation of virulence mechanisms.

#### Contacts



**Dipl.-Biol. Silke Palzer**  
Phone +49 711 970-4079  
silke.palzer@igb.fraunhofer.de



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

#### Funding

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- 1 Hyphal morphology of *Candida albicans*.
- 2 The artificial amino acid *p*-azidophenylalanine.
- 3 Crystal structure of interacting Tup1 domains.
- 4 Identification of interacting proteins by mass spectrometry.



# CHEMISTRY

Dr. Christian Oehr

The chemical industry is one of the most important and research-intensive economic sectors in Germany. Many innovations in other sectors such as the automotive, electrical and electronic, construction and packaging industries would not be possible without the contribution of chemistry. The chemical industry is characterized by its resource- and energy-intensive processes. Dependence on imports of raw materials, the limited availability of fossil resources worldwide – including competition for their energetic utilization – and the necessity of considering the effects on both climate and the environment mean that our work, too, is concentrated on approaches focusing on more efficient utilization of fossil resources, or their substitution:

## Use of renewable resources

Our activities are aimed at developing biotechnological processes to manufacture chemicals and energy carriers from renewable raw materials and coupling these with chemical processes.

## Process intensification for a more efficient utilization of energy and resources

The focus here is on developments in the field of upstream and downstream processing, with effective separation of material flows by means of membranes or through the recirculation of material flows (recycling, sustainable waste management).

## Decoupling of volume and surface properties by means of interfacial process engineering

Tailored coatings which are themselves geared towards resource-efficient process engineering create new possibilities as to the choice of base materials for workpieces and thus for new products based on a selection of sustainable resources.

## Evaluation and substitution of critical substances

Chemical substances, insofar as they are represented in the market on a large scale, are systematically investigated with regard to their risk potential, in accordance with EU regulations.

The diversity of our research and development work shows how we are tackling the challenges of these new approaches. This may involve cooperation with other institutes of the Fraunhofer Group for Materials and Components – MATERIALS, or with the Fraunhofer Nanotechnology, Photocatalysis, Polymer Surfaces POLO<sup>®</sup>, and Cleaning Technology Alliances. New impulses for transferring the material utilization of renewable resources to industrial scale will also be given by the Fraunhofer Center for Chemical-Biotechnological Processes in Leuna, which is being jointly operated by the Fraunhofer IGB and ICT institutes.



# ANTIMICROBIAL SURFACES BY THE APPLICATION OF NATURAL ACTIVE SUBSTANCES

Dr. rer. nat. Michaela Müller, Dipl.-Ing. Christina Weber

## Undesirable biofilms

Bacteria and fungi preferably live in biofilms. These consist of cooperatively acting microorganisms surrounded by a self-produced layer of slime, to protect from external attacks. They are omnipresent at natural and technical boundaries in humid or wet environments. Biofilms in the wrong place or those containing pathogenic organisms can represent a health hazard, cause damage to materials, or greatly increase the energy demand in plant operation (Fig. 1). This is why biocides are used in many areas. Their approval and application is controlled by a series of laws, ordinances and European regulations. With increasing statutory restrictions for their use comes an increase in the need for biocide-free antimicrobially active equipment for technical surfaces. At the Fraunhofer IGB, materials scientists, micro, molecular and cell biologists work together, across divisions, to develop suitable systems.

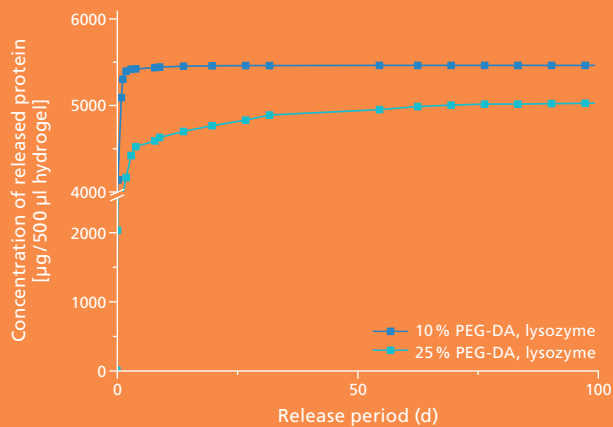
## Layer systems for antimicrobial combinations

In order to prevent biofilms we examine the effects of naturally occurring, antimicrobially active compounds such as plant extracts, cationic peptides and enzymes. Because technical application requires that active agents can be applied in a suitable form, we are developing layer systems for longer-term and targeted release and, particularly in the case of biomolecules, for the long-term maintenance of their function. The type of application of the active agents depends on the form and geometry of the surface and the agent to be immobilized.

## Immobilization in a polymer matrix

One option for the immobilization of active biomolecules is to embed them into a polymer matrix applied as a coating to a component. It releases the active agent over a determined period of time. We created active layers using lysozyme, DNase and LL-37. Lysozymes are innate immune system enzymes and damage the bacterial cell wall. The human antimicrobial peptide LL-37 is also produced by the immune system and destroys the cell walls of numerous Gram-positive and Gram-negative bacteria. It is also very resistant to proteolysis. The enzyme DNase cleaves DNA. As a great proportion of biofilms consists of the liberated DNA of dead microorganisms, DNase is able to reduce the biofilm.

The polymer matrix was constructed from short-chain poly(ethylene glycol) diacrylates by UV polymerization. This was done placing the active agent and additives into the aqueous polymer solution, applying it to the desired surface and curing for 3 seconds (Fig. 2). The UV light crosslinks the polymer chains and the active agent is thereby embedded into the hydrogel. We showed that the curing time used was sufficient for the formation of crosslinking and that the biomolecule is not significantly altered in its secondary structure or activity.



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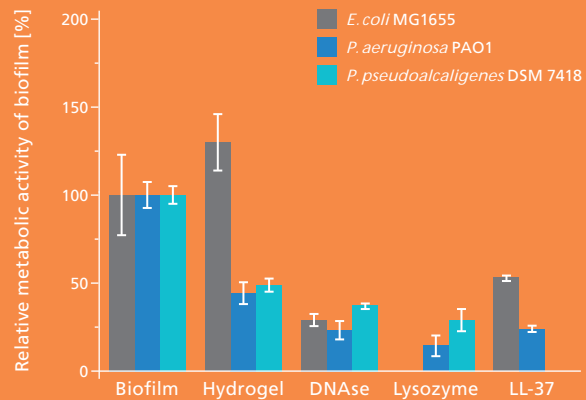
### Control of release and antimicrobial action

The release characteristics were studied at room temperature and in a phosphate-buffered saline solution, which was regularly changed. Fig. 3 shows the quantity of lysozyme released over 100 days, depending on the network density. The largest amount is released within the first days but output was still detected after even 100 days. At this point, 50 percent of the total lysozyme applied had been released. The release itself can be adjusted via the prepared network density.

The systems described were investigated for their antimicrobial, bacteriostatic action with *E. coli*, *P. aeruginosa* and *P. pseudoalcaligenes*. Their effect was examined in planktonic and biofilm cells. Fig. 4 shows the statistically significant reduction in the metabolic activity of the microorganisms studied, in comparison to the reference biofilm, by the prepared systems. A statistically significant reduction in the planktonic cell count was also achieved for hydrogels with lysozyme and LL-37.

### Outlook

We were able to show that natural antimicrobial agents can be embedded in deposit layers, while retaining their function and their release can be controlled through the design of this layer. The prepared systems had an antimicrobial action in the microorganisms studied. Natural antimicrobial materials usually have a narrow spectrum of action, so technical applications may require combinations of agents for the prevention of the undesirable microorganisms present. The deposit layer must thereby be matched to the agent to be released in each case.



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### Contacts



**Dr. Michaela Müller**

Phone +49 711 970-4140

michaela.mueller@igb.fraunhofer.de



**Dr. Iris Trick**

Phone +49 711 970-4217

iris.trick@igb.fraunhofer.de

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- 1 *Water filter clogged with biofilm.*
- 2 *Coating of a hydrogel containing an antimicrobial agent to the surface of a material.*
- 3 *Release characteristics of an active agent from a hydrogel.*
- 4 *Reduction of the biofilm by hydrogel loaded with active agent.*



## FUNCTIONAL POLYMER FOAMS

Dr. rer. nat. Michaela Müller

### Potential applications

Open-pored polymer foams are interesting materials for numerous applications, especially as adsorber materials for separation or accumulation, as carriers for chemo- or biocatalysis, as well as three-dimensional carriers for mammalian cells or microorganisms. Conductive foams, formed by suitable additives, are even suitable as materials for electrodes for biofuel cells. For the named applications the inner surface of the pores must generally be equipped with functional groups or molecules. Depending on the pore structure and type of the polymer used for the foam, this is currently impossible or extremely difficult.

### New single-stage production

We have developed a single-stage synthesis strategy for the simple production of macroporous polymer foams with functional groups that can easily be implemented using the so-called click reaction.

An emulsion polymerization process (high internal phase emulsion) was used to produce a crosslinked polymer foam with azide functions for this. The organic phase contains the monomer, the crosslinker and a surfactant. The aqueous phase, which is placed into a reaction vessel together with the organic phase, contains the initiator for the radical polymerization (Fig. 3).

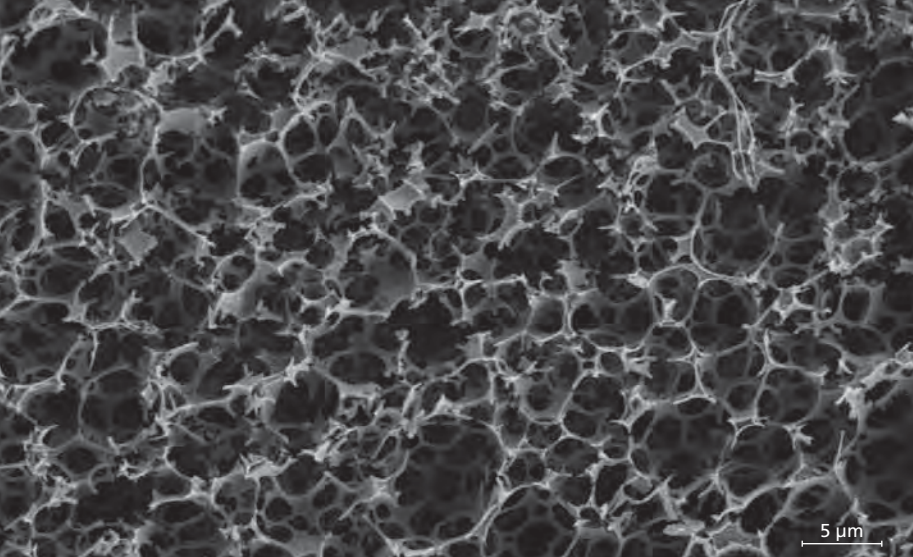
### Foam with functional pores

The end material shown as an example in Fig. 1 has a porosity of approx. 90 percent. The scanning electron microscope image in Fig. 2 shows the structure with open macropores in the range of approx. 5–10  $\mu\text{m}$  and micropores below 1  $\mu\text{m}$ .

Azide functions react with alkyne functions (click reaction) under very mild conditions, such as biomolecules require for example, and without side reactions. We were able to show the binding of small molecules and polymers at the inner surface of the synthesized foam using an azide-alkyne cycloaddition (Fig. 4) in the examples of propargyl alcohol (Fig. 4A) and propargyl-poly(methyl methacrylate) (Fig. 4B).

### Biocompatibility/biofunctionality

In order for the material to be used as a cell carrier its biocompatibility is a necessary prerequisite. Initial tests with human skin cells on the PMMA-modified foams showed, after incubation for 24 hours, improved cell adhesion in comparison to unmodified foam. Live/dead staining of the human cells that had been cultured at the surface for 24 hours, showed a high number of living cells.



### Outlook

In the technology developed here, in contrast to conventional polymer foams, not the finished polymer is foamed. The material therefore has all the advantages of a synthetically producible polymer. The material's crosslinked structure makes it resistant to organic solvents. Furthermore, the freedom of choice of chemical components enables targeted setting of the desired properties, such as e.g. hydrophilic properties or elasticity.

Now that the production of easily modified polymer foams with ideal porosity in a single-stage synthesis has been shown, the macroporous material should continue to be developed so that it can be applied for colonization with microbial cells for material enrichment.

### Contacts



**Dr. Michaela Müller**

Phone +49 711 970-4140

michaela.mueller@igb.fraunhofer.de



**Dr. Christian Oehr**

Phone +49 711 970-4137

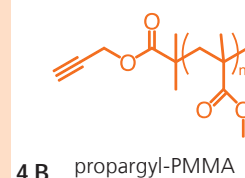
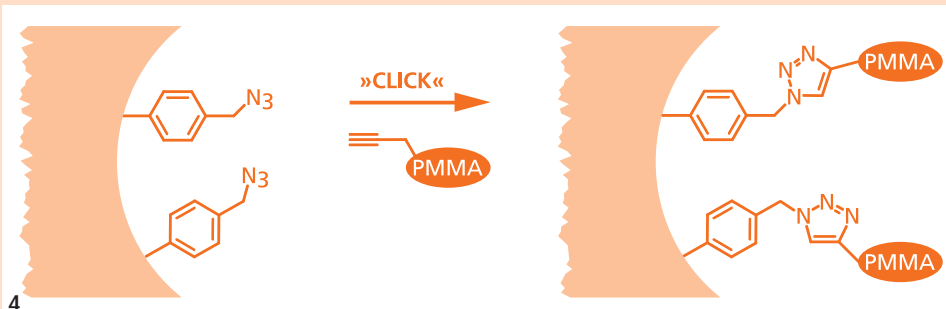
christian.oehr@igb.fraunhofer.de

### Funding

We would like to thank the Fraunhofer-Gesellschaft for funding the project "Bakterien hinter Gittern zur Rückgewinnung von Phosphor" within the Fraunhofer "Netzwerk" symposium 2011.

- 1 Manufactured functional polymer foam.
- 2 Scanning electron microscope image of the manufactured foam.
- 3 Single-stage synthesis of the foam using an emulsion polymerization process.

### Click reaction of the functional foam with propargyl-PMMA





## EXTRACTING RUBBER, LATEX AND INULIN FROM DANDELION ROOTS

Dipl.-Chem. Thomas Hahn, Dipl.-Biol. (t. o.) Dipl.-Ing. (FH) Susanne Zibek

Rubber is a polymer used in a wide variety of everyday applications, including balls, household gloves, gaskets and car tires. This is reflected in the high global demand for rubber. In 2012, according to estimations 27.6 million metric tons [1] were used, two thirds of which were required for the production of car tires alone. Natural rubber, which consists of isoprene units, can only be substituted to a limited extent by synthetic rubber, polyisoprene, due to differing properties of the natural product if compared to chemically produced polymers. The natural polymer is therefore present in over 40,000 products including 400 medical products [2].

### Natural rubber from the Russian dandelion (*Taraxacum koksaghyz*)

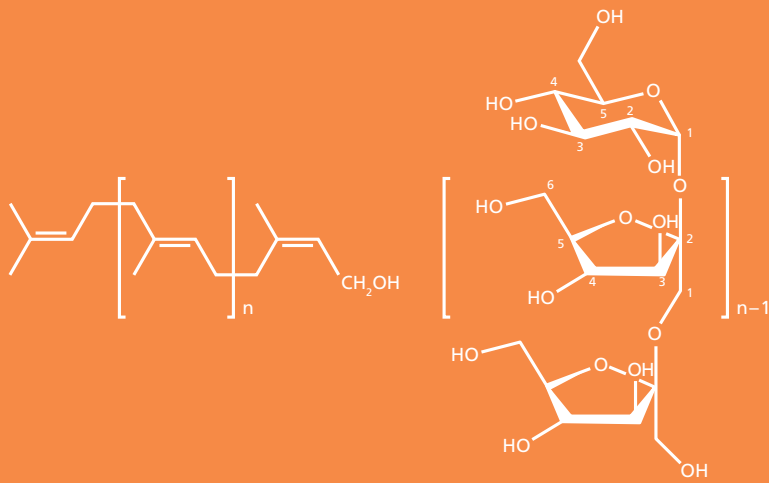
To date, rubber has been identified in approximately 2500 plants, but only one is used for commercial production purposes. This is *Hevea brasiliensis*, the rubber tree [3]. However, stocks of this tree are under threat from South American leaf blight. In addition, the milk-like sap of the rubber tree, the latex, contains not only rubber but also proteins which cause allergies in some people. As an alternative to *Hevea brasiliensis*, as early as at the beginning of the 20th century a possibility emerged to isolate rubber from a natural resource in the northern hemisphere: This alternative is the Russian dandelion (*Taraxacum koksaghyz*). *Taraxacum koksaghyz* is a robust plant that can also be grown on marginal soils. The rubber content in the latex of the Russian dandelion is, on average, close to 30 percent [3]. The content of latex in the root is about 4 percent of the dryweight according to our analyses.

### Extracting and processing the natural rubber

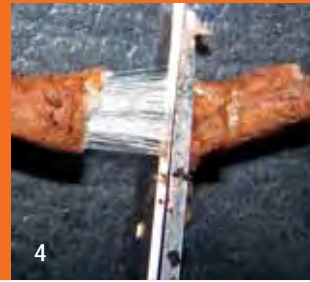
The rubber can be extracted directly as a chewing-gum-like substance from dried or fresh dandelion roots and separated from the biomass. To do this, a sequence of process engineering steps are used. This includes processes such as steam treatment, grinding, floating and sieving [4]. The Fraunhofer IGB is currently refining the methods which have been known for 60 years already and looking for cost-effective alternatives for industrial implementation.

On the other hand, latex can, either through exposure to acid or through evaporation of the water and the vulcanization process, agglomerate and subsequently coagulate and thus be obtained from the liquid latex. Approximately 90 percent of the latex is converted into rubber used e.g. for tires whilst the remaining 10 percent is processed into commercial latex products such as condoms or gloves which are more elastic [5]. In order to prevent the premature coagulation of the rubber molecules and retain the plasticity, the latex milk of *Hevea brasiliensis* is mixed with stabilizing agents and antioxidants immediately after extraction. The Fraunhofer IGB is comparing various extraction methods and a variety of additives that enables the prevention of agglomeration, which is the stage before coagulation also in Russian dandelion latex extracts. Using new combinations of additives, it is now possible to stabilize the latex solutions for at least 3 months. Currently, latices with a rubber content of up to 15 percent can be produced. The next step is the scale-up of the purification steps performed from a laboratory to an industrial scale.





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### Added value through the extraction of inulin

From an economic perspective the extraction of latex and rubber from *Taraxacum koksaghyz* is in itself already promising. Generation of further added value in ecological and economic terms is offered by the extraction of the sugar inulin, which is also present in the dandelion roots. Inulin is an oligo- or polysaccharide consisting predominantly of  $\beta$ -(2-1)-linked fructose and one  $\alpha$ -D-glucose molecule at the non-reducing end. It is used as a substitute for sugar and fat, as soluble fiber, and as a carrier and stabilizing agent in the pharmaceutical industry [6].

Hot-water extractions under optimized conditions have already been performed at the Fraunhofer IGB in batch operations and in a continuous process. It was possible to isolate up to 36 percent of the inulin from the root, prior to rubber extraction. The conversion of the extracted inulin with microorganisms in fermentative processes will be tested in the near future.

Pre-extraction of the inulin prior to rubber isolation has a number of advantages. For example, any contaminating substance that may be present can be separated off together with the inulin, thereby simplifying the subsequent rubber purification process. In addition, the hot-water extraction results in coagulation of the rubber molecules, which simplifies the purification: the roots become softer and this ultimately may substitute the steam treatment.

- 1 Cultivation of Russian dandelion on the roof of the Fraunhofer IGB.
- 2 Latex flow after injuring the dandelion root.
- 3 Chemical formula of inulin and poly-(cis)-1,4-isoprene.
- 4 Top left: latex flow; right: Russian dandelion; bottom left: rubber.

### Contacts



**Dipl.-Biol. (t. o.) Dipl.-Ing. (FH)  
Susanne Zibek**  
Phone +49 711 970-4167  
susanne.zibek@igb.fraunhofer.de



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

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### Project partners

AESKULAP GmbH, Steinach | Continental Reifen Deutschland GmbH, Hanover | Südzucker AG, Mannheim | Synthomer Deutschland GmbH, Marl | Julius Kühn-Institut, Quedlinburg | Fraunhofer IME, Münster | numares GROUP, Regensburg | IGVP, University of Stuttgart | Max Planck Institute for Plant Breeding Research, Cologne

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# CHIBIO – CHITIN FROM FISHERY WASTE AS A RAW MATERIAL FOR THE PRODUCTION OF SPECIALTY CHEMICALS

Dr. rer. nat. Lars O. Wiemann, Prof. Dr. rer. nat. Volker Sieber

## Initial situation and project aim

The processing of prawns, crabs and shrimps results in the accumulation of large quantities of shell waste that contains chitin. Every year over six million metric tons of these crustacean shells land in the waste, with an estimated several hundred thousand tons of these being within the EU alone [1]. A use has already been found for a small part of this biogenic resource and in Asia, for example, it is utilized for the production of chitosan for the use in biomedical applications or as a food additive [2]. Because of the higher proportions of calcium carbonate, the utilization of European shells is less economical and not very common. Nevertheless, proper disposal of the shell waste – material which poses a contamination risk – is complex and costly owing to EU and country-specific regulations.

