FRAUNHOFER INSTITUTE FOR INTERFACIAL ENGINEERING AND BIOTECHNOLOGY IGB

ANNUAL REPORT 2016 | 17

Bioreactor for the conversion of renewable raw materials using microorganisms. At BioCat, the Straubing branch of the institute, biotechnological processes are also combined with chemical and electrochemical processes, to convert biomass into new products for the chemical industry.

ANNUAL REPORT

2016|17

CONTENTS


HC
CO2
CO

DEAR READERS,

In 2016 we reviewed our strategy and defined three business areas that we intend to focus on. These are Health, Chemistry and Process Industry, and Environment and Energy. The aim is to create innovative products and to develop new processes in all three areas. To do this, we first develop the processes on a laboratory scale and then scale them up to an industry-relevant level.

Until now the scaling up was carried out mainly at the Fraunhofer CBP in Leuna. Working with large volumes of up to 10 cubic meters is almost a matter of routine there, both for public-sector projects and directly under contract for industry. In the meantime over 100 conversion batches have been processed in the Leuna lignocellulose biorefinery pilot plant and several 100 kilograms of product samples based on lignin and celluloses have been supplied to various users. In view of this successful development, the state of Sachsen-Anhalt has made available funds for extending the plant. The first projects were successfully completed in 2016 within the BioEconomy Cluster of Excellence. Further processes for scaling up in Leuna are already in the pipeline in Stuttgart and our branch institute in Straubing. With the CBP in Leuna we have closed the gap in scaling up from laboratory tests to the industrial scale and now offer a flagship biorefinery at the European level.

An important issue across the various business areas is the use of carbon dioxide as a raw material. In this area, our colleagues in Straubing have succeeded in procuring funds for a European project which deals with the electrochemical and biochemical conversion of CO_2 (see p. 82).

The scale-up and scalability of processes is a matter of crucial importance for an institute oriented towards process engineering. In 2009, for example, we already planned technical departments at the Stuttgart location that enable us to develop further processes at an industry-relevant level. A new building was needed for this, and it has been available and operative since December 2016. We will realize our newly developed processes, and combine processes, in various technical departments with pilot facilities. For example, one of the technical departments will be dedicated to the subject of "Water" and will cater for various biological, chemical and physical processes and combinations of processes for the purification of industrial and urban wastewater. At the same time, valuable residual substances such as phosphorus will be recovered for use as agricultural fertilizers – in a process developed and patented by us.

We are also pleased that, with the completion of the pilot plant building, it will be possible to handle the projects more rapidly and that our "Organ-on-a-chip" Attract Group, which was set up in spring 2016, can develop in a suitable laboratory environment. Being able to use the new building also means an easing of the situation in the existing laboratory, to which special safety guidelines apply, such as for S2 and GLP laboratories.

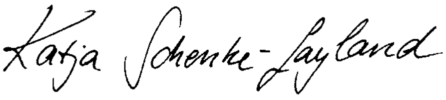
At the end of the year we began with a further innovation. To make even better use of our experts' know-how in our core competences, we are supporting the creation of interdepartmental specialized groups. Up till now different aspects of our key topics such as "Water" or "Biomaterials" were worked on in different departments. Now, due to the more intensive cooperation, we can give more weight and better visibility to these topics.

Also, we are especially pleased that the first of our four planned spin-off companies has already been established – the Noscendo GmbH. Currently the conditions for the further development of the company and cooperation between Fraunhofer and the firm are being negotiated.

Finally we would like to inform you that the appointment for the successor of Professor Hirth, the former director of our institute, is progressing and that the search committee will probably agree on a candidate this spring.

We would now like to thank all our customers and partners for the trust you have placed in us. We look forward to successfully completing the projects that we have begun together and also of course to tackling new projects with you. We hope you will find this report fascinating reading and trust that the present annual report that you have in your hands provides new impulses for further cooperation.

We look forward to working with you and to a lively exchange of views.



Katja Schenke-Layland

Christian Oehr

FRAUNHOFER IGB IN PROFILE 2016

18 Apprentices

42 Doctoral students

11 Associate lecturers

200 Students

469 Employees

25 Nationalities

2 Prizes and awards

75 University employees

394 Fraunhofer employees

51 % Proportion of women

14 BoGy high school students

2.9 million € Investments

29.4 million € Total budget

11.6 million € Non-personnel costs

14.9 million € Personnel costs

71 % Own revenues

18 Members of Advisory Board

3 Branches

11 Fraunhofer Alliances

2 Fraunhofer Groups

5 Departments

PROFILE

INNOVATIONS AT INTERFACES

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

Application-oriented and interdisciplinary

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

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

Competences

Departments in Stuttgart

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

Branches of the institute

- Fraunhofer Center for Chemical-Biotechnological Processes CBP, Leuna branch
- Bio, Electro, and Chemocatalysis BioCat, Straubing branch
- Translational Center "Regenerative Therapies for Oncology and Musculoskeletal Diseases", Würzburg branch

Mission

"At 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 health, chemistry and process industry as well as environment and energy. With our innovations, we contribute to a sustainable development of the economy, society and the environment."

BOARD OF TRUSTEES

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

SERVICES AND INFRASTRUCTURE

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

Infrastructure and laboratory equipment

State-of-the-art technologies and extensive, modern equipment are indispensable to our scientific work – and an added benefit for you as our customer. We have modern laboratories, including BSL2 (biological safety level 2) laboratories. A new technical center commenced its operations at the turn of the year. Our central chemical and pollutant storage facility is used by the entire Stuttgart Fraunhofer Institute Center.

Quality management and assurance systems

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

Accredited testing

The accreditation of reference laboratories and test procedures of our analytics guarantees that our proprietary, in-house test methods and procedures are validated and that the quality of our tests is assured even where no standardized methods are available.

The following analytical methods and test procedures are accredited according to DIN EN ISO/IEC 17025:

- High-performance liquid chromatography (HPLC)
- Ion chromatography (IC)
- Gas chromatography (GC, GC/MS)
- Atomic emission spectrometry (ICP-OES)
- Electron spectroscopy for chemical analysis (ESCA/XPS)
- *In vitro* cytotoxicity testing
- *In vitro* phototoxicity testing of solutions and substances

Accredited biocompatibility and phototoxicity testing

We perform tests for *in vitro* cytotoxicity according to DIN EN ISO 10993-5 using cell lines. With our in-house method for *in vitro* phototoxicity testing, we can investigate solutions and substances with respect to their phototoxic potential on our in-house designed three-dimensional skin model. The test method is in accordance with the OECD Guideline 432 and the INVITTOX Protocol no. 121.

Good laboratory practice (GLP) test facility

Several non-clinical tests are running at our category 9 GLP unit ("Cell-based test systems for the determination of biological parameters") to support research and development projects that investigate biological parameters of samples/substances using cell-based assays. Examples are the testing of bioactivity, cytotoxicity and immunogenicity of compounds using immune receptor-based assays, screening of TLR agonists/antagonists, testing of antimicrobial properties of substances or surfaces, as well as detection of pyrogens and microbial residues (pathogen-associated microbial patterns, PAMPs).

Spectrum of services

Process and product development

- Design and construction of demonstration plants and prototypes
- Implementation of new technologies
- Licensing of technologies and processes

Studies and consultancy

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

Analysis and testing services

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

Physico-chemical analysis

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

High-resolution 400 MHz NMR analysis

Molecular structure elucidation, reaction monitoring, development of novel experimental NMR methods, low-temperature analysis

Surface and particle analysis

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

Microbial evaluation

Testing of antimicrobial effects and photocatalytic properties of surfaces

Biochemical and biomolecular analysis

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

Next-generation sequencing

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

Cell biology analysis

Cell characterization, single cell preparation/microdissection, flow cytometry, quality and sterility control of tissue engineering products

Cell-material interactions

Testing of cytotoxicity/biocompatibility of R&D materials and industrial products, assessment of phototoxicity of substances and solutions, evaluation and testing of chemicals (REACH) and nanomaterials

For detailed information on the analytical services we offer, please visit:
www.igb.fraunhofer.de/analytics

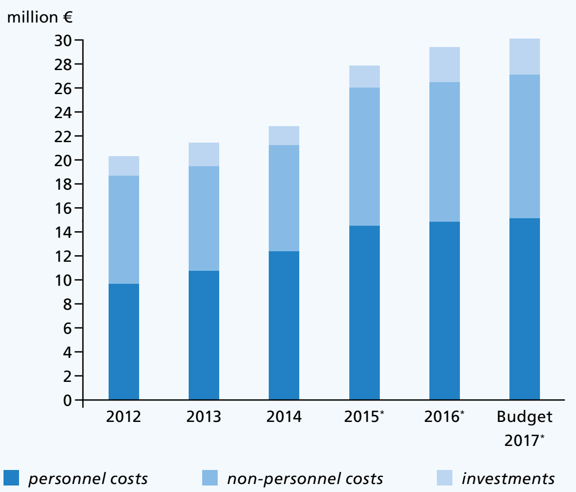
KEY FIGURES

Budget of Fraunhofer IGB

The total budget for 2016 amounted to 29.4 million euros, of which 26.5 million euros were allocated to the operational budget (personnel costs: 14.9 million euros; non-personnel costs: 11.6 million euros). A total of 2,9 million euros was spent on investments.