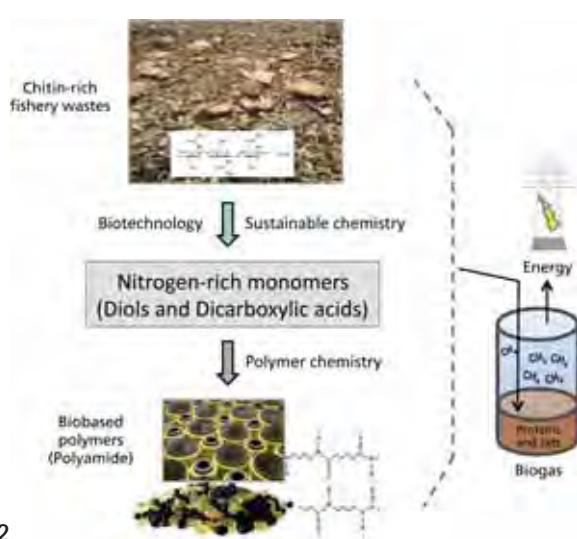
In the EU-funded ChiBio project, an international team of researchers under the direction of the Fraunhofer BioCat project group in Straubing is working on new processes for developing the shell waste accumulating in the EU as a raw material's source for specialty chemicals. ChiBio is adopting the approach of a biorefinery in order to use the biogenic waste material in a holistic way, in other words materially and energetically.

## Stabilization of the shells and mobilization of chitin

In a first process step, methods are being developed to pre-treat and stabilize the waste shells thereby making them storage-stable and transportable. A further important process step is the mobilization of chitin, an N-containing biopolymer. ChiBio, under the direction of the Letterkenny Institute of Technology, is developing process solutions for mild (benign) mobilization of the chitin, protein and lipid fractions using sustainable chemical, microbiological and enzymatic methods.

## Enzymatic cleavage of chitin

A further fundamental process step is the cleavage of the chitin or of the chitosan obtained through deacetylation into its monomeric sugar units N-acetylglucosamine and glucosamine, respectively. Chemo-catalytic methods used in this context are not particularly sustainable. ChiBio is therefore developing biocatalytic digestion methods and for this purpose is using chitin-degrading enzymes from prokaryotic and eukaryotic organisms such as strains of *Trichoderma*, *Aspergillus*, *Bacillus* and *Aeromonas*. Of particular use here is the expertise of our Norwegian partner Prof. Dr. Vincent Eijsink (UMB) in dealing with enzymes from the CBM33 family. These enzymes significantly increase the rates of chitin degradation [3], but in some cases still need to be optimized. This work is being complemented by our own chitinases and also chitin-deacetylases at the Fraunhofer IGB in Stuttgart [4]. Intensive work is currently underway to match the enzyme cocktails in the best way possible and to adapt them to industrial process conditions and/or production methods on an industrial scale.



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### Conversion of glucosamine into N-containing polymers

The degradation products of chitin/chitosan (hydrolysates and monomers) serve as substrates for biotechnology processes for the production of N-containing functional monomers for the polymer industry. N-containing compounds for the production of polyamides and isocyanates are of particular interest for the polymer industry and so far it has not been possible to produce them on the basis of renewable raw materials. ChiBio is taking two different routes here: the Industrial Biocatalysis Working Group at the Technische Universität München under the direction of Prof. Dr. Thomas Brück is developing optimized yeast strains in order to convert the chitin hydrolysates or glucosamine through fermentation into functionalized fats/fatty acids and the corresponding aminocarboxylic acids. In parallel, the BioCat project group is using cell-free biotechnology methods in a multi-enzyme process to produce functionalized heterocycles from glucosamine. A large proportion of the required enzymes is now available recombinantly and is currently being optimized using enzyme engineering methods. The purified products from both routes are then used directly in the polymer industry as bifunctional monomers.

### Additional work

Work on efficient purification methods is being carried out by the ChiBio partners Clariant and the Fraunhofer ICT. Polymerization trials, together with characterization of the polymer properties, are being carried out at the laboratories of Evonik Industries AG. Biological by-products that accumulate, such as proteins and lipids, are being tested for their suitability as substrates for biogas generation.

1 *Crustacean shells accumulate in large quantities as waste.*

2 *Process chain in the ChiBio project.*

### Contacts



**Dr. Lars O. Wiemann**

Phone +49 9421 187-353

[lars.wiemann@igb.fraunhofer.de](mailto:lars.wiemann@igb.fraunhofer.de)



**Prof. Dr. Volker Sieber**

Phone +49 9421 187-300

[volker.sieber@igb.fraunhofer.de](mailto:volker.sieber@igb.fraunhofer.de)

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### Funding

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### Project partners and further information

[www.chibiofp7.eu](http://www.chibiofp7.eu)



## BIOSURF – NEW PRODUCTION PROCESSES FOR BIOSURFACTANTS

Priv.-Doz. Dr. Steffen Rupp

### Biosurfactants – surface-active compounds from microorganisms

Surfactants are an integral part of our daily life that can be found in applications spanning from washing and cleaning agents to additives in food production as well as in oil production. Every year about 18 million metric tons of surfactants are manufactured mainly chemically and on the basis of mineral oil. A quarter of it is meanwhile being produced from oils of renewable resources, usually from coconut and palm kernel oil.

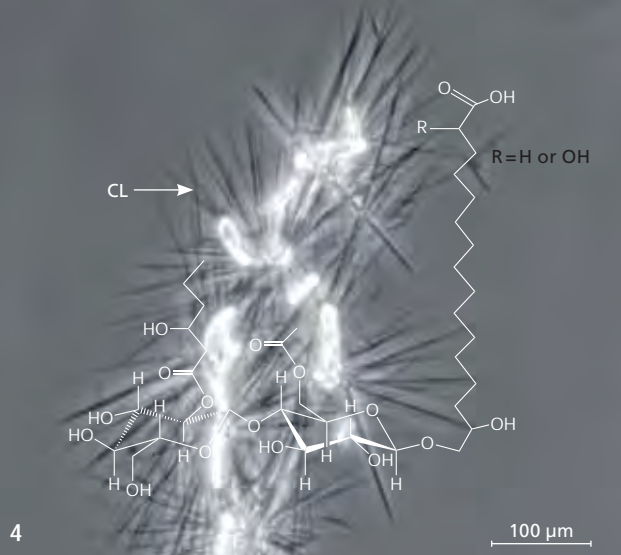
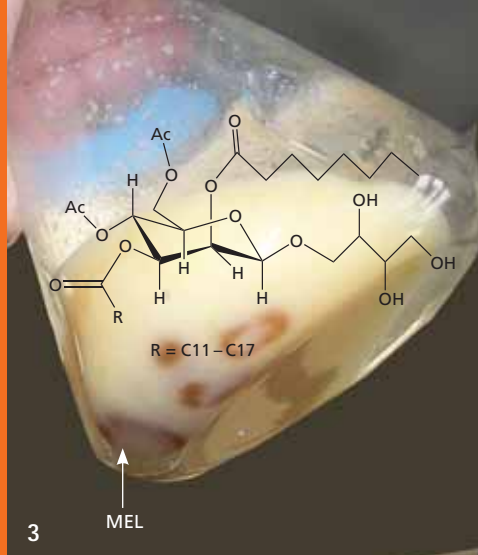
Microorganisms also produce surface-active compounds, also called biosurfactants. Only a few of these biosurfactants are already produced industrially as their manufacture is comparatively costly. In the BioSurf Project funded by the BMBF via the “ERA-NET Industrial Biotechnology” program, the Fraunhofer IGB coordinates a consortium of seven partners who drive the development of new cost-efficient processes for the microbial and enzymatic manufacture of biosurfactants. In this project both new enzymes for the biotechnological synthesis of surfactants are developed and microorganisms are selected, particularly fungi of the *Pseudozyma* species, and optimized using molecular biological methods. The aim is to optimize the properties of the surfactants and to improve the efficiency of their production.

### Optimized fermentation for glycolipids

Within the Fraunhofer IGB we focus particularly on the development of new fermentation processes for the production of mannosylerythritol lipids (MEL) and cellobiose lipids (CL) from the *Pseudozyma* species. Furthermore, the optimization of glycolipids following the fermentation process is also tested, with the aid of enzymes, for example. Important parameters for the fermentation process are optimized growth conditions and a high product formation rate. The aim is also to create the desired product composition by keeping contamination and the production of by-products as low as possible. Here we are trying to optimize the product range of the microorganisms and the fermentation conditions, also through metabolic engineering. A further challenge is the economical purification of the compounds in the fermentation broth. Many surfactants also create foams; a fact that may impair the fermentation process and which thus needs to be controlled.

### Benefits of biosurfactants

In comparison to conventionally manufactured surfactants made from mineral oil biosurfactants possess only little toxicity, are biocompatible and biodegradable as well as often possessing better surfactant characteristics. They can also show a more complex structure and possess a broader scope. Many biosurfactants have an antimicrobial effect, which makes them an interesting component for skin cleansing products. Some biosurfactants have excellent foam-forming and dirt-binding properties which render them ideal for applications in shower gels, shampoos and washing-up liquids. For the pharmaceutical industry biosurfactants are interesting due to their bioactive effect on human cells.



### Biosurfactant variants for application tests

Depending on the microorganism the MEL and CL produced come in different variants. In order to be able to evaluate as many of these variants as possible, 11 strains have been tested to date as to their product range. Currently we are producing sample substances of MEL and CL at a small scale for application tests within the consortium. Product concentrations for MELs reached up to 100g/L and for CL up to 33 g/L.

### Enzymatic optimization and metabolic engineering

For the creation of further surfactant variants a MEL blend generated from *P. aphidis* was deacetylated using a lipase. The product generated was tested as to its surfactant effect. Various structural variants with modified surfactant properties were also produced from cellobiose lipids. By carrying out genome-wide studies on a particularly efficient MEL producer using Next Generation Sequencing, we were able to identify the genes required for MEL biosynthesis. These data will now serve as a blue print for the metabolic engineering of the strain with the aim of obtaining MEL variants with tailor-made properties.

Future work will focus on the scale-up of the fermentation process to a cubic meter scale and the relevant downstream processes.

- 1 *Some biosurfactants are good foaming agents.*
- 2 *Fermentative synthesis of cellobiose lipids in the 1-liter bioreactor.*
- 3 *At high product concentrations, mannosylerythritol lipids (MEL) are deposited as oily pearls.*
- 4 *Cellobiose lipids (CL) as needle-shaped crystals.*

### Contacts



**Dipl.-Biol. (t. o.) Dipl.-Ing. (FH)  
Susanne Zibek**

Phone +49 711 970-4167  
susanne.zibek@igb.fraunhofer.de



**Priv.-Doz. Dr. Steffen Rupp**

Phone +49 711 970-4045  
steffen.rupp@igb.fraunhofer.de

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### Funding

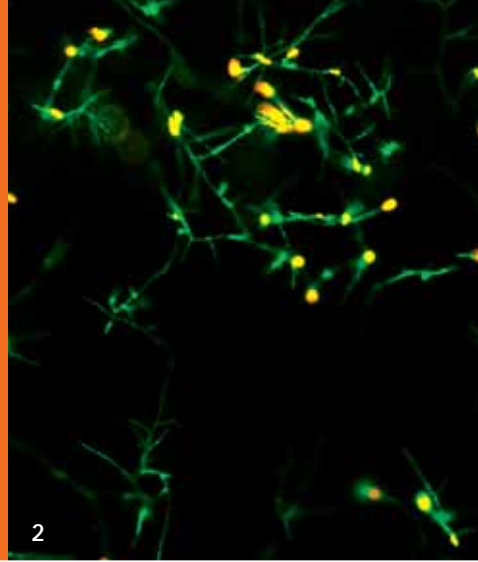
We would like to thank the German Federal Ministry of Education and Research (BMBF) for funding the project "BioSurf – Novel production strategies for biosurfactants" via the ERA-NET Industrial Biotechnology 2<sup>nd</sup> Joint Call (ERA-IB), promotional reference 0315928A, ERA-IB10.039.

### Project partners

Karlsruher Institut für Technologie KIT, Karlsruhe | c-LEcta GmbH, Leipzig | Flemish Institute for Technological Research, Mol, Belgium | Tormans Engineering Noord BVBA, Geel, Belgium | Ecover Belgium NV, Malle, Belgium | LISBP, Toulouse, France

### Further information

www.biosurf.de



# A MODEL-BASED PROCESS DEVELOPMENT AND THE OPTIMIZATION OF BIOPROCESSES

Dipl.-Ing. Tino Elter, Dipl.-Ing. Matthias Stier, Thilo Haitz M.Sc.

## Initial situation

The aim of our work in the field of industrial biotechnology is to analyze and describe bioprocesses in as much detail as possible by means of modern measurement engineering and mathematical modeling. This facilitates the efficient optimization of processes and their transfer from laboratory to production scale as changes to processes can be calculated in advance on the computer. This way only promising approaches will be validated experimentally. This approach saves development time and costs whilst increasing the understanding of the process. Additionally, software sensors provide further potential for cost savings. In this offline process parameters such as biomass and product concentration are estimated on the basis of online readings such as the pH value, exhaust gas data and consumption of acid and base, which considerably simplifies the monitoring of the process and reduces the necessity of sampling.

## Approach

The basic condition for the scale-up is a test system that comes as close as possible to the production plant in design and geometry. For this reason we mainly work with mini bioreactors. Designed as multi-fermentation systems they permit the parallel screening of different strains and conditions. Through the selection of suitable systems for online measurement and control, it is possible to maintain critical parameters constant and to generate a data base for a mathematical description of the production process. In this regard we succeeded in establishing a real-time measurement of volatile components in a medium with an online mass spectrometer developed by the Fraunhofer ICT. We also possess offline process analytics to promptly determine substrate and product

concentrations. Based on this data, a mathematical model describing the behavior of different production strains can be designed. This covers the establishment of software sensors, hybrid models up to a first-principles description of the entire fermentation process.

## Screening of microorganisms

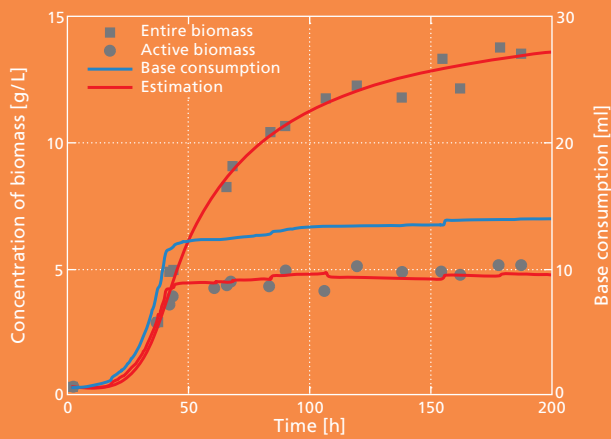
The selection of a suitable production strain is a key component of the development of bioprocesses such as the generation of ethanol from lignocellulose. It has been possible to successfully characterize different ethanol producers by using the multi-fermentation systems (Fig. 1). Important parameters in this were the ethanol productivity and yield, the product selectivity and the inhibitor tolerance of the individual microorganisms.

## Process observations through online measurement

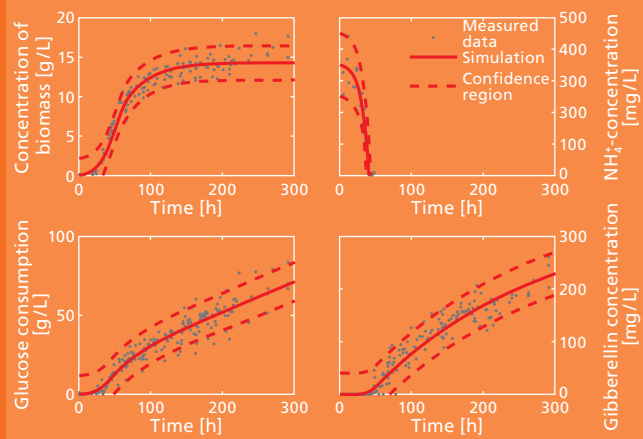
We have already applied the online mass spectrometer to observe enzyme catalysis in aqueous solution by measuring the concentration of several substances simultaneously. This way it has been possible to monitor reaction processes whose sensitivity is in the lower ppm region. Currently the mass spectrometer is being implemented and optimized as an analysis tool in a biotechnologically used pressure reactor in order to study biotechnological processes with gaseous substances and volatile products.

## Modeling and soft-sensing

The Gibberellin Project, whose aim was the fermentative production of the plant hormone Gibberellin by the fungus *Fusarium fujikuroi*, is an example of software sensors and process modeling. A general problem regarding the fermentation of



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filamentous fungi is that only a part of the entire biomass is metabolically active. For one, hyphae die off during the fermentation process (Fig. 2). Furthermore, the fungus accumulates storage lipids and carbohydrates that increase the biomass (Fig. 3). We have been able to successfully estimate the concentration of active biomass on the basis of the base consumption (Fig. 4). This facilitates the calculation of other process variables, for example of substrate and product concentrations during the fermentation process. Moreover, we have developed a mathematical model based on first-principles which predicts the biomass, substrate and product concentrations. Fig. 5 shows the course of 19 fermentations and the relevant simulation. It becomes apparent that the model represents the measured data very well.

### Outlook

The combination of parallel fermentation technology, online measurement and control technology and mathematical modeling forms the basis for the understanding of a biotechnological process and thus facilitates a more efficient process optimization and transfer to production scale. This approach is mainly demanded by the pharmaceutical industry. In 2004 the U.S. Food and Drug Administration started the Process Analytical Technology initiative, PAT [1] for short. The work of the Fraunhofer IGB shows that this is also groundbreaking for the white biotechnology.

- 1 *Screening of various ethanol producers in the multifermenter.*
- 2 *Microscope image of intact (green) and damaged cells (red).*
- 3 *Cells with lipid deposits.*
- 4 *Estimation of the biomass concentration based on base consumption.*
- 5 *Modeling the gibberellin production with *Fusarium fujikuroi*.*

### Contacts



**Dipl.-Ing. Tino Elter**

Phone +49 3461-43 9118  
tino.elter@igb.fraunhofer.de



**Dr. Wolfgang Krischke**

Phone +49 711 970-4218  
wolfgang.krischke@igb.fraunhofer.de

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### Funding

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### Project partner

Institute of Plant Biology and Biotechnology, work group Molecular Biology and Biotechnology of Fungi, University of Münster





# ENVIRONMENT

Dipl.-Ing. Siegfried Egner

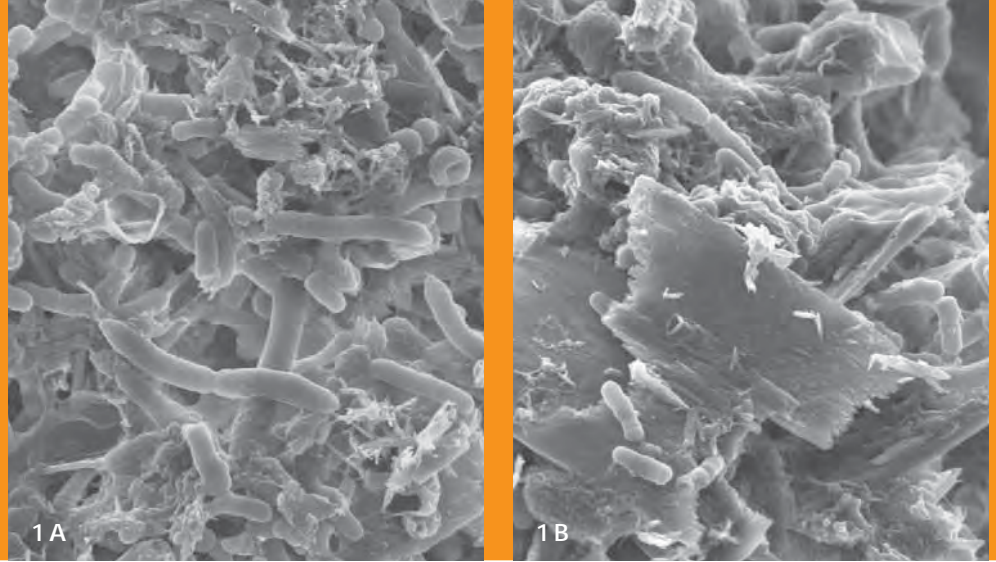
Against the background of worldwide discussions concerning the greenhouse effect and the shortage of resources, resource-efficient economic management and protection of the environment are further gaining in importance. Resource-conserving industrial activities and protection of the environment are interdisciplinary tasks requiring extensive research and development. In this context, the environment business area at the Fraunhofer IGB stands for technological developments which contribute towards avoiding negative environmental impacts and ensuring technological progress – above all by interweaving ecological and economic sustainability. Typically, tasks and approaches in the environment business area are often directly linked with topics in the energy and chemistry business areas.

In the framework of a number of joint European and national projects with partners from research and industry, the Fraunhofer IGB is developing processes and system components which help to save resources such as raw materials and water, are climate-friendly, improve material recycling and in general contribute to improving the use of renewable resources. An example is the innovative DEUS 21 infrastructure concept for semi-decentralized energy and water management. This is being further developed to allow its use in urban redevelopment. Another example is research on how to avoid the emission of particulate or dissolved, persistent or endocrine micro-pollutants.

Approaches to minimizing the demand for finite resources include the substitution of chemical solvents with dry physical processes, for instance in the industrial cleaning of structural components, the service life extension of metal-working lubricants, the recovery of substances from agro-industrial process water as high-quality fertilizers or the generation of algae biomass for material and energetic utilization.

A common additional feature of our research projects is proof of the sustainability of the products and processes developed. This involves the systematic analysis of all environmental impacts of a product during its life cycle – from production via use to its disposal or recycling – from a holistic perspective which takes into account both economical and ecological aspects. We perform this analysis called life-cycle assessment together with various specialized partners.

Comprehensive, complex projects in the environment business area are carried out by interdisciplinary teams drawn from the natural sciences and engineering. Access to further technical competence and opportunities for collaboration on projects arises through the Fraunhofer IGB's participation in the Fraunhofer Cleaning Technology, Building Innovation and Water Systems (SysWater) Alliances, as well as in the national technology platform SusChem Deutschland. Moreover, the Fraunhofer IGB has excellent international networks, particularly within Europe.



## MOLECULAR SORTING – RECOVERY OF METALS

Dr. rer. nat. Thomas Schiestel, Dr. rer. nat. Iris Trick, Alexander Karos M.Sc.

### Waste as a source of raw materials

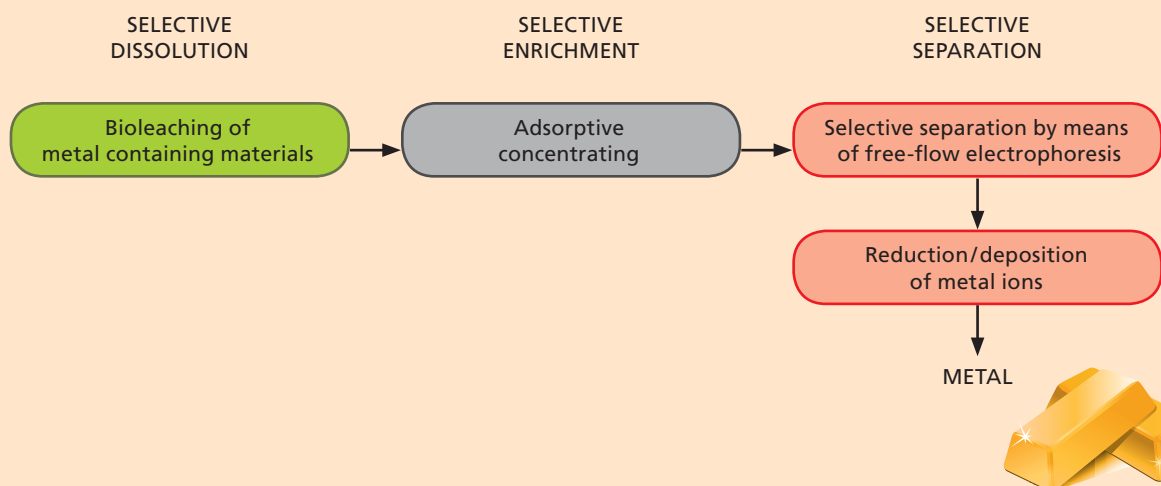
The recycling of raw materials, in particular special metals, because of their value (precious metals), their availability (rare earths) or their toxicity (heavy metals) is of great importance, both for industrial production and for the environment. Process and wastewater streams, for example from alkaline solution baths in the electroplating industry, and also landfill leachate, may contain significant quantities of dissolved metals. Also in the recycling of solids such as waste electronic equipment or ashes from combustion processes, the dissolution of metals (leaching) in bioreactors (bioleaching) can be an efficient method of transferring these metals to an aqueous solution. After that, further processes such as “enrichment”,

“separation” and “deposition” are necessary to recover a utilizable metal. The design of these process steps is of decisive importance for the efficiency and sustainability of the whole process.

### Need for new technologies

Economical and ecological efficiency on the industrial scale is only possible to a limited extent with the technologies available today, especially when there are only low concentrations of the metal ions in a solution. Of course, there are technologies for the selective separation of individual metals from a solution. However, these technologies are generally very cost-intensive, and neither environmentally friendly nor universally

### Process chain for an efficient recovery of metals





applicable. Furthermore, the precision of separation is not sufficient to achieve a quality equal to that of the primary material. To close the material cycles within production processes and in recycling there is therefore a great need to develop new technologies that are efficient, easy to integrate and can be applied flexibly to various groups of metals.

### Process steps and an integrated concept

In the project “Molecular Sorting”, funded as part of the Fraunhofer-Gesellschaft’s “Markets Beyond Tomorrow” research program, the Fraunhofer IGB is developing new metal-recovery technologies based on the microbiological, separation [1, 2] and electrophysical technology know-how available at the IGB. For this purpose the technologies bioleaching (to dissolve the metals), adsorption and membrane filtration (to concentrate the dissolved metal ions), electrophoretic separation and the use of ionic liquids for electrolytic processes (for fractionation and galvanic deposition of metals) are being studied, further developed and incorporated in an integrated process.

### Selected reference substances

For the development work, the following substances were chosen as reference substances:

- Precious metals: gold, silver, copper, palladium
- Rare earths: neodymium
- Toxic metals: lead, mercury.

Here, both economic criteria (economic significance, range) and ecological reasons (toxicity, prevalence) were decisive.

1 A: A microbial mixed population on recyclable material particles.

B: Precipitation of metals.

2 Process chain for an efficient recovery of metals.

3 Bioleaching.

### Bioleaching

Interactions of metallic surfaces with microorganisms are generally not noticed until they cause damage as a result of biocorrosion. The same processes can be used to dissolve metal ions from materials and to make them recyclable. Without knowing the scientific background, people used microbiological processes centuries ago to obtain metals such as copper from natural deposits. The field of bioleaching includes enriching microbial populations with the aim of recovering metals from industrial waste materials, consumer goods or various types of process water by using technical processes.

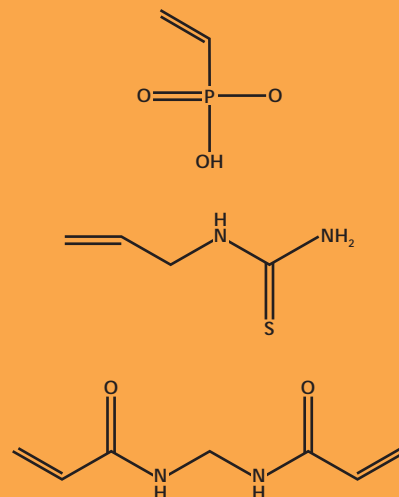
Two procedures for bioleaching were established at the Fraunhofer IGB:

- An anaerobic process
- An aerobic process

The bioleaching processes were tested on metallic recyclable materials as well as on waste wood and rail sleepers and were initially set up on the laboratory scale. In the first process step suitable microbial mixed populations were enriched and then metal ions were successfully solubilized from particulate source material. Fig. 1A shows an example of a micropopulation of various types of bacteria that had colonized the source material (metal shavings). The process of metal solubilization was evaluated analytically by means of ICP spectroscopy. Considerable quantities of manganese, nickel, iron, copper, zinc and titanium were solubilized especially from waste wood and rail sleepers. There was also evidence of a precipitation of the metals in the suspension (Fig. 1B).

The conception for a technical process was developed on the basis of these results. For the bioleaching process the design includes a fixed-bed reactor that ensures a sufficiently high catalyst density by means of biomass retention.





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### Increasing the concentration

In order to achieve efficient separation of metal ions from low-concentration metal solutions, an adsorption process for concentrating the ions is required. In this project, adsorber materials are being developed that permit the selective adsorption of metal ions from aqueous solutions. For this, we are pursuing two different concepts:

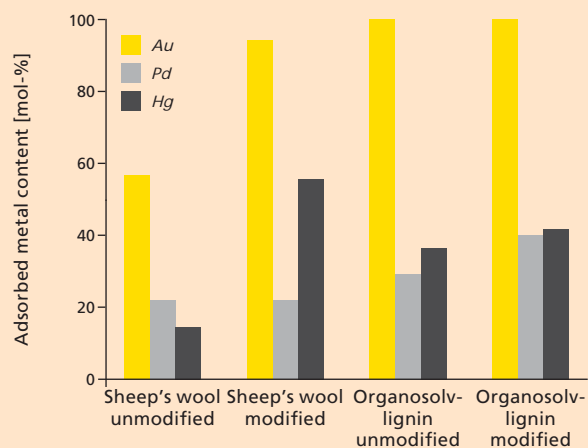
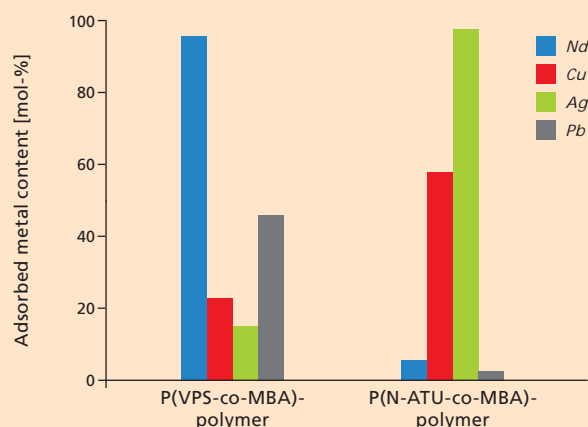
### Adsorbers on polymer basis

So as to find suitable functional groups for the specific adsorption of metal ions, a screening was carried out with various functional groups. On the basis of these results polymers were synthesized with the functional groups that demonstrated the best adsorption characteristics with regard to certain metals. Fig. 4 shows examples of two of the monomers used (top, middle) as well as the crosslinker (bottom).

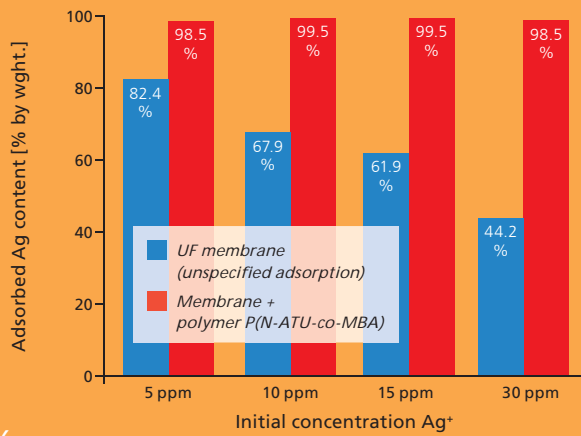
### Adsorbers from renewable resources

Lignin and sheep's wool were selected as renewable resources. On the one hand, the two classes of substances lignin and keratin already possess a high density of functional groups, on the other they tend to be waste materials and are therefore easily available. These materials were used untreated and also in a modified state for the adsorption experiments.

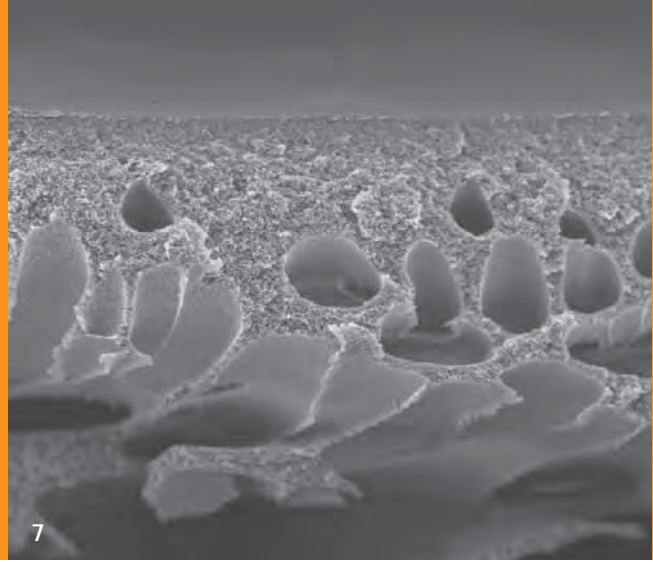
Fig. 5 shows results of adsorption experiments in which the selectivity of the polymer adsorbers is determined. For this purpose, the adsorbers are brought into contact with an aqueous solution containing various metals of the same molar concentration. It can be seen clearly in the diagram at the



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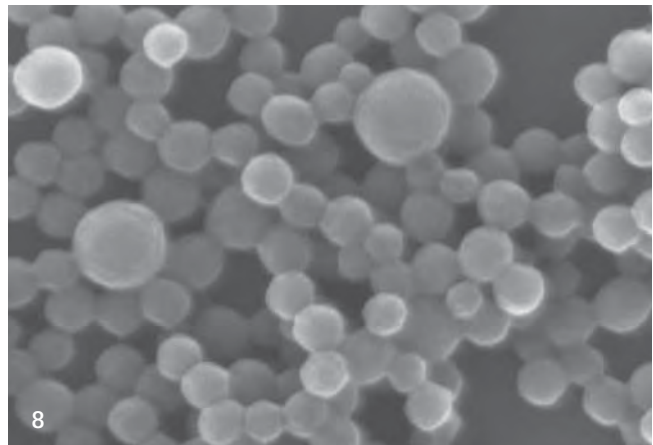
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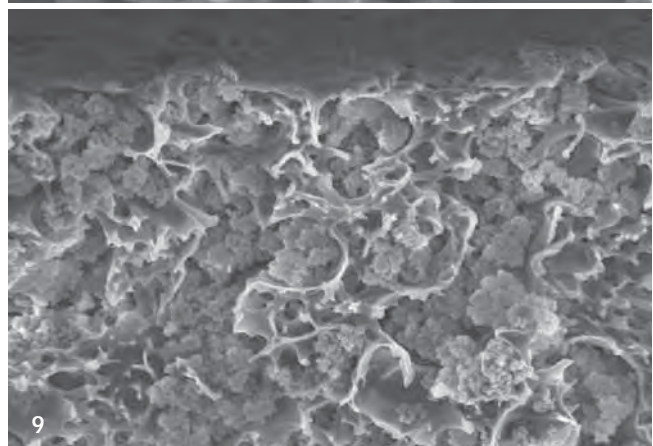
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top of Fig. 5 that the synthesized polymers exhibit greatly differing selectivities. The P(VPS-co-MBA) polymer favors the adsorption of neodymium, followed by lead. However, the P(N-ATU-co-MBA) polymer favors the adsorption of silver, followed by copper. The diagram at the bottom of Fig. 5 shows the adsorption characteristics of sheep's wool and lignin. It can be seen that after modification the sheep's wool adsorbs significantly more gold and mercury. Lignin favors the adsorption of gold.

To achieve an intensification of the process, adsorption will be combined with a membrane separation in the project. For the polymer P(N-ATU-co-MBA) a so-called polymer-enhanced ultrafiltration (PEUF) was carried out in which a silver solution was filtered by means of a UF. The result of this experiment is shown in Fig. 6. For comparison, the filtration process was carried out once again with the addition of the polymer. The results indicate clearly that due to the addition of the polymer (red bar), even when the silver concentration in the solution is increased, more silver was retained by the adsorption on the polymer than compared with the UF membrane (blue bar). The adsorbers are also to be incorporated direct in the membrane. For example, lignin was used in the production of membranes by mixing it directly into an initial polymer solution (Fig. 7). In addition, particles of the polymer adsorbers were also integrated into membranes (Figs. 8, 9). We could demonstrate that the adsorption properties of the polymer materials are preserved when incorporated in the membrane.



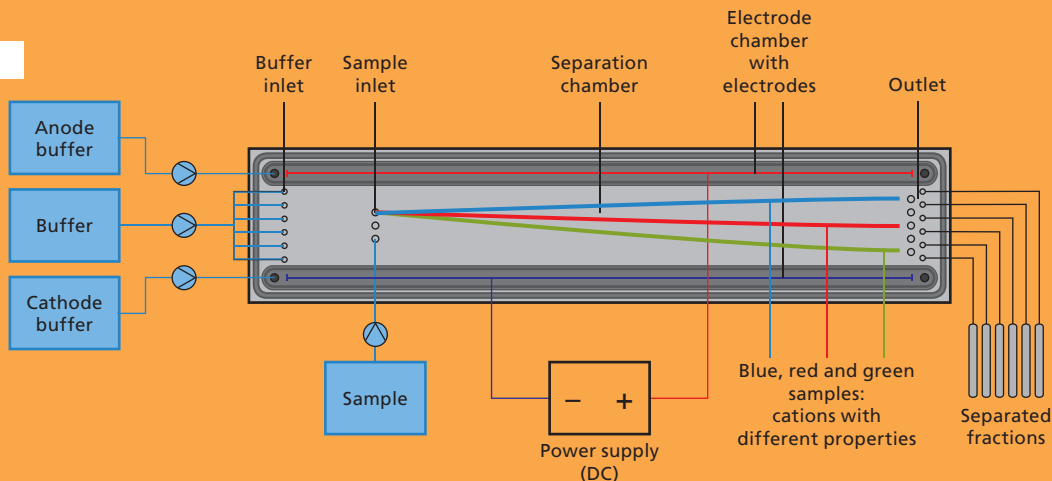
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- 4 *Vinylphosphonic acid, N-allylthiourea, N,N'-methylenebisacrylamide (from top).*
- 5 *Results of adsorption experiments to determine selectivity.*
- 6 *Polymer-enhanced ultrafiltration (PEUF).*
- 7 *Lignin-filled membranes.*
- 8 *Polymer nanoparticles carrying phosphonic acid groups on their surface for selective binding of metal ions.*
- 9 *Membrane adsorbers filled with functional polymer nanoparticles.*





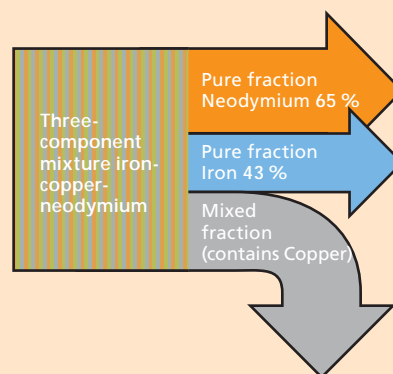
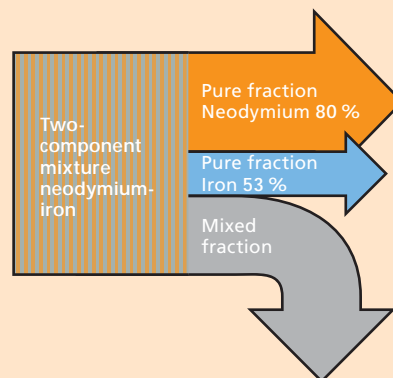
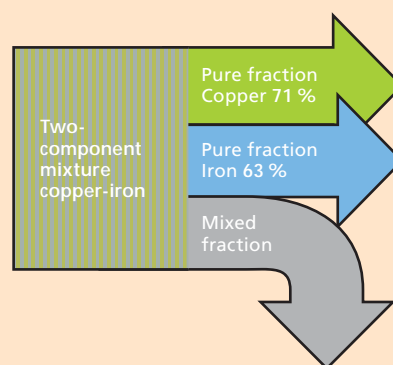
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**Electrophysical processes**

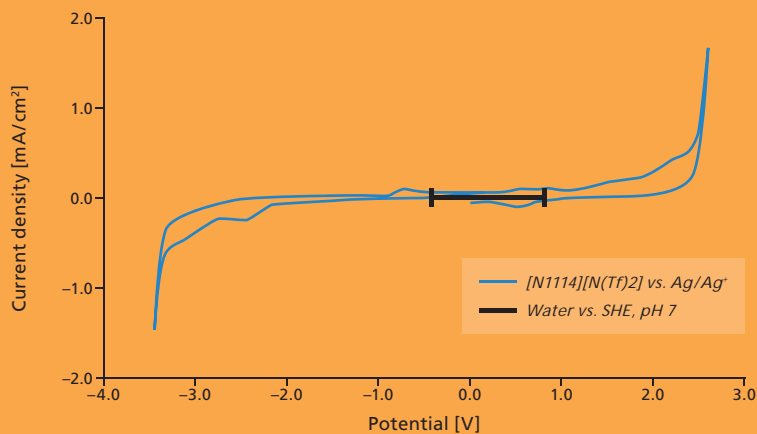
For the fractionation and subsequent deposition of the various metal ions as a metallic solid we give preference to further developing electrophysical processes such as electrophoresis and galvanic deposition. For the separation of various metal ions in solution we have developed a laboratory prototype that works on the principle of free-flow electrophoresis (Fig. 10). This procedure also permits the separation of metal ions which are very similar due to their chemical and physical properties and which can therefore only be separated to a limited extent using conventional technologies (e.g. rare earth ions).

The experiments to date confirm the feasibility of a fractionation with a high degree of selectivity of the metal ions. Here, for example, the metal ion mixtures copper-iron, neodymium-iron and the three-component mixture iron-copper-neodymium were separated (Fig. 11). In the case of the two-component mixtures we were able to increase the purity of the fractions to over 90 percent by means of a single cycle. In order to increase the efficiency even further, complexing agents were used, resulting in an almost complete separation of the substance mixtures. A transfer of the proven successful separation to other systems of substances is planned for subsequent experiments.

For the deposition of rare earths and metals following the fractionation, suitable ionic liquids were chosen as electrochemically stable electrolytes. In order to test the application, a trial setup including a reactor system was developed. First experiments to investigate the stability of the selected ionic liquids were carried out successfully and, compared with water, they show a very broad electrochemical window (Fig. 12).