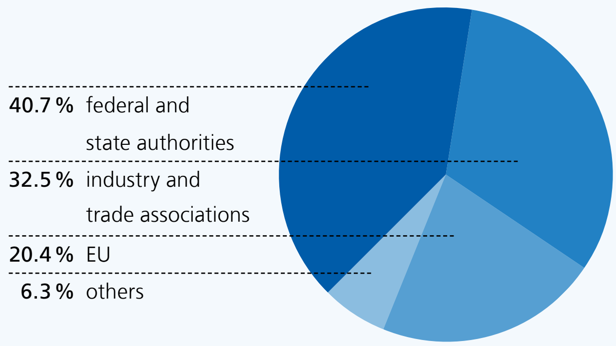
71.0 percent of the operational budget was financed from Fraunhofer IGB's own revenues generated from contract research projects. 32.5 percent of the institute's revenues came directly from industry.

Development of budget



* incl. CBP (after state government initial financing completed)

Revenue from contract research 2016



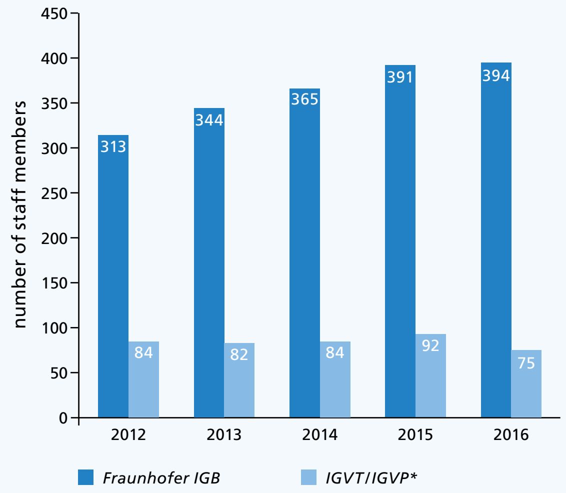
Personnel

At the end of 2016, Fraunhofer IGB (in Stuttgart and its branches in Straubing, Würzburg, and Leuna) had a staff of 394 of which some 90 percent were scientific or technical employees. Women made up 55 percent of the total.

The Institute of Interfacial Process Engineering and Plasma Technology IGVP at the University of Stuttgart counted a staff of 75 as of December 31, 2016, predominantly scientists and doctoral students as well as technical staff and student research assistants. Women constituted 27 percent of the total.

The employees of Fraunhofer IGB, of its branches, and of IGVP work together closely and have very culturally diverse backgrounds, with 33 staff members coming from 25 different countries outside Germany.

Development of staff members



* Stuttgart University's Institute for Plasma Research IPF was integrated into the Institute for Interfacial Engineering IGVT in January 2013.

Staff composition as of December 31, 2016	**Fraunhofer IGB**	**IGVP**
Scientists	95	12
Technical staff	101	13
Doctoral students	2	31
Administrative and secretarial staff	39	4
Apprentices	13	5
Scholarship holders	–	9
Work students/Master students/student apprentices	49	(55)*
Student research assistants	95	1
	394	**75**

* Academic theses at IGVP did not count as staff.

ORGANIZATION CHART

**Director
(acting, executive)**

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

**Director
(acting)**

Hon.-Prof. Dr. Christian Oehr
Phone +49 711 970-4137
christian.oehr@igb.fraunhofer.de

Deputy Director

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

Assistant to Director

Sara Bevilacqua
Phone +49 711 970-4402
sara.bevilacqua@igb.fraunhofer.de

INTERFACIAL ENGINEERING AND MATERIALS SCIENCE

Hon.-Prof. Dr. Christian Oehr
Phone +49 711 970-4137
christian.oehr@igb.fraunhofer.de

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

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

- Membranes
- Particle-based Systems and Formulations
- Plasma Technology and Thin Films
- Polymeric Interfaces and Biomaterials

MOLECULAR BIOTECHNOLOGY

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

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

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

- Infection Biology and Array Technologies
- Functional Genomics
- Molecular Cell Technologies
- Industrial Biotechnology
- Analytics

PHYSICAL PROCESS TECHNOLOGY

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

Dr. Thomas Scherer
Phone +49 711 970-4091
thomas.scherer@igb.fraunhofer.de

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

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

Administration
Controlling and Finance


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

Administration
Human Resources and Organization


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

Business Development


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

Business Development


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

Press and Public Relations


Dr. Claudia Vorbeck
Phone +49 711 970-4031
claudia.vorbeck@igb.fraunhofer.de

ENVIRONMENTAL BIOTECHNOLOGY AND BIOPROCESS ENGINEERING


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


Prof. Dr. Dieter Bryniok
Phone +49 711 970-4211
dieter.bryniok@igb.fraunhofer.de


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

- Algal Technology
- Bioprocess Engineering
- Bioenergy
- Integrated Water Management

CELL AND TISSUE ENGINEERING


Prof. Dr. Petra Kluger
Phone +49 711 970-4072
petra.kluger@igb.fraunhofer.de


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


Dr. Svenja Hinderer
Phone +49 711 970-4196
svenja.hinderer@igb.fraunhofer.de

- Cardiovascular Systems, Biomaterials and Bioimaging
- Attract Group "Organ-on-a-chip"

BRANCHES OF THE INSTITUTE

Fraunhofer CBP, Leuna


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

BioCat, Straubing


Prof. Dr. Volker Sieber
Phone +49 9421 187-300
volker.sieber@igb.fraunhofer.de

Translational Center Regenerative Therapies, Würzburg


Prof. Dr. Heike Walles
Phone +49 931 31-88828
heike.walles@igb.fraunhofer.de

FRAUNHOFER IGB'S NETWORKING ACTIVITIES

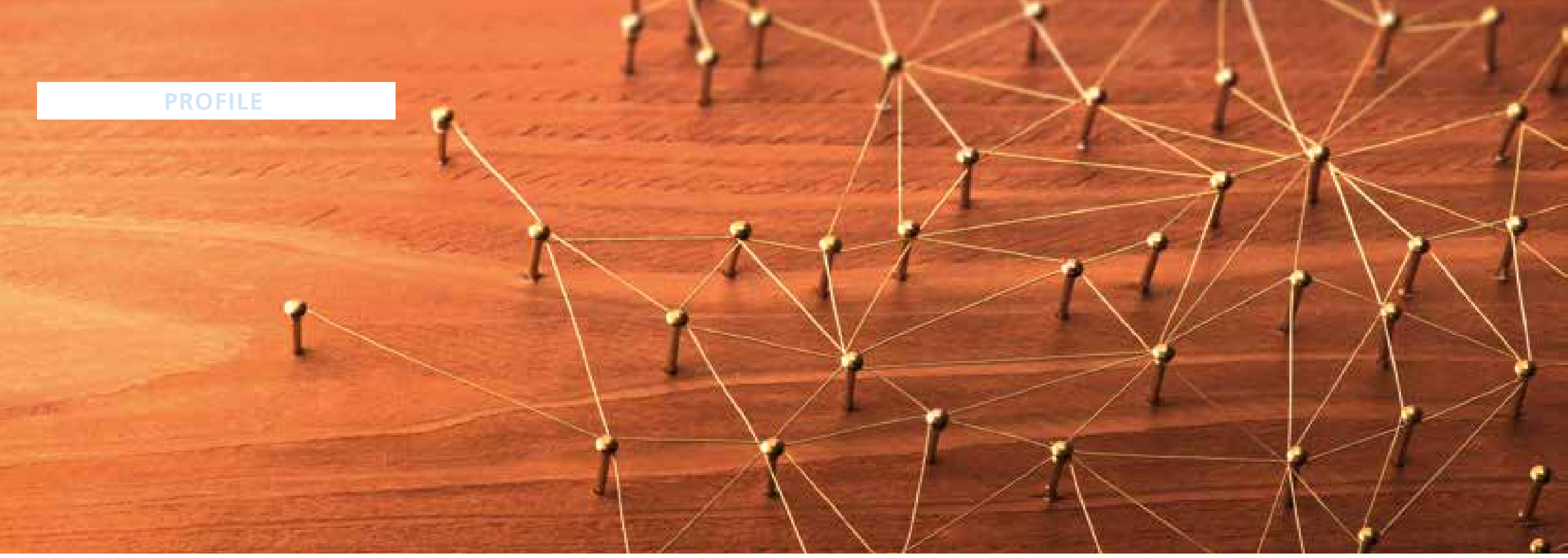
Fraunhofer IGB is an active participant in numerous national and international research networks. Cooperative ventures with various universities and non-university research institutes, as well as interdisciplinary collaboration with other Fraunhofer Institutes, complement our own expertise and enable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