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## Outlook

The aim of recycling substances is to provide an efficient supply of secondary resources in the same quality as the original raw material. For industrial implementation, it is not sufficient just to make available the separate stages of the process. Rather, what is required is a well-thought-out process chain for an integrated metal-recycling concept. These concepts are transferred into pilot scale, tested and validated in practice and verified with investigations into environmental compatibility by means of life-cycle assessments.

- 10 Free-flow electrophoresis (FFE) plant.
- 11 Separation of various metal ions by means of FFE, figures refer to the initial amount.
- 12 Cyclic voltammogram – Comparison of the electrochemical window of an ionic liquid with that of water.

## Contacts



### Dr. Iris Trick

Bioleaching

Phone +49 711 970-4217

iris.trick@igb.fraunhofer.de



### Dr. Thomas Schiestel

Adsorption, membranes

Phone +49 711 970-4164

thomas.schiestel@igb.fraunhofer.de



### Alexander Karos M.Sc.

Electrophysical processes

Phone +49 711 970-3564

alexander.karos@igb.fraunhofer.de

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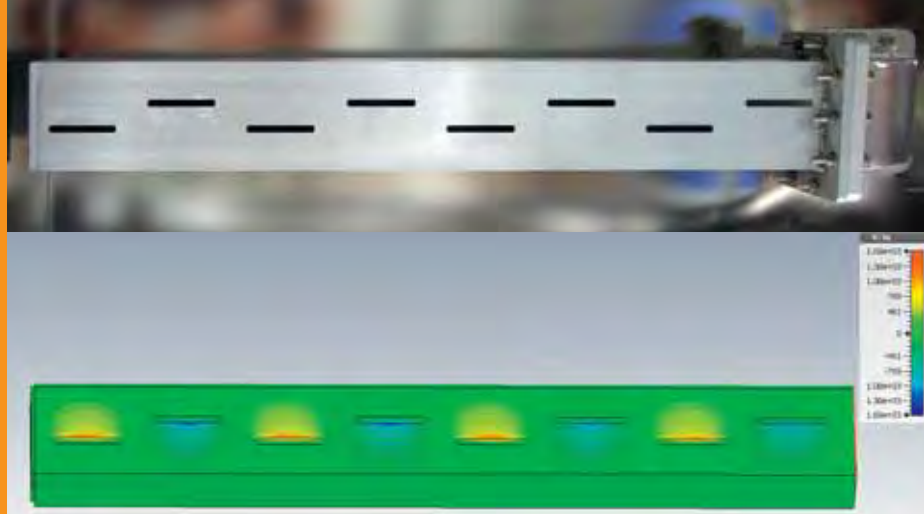
We would like to thank the Fraunhofer-Gesellschaft for funding the project "Molecular Sorting for Resource Efficiency" within the framework of the "Markets Beyond Tomorrow" research program.

## Project partners and further information

[www.molecular-sorting.fraunhofer.de](http://www.molecular-sorting.fraunhofer.de)



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## RECYCLING OF WOODEN AND PLASTIC WASTE BY ELECTROMAGNETIC FIELDS

Ali Imran Javaid M.Sc.

### Electromagnetic fields in process engineering

High frequency electromagnetic fields are applied in numerous industrial processes including material processing. This technology, known as “Electromagnetic Processing of Materials” (EPM) [1], enables a rapid and controlled application of energy to materials. The volumetric and homogeneous application of energy to materials, in particular, results in very good efficiency [2] compared to processes relying on heat transfer by convection or conduction.

The interaction of electromagnetic fields with various media occurs by means of forces, including Lorentz, Kelvin, and diamagnetic forces. This enables the processing or alteration of materials in a controlled manner. To ensure that the microstructure of the material subjected to energy will be not compromised [1], the basic relationships of these interactions must be examined and considered for each application.

### Electromagnetic fields in recycling technology

The application of electromagnetic energy in recycling processes not only offers economic benefits, but also helps to reduce the environmental footprint on the planet. The EU-funded project FurnitReUse is an excellent example of such an application. The project goal is to develop a sustainable recycling technology for domestic wooden and plastic waste using electromagnetic fields. This project offers both, a solution for the utilization of waste materials, as well as providing a novel eco-friendly material processed by electromagnetic fields.

### Wooden and plastic waste from homes and offices

Every year thousands of tons of wood-based furniture, including particle boards and panels, are discarded and scrapped by European households. Currently, this waste is generally incinerated but, depending on national legislation, it may also be dumped in landfills. Apart from landfilling or incineration, after sorting out the metal and electronic components, there are only few approaches available for recycling or utilizing the plastics contained in desktop computers, monitors and peripherals.

Due to the growing volume of such waste, those “state of the art” processes require more landfill space, while incineration contributes to global warming by generating carbon dioxide. Highly specialized system technology is particularly necessary for incineration of boards coated with different lacquers and surface varnishes, in order to avoid the release of harmful substances.

### Electromagnetic recycling process

The FurnitReUse project has developed an innovative electromagnetic process to recycle these waste materials and obtain a novel composite material in the strictly controlled environment of a closed reactor equipped with automated sensors. The crushed and shredded wooden and plastic waste is mixed and heated by electromagnetic fields in a controlled and automated process chamber. Subsequently, processed material is pressed into sheets or other shapes. The process is environmentally friendly and economical as no chemical compounds need to be added to activate and control it.





The measurements of the dielectric properties, the design of the reactor and the antenna, as well as the modeling and numerical simulation were carried out at the Fraunhofer IGB. Various options were investigated for controlling the radiation of the microwaves. Depending on the size of the system within a subsequent large-scale plant construction, the microwave energy can be radiated directly by means of waveguides, wherein the magnetron radiates directly into the reactor without an antenna. Alternatively, the microwaves can be fed via an antenna, wherein the magnetron feeds energy to an antenna, which then distributes it to the reactor. It was decided to use a slotted waveguide antenna for the industrial prototype of the FurnitReUse reactor.

Initial experiments with this novel composite material confirmed its expected physical and mechanical characteristics in terms of stability and further use as sound insulation. Even at the end of its lifetime this new composite material can be recycled again without compromising its characteristics.

### Outlook

There are various potential applications for the novel material that is prepared by electromagnetic processing and for which all recyclable plastics can be utilized. Due to its sound insulating effect, an exemplary application would be the production of noise barriers. Another possible application is in the transportation sector to replace the standard wooden pallets. The technology presented here has the potential to offer a novel method of waste management, leading to a green and sustainable recycling economy and a business opportunity for small and medium enterprises engaged in the recycling sector.

### Contacts



**Ali Imran Javaid M.Sc.**  
Phone +49 711 970-3628  
ali.imran.javaid@igb.fraunhofer.de



**Dipl.-Ing. Siegfried Egner**  
Phone +49 711 970-3643  
siegfried.egner@igb.fraunhofer.de

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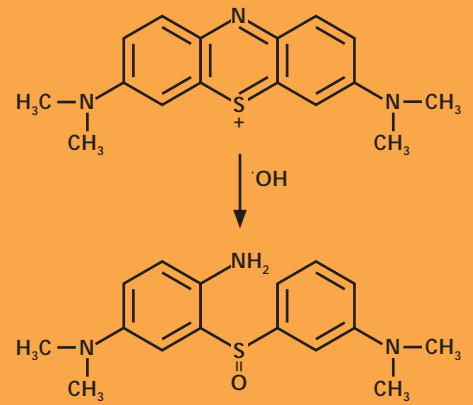
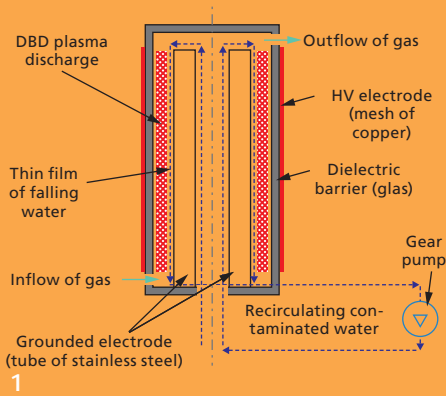
### Funding

We would like to thank the European Union for funding the research project “FurnitReUse” in the Seventh Framework Programme (FP7/2007-2013), grant agreement no. 262337.

### Project partners and further information

<http://furnitreuse.polsl.pl>

- 1 *Automated electromagnetic processing reactor to produce a novel composite material from wooden and plastic waste.*
- 2 *Slotted waveguide antenna simulated and developed at Fraunhofer IGB.*
- 3 *Shredded wooden and plastic waste.*



# PLASMA-CHEMICAL DEGRADATION OF ORGANIC CONTAMINANTS IN WATER

Dr. rer. nat. Michael Müller

## Initial situation

There is only a limited supply of drinking water available as a resource. At the same time, since the beginning of industrialization the worldwide level of water consumption has increased on a massive scale and will continue to grow further along with the tremendous technological development in Asia. Today, the provision of water in potable quality, above all to supply a growing world population with clean water, is a global challenge. For this reason, improved water management and, especially, efficient methods for treating wastewater are becoming more important.

## Conventional wastewater treatment

The pollutants contained in wastewater are conventionally removed in central treatment plants after separation of the solid content by biological and chemical means. However, to an increasing extent the substances that are not easily biodegradable remain issues of concern. These include for example medications in the wastewater from clinics, hospitals and old people's homes, organic halogen compounds and cyanides from industrial plants or pesticides used in agriculture. To remove these compounds, physical-chemical methods such as advanced oxidation processes (AOPs) with ozonation, UV irradiation or the addition of iron salts can be used in combination with hydrogen peroxide. However, these purification processes generally require chemical additives that are classified as hazardous substances and that have to be disposed of as special waste.

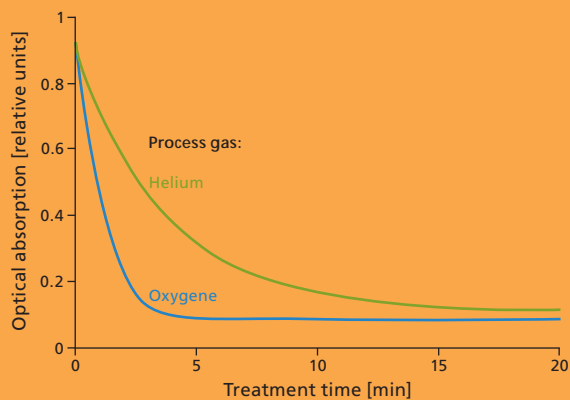
## Plasma processes for water purification

The use of atmospheric pressure plasma processes could provide an environmentally compatible and cost-effective alternative. Ions, highly reactive radicals and short-wave radiation, that degrade the contents of the wastewater are formed simply by applying a high voltage, which is igniting a plasma discharge in ambient air or oxygen. This renders the use of chemicals and their subsequent disposal unnecessary. The aim of the EU-funded "WaterPlasma" project was therefore to develop a plasma process for purifying water and a suitable plasma reactor as a prototype.

## New type of plasma reactor

The special design of the plasma reactor insures an effective transmission rate of the highly reactive species formed in the plasma to the contaminated water. This is achieved by forming the plasma in direct contact with a flowing water film (Fig. 1). The water to be purified falls through the plasma zone by the force of gravity, directly onto the outer surface of a grounded electrode (stainless steel cylinder). Hydroxyl radicals, among others, are created in the plasma and transmitted to the water. By means of their high oxidation potential these radicals and short wavelength UV radiation break down the dissolved contaminants until they are mineralized (Fig. 3).

A decisive advantage of the plasma decontamination method is its durability. The water surface is constantly renewed and, unlike conventional UV treatment, is not soiled with contaminants, which normally reduces the efficiency within a short time. With the plasma water treatment there is no need for elaborate cleansing of surfaces to remove biofilms and other surface contaminants.



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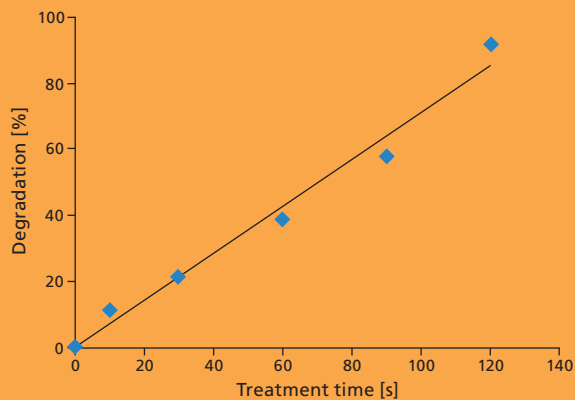
### Energy-efficient and effective degradation

A method for comparing the efficiency of advanced oxidation processes is the measurement of the energy input that is required to decolor methylene blue by one order of magnitude [1]. Using the plasma process 4 g/kWh (Fig. 4) is achieved. This value is nearly one order of magnitude better than the energy efficiency measured with a UV H<sub>2</sub>O<sub>2</sub> treatment of methylene blue [2]. In another application of the water plasma method the project showed that cyanide (Fig. 5) is broken down by 90 percent within 2 minutes [3].

### Outlook

Unlike well-established advanced oxidation processes the plasma process for water decontamination has no barrier between the plasma and the medium that is to be purified. It therefore requires almost no maintenance and is characterized by a long life. A very high degree of efficiency is achieved even without the introduction of hazardous substances such as hydrogen peroxide or ozone. As a result of the project a demonstrator is now available that is suitable for purifying substantial quantities of contaminated water (240 L/h). At the moment further possible applications for the procedure are being examined.

- 1 Schematic view of a plasma reactor for water purification.
- 2 Experimental setup of a plasma reactor for water purification.
- 3 Hydroxyl radicals formed in the plasma decompose the dye methylene blue.
- 4 Degradation kinetics of 1 mg/L methylene blue (efficiency<sub>90% reduction</sub> of 4 g/kWh).
- 5 Degradation of 0.8 mg/L cyanide in water using plasma treatment.



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### Contacts



**Dipl.-Ing. (FH) Hendrik Schikora**

Phone +49 711 970-4144

hendrik.schikora@igb.fraunhofer.de



**Dr. Michael Haupt**

Phone +49 711 970-4028

michael.haupt@igb.fraunhofer.de

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### Funding

We would like to thank the European Union for funding the project "Water decontamination technology for the removal of recalcitrant xenobiotic compounds based on atmospheric plasma technology" in the Seventh Framework Programme (FP7/2007-2013), grant agreement no. 262033.

### Project partners and further information

[www.waterplasma.eu](http://www.waterplasma.eu)



# CLEANLEACHATE – ELECTROCHEMICAL TREATMENT OF LANDFILL LEACHATE

Dipl.-Ing. Christiane Chaumette

## Highly contaminated landfill leachate

The most frequently employed method of waste management is disposal of waste on a landfill site. However, a major disadvantage of landfill operations is the generation of contaminated leachate caused by rainfall. Water contained in the waste and water released by biological degradation processes also adds to the landfill leachate. Together with the leachate, contaminants are released which come from biological decomposition processes of the landfill material, or are simply washed out. The leachate therefore has toxic properties and contains substances that are not easily biodegradable. Treatment plants with biological processes can only treat the wastewater to a limited extent. Above all, persistent organic substances (measured as chemical oxygen demand, COD), ammonium and halogenated organic substances (measured as dissolved organic halogens, AOXs) are present in the landfill leachate in critical concentrations and have to be removed before discharge into the aquatic environment or transfer to a municipal, biological wastewater treatment plant.

## Processing landfill leachate

The treatment of landfill leachate is a considerable cost factor for the landfill site operator. Contaminated leachate requiring treatment is generated even decades after the closure of a landfill site. Membrane and adsorption processes (e.g. with activated carbon) are frequently used. However, these have the disadvantage that the contaminants are not eliminated but are merely concentrated. Subsequently the concentrate has to be disposed of or further processed. On a worldwide scale the quantity of landfill waste is increasing, while at the same time the legislation is becoming more stringent. This

results in a growing demand for cost- and energy-efficient as well as reliable processes for the treatment of landfill leachate.

## Combination of electrochemical oxidation and reduction

Within the EU-funded project CleanLeachate and together with European partners from industry and research, the Fraunhofer IGB has developed an electrochemical process that permits the reliable treatment of landfill leachate without the need to add auxiliary substances to the wastewater. Both ammonium and dissolved organic substances can be eliminated from the landfill leachate by means of electrochemical oxidation at the anode of the reactor and dissolved organic halogens by the subsequent reduction at the reactor cathode. In contrast to membrane filtration, electrochemical treatment completely degrades the dissolved substances. There is no need for the disposal of residues.

## Divided electrolytic cell

For oxidation and reduction reactions, the electrolytic cell is separated into two chemical reaction compartments by means of an ion exchange membrane; the water passes through them one after another, but nevertheless the two compartments form one electric circuit. The contaminants in the water are thus subjected to two treatment processes. The basis for developing the process was first established in laboratory experiments. The divided electrolytic cell was then developed in cooperation with our project partner Eilenburger Elektrolyse- und Umwelttechnik GmbH (EUT, Electrolysis and Environmental Technology). Six different anode materials provided by our project partner MAGNETO were tested in the lab with a view



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to the degradation of organic substances and ammonium by anodic oxidation. Stainless steel cathodes with varying geometries were tested to investigate the dehalogenation of the AOX.

#### Pilot plant – test operation at a landfill site

A pilot plant with a throughput of 20 L/h was designed in accordance with the laboratory findings, and built by our project partner EUT. Continuous operation tests were carried out by our project partner ASIO at a landfill site in the Czech Republic. The process was successfully optimized and able to reduce the COD concentration in the landfill leachate to below 200 mg/L and the total nitrogen concentration to below 70 mg/L. This means compliance to the legal requirements for COD and overall nitrogen concentration in the treated landfill leachate. The energy requirement for the removal of contaminants was 43 kWh to degrade one kilogram of COD and 22 kWh to eliminate one kilogram of ammonium.

#### Outlook

An automated and transportable prototype plant is now available for further development in view of market introduction. It could be demonstrated that the electrochemical treatment of landfill leachate meets pollutant discharge limits. The technology will now be further tested and demonstrated in a variety of industrial wastewaters.

#### Contacts



**Dipl.-Ing. Christiane Chaumette**

Phone +49 711 970-4131  
christiane.chaumette@  
igb.fraunhofer.de



**Dipl.-Ing. Siegfried Egner**

Phone +49 711 970-3643  
siegfried.egner@igb.fraunhofer.de

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#### Project partners

Eilenburger Elektrolyse- und Umwelttechnik GmbH, Eilenburg | MAGNETO special anodes B. V., Schiedam, Netherlands | ASIO spol. s r. o., Brno, Czech Republic | Initial Projects Limited, Wolverhampton, UK | Centre de Recerca i Innovació de Catalunya, S. A., Barcelona, Spain

#### Further information

[www.cleanleachate.eu](http://www.cleanleachate.eu)

- 1 Activated sludge tank of a plant for the treatment of landfill leachate.
- 2 Electrolytic cell on a laboratory scale.
- 3 Leachate samples during the electrochemical treatment.
- 4 Schematic view of the prototype plant.



# ENERGY

Dr.-Ing. Ursula Schließmann

Ensuring an adequate future supply and efficient use of energy is of the highest economic priority, since the primary energy sources that we currently use to meet the greatest part of our energy needs are finite. The use of crude oil, natural gas and coal also leads to a rapidly rising concentration of CO<sub>2</sub> in the atmosphere – and consequently incalculable climate change. As a result of the use of these fossil energy carriers and the reduction of the overall capacity for photosynthesis, the Earth's net energy content is continually decreasing.

Making the transition to a sustainable energy supply is thus one of the 21<sup>st</sup> century's major challenges. Energy efficiency, the use of regenerative energies and energy storage are fundamental components here. At the Fraunhofer IGB we take on this challenge: key fields of action are sustainable energy conversion, the optimization of the energy efficiency of processes, e.g. through coupling processes, and developing suitable energy storage systems.

We contribute, for instance, to expanding photosynthesis capacity by developing methods for cultivating microalgae; we also advance the exploitation of regenerative energy sources by means of highly innovative membrane technology (gas separation, fuel cells, osmosis power plants). A specific example is the development of membranes for oxygen enrichment to facilitate more efficient combustion reactions in energy-intensive sectors such as the cement or steel industries. A further focal point is the development of absorption and membrane processes or ionic liquids that have a high capacity to bind CO<sub>2</sub> and separate it efficiently from biogas.

Further developmental work to improve energy efficiency includes the production of biogas from organic waste, by-products of the food industry and primary agricultural production, as well as energy savings achieved through process optimization at municipal and industrial sewage plants and anaerobic wastewater treatment. Noteworthy in this context are also industrial processes such as the drying of biomass and porous materials with super-heated steam at ambient pressure, and methods for rapid energy input, e.g. microwave pyrolysis. Additionally, the Fraunhofer IGB is developing systems for stable long-term storage of thermal energy in order to make waste heat available for temporally and spatially decoupled heat requirements. A further project is refining biogas for CNG-powered vehicles.

We are also active in designing integrated material flow and energy concepts for municipalities and regions, replacing the current, historically grown solutions with systematic approaches using state-of-the-art technologies. For this purpose, the Fraunhofer IGB is an active partner in the Fraunhofer Energy, Building Innovation and Water Systems (SysWasser) Alliances, as well as the Fraunhofer "City of the future" initiative.



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## ENHANCED HIGH-LOAD DIGESTION IN BAD DÜRRENBURG REDUCES COSTS

Dr.-Ing. Werner Sternad

### Wastewater treatment plants as energy consumers

Wastewater treatment plants make up on average 20 percent of the energy consumption of the municipalities. Thus they belong among the big energy consumers [1]. For this reason, in 2008, the water and wastewater administration union "Zweckverband" Bad Dürrenberg together with engineering consultants Ingenieurbüro Stockleben were looking for opportunities to reduce the energy consumption of the wastewater treatment plant ABA Bad Dürrenberg (conversion for about 26,000 population equivalents). It was decided to convert the simultaneous aerobic sludge stabilization with high energy consumption for aeration into an anaerobic sludge stabilization plant that creates energy in the form of fermentation gas.

### Conversion of the treatment plant from aerobic to anaerobic sludge stabilization

In order to achieve this task efficient technology was required with which the conversion could be implemented at the lowest possible cost. This was when the Fraunhofer IGB and its high-load digester came into play. In 2010 and 2011 preliminary studies concerning the digestion capacity of the raw sludge from Bad Dürrenberg were carried out. Planning documents were created together with the customer and submitted to the authorities. In addition, tender documents were prepared. Eisenmann Anlagenbau won the public tender. In close cooperation and agreement with the individual parties the conventional high-load digestion system was enhanced by means of a new reactor type and implemented for the first time in Bad Dürrenberg. Construction work started in March 2012 upon completion of the necessary preliminary work on

pipelines and foundations, and the installation of primary treatment plant at the ABA. On June 14, 2012 the high-load digestion plant was officially dedicated.

### Enhancement of high-load digestion

In contrast to conventional sludge digestion in municipal treatment plants that, according to bulletin "Merkblatt ATV-DVWK M 368", are designed to operate in the mesophilic range (around 37°C) and with a hydraulic residence time (HRT) of at least 18 days, high-load digestion plants are operated under considerably higher organic volume load and a HRT of only 7 days. High-load digestion is based on the two-stage Schwarting-Uhde-process that was developed and patented in 1979 by the then company Schwarting and the Fraunhofer IGB. The first high-load digestion plant for municipal sewage sludge was commissioned as early as 1994 at the treatment plant Mittleres Glemstal (Leonberg). Further installations followed in Eching, Heidelberg, Tauberbischofsheim, Wutöschingen, Ilsfeld, and the latest in Bad Dürrenberg.

Original high-load digestion was characterized by the so-called phase mixing system in which the sludge is mixed in the reactor several times an hour by means of a strong impulse pump and integrated perforated plates. This system works well and requires relatively little energy input. Its disadvantage is that the effort in terms of the equipment required is rather high and that deposits can form between the individual plates in the course of several years as an inspection after about 10 years of operation showed. A similarly efficient and low-energy mixing action can also be achieved by means of a gas lift





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loop reactor [2]. However, there had been hardly any experience at the necessary scale of approximately 360 m<sup>3</sup> reactor volume.

### Calculation of the gas lift loop reactor

Through careful simulation calculations and analysis of the necessary hydraulic and geometric data, we were able to find a solution which required the precise observation of the specifications for the geometry of the reactor and the draft tube. For this reason the geometric data was repeatedly checked during the construction phase.

### Operating results and outlook

Immediately after the inoculation in May 2012 it became apparent that high-load digestion with gas injection works very well hydraulically as a gas lift loop reactor. To date there have neither been any problems with the formation of foam nor of a scum layer. The amount of sludge gas generated met the expectations. In Bad Dürrenberg the simplified design of the high-load digestion plant as a gas lift loop reactor resulted in savings of 100,000 to 200,000 euros. The conversion of the ABA Bad Dürrenberg from simultaneous aerobic to anaerobic sludge stabilization while the plant was operating was possible due to the excellent cooperation of all parties involved.

Particularly for population equivalents of between 10,000 and 50,000 there are a lot of wastewater treatment plants which had originally been planned as aerobic stabilizing plants and whose conversion would be worthwhile from an economic point of view.

### Contacts



**Dr.-Ing. Werner Sternad**  
Phone +49 711 970-4110  
werner.sternad@igb.fraunhofer.de



**Barbara Waelkens M.Sc.**  
Phone +49 711 970-4124  
barbara.waelkens@igb.fraunhofer.de

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### Project partners

ZWA Bad Dürrenberg | Ingenieurbüro Stockleben GmbH, Bad Dürrenberg | Eisenmann Anlagenbau, Holzgerlingen

- 1 Foundations for the gas storage (left) and the high-load digestion installation (right in the rear).
- 2 Construction of the high-load digestion plant. The reactor is lifted above the draft tube.
- 3 High-load digestion with scaffolding for the assembly of the pipelines, sensors and insulation.
- 4 Commissioning of the double-membrane gas storage.
- 5 Professor Hirth giving his speech during the official dedication.
- 6 View of the finished and insulated high-load digestion plant.



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## SYSTEM DESIGN FOR THE TREATMENT OF WASTEWATER FROM VINIFICATION

Dr.-Ing. Tosca Zech

### Heavily loaded industrial wastewater from vinification

Wastewater from vinification contains very high concentrations of organic carbon compounds. Therefore, they are especially suitable for energy recovery by fermenting energy-rich compounds into biogas. In Germany, wastewater from vinification is mostly co-treated in municipal wastewater treatment plants because with few exceptions the annual volume of this wastewater is less than the annual volume of wastewater from an average household. However, wastewater from vinification is mainly produced in autumn after harvesting and wine production. Due to the multitude of wineries as well as wastewater volume and composition, in wine-growing regions (Fig. 1) many wastewater treatment plants have to face problems during operations and additional costs [1], like in the collective municipality Edenkoben on the southern German Wine Route in Rhineland-Palatinate.

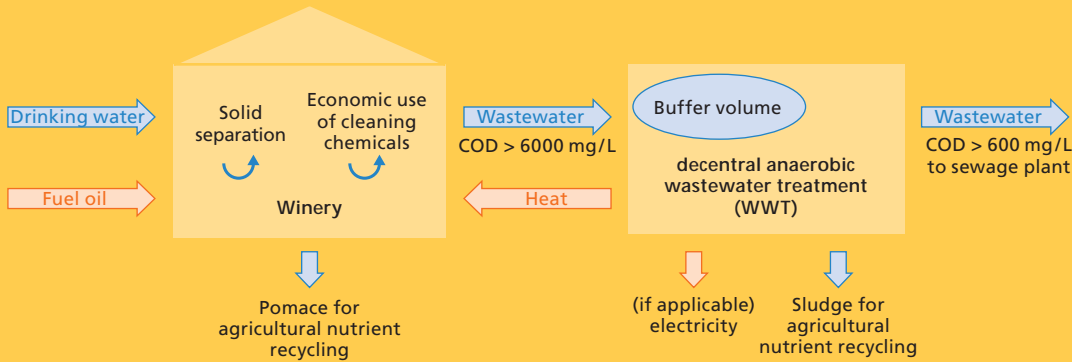
The aim of our investigation was the determination of a process concept for the management of loads of the wastewater treatment plant of Edenkoben by construction of decentralized pre-treatment plants and the creation of storage capacities in the bigger wine companies and cooperatives. Our approach takes into consideration the whole process chain from wastewater production during vinification, wastewater discharge and wastewater treatment to sludge treatment and disposal. By taking into account technological, economic and ecological aspects a concept for the decentralized anaerobic treatment of wastewater from vinification was designed across organizational and geographic boundaries (Fig. 3).

### Decentralized anaerobic wastewater treatment for biogas production

According to our concept drinking water used in the process of vinification is distributed economically in order to save costs for the wine company and to maintain high concentrations of organic compounds in the wastewater produced. Further important principles during production are solid separation to a great extent (grape marc is recycled in agriculture) and economic use of cleaning chemicals for the protection of microorganisms of biological wastewater treatment. Produced wastewater with a chemical oxygen demand (COD) of more than 6000 mg/L is buffered in mixing and equalizing tanks. The core is the decentralized anaerobic wastewater treatment plant for pre-treatment (Fig. 2). Anaerobic microorganisms are producing biogas and reducing COD up to 90 percent in a one-stage plant (Fig. 4). The biogas (methane) is directly utilized and burned in a combined heat and power plant. The decentralized thermal utilization of bioenergy ensures high power efficiency and substitutes parts of conventional oil firing.

During anaerobic biological wastewater treatment little surplus sludge is produced that can be directly recycled in agriculture. Treated wastewater can be discharged into the municipal wastewater treatment plant without further costs for companies in terms of green taxes on heavy pollution. Professional operation of the plant is ensured by applying a BOT model.

Our own measurements have confirmed that wastewater from the chosen wineries is especially suitable for anaerobic pretreatment. COD concentrations are typically between 6000 and 16,000 mg/L. At the same time nutrient concentrations are comparatively low.



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### Improved energetic efficiency of the municipal wastewater treatment plant

Decentralized anaerobic pre-treatment of wastewater from vinification has beneficial effects on the mode of operation of the central municipal wastewater treatment plant. Because carbon compounds are already degraded beforehand peak loads on the central municipal wastewater treatment plant are reduced and nutrient proportion is better balanced. Thus the wastewater treatment plant is loaded more evenly and consumes less energy in total as well as per person equivalent. Because wastewater treatment plants usually require the highest energy consumption of a municipality, the potential for savings is also very high. Furthermore, danger of sludge foaming and bulking and, thus, deleterious effects in the clarification tank is reduced as well as the required volume of the aeration tank. Likewise surplus sludge production is reduced and, thus disposal costs.

Measures put in place directly at the wastewater treatment plant are the construction of a buffer tank in the inflow and primary sedimentation as well as the conversion of the simultaneous and external aerobic sludge stabilization to anaerobic sludge stabilization. The planning of a high load digester was realized within the presented project for sludge production in wastewater treatment plant at times of basic loads. Additional sludge production during harvesting grapes and wine production at peak season is buffered in high-load digestion and the existing external aerobic sludge stabilization.

### Outlook

Gradual implementation of the concept for treating wastewater from vinification demonstrated in the collective municipality Edenkoben is intended. First measures to improve energetic efficiency of the central wastewater treatment plant of Edenkoben have already been taken by the VGW Edenkoben factories themselves. Engineering of the high-load digestion was finished in 2012. The construction of the high-load digestion stage at the wastewater treatment plant of Edenkoben is planned for 2013. Scientific supervision and monitoring are managed by the Fraunhofer IGB.

### Contacts



**Dr.-Ing. Tosca Zech**  
Phone +49 711 970-4115  
tosca.zech@igb.fraunhofer.de



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

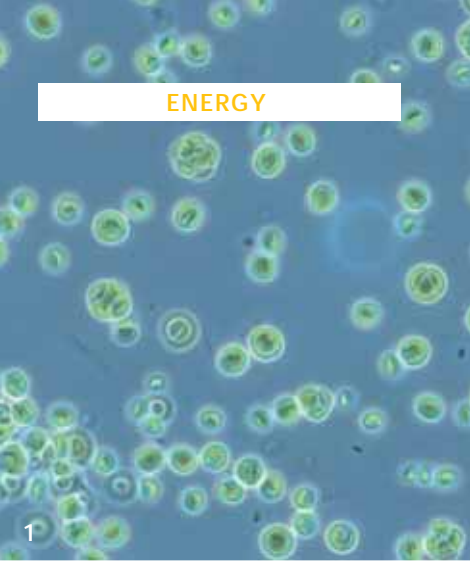
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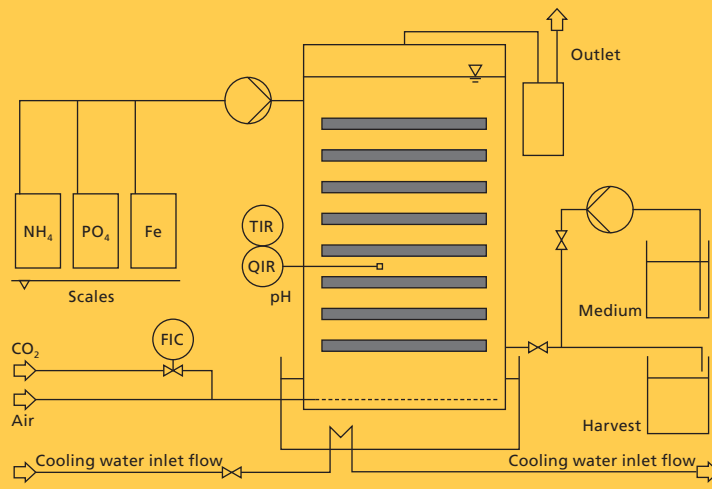
### Project partner

Verbandsgemeindewerke (VGW) Edenkoben, Edenkoben

- 1 Wineries produce large quantities of wastewater after harvesting in autumn.
- 2 Scheme of the concept for the decentralized anaerobic treatment of wastewater from vinification.
- 3 Example of decentral anaerobic reactors in technical application.
- 4 Methane bacteria fluoresce in UV light and appear shining blue in the microscope.



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## ROBUST AUTOMATION CONCEPT FOR THE OUTDOOR PRODUCTION OF ALGAL BIOMASS

Dipl.-Ing. Ronja Mönkel, Dr. rer. nat. Ulrike Schmid-Staiger

### Microalgae as a sustainable energy source

The production of biofuels on the basis of food crops or feed crops (e.g. biodiesel from rapeseed oil or palm oil) is in direct competition with food and feedstuff production. Producing second-generation biofuels with plants not used as food or feedstuffs, for example *Jatropha*, results in competition in terms of water consumption and cropland. Oil from microalgae is a potential alternative to plant biofuels and belongs to the third generation of biofuels. Compared with the cultivation of higher plants, the cultivation of microalgae offers numerous advantages. These include a higher yield per area, a reduced requirement for water and the possibility of growing microalgae on land that can not be used for agriculture. Oils produced by algae can be used as a biofuel, resulting waste gases fed back into the process and the residual biomass that remains is fermented to produce biogas. In order to convert the process to an industrial scale, we have developed a standardized process automation concept for the cultivation of microalgae.

### Production process requirements

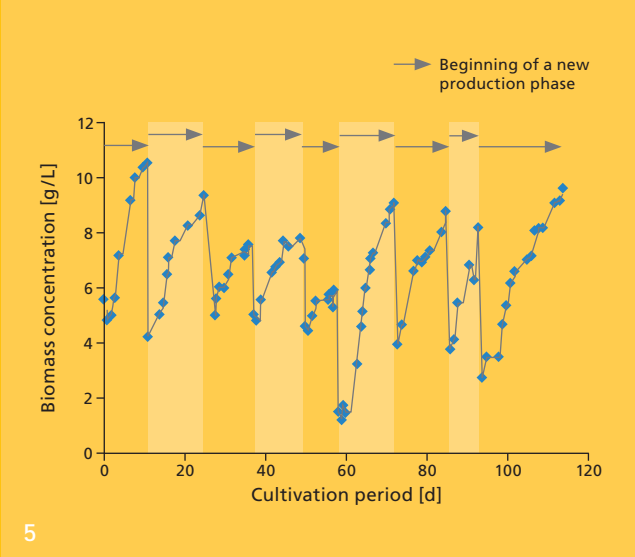
For the commercial production of microalgae and their use as a sustainable energy source, outdoor cultivation using solar energy is essential. Here, special challenges for the process control are the changeable weather conditions and the inherent day-night-rhythm. To deal with these circumstances, it is important to establish as robust a biomass production process as possible, comprising a high degree of automation and simple measurement technique. The process control should therefore be based exclusively on the measurement of the pH value and the reactor temperature.

### Key parameters

The starting point for all experiments was the biomass production process with the microalga *Chlorella vulgaris* (Fig. 1) in a 30-liter flat panel airlift (FPA) reactor. In order to achieve a stable production process, it is vital to supply the microalgae culture continually with carbon dioxide, to make required nutrients such as ammonium available and to maintain the pH value and temperature within an optimum range. The higher the CO<sub>2</sub> concentration in the supply air, the more becomes dissolved as carbon dioxide in the culture medium. This lowers the pH value. This is counteracted by the ammonium dissolved in the medium: the higher the ammonium concentration, the higher the pH value in the culture medium. In addition, the solubility of CO<sub>2</sub> in the medium is influenced by its composition and by the temperature. If, in such a system, the pH value is constantly regulated by means of the carbon dioxide concentration in the supply air, this allows conclusions to be drawn about the ammonium concentration in the reactor. This link was used to determine the consumption of nutrients in the reactor. On the basis of these calculations, we were able to successfully control feeding cycles and exclude nutrient and carbon dioxide limitation.

### Programmable logic controller

The automation concept was achieved – in line with the current industry standard – with the aid of a programmable logic controller (SIMATIC S7-1200, Siemens) and set up outdoors on a test rig with 30-liter flat panel airlift reactors (Figs. 2 and 3). When setting up the control software, it was ensured that it was very user and operator-friendly. The overall process was visualized on a display screen (Fig. 4) and all online data continuously recorded. The control software is constructed in a



modular way and hence can be easily used for new production facilities. Individual program modules can be recombined and may also contribute to controlling other production processes in algal biotechnology.

### Successful biomass production process

With the aid of automation we were able to establish a stable growth process outdoors. Biomass was produced over a period of 113 days with an average productivity of 0.50 g/(L\*d) (Fig. 5), with the average biomass concentration at the point of harvesting being 8.5 g/L. Process monitoring and control were performed exclusively on the basis of reactor temperature and pH value. The established process does not depend on constant productivity and is therefore suitable for outdoor production with changing light and temperature conditions. On the basis of these trials, the production process now needs to be transferred to an industrial scale and production costs reduced further.

- 1 Microscope image of the microalga *Chlorella vulgaris* SAG 211-12.
- 2 Flow diagram of a 30-liter FPA reactor in the outdoor facility.
- 3 Outdoor facility for microalgae production with 30-liter FPA reactors.
- 4 Process visualization on the display screen of the SIMATIC S7-1200 controller.
- 5 Variations in biomass concentration of outdoor cultures of *Chlorella vulgaris* over the trial duration of 113 days.

### Contacts



**Dipl.-Ing. Ronja Muenkel**  
 Phone +49 711 970-4069  
 ronja.muenkel@igb.fraunhofer.de



**Dr. Ulrike Schmid-Staiger**  
 Phone +49 711 970-4111  
 ulrike.schmid-staiger@igb.fraunhofer.de

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### Project partners

Daimler AG | EnBW Baden-Württemberg AG | FairEnergie GmbH | Fraunhofer IVV | Karlsruhe Institute of Technology (KIT) | Netzsch Mohnopumpen GmbH | Paul Scherrer Institute PSI | City of Stuttgart | Stulz Wasser- und Prozesstechnik GmbH



## TOTAL ENERGETIC AND MATERIAL UTILIZATION OF CROP PLANTS: MORE BIOGAS WITHOUT LIGNIN?

Dr. rer. nat. Yasemin Sterr, Prof. Dr. rer. nat. Dieter Bryniok

### Lignin in anaerobic digestion

Alongside liquid manure, agricultural biogas plants primarily use renewable raw materials or “energy crops”. Against this backdrop, recent cultivation attempts have been aiming at increasing the yields per hectare. Higher yields, which appear to promise a higher biogas yield per area of cultivation, usually come at the cost of an increased proportion of lignin, the structural and support substance in plants. Lignin, however, is not metabolized by the anaerobic mixed bacterial culture in biogas plants, which means that the increased biomass can only partially be converted into biogas [1]. The remainder (lignin) causes an increase in digestion residues and generally requires disposal. The overall efficiency and economic attractiveness of the anaerobic digestion process for generating methane can be considerably improved by pre-treating the substrates and through utilization of the product as a raw material.

### Aims of the project

The aim of the project being presented is the complete utilization of the substrates typically used by renewable raw materials plants by means of integrated material and energetic use. Carbohydrates, fats and proteins are digested to produce biogas and the non-digestible lignin is separated off and used as a raw material. In addition, the intention is to convert methane in the presence of carbon dioxide oxidatively to C1-oxygenates (formaldehyde and methanol) using membrane reactors. These compounds may either be utilized materially for the synthesis of chemical raw materials or for improving the transport and storage properties of the gaseous methane

(project partner LIKAT). This lays important foundations for an integrative concept as envisaged by cascade utilization and improves the international competitiveness of German technology providers.

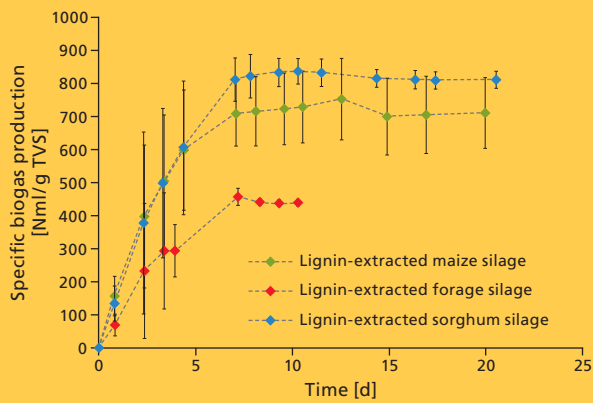
### The latest technology

In methanogenic mixed cultures, organic material is converted into methane in several reaction steps. Macromolecules like carbohydrates, fats and proteins are initially hydrolyzed before being converted into organic acids, alcohols (acidogenic bacteria), acetic acid (acetogenic bacteria) and ultimately to methane and CO<sub>2</sub> (methanogenic archaea) [2].