Networking with universities

Basic research is a prerequisite for the applications of tomorrow. Hence, Fraunhofer IGB maintains close contacts with neighboring universities, both through scientific cooperation and through professorial or other teaching commitments of Fraunhofer employees. In addition, our branches in Straubing, Würzburg and Leuna have enabled us to extend our scientific network to locations outside of Stuttgart. Fraunhofer IGB is particularly closely allied to the Institute of Interfacial Process Engineering and Plasma Technology IGVP at the University of Stuttgart through various teaching activities as well as joint operations.

- **Priv.-Doz. Dr. Susanne Bailer**
  Private lecturer in the Faculty of Energy Technology, Process Engineering and Biological Engineering at the University of Stuttgart
- **Dr. Kirsten Borchers**
  Associate lecturer in the Faculty of Energy Technology, Process Engineering and Biological Engineering at the University of Stuttgart
- **Prof. Dr. Dieter Bryniok**
  Professor of Environmental Biotechnology at Hamm-Lippstadt University of Applied Sciences
- **Prof. Dr. Petra Kluger**
  Professor of Tissue Engineering at Reutlingen University, Faculty of Applied Chemistry
- **Hon.-Prof. Dr. Christian Oehr**
  Associate lecturer in the Faculty of Energy Technology, Process Engineering and Biological Engineering at the University of Stuttgart
- **apl. Prof. Dr. Steffen Rupp**
  Adjunct professor in the Faculty of Energy Technology, Process Engineering and Biological Engineering at the University of Stuttgart
- **Prof. Dr. Katja Schenke-Layland**
  Professor of Biomedical Technologies and Regenerative Medicine at the University Hospital for Women of the Eberhard Karls University Tübingen;
  Adjunct Associate Professor at the David Geffen School of Medicine, Department of Cardiology of the University of California Los Angeles (UCLA), Los Angeles, CA, USA
- **Dr.-Ing. Ursula Schließmann**
  Teaching activity 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 Technical University of Munich (TUM)

- **apl. Prof. Dr. Günter Tovar**
  Adjunct professor at the Faculty of Energy Technology, Process Engineering and Biological Engineering at the University of Stuttgart; Director (acting) of the Institute of Interfacial Process Engineering and Plasma Technology IGVP at the University of Stuttgart (since 2016)
- **Prof. Dr. Heike Walles**
  Professor and Chair of Tissue Engineering and Regenerative Medicine at the University of Würzburg



Selected networks of Fraunhofer IGB

- BioMedTech e. V.
- Brennstoffzellen- und Batterie-Allianz BW (BBA-BW)
- CLIB2021 Cluster Industrielle Biotechnologie e. V. – The Bioeconomy Network
- Deutsche Phosphor-Plattform DPP e. V.
- EU Working Group for Research and Technological Development Organizations (RTOs) in Baden-Württemberg
- European Sustainable Phosphorus Platform ESPP
- European Technology Platform for Water WssTP
- Forum MedTech Pharma e. V.
- Forschungsallianz Kulturerbe
- Fraunhofer EU Network
- Fraunhofer Sustainability Network
- Fraunhofer International Business Development (IBD) Network
- German Water Partnership e. V.
- Industrielle Biotechnologie Bayern Netzwerk GmbH – IBB Netzwerk
- Innovationsnetzwerk Regeneratives Methanol

Selected networks of Fraunhofer CBP

- BioEconomy Cluster e. V.
- Science Campus Halle – Plant-Based Bioeconomy (WCH)
- HYPOS – Hydrogen Power Storage & Solutions East Germany
- Fraunhofer High Performance Center "Chemical and Biosystems Technology"
- ERIFORE – European Research Infrastructure for Circular Forest Bioeconomy
- SmartPilots Interreg Europe
- COST Action FP1306 "Valorisation of lignocellulosic biomass to Chemicals, Materials and Fuels"
- BioRaf – ZIM Cooperation Network Biorefineries
- ProIDRA – ZIM Cooperation Network Iberischer Drachenkopf (dragon's head)
- Wood K plus – Competence Center for Wood Composites and Wood Chemistry

For further information on IGB's networking activities please visit:
www.igb.fraunhofer.de/network

For further information on CBP's networking activities please visit:
www.cbp.fraunhofer.de/network

FRAUNHOFER GROUPS AND ALLIANCES

Fraunhofer Institutes working in related subject areas cooperate as groups, foster a joint presence on the R&D market and help define the Fraunhofer-Gesellschaft's business policy. Institutes or departments of institutes with complementary expertises collaborate in Fraunhofer "Alliances" to develop business areas together and offer market solutions along the entire value chain. Fraunhofer IGB is an active member of the Fraunhofer Group for Life Sciences and, due to its strong focus on materials science, an associated institute of the Fraunhofer Group for Materials and Components – MATERIALS. Furthermore, it is a member of various Fraunhofer Alliances and thus optimally integrated within the Fraunhofer network.

Fraunhofer Groups

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

Fraunhofer Alliances

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

In addition, Fraunhofer Institutes carry out joint activities within Fraunhofer internal research programs. Examples of IGB's involvement are the Fraunhofer lighthouse projects "Theranostic Implants", "Critical Rare Earths", "E^3-Production", and "Electricity as a Raw Material".

For further information on our networking activities please visit:
www.igb.fraunhofer.de/network

HIGHLIGHTS 2016

RESEARCH – COLLABORATIONS AND PROJECTS

CO_2 interconnected – from a climate risk factor to a highly sought-after raw material

The ZIM cooperation network, 'UseCO_2', funded by the German Federal Ministry for Economic Affairs (BMWi), was approved in July 2016. The network extends across 19 partners from research and industry who are amongst others developing biotechnological and physico-chemical processes to bind carbon dioxide from the air, and make it reusable as a raw material for the production of basic and specialty chemicals or fuel. Fraunhofer IGB is involved in the network through its Straubing-based branch: Bio, Electro and Chemocatalysis BioCat.

Gasoline additives from sugar 1

Until now, fuel additives such as isooctane have been produced from mineral oil. Commissioned by the French-German company Global Bioenergies, the Fraunhofer Center for Chemical-Biotechnological Processes CBP in Leuna will soon produce biobased additives for gasoline. The CBP researchers develop the appropriate chemical processes, validate them and transpose them onto an industrial scale. The starting material is biobased isobutene that has been produced since the end of 2016, in a pilot plant installed at Fraunhofer CBP by Global Bioenergies.

Effective polio vaccines by means of electron irradiation

Since September 2016, four Fraunhofer Institutes have been working to produce more effective vaccines against polio in a project funded by the Bill & Melinda Gates Foundation (BMGF) and coordinated by Fraunhofer IZI. For inactivating polio viruses and other pathogens, a new technology based on low-energy electron irradiation is developed. The advantage: irradiation destroys the genetic material that the viruses need to multiply, whilst achieving better preservation of the antigenic structural proteins important for the immune response compared to conventional inactivation methods. The Bill & Melinda Gates Foundation is funding the project with a grant of USD 1.85 million. The aim is that the new process will save costs in manufacturing, enabling poorer countries too to better access the urgently-required polio vaccines. Fraunhofer IGB will carry out the investigations of antigen quality of the new polio vaccine after inactivation of the virus by means of electron beams.