Experience to date concerning the separation of lignin from plant material leads one to expect that through disintegration and separation of the lignin the lignocellulose structure will be broken up. This ought to produce better substrate availability of freely available carbohydrates in the form of cellulose, a reduction in the proportion of compounds that are difficult to hydrolyze, and hence higher conversion rates in the digestion process. The substrate samples were initially tested on a laboratory scale and are currently being tested on an industrial scale in a methanogenic degradation process with high loading rate in ideally mixed bioreactors.

### Results from the anaerobic degradation

The substrates forage rye silage, maize silage and sorghum silage were each used in unground form, in ground form and after lignin extraction (Fig. 2) for biogas production on a 1-liter laboratory scale (Fig. 1). In the three or four loading



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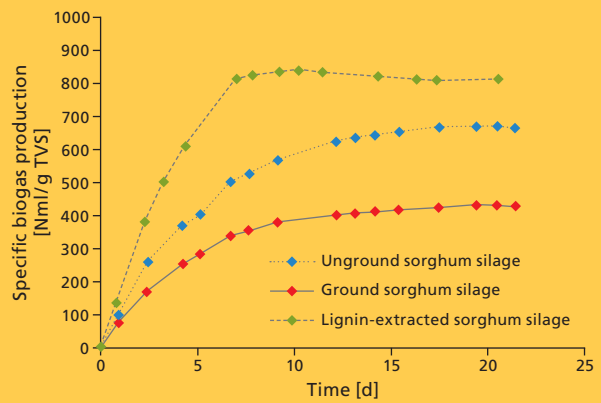
cycles, all substrates were converted into biogas within 7 days at stable pH values and fatty acid concentrations. In addition, the chemical oxygen demand (COD) was reduced. Nutrients important for the digestion process such as  $\text{NH}_4^+\text{-N}$  and  $\text{PO}_4^{3-}\text{-P}$  were present in sufficient concentrations in the reactor throughout the whole fermentation.

With sorghum silage from which the lignin had been extracted, a higher biogas yield of approx. 800–850 NmL (norm milliliters)/g total volatile solids (TVS) (Fig. 3) was achieved compared with maize and forage rye silage from which the lignin had been extracted. As a general principle, the substrates without lignin showed a greater biogas yield (Fig. 4: 800–850 vs. 430–680 NmL/g TVS) because of the expanded lignocellulose structure. The mechanically ground substrates showed, in general, a higher production of biogas compared with unground substrates. Only for sorghum silage was this not observed. Here we assume that components are released that impair the biogas process.

### Outlook

Extraction of lignin taking place before the biogas production represents a very promising increase in the biogas yield with simultaneous creation of value of the raw material lignin as a starting material for the chemical industry. Lignin is an adequate substitute for phenol in the production of resins, for example. Following on from the project, it is intended that the technical results be transferred to an industrial scale in order to enable, in the medium term, the series production of facilities for lignin preparation, biogas production and utilization.

- 1 Double-walled 1-liter laboratory biogas reactors for monitoring anaerobic degradation.
- 2 Used substrates.
- 3 Specific biogas production for substrates with lignin extracted.
- 4 Specific biogas production of sorghum silage.



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### Contacts



**Dr. Yasemin Sterr**

Phone +49 711 970-4116  
yasemin.sterr@igb.fraunhofer.de



**Prof. Dr. Dieter Bryniok**

Phone +49 711 970-4211  
dieter.bryniok@igb.fraunhofer.de

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### Project partners

Fraunhofer ICT, Pfinztal | Leibniz Institute for Catalysis at the University of Rostock (LIKAT), Rostock | Hüttenes-Albertus Chemische Werke GmbH, Düsseldorf | Hölle & Hüttner AG, Tübingen | Johann Dudek Maschinenbau, Berlin | SLP GmbH, Wurmannsquick | BL1 GmbH Lichtenau, Lichtenau



# HIPEL – METAL-COATED SORPTION PELLETS FOR THERMAL STORAGE AND ADSORPTION APPLICATIONS

Dipl.-Ing. Mike Blicher

## Adsorbents for heat storage and material separation

The principle of adsorption is used in many technical applications, for instance to dehumidify air or gases or to separate mixtures of materials. A further application is sorptive thermal storage, which can be used to increase energy efficiency in industrial processes and thermal technology applications. Due to ease of handling and manufacture, pelleted adsorbents (e.g. zeolites, activated carbon, silica gel etc.) in spherical or cylindrical forms are generally used. However, these often have restricted mechanical stability and extremely limited thermal conductivity. This is a disadvantage for the performance of many applications and thermal storage in particular.

## Improved sorption pellets – increased stability and thermal conductivity

Within a project funded by the Fraunhofer-Gesellschaft, the Fraunhofer Institutes IGB, IKTS and IWU are developing metal-coated pellets that, when used as packing provide distinctly increased thermal conductivity, while retaining the same adsorption capacity and are mechanically stable. When used in heat storage devices or heat pumps, increased heat conduction enables significantly increased power density through faster loading and unloading. This should make the temperature regulation of the sorption bed in chemical reaction technology simpler and more effective. An additional goal is to minimize abrasion losses in the transport of materials and filling of the reactor due to increased mechanical stability. This leads to longer lifetimes in sorbent packing and enables new reactors (flow reactor) and mobile applications. In order to achieve the best possible adsorption characteristics the pellets

should have a high internal porosity. The manufacturing method should be suitable for the production of large quantities.

## Manufacturing process and material tests

The project involves the manufacture of cylindrical pellets coated with copper, aluminum or other metals, in which sorbent granules are filled into thin-walled metal tubes. The initial step was the design of a suitable manufacturing process, which consists of the four partial steps of granulation, filling the metal tubes, flow-rolling and separation of the pellets. It is a particular challenge here to carry out the thickening of the material so that the sorbent remains in the metal casing but still retains sufficient porosity to maintain the adsorption characteristics. Model experiments were carried out at the Fraunhofer IKTS using NaY zeolite and various binders. The output pellets are pressed into cylindrical pellets and their strength and specific surface are determined.

Based on these previous experiments, the Fraunhofer IWU designed and constructed a test facility for the manufacture of 5–10 kg of adsorption pellets. The facility will shortly make larger quantities of coated pellets available, in order to test these in the model thermal storage unit at the Fraunhofer IGB.

## Examination of the adsorption characteristics

In parallel, reference measurements were carried out using uncoated pellets at the Fraunhofer IGB. Two qualities of zeolite spheres (diameter 1.6–2.5 mm and 2.5–5 mm), as well as uncoated cylinders (5.25x10 mm) with an alternative binder, which is also used in the coated pellets, were tested with





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regard to their performance in a closed adsorption storage unit. It was shown that size and alternative binders had little effect on the sorption characteristics, such as adsorption capacity and mass-specific heat storage density, in the cylindrical pellets compared to spheres.

#### Measurement of the thermal conductivity of packing

In addition, the Fraunhofer IGB has designed and constructed an apparatus for the measurement of the thermal conductivity of packed beds under variable air or gas pressure in the reactor. The measuring principle is based on the hot wire method, which enables fast and accurate measurements. Measurements are taken in a high vacuum tight container that can be equipped with differently sized sample containers, depending on the quantities of adsorber material. This enables fast reference measurements of the thermal conductivity of sorption pellets under various process conditions.

#### Outlook

Once sufficient quantities of coated pellets are available, these will be examined in the adsorption thermal storage unit (standard 5–10 L storage capacity) at the Fraunhofer IGB under various operating conditions and the results will be compared with the reference data. Investigations of the mechanical stability of the pellets are carried out in parallel. It is then possible to determine the application-relevant use of the novel pellets and the increase in performance achieved. In regard to thermal storage, a significant increase in the power density achieved and therefore greatly reduced loading and unloading times are expected. Finally, a cost-benefit calculation for industrial production will be created.

#### Contacts



**Dipl.-Ing. Mike Blicher**  
Phone +49 711 970-3539  
mike.blicker@igb.fraunhofer.de



**Dipl.-Ing. Siegfried Egner**  
Phone +49 711 970-3654  
siegfried.egner@igb.fraunhofer.de

#### Funding

We would like to thank the Fraunhofer-Gesellschaft for funding the project "HiPel", within the scope of its SME-oriented internal research program (MEF).

#### Project partners

Fraunhofer IKTS, Dresden | Fraunhofer IWU, Chemnitz

- 1 Aluminum and copper coated sorption pellets, Fraunhofer IKTS.
- 2 Experimental set-up for measurement of thermal conductivity of packing in a vacuum.
- 3 Model thermal storage unit.
- 4 Sorption pellets made of NaY zeolite in various sizes and shapes.
- 5 Filling device for metal tubes, Fraunhofer IWU.



# APPENDIX

## PATENTS GRANTED IN 2012

In the year 2012 eleven patents were granted. These patents are assigned to our business areas as follows:

Medicine	Pharmacy	Chemistry	Environment
Arrangement and method for analysis of biological samples US 8,279,434, granted October 2, 2012	In vitro test system for viral infections DE 10 2010 023 156, granted July 5, 2012	Method for producing functional fluorocarbon polymer layers by means of plasma polymerization of perfluorocycloalkanes DE 10 2005 034 764, granted August 2, 2012	Device for generating UV light DE 10 2010 015 495, granted April 26, 2012
Hyphae-specific cell wall proteins of <i>Candida</i> EP 1 727 829, granted February 15, 2012	Three dimensional skin model US 8,222,031, granted July 17, 2012		Method for recovering phosphate salts from a liquid, Reactor for recovering phosphate salts from a liquid
Microfluidic bioreactor DE 10 2008 056 037, granted October 31, 2012	Three dimensional skin model CA 2410956, granted December 4, 2012		DE 10 2010 050 691 and DE 10 2010 050 692, granted March 22, 2012
Three-dimensional biocompatible skeleton structure containing nanoparticles DE 10 2007 020 302, granted March 22, 2012			

## TRADE FAIRS AND EVENTS 2012

### Trade fairs and exhibitions

#### Energy Storage

International Summit for the Storage of Renewable Energies

Fraunhofer Energy Alliance  
March 13–14, 2012,  
Düsseldorf

#### Anuga FoodTec

The international supplier fair for the food and drink industry

Fraunhofer Food Chain Management Alliance  
March 27–30, 2012, Cologne

#### Hannover Messe Research & Technology

Leading Trade Fair for R&D and Technology Transfer  
Joint Fraunhofer booth

April 23–27, 2012, Hanover

#### Hannover Messe Energy

Leading Trade Fair for Renewable and Conventional Power Generation, Power Supply, Transmission, Distribution and Storage

Fraunhofer Energy Alliance  
April 23–27, 2012, Hanover

#### Hannover Messe Metropolitan Solutions & IndustrialGreenTec

Leading Trade Fair for Environmental Technology

Fraunhofer Building Innovation Alliance  
April 23–27, 2012, Hanover

#### IFAT Entsorga

World's leading trade fair for water, sewage, waste and raw materials management

Fraunhofer Water Systems Alliance (SysWasser) and German Water Partnership  
May 7–11, 2012, Munich

#### 3<sup>rd</sup> International Conference Strategies in Tissue Engineering

Fraunhofer Group for Life Sciences  
May 23–25, 2012, Würzburg

#### MS Wissenschaft (MS Science)

Exhibition "Project Earth: Our Future"  
May 30 to October 15, 2012

#### Woche der Umwelt

June 5–6, 2012, Berlin

#### ACHEMA

International Exhibition Congress on Chemical Engineering, Environmental Protection and Biotechnology

Joint Fraunhofer booth  
June 18–22, 2012,  
Frankfurt am Main

#### ESOF 2012

Euroscience Open Forum  
Joint booth Research in Germany  
July 11–15, 2012, Dublin,  
Ireland

#### BIO International Convention

Fraunhofer Group for Life Sciences  
June 18–21, 2012,  
Boston, MA, USA

#### PSE 2012

13<sup>th</sup> International Conference on Plasma Surface Engineering  
September 10–14, 2012,  
Garmisch-Partenkirchen

#### parts2clean

10<sup>th</sup> Leading International Trade Fair for Industrial Parts and Surface Cleaning  
Fraunhofer Cleaning Technology Alliance  
October 23–25, 2012,  
Stuttgart

#### 3<sup>rd</sup> Cooperation Forum

"Biopolymers 2012"  
November 20, 2012,  
Straubing

### Events

#### Checkpoint Zukunft (Checkpoint Future)

Day for students at Fraunhofer  
January 16, 2012, Fraunhofer Institute Center Stuttgart

#### BMBF status seminar "BioEnergie 2021"

February 14–15, 2012,  
Fraunhofer IGB, Stuttgart

#### 16<sup>th</sup> Colloquium of municipal wastewater and waste treatment

"Technologie mit Zukunft"  
February 16, 2012,  
Fraunhofer IGB, Stuttgart

#### Workshop of DGM, BioRegio STERN and BIO Germany

"Neue Biomaterialien und Technologien für die Regenerative Medizin"  
March 29, 2012, Stuttgart

#### Girls' Day

Future Prospects for Girls  
April 26, 2012, Fraunhofer Institute Center Stuttgart

#### Anniversary event of BIOPRO

"Biotechnologie zum Anfassen"  
May 2, 2012,  
Fraunhofer IGB, Stuttgart

#### Spring meeting of Plasma Germany

May 7–8, 2012,  
Fraunhofer IGB, Stuttgart

**“BioRap – 3D-strukturier-  
tes Biomaterial mittels  
Rapid Prototyping”  
Workshop**  
May 16, 2012,  
Fraunhofer IGB, Stuttgart

**9<sup>th</sup> WPC, Natural Fibre  
and other innovative  
Composites 2012**  
June 19–20, 2012, Stuttgart

**13<sup>th</sup> Wörlitz Workshop  
“Membrantechnologien  
und Plasmamodifizierung  
von Membranen”**  
June 20, 2012, Wörlitz

**“Tag der Nachhaltigkeit”  
(Sustainability Action Day)**  
June 29, 2012, Fraunhofer In-  
stitutes Center Stuttgart

**Tag der Wissenschaft (Day  
of Science)**  
June 30, 2012,  
University of Stuttgart

**“Bioenergie – Chancen  
und Grenzen”**  
Panel discussion and exhi-  
bitions  
June 27, 2012, Berlin

**Open house at Leuna  
chemical site**  
September 1, 2012, Leuna

**OTTI expert forum  
“Funktionale Implantat-  
oberflächen”**  
September 17–18, 2012,  
Regensburg

**unitag (University Day)**  
November 21, 2012,  
University of Stuttgart

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## TRADE FAIRS AND EVENTS, PREVIEW 2013

**BAU**  
World’s Leading Trade Fair  
for Architecture, Materi-  
als, Systems  
Fraunhofer Building Innova-  
tion Alliance  
January 14–19, 2013,  
Munich

**International Green Week  
Fair for food, agriculture  
and horticulture**  
Joint Fraunhofer booth  
January 18–27, 2013, Berlin

**Checkpoint Zukunft  
(Checkpoint Future)  
Day for students at Fraun-  
hofer**  
February 4, 2013, Fraunhofer  
Institute Center Stuttgart

**Annual Meeting of the  
German Society for Matrix  
Biology**  
March 7–9, 2013, University  
Hospital, University of Tübingen

**8<sup>th</sup> International Congress  
“Forum Life Sciences”**  
Fraunhofer Group for  
Life Sciences  
March 13–14, 2013,  
TU München

**17<sup>th</sup> Colloquium of municip-  
al wastewater and waste  
treatment  
“Technologie mit Zukunft”**  
March 14, 2013,  
Fraunhofer IGB, Stuttgart

**Fraunhofer Talent School**  
March 15–17, 2013, Fraun-  
hofer Institute Center Stutt-  
gart

**Energy Storage  
International Summit for  
the Storage of Renewable  
Energies**  
Fraunhofer Energy Alliance  
March 18–19, 2013,  
Düsseldorf

**Hannover Messe Energy**  
Leading Trade Fair for Re-  
newable and Conventional  
Power Generation, Power  
Supply, Transmission, Dis-  
tribution and Storage  
Fraunhofer Energy Alliance  
April 8–12, 2013, Hanover

**Hannover Messe Surface  
Technology**  
Leading Trade Fair for Sur-  
face Technology  
Joint Fraunhofer booth  
April 8–13, 2013, Hanover

**Metropolitan Solutions**  
Innovations for Urban In-  
frastructures  
Fraunhofer Building Innova-  
tion and Water Systems (Sys-  
Wasser) Alliances  
April 8–12, 2013, Hanover

**Wasser Berlin  
Trade Fair and Congress  
for Water and Wastewater**  
April 23–26, 2013, Berlin

**Girls’ Day**  
Future Prospects for Girls  
April 25, 2013, Fraunhofer In-  
stitute Center Stuttgart

**Deutsche Biotechnologie-  
tage 2013**  
May 14–15, 2013, Stuttgart

**DECHEMA status work-  
shop  
“Biosurfactants – Chal-  
lenges and Surfactants”**  
May 16–17, 2013,  
Frankfurt am Main

**Tag der Wissenschaft (Day  
of Science)**  
June 22, 2013, University of  
Stuttgart

**Gordon Research Seminar  
und Gordon Research  
Conference (GRS/GRC)  
Elastin, Elastic Fibers &  
Microfibrils**  
July 20–26, 2013,  
University of New England,  
Biddeford, ME, USA

**Anniversary event  
60 years Fraunhofer IGB**  
September 25, 2013,  
Fraunhofer IGB, Stuttgart

**Biotechnica  
Europe's Event for Biotech-  
nology, Life Sciences and  
Lab Technology**  
Fraunhofer Group for  
Life Sciences  
October 8–10, 2013,  
Hanover

**K Trade Fair**  
Joint Fraunhofer booth  
October 16–23, 2013,  
Düsseldorf

**parts2clean**  
11<sup>th</sup> Leading International  
Trade Fair for Industrial  
Parts and Surface Cleaning  
Fraunhofer Cleaning Technol-  
ogy Alliance  
October 22–24, 2013,  
Stuttgart

**World Conference on  
Regenerative Medicine**  
Fraunhofer Group for  
Life Sciences  
October 23–25, 2013,  
Leipzig

**TERMIS-Americas**  
Annual Conference of the  
Tissue Engineering & Re-  
generative Medicine Inter-  
national Society  
November 10–13, 2013,  
Atlanta, GA, USA

**unitag (University Day)**  
November 20, 2013,  
University of Stuttgart

**bone-tec**  
International Bone-Tissue-  
Engineering Congresses  
December 16–19, 2013,  
Singapore

*Details may be subject to  
alterations.*

*Get further information here:  
[www.igb.fraunhofer.de](http://www.igb.fraunhofer.de)*

## COMMITTEE MEMBERSHIPS

-----  
**Borchers, K.**  
-----

**Deutsche Gesellschaft für  
Materialkunde e. V. (DGM),**  
expert committee "Biomateri-  
alien", leader of work group  
"Biomimetische Biomateria-  
lien"

-----  
**Bryniok, D.**  
-----

**DECHEMA (Society for  
Chemical Engineering and  
Biotechnology),** subject di-  
visions "Biotechnologie" and  
"Chemische Biologie", mem-  
ber

**Fraunhofer Water Systems  
Alliance (SysWasser),**  
managing director

**German Water Partner-  
ship,** regional section South-  
eastern Europe, member

**German Scientific-Techni-  
cal Association for Envi-  
ronmental Remediation  
and Brownfield Redeve-  
lopment (ITVA),** member

**The Association of German  
Engineers (VDI),** expert as-  
sociations "Umwelttechnik"  
and "Reinhaltung der Luft",  
member

**Association for General  
and Applied Microbiology  
(VAAM),** expert group "Um-  
weltmikrobiologie", member

-----  
**Funk, M.**  
-----

**Bundesverband der Phar-  
mazeutischen Industrie  
e. V. (BPI),** work group "Ad-  
vanced Therapies", member

-----  
**Hirth, T.**  
-----

**Bio<sup>M</sup> WB,** advisory board,  
member

**DECHEMA (Society for  
Chemical Engineering and  
Biotechnology),** subject di-  
visions "Reaktionstechnik"  
and "Chemische Nanotech-  
nologie", member

**Faculty of Energy Techno-  
logy, Process Engineering  
and Biological Engineering  
at the University of Stutt-  
gart,** Vice Dean

**Fraunhofer Group for Life  
Sciences,** Group Chairman

**Bioeconomy Research  
and Technology Coun-  
cil (BioEconomyCouncil)  
at National Academy of  
Science and Engineering  
(acatech),** member until May  
2012

**German Chemical Society  
(GDCh),** work group "Nach-  
haltige Chemie", member

**Gesellschaft für Umwelt-  
simulation e. V. (GUS),**  
member

**Institute of Textile Techno-  
logy and Process Enginee-  
ring Denkendorf (ITV),** ad-  
visory board, member

Max Planck Institute for Intelligent Systems, advisory board, member

ProcessNet – an Initiative of DECHEMA and VDI-GVC, member of executive board; leader of working committee “Industrielle Nutzung nachwachsender Rohstoffe”; leader of expert group “SuPER”

SusChem Deutschland, coordination group, member

The Association of German Engineers (VDI), member

VDI-Society Energy and Environment (VDI GEU), advisory board, member

VDI-Society for Chemical and Process Engineering (VDI-GVC), advisory board, member

Kluger, P. J.