1

2

3

More sustainability in research

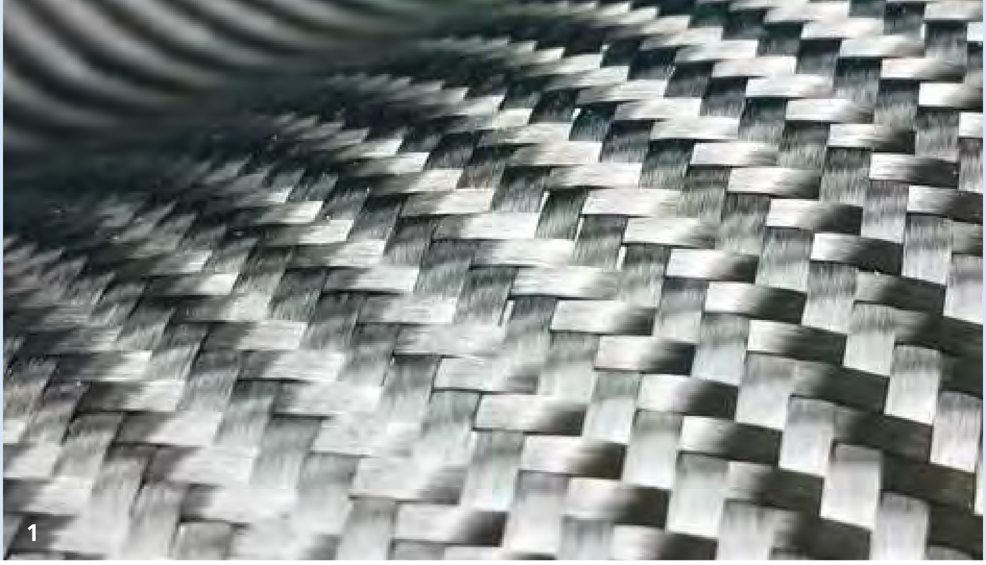
As a result of the LeNa joint project of the Fraunhofer-Gesellschaft, the Helmholtz Association and the Leibniz Association that was funded by the German Federal Ministry of Education and Research (BMBF), the guidelines "Sustainability Management in Non-university Research Institutions" and "Framework for Researching with Social Responsibility" were compiled. Both documents are intended to assist a systematic reflexion of research processes with respect to corporate social responsibility. At the BMBF symposium "Sustainability in Science" (SiSi) in Berlin on October 6, 2016, the presidents of the research institutes presented these guidelines "Sustainability Management in Non-university Research Institutions" to the Federal Research Minister, Johanna Wanka. For the first time the outcome of the LeNa project, in which Fraunhofer IGB played an important role, considers sustainability management in non-university research institutes and provides a uniform understanding of which fields of action non-university research institutions, as organizations and employers, can contribute to sustainable development in.

B2U – personalized products as a new business model 2

"Mass personalization – with personalized products for Business-to-User (B2U)" is a new concept of the Stuttgart-based Fraunhofer Institutes IPA, IAO, IBP, and IGB. For "mass personalized" products, the end consumers are involved in product production. In October 2016, the institutes conducted a study which identified three areas of need, which will play a central role in the future: mobility, health, and living. The concept also acts as the basis for the location initiative "Performance Center for Mass Personalization", which will start in July 2017. The central challenge here is the ability to develop, design and produce personalized products in quantity one, but maintaining the cost of a mass-produced product, and with consideration for sustainability.

Pilot plant for the production of "green" hydrogen is built in Leuna 3

Excess power from renewable energy sources can be used for the electrical splitting of water into oxygen and hydrogen. The Leuna chemical site offers the best conditions to establish an experimental and testing platform for electrolysis: the hydrogen can be fed directly into the pipeline network and can be used by local chemical companies. In October 2016, the Minister of Economy, Science and Digitalization in the state of Saxony-Anhalt, Jörg Felgner, handed over the letter of intent for funding contributions by the state. The joint research platform of the Fraunhofer Institute for the Microstructure of Materials and Systems IMWS in Halle, and the Fraunhofer CBP in Leuna, should be ready for operation as of 2018.



1

FRAUNHOFER IGB INTERNATIONAL

New EU projects in Horizon 2020

Horizon 2020 is the European Union's eighth Framework Programme for Research and Innovation as well as the world's largest coherent research and innovation program with almost 80 billion euros in funding available over seven years between 2014 and 2020.

The first three years of the seven-year Framework Programme have already concluded. The Commission is now assessing the program and its new aspects in an interim evaluation, and the preparations for the ninth Framework Programme for Research and Innovation have already started.

In 2016, Fraunhofer IGB was pleased to participate in three additional H2020 projects and to take on the coordinating role in one of them. Additional findings are still awaited.

New projects in section I "Excellent Science"

In Horizon 2020, Fraunhofer IGB is participating once again in the Marie Skłodowska-Curie network projects. The projects GreenCarbon and BIOCLEAN began in October 2016.

The objective of these projects is to provide outstanding doctoral students with a structured education in the framework of excellent research projects. The partners participating in this project come from various sectors. The young scientists' education is conducted in both an intersectoral and interdisciplinary manner.

GreenCarbon **1**

In the project GreenCarbon, carbon materials are produced on the basis of renewable resources and then developed further as catalysts or adsorbent materials for high-performance applications.

BIOCLEAN

The goal of the BIOCLEAN network project is to enable early-stage researchers from the areas of chemistry, engineering and experimental microbiology to effectively manage biofilms at the end of their education.


2

New projects in section II "Industrial Leadership"

ELSi **2**

During the past 25 years, there has been a rapid expansion in the deployment of photovoltaic (PV) systems throughout Europe. Early PV systems are now coming to the end of their working lives – a big disposal challenge that will increase in the coming years. Addressing this challenge, the two-year industry driven EU project ELSi started in May 2016 under the "Fast Track to Innovation" funding scheme. With Fraunhofer IGB as research partner, the ELSi team is working on a promising approach for an industrial scale recovery and reuse of all materials from end of life silicon-based photovoltaic modules.

ELSi project will demonstrate and validate a complete recycling system allowing appropriate disposal of PV modules and recovery of valuable materials.

N2B-patch

In January 2017, the N2B-patch project (Nose2Brain) coordinated by Fraunhofer started its four-year research plan. The aim is to develop an intranasal application platform for biopharmaceuticals that affect the central nervous system. To do so, an innovative galenical formulation based on biomaterials is to be combined with a special applicator and applied as a hydrogel bandage on the olfactory epithelium as a therapy for multiple sclerosis.

Completed projects from the seventh Framework Programme

In 2016, several projects from the EU's seventh Framework Programme for Research and Technological Development were successfully completed. These included the projects ECOWAMA, NAWADES, REWAGEN, BioEcoSIM and HiPerDry, all coordinated by Fraunhofer IGB. You can find more detailed information on the individual projects on the respective project websites as well as on the Fraunhofer IGB's homepage.

Outlook

In January 2017 Fraunhofer IGB had already responded to additional relevant calls and continues to hope that it will be awarded several interesting EU projects. In addition, we are eagerly awaiting the new work program for 2018–2020, which is to be published in the fall of 2017.

For further information on the Fraunhofer IGB EU-funded projects please visit:
www.igb.fraunhofer.de/eu-projects

Strategically linked networks 1

Applied research for Europe – strategically networked
In 72 projects together with more than 400 partners from numerous European countries, Fraunhofer IGB researches and develops solutions for the challenges of sustainable development. The focus is always on processes and products for the social areas of need – health, environment, and energy. Here, IGB is a sought-after partner for research institutions and businesses and makes particularly active contributions to the networks.

In 2016, the institute took another step in expanding its existing networks on strategic initiatives at the European level. It is active in projects such as ERIFORE (European Research Infrastructure for Circular Forest Bioeconomy), in which partners evaluate common infrastructures for a wood-based bioeconomy and build these up in a sustainable manner; or Interreg SmartPilots, in which companies across Europe are offered networking pilot facilities for a more efficient use of resources. The research platform for industrial biotechnology and synthetic biology (IBISBA, Industrial Biotechnology Innovation and Synthetic Biology Accelerator) that is currently being established are examples of how Fraunhofer IGB together with Fraunhofer CBP contributes to the development of resource-efficient and innovative European infrastructures. In doing so, it follows the requirements and objectives set down by the European Commission in the Horizon 2020 EU Research and Innovation programme: the integration of research findings from the previous Research Framework Programmes on system approaches and their implementation in the European Innovation Union.

In a national context, Fraunhofer IGB and CBP already have profound experience with the development and strategic expansion of system approaches in the area of bioeconomy. They can therefore conceptualize not only value chains for individual topics but also value cycles that cut across multiple topics faster than other institutions and can implement them together with long-term partners from the research, policy and business sectors.

Actively shaping EU policies
In the context of its membership in the Fraunhofer network "International Business Development", Fraunhofer IGB contributes to the internationalization of European research institutions. The findings of a conceptualization initiated by the Joint Research Centre (JRC) and supported by the European Association of Research and Technology Organizations (EARTO) were presented in Brussels at the end of January 2017 as the "Policy Brief on the Internationalization of RTOs". Here the objective is also to strategically link existing networks and establish long-lasting, resource-efficient infrastructures for European research institutions.

International training 2

Switching to a biobased economy

15 staff members of the Indonesian state research agency BPPT (Agency for the Assessment and Application of Technology) took part in a training seminar in November 2016 on the topic "From Petrochemicals to a Biobased Economy" organized by Fraunhofer. The participants first completed a week of training at Fraunhofer WKI in Braunschweig and got to know the basic sustainable aspects of a wood-based economy. After this, at Fraunhofer IGB in Stuttgart they gained insights into the laboratory methods for biotechnological production of sustainable, biobased products and then discussed implementation examples on a large industrial scale in detail with scientists at Fraunhofer CBP. At the same time, the training session offered opportunities to visit various companies.

Contact

Dipl.-Agr.-Biol. Sabine Krieg MBA
International inquiries,
project initiation
Phone +49 711 970-4003
sabine.krieg@igb.fraunhofer.de

Dipl.-Kffr. Jenny Ullrich
EU projects, project management
Phone +49 711 970-4070
jenny.ullrich@igb.fraunhofer.de

PERSONNEL – PRIZES AND ENCOUNTERS

Inauguration of extension-build in Straubing 1

With a ceremony and the symposium "Power-to-X", the IGB branch Bio, Electro and Chemocatalysis BioCat in Straubing officially opened its extension-building on March 9, 2016. Guests from science and industry as well as political representatives came to Straubing for the solemn inauguration; attendees included the Parliamentary State Secretary at the German Federal Ministry of Education and Research (BMBF), Stefan Müller, and the State Secretary at the Bavarian State Ministry of Economic Affairs, Media, Energy and Technology, Franz Pschierer.

Honorary professorship for Dr. Christian Oehr

For his achievements at Stuttgart University, Dr. Christian Oehr was appointed the title of honorary professor by the university senate. With this award, the university honors the many years of teaching of the acting IGB institute director who has been teaching at the Energy Technology, Process Engineering and Biological Engineering Faculty since 1996.

GreenTec Award for anti-icing coatings 2

The GreenTec Awards 2016, European´s most important awards for environmental technology, were presented on May 29, 2016 at a festive gala held to open the IFAT fair in Munich. Fraunhofer IGB received second prize in the category of "Aviation" for the self-adhesive anti-icing coatings developed at the institute.

Research Scholar Award for international eye research to Katja Schenke-Layland

In June 2016, Prof. Dr. Katja Schenke-Layland was awarded the Harold F. Spalter International Research Scholar Award of the American Organization "Research to Prevent Blindness (RPB)". The award means that the scientist will be able to commence strategic cooperation with the Eye Institute of the Keck School of Medicine at the University of Southern California (USC). The aim is the development of an *in vitro* model of the lacrimal gland to develop stem cell-based treatments for people suffering from the Sjögren's syndrome.

2

3

Heike Walles is a member of acatech

As early as in 2015, Prof. Dr. Heike Walles, head of the Fraunhofer IGB branch of the institute in Würzburg and the Chair of Tissue Engineering and Regenerative Medicine at the Würzburg University Hospital, was elected as a new member by the general meeting of the German Academy of Technical Sciences (acatech). As part of the acatech celebratory event held in Berlin on October 12, 2016, the acatech presidents Prof. Dr. Reinhard F. Hüttl and Prof. Dr. Henning Kagermann presented her with the official membership certificate at the associated meeting.

IGB spin-off company confident in business plan competition 3

With the idea of cell-free protein therapy after heart attacks, a team led by Prof. Dr. Katja Schenke-Layland is planning the foundation of a medical-technical start-up. With their business plan, the team secured their invitation to the final of the CyberOne Hightech Awards 2016 in November 2016. The prize offered by the bwcon network is awarded for particularly forward-looking business ideas. Shannon Layland will be the managing director of the spin-off company, Renovatum Therapeutics, and working in the capacity of scientist will be Prof. Dr. Ali Nsair, cardiologist, and acting director of the heart transplant program at the University of California in Los Angeles (UCLA).

1

PROMOTING YOUNG TALENTS

Facing the challenges of tomorrow today is an official motto here at Fraunhofer. Therefore, the Fraunhofer Institute Center Stuttgart and Fraunhofer IGB are committed to promoting young scientists. In 2016, there were various events and initiatives at the Stuttgart research campus aimed at getting high-school students interested in STEM subjects (Science, Technology, Engineering, and Mathematics) and to present career opportunities at Fraunhofer to students majoring in life sciences.

Fraunhofer Talent School 1

At the Fraunhofer Talent School in Stuttgart, pupils aged 15 and older get a detailed insight into working and researching at Fraunhofer. The Stuttgart institutes offer their guests three-day hands-on workshops. At Fraunhofer IGB, pupils got immersed into the world of molecular biology. In the "CSI Stuttgart" workshop, they took on the role of investigators and solved an exciting criminal case by conducting DNA analyses themselves. Under the supervision of the research group "Functional Genomics", the participants isolated DNA from their saliva samples and subsequently undertook molecular characterization. In this way, they created a genetic fingerprint, which then allowed the "perpetrator" to be identified.
www.stuttgart.fraunhofer.de/talents

Girls' Day 2

The Girls' Day aims at motivating young girls for a career in STEM professions, which are traditionally perceived as "typically masculine". To fight such prejudices and obstacles, the German Federal Ministry of Education and Research launched the Girls' Day as a nationwide action day in 2001. Since 2003, the Fraunhofer Institute Center Stuttgart has also been participating in the Girls' Day – every year, it offers a broad program with guided tours to the institutes. Since then, the number of events and participants has been steadily increasing. In April 2016, 63 female students aged 10 to 16 came to the Girls' Day at the Fraunhofer campus in Stuttgart. Fraunhofer IGB took part with guided tours on the topics "Tailored tissue from the laboratory" and "Nature's own chemical plant".
www.stuttgart.fraunhofer.de/girlsday

BOGY – Career and study orientation at grammar schools

The Fraunhofer Institute Center Stuttgart offers numerous internships for high-school student every year as part of the BoGy program (Career and Study Orientation at Grammar Schools) of the German state of Baden-Württemberg. In this way, Fraunhofer wants to inspire young people for science at an early stage. The key requirement for a week-long BoGy internship is a special interest in natural sciences and engineering. In 2016, a total of 14 BoGy interns came to the institute – 7 boys and 7 girls.
www.stuttgart.fraunhofer.de/bogy


2

"The future lies in science" – Your career at Fraunhofer in Stuttgart

In 2016, the annual career at the Fraunhofer Institute Center Stuttgart took place for the first time under a new title and with a revised concept. Under the slogan "The Future Lies in Science", the institute center invited students to a career event at the Stuttgart research campus. Instead of offering conventional lectures, the visitors took part in discussions. These "insider insights" offered them the opportunity to speak in person with Fraunhofer employees from various disciplines and career backgrounds. At the same time, the institutes offered guided tours through their research departments. Fraunhofer IGB participated with tours on the topics "Tissue Engineering" and "Algal Technology".
www.stuttgart.fraunhofer.de/karrieretag

"Your future in Stuttgart" – Open house for international students

For two years, the city of Stuttgart has been offering an annual open house, directed specifically at international students enrolled at Universities in the Stuttgart region. The aim of this event is to inspire talented young professionals for a career in the city and the surrounding region. In addition to well-known regional companies, the Stuttgart-based Fraunhofer Institutes also took part and offered a workshop for the participants on the topic of postgraduate studies at Fraunhofer. Employees shared their personal experiences and answered questions posed by international students.
www.stuttgart.de/en/your-future-in-stuttgart

Dual training at Fraunhofer IGB

As a research institution, Fraunhofer IGB is very committed to promoting students. However, the non-university vocational training of young women and men is also of great importance to the institute. In 2016, for example, the institute offered six new apprenticeships. In the autumn, three biotechnology and two chemical laboratory assistants started their training at Fraunhofer IGB. Another new colleague was hired in the institute's administration, starting her training to become an office manager. In addition to the vocational training, the trainees rotate through several departments at the institute in order to familiarize themselves with the diverse work areas of a research facility in order to qualify for future research or industry jobs. If trainees decide to pursue a course of study following their training, the institute offers its support.