Deutsche Gesellschaft für Biomaterialien, member

Deutsche Gesellschaft für Materialkunde e. V. (DGM), expert committee “Biomaterialien”, leader of work group “Tissue Engineering”

VDI expert committee “Nanotechnologie in der Medizintechnik”, member

Müller, Michaela

Deutsche Gesellschaft für Materialkunde e. V. (DGM), expert committee “Biomaterialien”, work group “Grenzflächen”, member

Joint Expert Panel “Combined Surface Technology” of the alliances DFO, DGO, EFDS and INPLAS, member

Oehr, C.

BALTIC-NET, member

Bundesverband der pharmazeutischen Industrie e. V. (BPI), work group “Stoffliche Medizinprodukte”, member

Deutsche Gesellschaft für Galvano- und Oberflächentechnik e. V., member

European Society of Thin Films (EFDS), member

Fraunhofer Polymer Surfaces Alliance POLO®, deputy director

13<sup>th</sup> International Conference on Plasma Surface Engineering PSE 2012, vice chairman; editorial board

Network of Competence Industrial Plasma Surface Technology INPLAS, member of executive board

PLASMA Germany, chairman; member of coordination committee; member of expert committee “Plasmabehandlung von Polymeren”

Plasma Processes and Polymers, WILEY-VCH, Weinheim, co-editor in chief

Vakuum in Forschung und Praxis, WILEY-VCH, Weinheim, editorial board

The Association of German Engineers (VDI), steering committee “Qualitätssicherung bei der Vakuumbeschichtung von Kunststoffen”, member

VDI expert committee “Nanotechnologie in der Medizintechnik”, vice chairman

Rupp, S.

German Society for Hygiene and Microbiology (DGHM), expert group “Eukaryontische Krankheitserreger”, executive board

Deutschsprachige Mykologische Gesellschaft e. V. (DMykG), member

European Union, evaluator for the Seventh Framework Programme of Research

FEBS Advanced Lecture Course, organization committee, member

Society for Biochemistry and Molecular Biology (GBM), member

Stuttgart Research Center (SRC) Systems Biology, member

Schenke-Layland, K.

L’Agence nationale de la recherche – ANR, expert evaluator for single application procedure

American Association of Anatomists, scientific affairs committee; evaluator of Young Investigator Awards

Arthritis Research UK, expert evaluator for single application procedure

German Research Foundation (DFG), expert evaluator for research fellowships and single application procedure

German Society for Matrix Biology, member

European Society for Biomaterials (ESB), member

International Society for Stem Cell Research (ISSCR), member

Research Council – Katholieke Universiteit Leuven, expert evaluator for single application procedure

----- <b>Schiestel, T.</b> -----	<b>Society for Biochemistry and Molecular Biology (GBM), member</b>	----- <b>Unkelbach, G.</b> -----	<b>Scientific and Technical Council of Fraunhofer-Gesellschaft, member</b> -----
<b>Deutsche Gesellschaft für Materialkunde e. V. (DGM), community committee "Hochleistungskeramik", work group "Keramische Membranen", member</b>	<b>Straubing Center of Science, member of directorate</b> -----	<b>American Chemical Society (ACS), "Division of Cellulose and Renewable Materials", "Division of Biochemical Technology" and "Division of Catalysis Science and Technology", member</b>	<b>Walles, H.</b> -----
----- <b>Schließmann, U.</b> -----	<b>HACH LANGE GmbH, consumer advisory board, member</b>	----- <b>DECHEMA (Society for Chemical Engineering and Biotechnology), member</b>	<b>German Federal Ministry of Education and Research (BMBF), expert evaluator</b>
<b>DECHEMA (Society for Chemical Engineering and Biotechnology), subject division "Membrantechnik", member</b>	----- <b>Tovar, G. E. M.</b> -----	----- <b>Vohrer, U.</b> -----	<b>Bundesverband der Pharmazeutischen Industrie e. V. (BPI), work group "Tissue Engineering", member</b>
----- <b>Schmid-Staiger, U.</b> -----	<b>German Bunsen Society for Physical Chemistry (DBG), member</b>	----- <b>German Bunsen Society for Physical Chemistry (DBG), member</b>	<b>German Academic Exchange Service, expert evaluator for special program "Moderne Anwendungen in der Biotechnologie"</b>
<b>aireg – Aviation Initiative for Renewable Energy in Germany e. V., work group "Rohstoffbereitstellung", member</b>	<b>DECHEMA (Society for Chemical Engineering and Biotechnology), subject division "Nanotechnologie", member</b>	<b>Deutsche Physikalische Gesellschaft (DPG), member</b>	<b>German Research Foundation (DFG), expert evaluator for SFB (TransRegio), doctorate program, single application procedure</b>
<b>European Algae Biomass Association (EABA), member</b>	<b>Deutsche Gesellschaft für Materialkunde e. V. (DGM), Expert committee "Biomaterialien", leader work group "Biomimetische Biomaterialien"</b>	<b>Expert forum "Reinigung und Vorbehandlung vor der Beschichtung" of Ostbayerischen Technologie-Transfer-Institut e. V. (OTTI), conference advisory board/specialist manager</b>	<b>DECHEMA (Society for Chemical Engineering and Biotechnology), work group "Medizinische Biotechnologie", member</b>
----- <b>Sieber, V.</b> -----	-----	<b>Research Alliance Cultural Heritage FALKE, founding member</b>	<b>German Society for Regenerative Medicine, advisory board</b>
<b>German Federal Ministry of Education and Research (BMBF), expert evaluator</b>	<b>Fraunhofer Nanotechnology Alliance, spokesman and steering committee</b>	<b>Fraunhofer Cleaning Technology Alliance, founding member</b>	<b>DIN, the German Institute for Standardization, standards committee "Feinmechanik und Optik NAFuO", collaboration on working committee "Medizinische Produkte auf Basis des Tissue Engineering"</b>
<b>German Research Foundation (DFG), expert evaluator</b>	<b>German Chemical Society (GDCh), member</b>	<b>German Chemical Society (GDCh), member</b>	<b>European Union, evaluator for Seventh Framework Programme for Research</b>
<b>DECHEMA (Society for Chemical Engineering and Biotechnology), member</b>	<b>ProcessNet – an Initiative of DECHEMA and VDI-GVC, expert group "Nanotechnologie", appointed member</b>	<b>Standing committee of Fraunhofer-Gesellschaft, member</b>	
<b>Research Center for Industrial Biotechnology at the TUM, member of directorate</b>	<b>Kolloid-Gesellschaft, member</b>	<b>The Association of German Engineers (VDI), member</b>	
<b>German Chemical Society (GDCh), member</b>	<b>NanoMAT, member</b>		



Gesundheitsforschungsrat  
des BMBF, member of medi-  
cal-technical committee

German National Academ-  
ic Foundation, person of  
confidence

VDI expert committee  
"Nanotechnologie in der  
Medizintechnik", member

-----  
**Weber, A.**  
-----

DECHEMA (Society for  
Chemical Engineering and  
Biotechnology), member

GMM VDE/VDI-Society Mi-  
croelectronics, Microsys-  
tems and Precision Engi-  
neering, expert committee  
4.7 (Mikro-Nano-Integration),  
evaluator in program com-  
mittee

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## SCIENTIFIC COOPERATIONS

-----  
**With universities**  
-----

Aristotle University of  
Thessaloniki, Greece

Charles University,  
Prag, Czech Republic

Comenius University,  
Bratislava, Slovakia

Cranfield University,  
Cranfield, UK

Eberhard Karls Universität  
Tübingen

Energieinstitut an der  
Johannes Kepler Universität  
Linz GmbH, Austria

Ernst-Moritz-Arndt-  
Universität Greifswald

Escola de Engenharia de  
Piracicaba (EEP), Brazil

Escola Superior de Agricultu-  
ra "Luiz de Queiroz" (ESALQ),  
Piracicaba, Brazil

Georgia Institute of Technol-  
ogy, Atlanta, GA, USA

Gottfried Wilhelm Leibniz  
Universität Hannover

Hebrew University of  
Jerusalem, Israel

Hochschule Hamm-Lippstadt

Julius-Maximilians-  
Universität, Würzburg

Katholieke Universiteit  
Leuven, Belgium

Letterkenny Institute of Tech-  
nology, Letterkenny, Ireland

Linnéuniversitetet,  
Kalmar, Sweden

Ludwig-Maximilians-  
Universität München

Lunds Universitet,  
Lund, Sweden

Martin-Luther-Universität  
Halle-Wittenberg

McGill University,  
Montreal, Canada

Medizinische Hochschule  
Hannover MHH

Medizinische Universität  
Innsbruck, Austria

National University of Ireland,  
Galway, Ireland

Queensland University of  
Technology,  
Brisbane, Australia

Rheinisch-Westfälische  
Technische Hochschule  
(RWTH) Aachen

Royal Institute of Technology,  
Stockholm, Sweden

Ruhr-Universität Bochum

Stanford University, CA, USA

Stichting Dienst Landbouw-  
kundig Onderzoek,  
Wageningen, Netherlands

Stockholms Universitet,  
Stockholm, Sweden

Technische Universität  
Darmstadt

Technische Universität  
Kaiserslautern

Technische Universität  
München

Technische Universiteit  
Eindhoven, Netherlands

Tierärztliche Hochschule  
Hannover

Trinity College Dublin, Ireland

Universidad de Sevilla, Spain

Universidade Metodista de Piracicaba (UNIMEP), Brazil	Univerza v Mariboru, Maribor, Slovenia	Deutsches Krebsforschungszentrum (DKFZ), Heidelberg	Leibniz-Institut für Plasmaforschung und Technologie e. V. (INP), Greifswald
Universita degli Studi di Bari, Italy	Uppsala Universitet, Uppsala, Sweden	Deutsches Zentrum für Biomaterialien und Organersatz Stuttgart-Tübingen	Ludwig Institute for Cancer Research, Stockholm, Sweden
Universita degli Studi di Milano-Bicocca, Italy	VTT Technical Research Centre of Finland, Finland	Dr. Margarete Fischer-Bosch-Institut für Klinische Pharmakologie (IPK), Stuttgart	Max-Planck-Institut für Dynamik komplexer technischer Systeme, Magdeburg
Universität Hamburg	-----	-----	-----
Universität Heidelberg	<b>With other research organizations</b> -----	European Molecular Biology Laboratory EMBL, Heidelberg	Max-Planck-Institut für Festkörperforschung, Stuttgart
Universität Hohenheim	AIT – Austrian Institute of Technology, Vienna, Austria	Flanders Institute for Biotechnology (VIB), Gent, Belgium	Max-Planck-Institut für Intelligente Systeme, Stuttgart
Universität Innsbruck, Austria	Asociación Acondicionamiento Tarrasense (LEITAT), Terrassa (Barcelona), Spain	Institut Carnot CIRIMAT, Toulouse, France	Max-Planck-Institut für Kolloid- und Grenzflächenforschung, Golm
Universität Konstanz	-----	-----	-----
Universität Leipzig	Association pour la Recherche et le Developpement des Methodes et Processus Industriels – ARMINES, Paris, France	Institut Dr. Schrader Creachem GmbH, Holzmin-den	Max-Planck-Institut für Polymerforschung, Mainz
Universität Stuttgart	-----	-----	-----
Universität Vienna, Austria	-----	Institut für Textil- und Verfahrenstechnik ITV, Denkendorf	National Institute of Laser, Plasma and Radiation Physics, Magurele-Bucharest, Romania
Université Paul Sabatier Toulouse III, Toulouse, France	Bundesanstalt für Materialforschung und -prüfung (BAM), Berlin	Institut für Textilchemie und Chemiefasern ITCF, Denkendorf	-----
Universitetet for Miljo og Biovitenskap, Aas, Norway	Centre de Recerca i Innovació de Catalunya CRIC, Barcelona, Spain	Institut National des Sciences et Technologies de la Mer, Salammbou, Tunisia	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek TNO, Netherlands
Universitetet i Bergen, Bergen, Norway	-----	-----	-----
University of California Los Angeles (UCLA), Los Angeles, CA, USA	Centre for Process Innovation CPI, Wilton, Redcar, UK	Institut Pasteur, Paris, France	Norwegian Institute of Food, Fisheries and Aquaculture Research Nofima, Oslo, Norway
University of Novi Sad, Novi Sad, Serbia	Centro tecnológica CARTIF, Valladolid, Spain	IVL Swedish Environmental Research Institute Ltd., Stockholm, Sweden	Austriaische Akademie der Wissenschaften, Innsbruck, Austria
University of Southern California (USC), Los Angeles, CA, USA	Centro Tecnológico Agrario y Agroalimentario Asociacion, Palencia, Spain	Karlsruher Institut für Technologie (KIT), Karlsruhe	-----
University of Sydney, Australia	Chemical Process Engineering Research Institute (CPERI), Thessaloniki, Greece	Laboratoire Phenobio SAS, Martillac, France	PROFACTOR GMBH, Steyr-Gleink, Austria
University of West Hungary, Sopron, Hungary	Consiglio Nazionale Delle Ricerche – ITM-CNR, Rome, Italy	Leibniz-Institut für Katalyse e. V. (LIKAT), Rostock	Research & Development centre Re/genT, Helmond, Netherlands

Robert-Koch-Institut, Berlin	Herz- und Diabeteszentrum Nordrhein-Westfalen, Univer- sitätsklinik der Ruhr-Universi- tät Bochum	Universitätsklinikum Innsbruck, Austria	Deutsches Bergbaumuseum, Bochum
Teknologisk Institutt (TI), Oslo, Norway		Universitätsklinikum Lübeck	Deutsches Museum, München
Vlaamse Instelling Voor Tech- nologisch Onderzoek N. V (VITO), Mol, Belgium	Karl-Olga-Krankenhaus, Stuttgart	Universitätsklinikum Tübingen	Deutsches Schifffahrts- museum, Bremerhaven
-----	Klinik Charottenhaus, Stuttgart	Universitätsklinikum Ulm	Germanisches National- museum, Nürnberg
<b>With hospitals</b>		Universitätsklinikum Würzburg	Landesmuseum Württem- berg, Stuttgart
-----	Klinik Schillerhöhe, Gerlingen	University Hospital Lausanne, Switzerland	Stiftung Preußischer Kultur- besitz, Rathgen-Forschungs- labor, Berlin
Charité – Universitätsmedizin Berlin	Robert-Bosch-Krankenhaus, Stuttgart	-----	
Haukeland University Hospi- tal, Bergen, Norway	Sana Herzchirurgie Stuttgart	<b>With museums</b>	
	Universitätsklinik Frankfurt am Main	-----	
		Bayerisches Hauptstaats- archiv, München	Zentrum für Bucherhaltung, Leipzig

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## LECTURES AND SEMINARS

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<b>Esslingen University of Applied Sciences</b>	Bryniok, D. <b>Lecture "Technische Mechanik II"</b>	Bryniok, D. <b>Seminar "Energie und Wasser"</b>	Bryniok, D. <b>Exercises for lecture "Tech- nische Mechanik I"</b>
<b>Summer semester 2012</b>	Study course Energy Engi- neering and Resource Opti- misation, 1 SH	Study course Energy Engi- neering and Resource Opti- misation, 1 SH	Study course Energy Engi- neering and Resource Opti- misation, 4 SH
Zech, T. (with Biener, R.) <b>Lecture "Umweltbiotech- nologie"</b>	Bryniok, D. <b>Exercises for lecture "Tech- nische Mechanik II"</b>	<b>Winter semester 2012/2013</b>	Bryniok, D. <b>Consolidation practical course "Bioenergie"</b>
Faculty of Natural Sciences, Biotechnology B.Sc., 2 SH	Study course Energy Engi- neering and Resource Opti- misation, 3 SH	Bryniok, D. <b>Lecture "Technische Mechanik I"</b>	Study course Energy Engi- neering and Resource Opti- misation, 2 SH
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<b>Hamm-Lippstadt University of Applied Sciences</b>	Bryniok, D. <b>Lecture "Energie und Was- ser"</b>	Study course Energy Engi- neering and Resource Opti- misation, 2 SH	Bryniok, D. <b>Mentoring practical se- minars</b>
<b>Summer semester 2012</b>	Study course Energy Engi- neering and Resource Opti- misation, 1 SH		Study course Energy Engi- neering and Resource Opti- misation
Bryniok, D. <b>Lecture "Bioenergie I"</b>			
Study course Energy Engi- neering and Resource Opti- misation, 1 SH			