In addition to scientific research and business administration jobs, Fraunhofer IGB also offers apprenticeships in the IT sector for IT specialists for system integration.
www.igb.fraunhofer.de/ausbildung

For further information on promotion of young scientists and training please visit
www.igb.fraunhofer.de/career

COMPETENCES

FRAUNHOFER-GESELLSCHAFT

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

At present, the Fraunhofer-Gesellschaft maintains 69 institutes and research units. The majority of the 24,500 staff are qualified scientists and engineers, who work with an annual research budget of 2.1 billion euros. Of this sum, 1.9 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 state governments in the form of base funding, enabling the institutes to work ahead on solutions to problems that will not become acutely relevant to industry and society until five or ten years from now.

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

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

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

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

Figures are for January 2017.

www.fraunhofer.de

Joseph von Fraunhofer (1787 – 1826).

INTERFACIAL ENGINEERING AND MATERIALS SCIENCE

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

Technology and expertise

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

Research focus

- Protective layers, permeation barriers, release coatings
- Coatings with minimized interfacial energy for improved emptying behavior or reduced ice adhesion
- Biofunctional coatings
- Formulation of bio-inks for bioprinting
- Water purification with membranes, adsorbers and water contact plasmas
- Plasma cleaning and sterilization processes
- Nano- and micro-structured materials
- Core-shell particles for separation and formulation of substances
- Membranes for gas separation, pressure-retarded osmosis (PRO), PEM fuel cells and membrane reactors

Contact

Hon.-Prof. Dr. Christian Oehr
Head of Department, Director (acting)
Phone +49 711 970-4137
christian.oehr@igb.fraunhofer.de

MOLECULAR BIOTECHNOLOGY

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

Technology and expertise

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

Research focus

- Infection biology
  - Mycology – pathogenic *Candida* spp.
  - Virology – herpes viruses, polio
  - Host-pathogen infection models (3D tissue models)
  - Target and drug screening
- Diagnostics
  - Diagnostic microarrays
  - Next-generation diagnostics
  - Cell-based assays
- Therapeutic proteins
  - Production cell lines for recombinant production of e.g. interferons, factor VII
- Enzyme screening and characterization
  - Ligninolytic enzymes, hydrolases, oxidoreductases
- Fermentation processes for industrial biotechnology
  - Enzyme production
  - Platform chemicals, e.g. furan dicarboxylic acid, itaconic acid, maleic acid, long-chain dicarboxylic acids
  - Microbial biosurfactants
  - Scale-up
- Processing of raw and residual materials for industrial biotechnology
  - Processing of lignocellulosic material
  - Vegetable fats and oils
  - Isolation of chitin derivatives from waste materials
- Isolation of natural products

Contact

apl. Prof. Dr. Steffen Rupp
Head of Department, Deputy Director
Phone +49 711 970-4045
steffen.rupp@igb.fraunhofer.de

PHYSICAL PROCESS TECHNOLOGY

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

Technology and expertise

- Thermal process technology
- Processes and systems for heat transfer and sorption
- Advanced oxidation processes (AOP) by electrolytic and photolytic (UV) processes for water treatment
- Electro-physical separation of materials
- Processes for recovery of organic and inorganic substances for agriculture
- Stabilization of liquid food and biogenic products
- Numeric simulation and theoretical modeling
- Design and system integration into industrial applications

Research focus

- Heat storage using thermochemical processes for temporally and spatially decoupled use of waste heat or solar thermal heat
- Use of sorption systems to remove moisture from gases, in particular from air to provide or recover water
- Drying in a superheated steam atmosphere with integrated recovery of volatile materials
- Recycling of inorganic nutrients for the production of ‘fertilizers on demand’
- Production of soil improving substrates from organic residues
- Electrolytic and photolytic oxidation raw and process water treatment processes
- Gentle stabilization of liquid foods using pressure change technology (PCT)
- PCT for efficient disruption of microbial cells combined with extraction of valuable cell components
- Microwave technology for directed and rapid application of energy

Contact

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

ENVIRONMENTAL BIOTECHNOLOGY AND BIOPROCESS ENGINEERING

The core areas of the department are the development of (bio)engineering processes in the fields of water management, bioenergy, environmental technology, algal technology, product recovery from organic raw/waste materials and interfacial biology. Based on these processes, we are following new approaches to the development of system concepts for energy, waste and water management in industry and for communities. Maximum efficiency is achieved through the integration of several steps to establish short process chains.

Technology and expertise

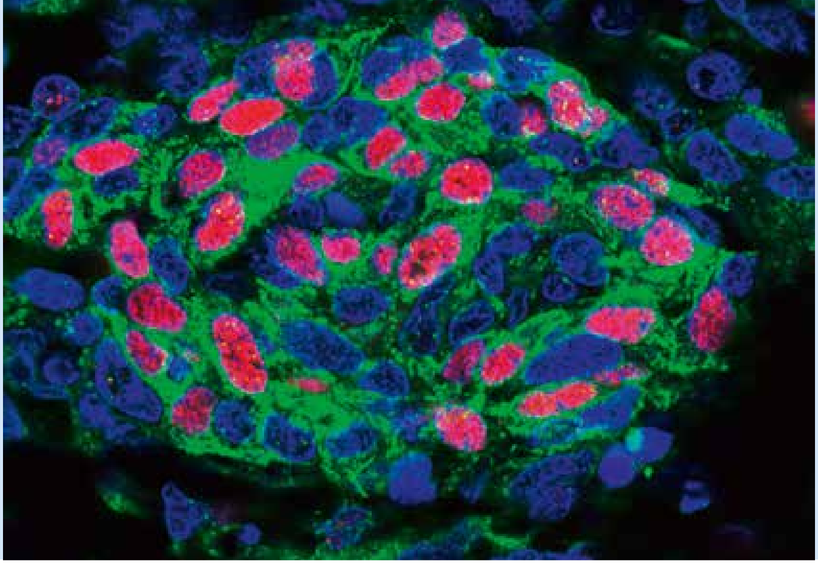
- Isolation and downstream processing of bioproducts (membrane-based filtration processes, process chromatography, liquid-liquid extraction, extraction with supercritical CO_2)
- Process development in bioreactors from laboratory to pilot and technical scale
- Development and operation of demonstration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

Research focus

- Wastewater purification and water processing methods for industry and municipalities
- Real-time monitoring of water using biosensors
- Evaluation of microbial contaminations
- Concepts for resource-conserving production in companies – the ultra-efficient factory
- Digestion processes for producing biogas from a wide range of organic substrates in different temperature ranges
- High-value products from microalgae and cyanobacteria for cosmetic, food, feed and pharmaceutical industry
- Downstream processing
- Biotransformation of organic raw and waste materials as well as of biogas into basic chemicals
- Bioleaching, biosorption and bioprecipitation processes for recovery of valuable substances from residues

Contact

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



CELL AND TISSUE ENGINEERING

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

Technology and expertise

- Tissue engineering using tissue-specific human primary cells as well as adult, embryonic* and induced-pluripotent stem cells (iPS cells) for development of 3D tissue models
- Patented 3D human skin equivalent
- Microfluidic organ-on-a-chip systems
- Accredited in vitro cytotoxicity testing of R&D materials and industrial products (DIN ISO 10993-5)
- Accredited phototoxicity testing of substances
- Development and modification of biomaterials (electrospinning, hydrogels, extracellular matrix)
- Production of human recombinant extracellular matrix proteins
- Non-invasive characterization of cells and tissues using Raman microspectroscopy

Research focus

- Design and modification of biocompatible hybrid materials as carrier substrates for medical engineering
- Investigation of cell-material interactions
- Click chemistry for the coupling of extracellular matrix proteins to surfaces
- Skin models of varying complexity as test systems for cosmetics and drugs
- Validation and parallelization of organ-on-a-chip systems (heart muscle cells, white fat tissue) for drug candidates testing
- Bioprinting of human 3D tissues
- Cardiovascular tissue engineering: test tissues, regenerative molecular and cell therapies, implants for heart muscle and heart valves

Contact

Prof. Dr. rer. nat. Katja Schenke-Layland
Head of Department, Director (acting, executive)
Phone +49 711 970-4082
katja.schenke-layland@igb.fraunhofer.de

Prof. Dr. rer. nat. Petra Kluger
Head of Department
Phone +49 711 970-4072
petra.kluger@igb.fraunhofer.de

* Approved by the Robert Koch-Institute AZ: 3.04.02/0086 and 3.04.02/0111

FRAUNHOFER CENTER FOR CHEMICAL-BIOTECHNOLOGICAL PROCESSES CBP

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

Technology and expertise

- Processing of raw materials – integrated pilot plant for pulping and fractionation of lignocellulose
- Biotechnological processes – modular process units up to 10 m³ reactor volume for fermentations and reactors for enzymatic processes up to 1000 liters
- Cultivation of microalgae in automated greenhouse and outdoor pilot plants, with a total volume of photobioreactors of 11.7 m³
- Chemical processes – various process units for chemical reactions under ATEX conditions (continuous up to 20 kg/h or batch up to 100 liters at temperatures up to 500°C and pressures up to 300 bar)
- Downstream processing for separation, purification and reconditioning of products, e.g. by distillation or extraction methods

Research focus

- Obtaining high-quality extractives from biogenic raw and residual materials
- Pulping of lignocellulose, separation and use of its components to make further products
- Development of processes to obtain new technical enzymes
- Functionalization and modification by enzymatic or chemical catalysis
- Manufacturing of biobased alcohols, acids and olefins using fermentation and chemical processes
- Cultivation of microalgae for the production of high-quality ingredients

Contact

Fraunhofer Center for Chemical-Biotechnological Processes CBP
Am Hauptor | Tor 12, Bau 1251
06237 Leuna | Germany
Fax +49 3461 43-9199 | www.cbp.fraunhofer.de

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

BIO, ELECTRO AND CHEMOCATALYSIS BIOCAT, STRAUBING BRANCH

The focus of BioCat, the Straubing branch of the institute, is on the development of new chemical catalysts and biocatalysts and their application in technically relevant synthetic and electrochemical processes. Based on substrates such as biomass, CO_2, organic and inorganic waste streams, the entire spectrum of catalysis is used to develop new sustainable and resource-efficient chemical products. When using plant biomass, our aim is the reasonable use of the material variety of biobased molecules and exploiting the potential of chemical and biocatalysis so as to achieve a material-friendly transformation while maintaining important functionalities. BioCat has also developed new catalytic methods of managing electrical energy by binding and converting CO_2 to produce long-chain hydrocarbons, making it possible to store electricity from regenerative power generation in the form of chemical energy for later use.

Technology and expertise

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

Research focus

- Biotechnical, chemical and electro(bio)chemical catalysis
- Special and fine chemicals from CO_2, terpenes, lignin and chitin-rich waste, e.g. terpene-derived transparent polyamides
- Lubricants and biosurfactants from vegetable oils and fatty acids
- Development of methods for integrating the use of renewable resources in existing processes
- Exploration of inorganic secondary raw materials
- Production of medium-chain to long-chain hydrocarbons (as fuels) from methane and/or CO_2

Contact

Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB
Bio, Electro and Chemocatalysis BioCat,
Straubing branch
Schulgasse 11a | 94315 Straubing | Germany
Fax +49 9421 187-310 | www.biocat.fraunhofer.de

Prof. Dr. rer. nat. Volker Sieber
Head of BioCat
Phone +49 9421 187-300
volker.sieber@igb.fraunhofer.de

TRANSLATIONAL CENTER "REGENERATIVE THERAPIES", WÜRZBURG BRANCH

The Translational Center Würzburg develops biologized medical products and cell-based therapies for individualized patient-centered care with the aim of a fast transfer to medical practice. The infrastructure has therefore been established for preclinical and clinical testing, CE certification and approval of new innovative therapies. A main focus is on the development of digital, transferable documentation systems. The clinical emphasis is on innovative implants and new therapies for defects of the musculoskeletal system and oncological diseases.

Technology and expertise

- Initiation of CE certification and approval of implants
- Consulting of SMEs concerning German Medicines Law (Arzneimittelgesetz) and Medical Devices Act (Medizinproduktegesetz)
- Development of GxP processes and documentation systems (transferable)
- Cell culture techniques: primary cells, stem cells, iPS cells – development of co-cultures and tissue models
- Development of specific bioreactors, sensors, and incubators for tissue engineering
- Human vascularized (tumor) tissue for the optimization of medical products, to establish individual diagnostics and personalized therapies, including ATMPs
- Development of technologies for tissue engineering and regenerative medicine

Research focus

- Validation and standardization of human tissue models
- Development of human disease models and infection models
- Development of human vascularized tumor models: melanoma, intestine, mamma carcinoma, lung carcinoma
- Stroma-tumor interaction studies for drug screening
- Use of in vitro models in the process development to optimize drugs, medical products or implants
- GMP process development, documentation and preparation of the approval process
- Personalized in vitro diagnostics concomitant to therapy

Contact

Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB
Translational Center "Regenerative Therapies for Oncology and Musculoskeletal Diseases", Würzburg branch
Röntgenring 11 | 97070 Würzburg | Germany

Prof. Dr. hum. biol. Heike Walles
Phone +49 931 31-88828
Fax +49 931 31-81068
heike.walles@igb.fraunhofer.de

INSTITUTE OF INTERFACIAL PROCESS ENGINEERING AND PLASMA TECHNOLOGY IGVP

The Institute of Interfacial Process Engineering and Plasma Technology IGVP is part of the Faculty of Energy Technology, Process Engineering and Biological Engineering of the University of Stuttgart. State-of-the-art labs, technical plants and workshops are available at the three IGVP facilities in Nobelstrasse 12, Allmandring 5b, and Pfaffenwaldring 31 for interdisciplinary engineering and natural scientific research. In 2016, the research budget accounted for 2.57 million euros. At the end of that year, a staff of 75 scientific, technical and administrative employees, among them 40 doctoral students, worked at the institute. In addition, 55 students have completed their master or bachelor thesis at the IGVP.

Research

The IGVP focuses on the design of functional materials and that of their interfaces and surfaces, on the biological interactions at these interfaces as well as on the development and engineering of interfacially driven processes. In plasma technology, low-temperature plasmas are applied for surface activation, microwaves for stabilization of high-temperature plasmas in fusion-related plasma physics, and the dynamic properties of plasmas and electromagnetic waves are analyzed and simulated. Cooperation of the IGVP with Fraunhofer IGB makes it possible to pursue projects from basic research to application.

Teaching

The IGVP is very actively involved in the teaching of master and bachelor study programs at Stuttgart University such as Process Engineering, Medical Engineering, Technical Biology, Energy Technology, Renewable Energy Engineering, Environmental Engineering, WASTE, etc.