<p>-----</p> <p><b>Offenburg University of Applied Sciences</b></p> <p>-----</p> <p><b>Winter semester 2012/13</b></p> <p>Kluger, P. J.</p> <p><b>Lecture "Werkstoffe in der Medizintechnik – Biologische Aspekte", 1 SH</b></p> <p>-----</p> <p><b>University of Stuttgart</b></p> <p>-----</p> <p><b>Summer semester 2012</b></p> <p>Hirth, T.</p> <p><b>Lecture "Biologische und chemische Verfahren zur industriellen Nutzung von Biomasse (Energieträger und Chemierohstoffe)"</b></p> <p>Faculty of Energy Technology, Process Engineering and Biological Engineering, Energy Technology M.Sc., Environmental Engineering M.Sc., 2 SH</p> <p>Hirth, T.; Rupp, S.</p> <p><b>Lecture "Biomaterialien – Biobasierte Materialien"</b></p> <p>Faculty of Energy Technology, Process Engineering and Biological Engineering, Technical Biology B.Sc., 2 SH</p> <p>Hirth, T.; Tovar, G. E. M.</p> <p><b>Lecture "Grenzflächenverfahrenstechnik I – Chemie und Physik der Grenzflächen"</b></p> <p>Faculty of Energy Technology, Process Engineering and Biological Engineering, Process Engineering M.Sc., Major study field, 2 SH</p>	<p>Hirth, T.; Bach, M.; Tovar, G. E. M.</p> <p><b>Lecture "Komplexe Fluide"</b></p> <p>Faculty of Energy Technology, Process Engineering and Biological Engineering, Process Engineering M.Sc., 2 SH</p> <p>Hirth, T.</p> <p><b>Lecture "Nachhaltige Rohstoffversorgung – Von der Erdölraffinerie zur Bioraffinerie"</b></p> <p>Faculty of Energy Technology, Process Engineering and Biological Engineering, Interdisciplinary key qualification, 2 SH</p> <p>Rupp, S.</p> <p><b>"Ausgewählte Kapitel der modernen Biochemie"</b></p> <p>Faculty of Chemistry, study course Biochemistry, 1 SH</p> <p>Rupp, S.</p> <p><b>Parts of lecture "Moderne Methoden in der Biochemie"</b></p> <p>Faculty of Chemistry, study course Biochemistry, 1 SH</p> <p>Rupp, S.</p> <p><b>Parts of "Biochemisches Forschungspraktikum für Diplom-Chemiker"</b></p> <p>Faculty of Chemistry, study course Biochemistry, 8 SH</p> <p>Tovar, G. E. M.; Borchers, K.</p> <p><b>Lecture "Biomaterialien – Biokompatible Materialien"</b></p> <p>Faculty of Energy Technology, Process Engineering and Biological Engineering, Technical Biology B.Sc., 2 SH</p>	<p>Tovar, G. E. M.; Hirth, T. (with Groß, J.)</p> <p><b>Lecture "Grundlagen der Verfahrenstechnik I"</b></p> <p>Faculty of Energy Technology, Process Engineering and Biological Engineering, Technical Biology B.Sc., 2 SH</p> <p>Tovar, G. E. M.; Rupp, S.; Hirth, T. (with Doser, M. and Planck, H.)</p> <p><b>Lecture "Medizinische Verfahrenstechnik I"</b></p> <p>Faculty of Energy Technology, Process Engineering and Biological Engineering and Faculty of Engineering Design, Production Engineering and Automotive Engineering, Process Engineering M.Sc. and Diploma, Mechanical Engineering Diploma, 2 SH</p> <p>Tovar, G. E. M.; Hirth, T.</p> <p><b>Lecture "Nanotechnologie I – Chemie und Physik der Nanomaterialien"</b></p> <p>Faculty of Energy Technology, Process Engineering and Biological Engineering, Process Engineering M.Sc., Major study field, Technical Biology Diploma, 2 SH</p> <p>Tovar, G. E. M.</p> <p><b>Lecture "Produktgestaltung mit Nano-, Bio- und Hybridmaterialien"</b></p> <p>Faculty of Chemistry, Chemistry Diploma, 2 SH</p>	<p><b>Winter semester 2012/13</b></p> <p>Barz, J.; Hampel, M.; Hansmann, J.; Hoppensack, A.; Kluger, P.; Linke, K.; Tovar, G. E. M. (with Doser, M.)</p> <p><b>Lecture "Medizinische Verfahrenstechnik II"</b></p> <p>Faculty of Energy Technology, Process Engineering and Biological Engineering and Faculty of Engineering Design, Production Engineering and Automotive Engineering, Process Engineering M.Sc. and Diploma, Mechanical Engineering Diploma, 2 SH</p> <p>Hirth, T.; Tovar, G. E. M.; Oehr, C.</p> <p><b>Lecture "Grenzflächenverfahrenstechnik II – Technische Prozesse"</b></p> <p>Faculty of Energy Technology, Process Engineering and Biological Engineering, Process Engineering M.Sc., Major study field, 2 SH</p> <p>Hirth, T.; Tovar, G. E. M.; Oehr, C.</p> <p><b>Lecture "Grundlagen der Grenzflächenverfahrenstechnik"</b></p> <p>Faculty of Energy Technology, Process Engineering and Biological Engineering, Process Engineering M.Sc., Major study field, 2 SH</p> <p>Hirth, T.; Tovar, G. E. M. (with Groß, J.)</p> <p><b>Lecture "Grundlagen der Verfahrenstechnik II"</b></p> <p>Faculty of Energy Technology, Process Engineering and Biological Engineering, Technical Biology B.Sc., 2 SH</p>
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Hirth, T. <b>Lecture "Nachhaltige Rohstoffversorgung und Produktionsprozesse"</b> Faculty of Energy Technology, Process Engineering and Biological Engineering, Process Engineering M.Sc., 2 SH	Tovar, G. E. M.; Hirth, T. <b>Lecture "Nanotechnologie II – Technische Prozesse und Anwendungen für Nanomaterialien"</b> Faculty of Energy Technology, Process Engineering and Biological Engineering, Process Engineering M.Sc., Major study field, Medical Engineering B.Sc., Materials Science M.Sc., Technical Biology Diploma, 2 SH	Hirth, T.; Tovar, G. E. M. <b>Excursion "Grenzflächenverfahrenstechnik"</b> Faculty of Energy Technology, Process Engineering and Biological Engineering, Process Engineering M.Sc., Major study field, Technical Biology Diploma, Medical Engineering B.Sc., 2 SH	Frank, D.; Haitz, T.; Hansmann, J.; Kahlig, A.; Stier, M.; Tovar, G. E. M. <b>"Arbeitstechniken und Projektarbeit (Exercise)"</b> Faculty of Energy Technology, Process Engineering and Biological Engineering, Process Engineering B.Sc., 2 SH
Hirth, T. <b>Lecture "Sustainable Production Processes"</b> Faculty of Energy Technology, Process Engineering and Biological Engineering, WASTE M.Sc., 2 SH	Tovar, G. E. M. <b>Seminar "Rezente Methoden der Medizintechnik auf Basis von Nanotechnologie und Grenzflächenverfahrenstechnik"</b> Faculty of Energy Technology, Process Engineering and Biological Engineering, Medical Engineering B.Sc., 2 SH	Tovar, G. E. M., Hirth, T. <b>Practical course "Grenzflächenverfahrenstechnik"</b> Faculty of Energy Technology, Process Engineering and Biological Engineering, Process Engineering M.Sc., Major study field, Technical Biology Diploma, 2 SH	----- <b>Technische Universität München</b> ----- <b>Summer semester 2012</b>
Oehr, C. <b>Lecture "Plasmaverfahren für die Dünnschicht-Technik"</b> Faculty of Energy Technology, Process Engineering and Biological Engineering, Process Engineering M.Sc., 2 SH	Tovar, G. E. M. und weitere <b>Practical course "Medizinische Verfahrenstechnik"</b> Faculty of Energy Technology, Process Engineering and Biological Engineering, Process Engineering and Cybernetics M.Sc., Technical Biology Diploma	Tovar, G. E. M. und weitere <b>Practical course "Nanotechnologie"</b> Faculty of Energy Technology, Process Engineering and Biological Engineering, Major study field, Technical Biology Diploma, Medical Engineering B.Sc., 2 SH	Sieber, V. <b>Lecture "Einführung in die Weiße Biotechnologie"</b> Study course Renewable Resources, 2 SH
Rupp, S. <b>Parts of "Biochemisches Praktikum für Technische Biologen"</b> Faculty of Chemistry, study course Biochemistry, 8 SH	<b>Summer semester 2012 and winter semester 2012/13</b>  Hirth, T.; Tovar, G. E. M. <b>"Mitarbeiterseminar für DoktorandInnen und DiplomandInnen"</b> Interdisciplinary course, 1 SH	Tovar, G. E. M. und weitere <b>Practical course "Nanotechnologie"</b> Faculty of Energy Technology, Process Engineering and Biological Engineering, Major study field, Technical Biology Diploma, Medical Engineering B.Sc., 2 SH	Sieber, V. <b>Lecture "Enzymengineering"</b> Study course Industrial Biotechnology, 2 SH
Rupp, S. <b>Seminar "Anleitung zu wissenschaftlichem Arbeiten"</b> Study course Process Engineering, Chemistry, Technical Biology	Hirth, T. <b>Seminar "Anleitung zu wissenschaftlichem Arbeiten"</b> Study course Process Engineering, Technical Biology, WASTE	Tovar, G. E. M. <b>Seminar "Anleitung zu wissenschaftlichem Arbeiten"</b> Study course Process Engineering, Technical Biology, Medical Engineering	Sieber, V. <b>Parts of lecture "Technologie und Verwertung sonstiger biogener Rohstoffe"</b> Study course Forestry, 5 SH
	Hirth, T.; Tovar, G. E. M. <b>"Grenzflächenverfahrenstechnisches Kolloquium"</b> Interdisciplinary course, 1 SH		Sieber, V. <b>Lecture "Biokatalyse und Proteintechnologie"</b> Study course Chemistry, 1 SH
			<b>Winter semester 2012/13</b>
			Sieber, V. <b>Lecture "Technische Biokatalyse"</b> Study course Industrial Biotechnology, 2 SH

Sieber, V.

**Lecture "Einführung in die Stoffliche Nutzung"**

Study course Renewable Resources, 2 SH

Sieber, V.

**Parts of lecture "Bioraffinerie und Naturstofftechnologien"**

Study course Renewable Resources, 4 SH

Sieber, V.

**Parts of lecture "Spezielle Biotechnologie"**

Study course Renewable Resources, 2 SH

**Heidelberg University  
Biochemistry Center**

**Summer semester 2012**

Sohn, K.

**Parts of seminar and practical course "Einführung in biochemische Methoden"**

Medical Faculty, Study course Biochemistry, Seminar: 2 SH, Practical course: 6 SH

**Winter semester 2012/13**

Sohn, K.

**Parts of seminar and practical course "Blut und Eisenstoffwechsel"**

Medical Faculty, Study course Biochemistry, Seminar: 2 SH, Practical course: 6 SH

**University of Hohenheim**

**Summer semester 2012**

Kluger, P. J.

**Lecture "Tissue Engineering"**

Faculty of Science, Nutritional Science B.Sc., Food Science and Biotechnology B.Sc., 2 SH

**University of Tübingen**

**Winter semester 2012/13**

Schenke-Layland, K.

**Lecture "Vitale Implantate – Biomaterialien"**

Faculty of Medicine, Medical Technologies B.Sc., 2 SH

**University of Würzburg**

Walles, H.

**Lecture "Grundlagen des Tissue Engineering", 5 SH**

Walles, H.

**Lecture/exercise "Mikrosysteme für biologische und medizinische Anwendungen", 5 SH**

Walles, H.

**Lecture "Tissue Engineering", 2 SH**

Walles, H.

**Practical course "Modellorganismen", 1 week full-time**

Walles, H.

**"Stammzellen"**

Integrated seminar for medical students, 2 SH

*Stated are the total semester hour(s) (SH) of the particular lecture or course.*

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# ACADEMIC THESES

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## Dissertations

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Blath, J.

**Ionische Flüssigkeiten in der Gasseparation**, Universität Stuttgart, Fraunhofer Verlag, ISBN 978-3-8396-0399-4

Gose, T.

**Analyse, Optimierung und Maßstabsübertragung der Herstellung und Aufarbeitung von Siliciumdioxid Nanopartikeln**, Universität Stuttgart, Fraunhofer Verlag, ISBN 978-3-8396-0422-9

Katzenmayer, V.

**Charakterisierung von Kohlenstoffnanoröhren mit Raman-Spektroskopie**, Universität Stuttgart

Mai, M.

**DNA-microarray for fungal species identification and monitoring of resistance-associated SNPs in *Candida albicans***, Universität Stuttgart, Fraunhofer Verlag, ISBN 978-3-8396-0408-3

Purschke, F. G.

**Phänotypische und molekularbiologische Untersuchungen der Interaktionen in gemischten Biofilmen**, Universität Stuttgart

Wojciukiewicz, D.

**Herstellung und Charakterisierung von Polymernanopartikeln als Adsorbentmaterialien für die Peptidsequenzen des Insulins**, Universität Stuttgart, Fraunhofer Verlag, ISBN 978-3-8396-0421-2

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## Diploma theses

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Dannenmann, B. A.

**Die Untersuchung des Einflusses N-limitierter Fed-Batch Verfahren auf die spezifische Gibberellinproduktion von *Fusarium fujikuroi***, Universität Hohenheim

Eigenstetter, G.

**Etablierung eines microarray-basierten Verfahrens zur Quantifizierung von *Candida glabrata* Deletionsmutanten**, Universität Stuttgart

Engelhardt, I.

**Charakterisierung des Wirkmechanismus einer neuen antimykotischen Substanz in humanpathogenen Hefen**, Technische Universität Darmstadt

Frey, T.

**Title protected**, Otto von Guericke Universität Magdeburg

Hoffmann, H.

**Wirt-Pathogen-Interaktionen von *Candida albicans* und *Candida dubliniensis* auf humanen Epithelzelllinien**, Universität Stuttgart

Kazenwadel, F.

**Molekulare Werkzeuge zur Optimierung der *in vivo* Integration unnatürlicher Aminosäuren in *Candida albicans***, Universität Stuttgart

Maucher, T.

**Untersuchungen zur Eignung eines neuartigen mikrobiellen Breitband-sensorsystems für die Detektion von chemischen und biologischen Kontaminationen in Trinkwasser**, Universität Stuttgart

Otrokov, I.

**Zeitaufgelöste Elektronenspinresonanz an Plasmapolymeren**, Universität Stuttgart

Rebscher, T.

**Etablierung einer neuartigen Automatisierungsstrategie für den Biomasseproduktionsprozess mit der Mikroalge *Chlorella vulgaris* im Flachplatten-Airlift-Reaktor**, Technische Hochschule Mittelhessen

Stolarow, J.

**Title protected**, Universität Stuttgart

Wettengel, J.

**Aufschlussverfahren zur Probenvorbereitung in der Diagnostik von Pilzen**, Universität Stuttgart

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## Master theses

---

Fecher, D.

**Development of technologies to engineer human lung tumor models**, Julius-Maximilians-Universität Würzburg

Grimmer, P.

**Inline-Charakterisierung in einer Miniplant-Anlage – Miniemulsions-Polymerisationen von Poly(MAA-co-EGDMA)**, Universität Stuttgart

Huang, J.

**Title protected**, Ruhr Universität Bochum

Huber, B.

**Isolation und Kultivierung von humanen primären subkutanen Adipozyten und Aufbau eines Subkuttis-Äquivalentes mithilfe von Adipozyten und ASCs**, Universität Hohenheim

Kendler, C.

**Design of a purification process for gibberellin 4 and 7 out of *Fusarium fujikuroi* fermentation broths**, Universität Stuttgart

- Kirch, H.  
Untersuchungen zur Eig-  
nung eines Fasermaterials  
auf Kieselgelbasis für den  
Einsatz im Tissue Enginee-  
ring, Julius-Maximilians-Uni-  
versität Würzburg
- König, L.  
Title protected, Hochschule  
RheinMain
- Kuhn, R.  
Inkjet printing of silver  
nanoparticle ink on glass  
substrates to produce  
miniaturized plasma elec-  
trodes, Hochschule Offen-  
burg
- Lagunes Diaz, G. E.  
Development of a model  
for mass and energy flows  
internally and externally  
via interface for self-sus-  
tainable greenhouse, Tech-  
nische Universität Berlin
- Liebscher, S.  
Identifikation von Protein-  
expressionsmustern in hu-  
manen sich entwickelnden  
semilunaren Herzklappen,  
Universität Rostock
- Purschwitz, I.  
Synthese und Charakteri-  
sierung von Polymeren aus  
biobasierten Rohstoffen,  
Hochschule Esslingen/Hoch-  
schule Aalen
- Penninger, C.  
Title protected, Universität  
Stuttgart
- Rivas Gonzalez, J. A.  
Title protected, Universität  
Stuttgart
- Ruppel, O.  
Untersuchung zum Abbau  
von Methylenblau in wäss-  
riger Lösung durch Plasma-  
entladung, Universität Stutt-  
gart
- Schmohl, L.  
Isolation and characteri-  
zation of adipose-derived  
stem cells and their adhe-  
sion and proliferation po-  
tential on low-pressure  
plasma modified surfaces,  
Universität Konstanz
- Stratmann, A.  
Establishment and valida-  
tion of complex 3D human  
tumor models, Julius-Maxi-  
milians-Universität Würzburg
- Votteler, M.  
Acquisition of RNA from  
FFPE fetal and adult hu-  
man heart valve leaflets  
for transcriptional profil-  
ing, Universität Tübingen
- Wenz, A.  
Einfluss VEGF-modifizier-  
ter Polymeroberflächen  
auf mikrovaskuläre Endo-  
thelzellen, Hochschule Alb-  
stadt-Sigmaringen
- Willig, M.  
Zellbiologische Evaluie-  
rung von modifizierten  
Polylactid-Hydroxylapa-  
tit-Proben als Träger-  
substanzen für das Kno-  
chen-Tissue-Engineering,  
Universität Hohenheim
- **Bachelor theses**  
-----
- Arnold, E.  
Title protected, Hochschule  
Biberach
- Auer, A.  
Plasmaverfahren zur Ge-  
ruchs- und Keimreduzie-  
rung in Gasströmen, Uni-  
versität Hohenheim
- Engelhardt, L.  
Electrophysiological char-  
acterization of *in vitro* skin  
models, Friedrich-Alexander-  
Universität Erlangen-Nürn-  
berg
- Gawrischenko, A.  
Implementierung einer  
Applikation zur Archivie-  
rung und Aufbereitung  
von Raman-Spektrosko-  
piedaten, Hochschule der  
Medien Stuttgart
- Götz, T.  
Herstellung und Funktio-  
nalisierung hochporöser  
azidhaltiger Polymerschäu-  
me, Hochschule Reutlingen
- Haller, B.  
Dynamische 3D-Kultivie-  
rung von mesenchymalen  
Stammzellen auf  $\beta$ -TCP,  
Hochschule Esslingen
- Hämmerl, A.  
*In vivo*-Lokalisation von  
Zellwandproteinen in  
*Saccharomyces cerevisiae*  
unter Verwendung des  
erweiterten genetischen  
Codes, Hochschule Mann-  
heim
- Königseder, A.  
Charakterisierung des Li-  
pidproduktionsprozesses  
im Freiland mit der Mikro-  
alge *Chlorella vulgaris*  
hinsichtlich der relativen  
Lichtverfügbarkeit, Fach-  
hochschule OberAustria
- Koronai, A.  
Title protected, Universität  
Stuttgart
- Lang, C.  
Präparation und Charak-  
terisierung funktioneller  
Silanschichten an Implan-  
tatoberflächen, Universität  
Stuttgart
- Leppert, A.  
Einfluss von entzündlichen  
Darmerkrankungen auf  
das enterische Nervensys-  
tem der Maus, Julius-Maxi-  
milians-Universität Würzburg
- Linder, S.  
Characterization of myo-  
cardial cells during heart  
development with Raman  
spectroscopy, Universität  
Hohenheim
- Meyer, R.  
Title protected, Hochschule  
Furtwangen
- Misterek, R.  
Title protected, Hochschule  
für Technik, Wirtschaft und  
Kultur Leipzig
- Molina Galindo, J. K.  
Charakterisierung eines  
3D Darmtumormodells  
mit Untersuchungen zur  
Induktion von Apoptose,  
Julius-Maximilians-Universität  
Würzburg



- Mugele, D.  
Tissue engineering of a vascularized meniscus by use of co-culture, Julius-Maximilians-Universität Würzburg
- Neusch, D.  
Effizienzsteigerung einer Elektrolysezelle – basierend auf dem Prozess der erweiterten Oxidation (AOP) – zur Aufbereitung von Deponiesickerwasser, Hochschule Esslingen
- Rathfelder, T.  
Title protected, Hochschule Mannheim
- Rautenberg, F.  
Title protected, Hochschule Bremerhaven
- Reich, S.  
Title protected, Hochschule Biberach
- Reiss, P.  
Title protected, Fachhochschule Düsseldorf
- Reisser, T.  
Title protected, Hochschule Biberach
- Ruetschle, I.  
Entwicklung einer vaskularisierten Trägerstruktur für das Tissue Engineering mittels plastischer Kompression eines Kollagen Hydrogels, Hochschule Ulm
- Schubert, V.  
Title protected, Hochschule Heilbronn
- Seitz, T.  
Herstellung und Charakterisierung von Benzophenon-funktionalisiertem Polyglycidol sowie dessen photochemische Anbindung an Silizium-Oberflächen, Hochschule Reutlingen
- Teubner, A.  
Charakterisierung verschiedener Gibberellin-produzierender Mutanten von *Fusarium fujikuroi*, Universität Stuttgart
- Töpfer, S.  
Title protected, Universität Hohenheim
- Unger, C.  
Establishment of 3D endothelial-mesenchymal co-cultures under static and dynamic conditions, Julius-Maximilians-Universität Würzburg
- Walz, M.  
Polymerisation biobasierter und sterisch anspruchsvoller Epoxide, Hochschule Reutlingen
- Weisser, S.  
Title protected, Hochschule Furtwangen
- Volk, E.  
Title protected, Hochschule Heilbronn
- Zhang, X.  
Radikale in Plasmapolymerschichtungen, Hochschule Hannover
- **Student research studies**  
-----  
Castrillón Torres, D. M.  
Methods of analysis of biofouling potential on filter membranes in bioreactors during the treatment of wastewater, industrial wastewater and leachate, Universität Stuttgart
- Wagenmann, A.  
Title protected, Universität Stuttgart
- **Internship reports**  
-----  
Bahret, E.  
Title protected, Universität Stuttgart
- Böhringer, D.  
Title protected, Universität Hohenheim
- Bosch, M.  
Prozessoptimierung der plastischen Verformung von Hautgewebemodellen, Universität Hohenheim
- Gordzielik, M.  
Title protected, Technische Universität Dortmund
- Hempelt, S.  
Title protected, Universität Hohenheim
- Löder, J.  
Title protected, Hochschule Mannheim
- Müller, H.  
Kultivierung von *Fusarium fujikuroi* zur Gewinnung von Gibberellin sowie anaerobe Abwasseraufbereitung, Hochschule Amberg-Weiden
- Rebholz, A.  
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- Rupp, S.  
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- Schiestel, T.  
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- Schiestel, T.  
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- Schließmann, U.  
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- Schmid-Staiger, U.; Seibert, A.; Hirth, T.  
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- Tovar, G.  
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- Vohrer, U. **Analytik I – Prozess- und Schadensanalytik, Oberflächenanalytische Methoden zur Sauberheitskontrolle**, 4. Grundlagenseminar "Reinigungstechnik – Reinigung in der Produktion", June 13–16, 2012, Dresden
- Vohrer, U. **Parylene – eine Alternative in der Konservierung und Restaurierung**, Präsentation der Forschungsallianz Kulturerbe, July 26, 2012, Dresden
- Vohrer, U. **Toxizität von Kohlenstoffnanoröhren**, 14. Chemnitzer Seminar "Nanotechnology, Nanomaterials und Nanoreliability", September 27, 2012, Chemnitz
- Votteler, M.; Schenke-Layland, K. **Acquisition of RNA from FFPE fetal and adult human heart valves leaflets for transcriptional profiling**, 3<sup>rd</sup> International Conference "Strategies in Tissue Engineering", May 23–25, 2012, Würzburg
- Weber, A. **Neue reaktive Tonerpartikel für dreidimensionale Elektrophotographie**, Workshop BioRap "3D-strukturierte Biomaterialien mittels Rapid-Prototyping", May 16, 2012, Stuttgart
- Zech, T. **Semidezentrales Abwassermanagement in Deutschland und China**, 16. Kolloquium zur Abwasser- und Abfallbehandlung, February 16, 2012, Stuttgart
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- Zibek, S. **Synthesis of microbial surfactants**, Seminar am Institut für physikalische Chemie, Universität Cologne, July 16, 2012, Cologne
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- Posters**
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- Appelt, A.; Slanina, H.; Rossi, A.; Groll, J.; Schubert-Unkmeir, A.; Walles, H. **Development of a human *in vitro* 3D model to simulate the human blood-cerebrospinal fluid (B-CSF) and blood brain barrier (BBB)**, XVIII<sup>th</sup> International Pathogenic Neisseria Conference (IPNC), September 9–14, 2012, Würzburg
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70569 Stuttgart | Germany

Phone +49 711 970-3601  
Fax +49 711 970-4200  
info@igb.fraunhofer.de  
www.igb.fraunhofer.de

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## EDITORIAL ADDRESS

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

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**Fraunhofer Institute  
for Interfacial Engineering  
and Biotechnology IGB**

Nobelstrasse 12  
70569 Stuttgart  
Germany

**Director**

Prof. Dr. Thomas Hirth  
Phone +49 711 970-4400  
thomas.hirth@igb.fraunhofer.de

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



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