Thematic focus

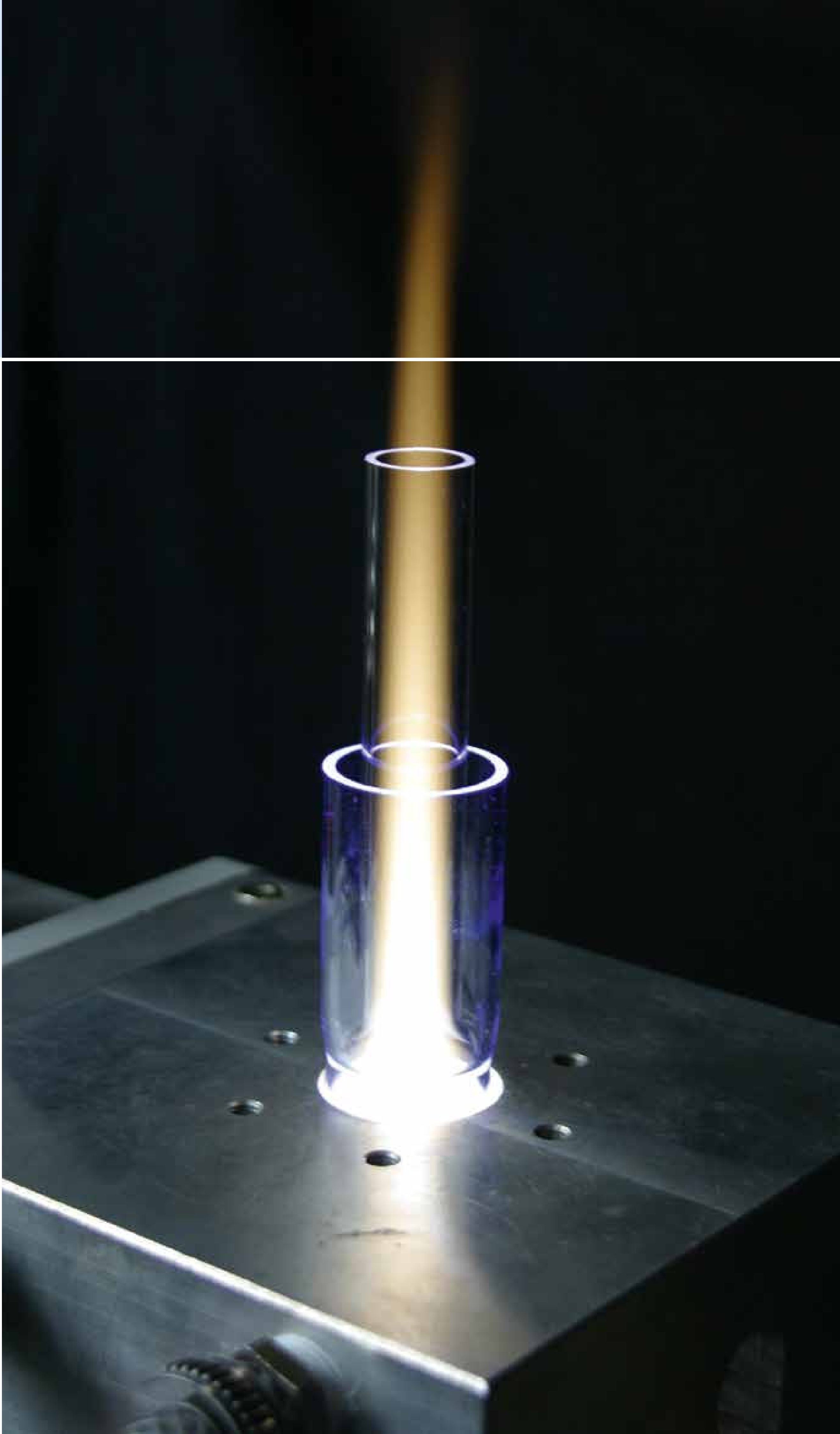
- Nanomaterials and nanotechnology
- Biomaterials and biotechnology
- Renewable raw materials, industrial biotechnology, and bioenergy
- Plasma technology and plasma physics

Contact

Institute of Interfacial Process Engineering and Plasma Technology IGVP
University of Stuttgart
Pfaffenwaldring 31 | 70569 Stuttgart | Germany
Fax +49 711 970-4006 | www.igvp.uni-stuttgart.de

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

Dr.-Ing. Matthias Walker, Akademischer Oberrat
Head of Administration
Phone +49 711 685-62300
matthias.walker@igvp.uni-stuttgart.de



SELECTED R&D RESULTS 2016

75 Industrial projects

26 Fraunhofer internal projects

24 EU projects

4 Fraunhofer lighthouse projects

40 Projects funded by German federal ministries

10 Projects with universities, municipalities or funded by foundations

5 Projects funded by German states

184 Projects

HEALTH

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

Fraunhofer IGB is developing solutions in these research areas. The aim is to improve medical care for patients and simultaneously reduce healthcare costs. Another focus is the development of three-dimensional in vitro organoid models derived from human tissues; preclinical research has already produced conclusions about effects and side effects of potential drug candidates and thus animal experiments are no longer required.

We take increased health awareness into account by using new extraction, preparation and stabilization processes that minimize damage to food products and can also be used for cosmetics.

Networking and cooperation

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

Coatings and biomaterials for medical technology

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

Personalized medicine

In the field of personalized medicine, the focus is developing cell-based therapeutics, autologous transplants and biologized implants. Fraunhofer IGB and its Würzburg branch, with the Translational Center for "Regenerative Therapies for Oncology and Musculoskeletal Diseases", are covering the entire value-added chain right up to GMP-compliant manufacturing of cell-based therapeutics and implants (Advanced Therapy Medicinal Products, ATMPs) and – together with a network of physicians – phase I clinical studies. We are analyzing contaminations of implants using non-destructive techniques with spectroscopic and multiphoton microscopic methods. A new approach to producing dimensionally stable, tissue-like structures (e.g. cartilage, fat tissue) is being pursued by 3D printing of cells onto UV-crosslinkable hydrogels. For the development of patient- and disease-specific test systems, Fraunhofer IGB is working on iPS-based organ-on-a-chip systems.

Molecular diagnostics

Fraunhofer IGB is developing novel molecular biology technologies based on nucleic acids (microarrays, high-throughput DNA sequencing) or using cellular reporter systems (pyrogen assay system) that can be used for clear and unambiguous diagnoses. This information helps to initiate measures for specific treatments or develop personalized medicines for different population groups. In particular for combating infectious diseases, the combination of methods of functional genome analysis with our expertise in cell culture technology and infection biology results in a unique position for developing infection models and diagnostics. We have established a versatile, non-invasive, marker-free diagnostic tool based on Raman microspectroscopy for real-time analysis of cells and tissues.

Drug development

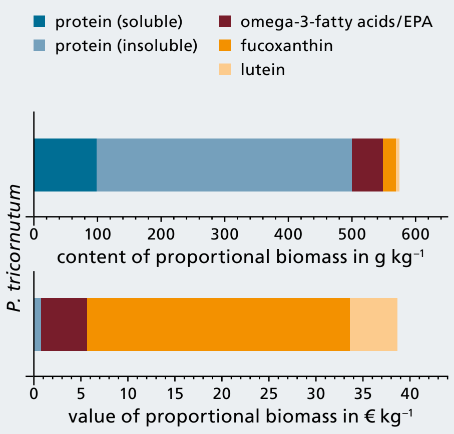
Using DNA-based technologies and human tissue models, we are elucidating host-pathogen interactions to identify new target structures for antibiotics and for boosting human immune defense. We are investigating potential active compounds using cell-based assays – e.g. for immunomodulatory substances – based structure-effect relationships. To analyze the effects and side effects of potential active compounds, we are developing three-dimensional *in vitro* tissue models and organ-on-a-chip systems based on human primary or iPS cells to replace animal tests. In addition, we are developing processes to produce pharmaceutical proteins: from the establishment of new expression vectors to strain development and purification of the pharmaceuticals.

Formulations and release systems

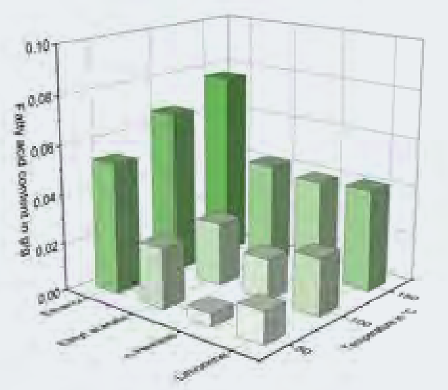
Transport of a substance to their destination – e.g. a tissue or cell – is a key factor in the development of functional ingredients or active compounds. At Fraunhofer IGB, we are developing structures that transport substances to their site of action in a targeted manner (drug delivery) and release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

Food and cosmetics

Our aim in this topic area is the extraction of functional ingredients from biogenic raw or residual materials, from intermediate products in agricultural and food production and from microalgae. For this purpose, we are developing gentle-to-product and efficient procedures to extract (supercritical fluids, high-pressure in combination with pressure change technology) and purify the products using electrophoretic and mechanic separation processes. In addition, we are developing new physical processes to stabilize and conserve food, cosmetics, drug substances and plant extracts. Since this procedure is carried out at low temperatures below 50°C, the biological function of valuable ingredients, such as vitamins is not affected during the treatment.



1



2

3

VALUABLE SUBSTANCES FROM MICROALGAE FOR FOOD APPLICATIONS

Felix Derwenskus, Ulrike Schmid-Staiger

Microalgae – integrated use for food and feed

Based on CO_2 and sunlight, microalgae can produce a large number of substances that are of interest for the food and feed sector as well as for cosmetic companies (Fig. 4). In addition to unsaturated omega-3 fatty acids such as eicosapentaenoic acid (EPA; $C_{20:5}$ n-3), photosynthesis-associated pigments, for example fucoxanthin or lutein and phytosterols, make a significant contribution to the value added from algal biomass. Many ingredients have health-promoting properties that can be beneficial in human nutrition.

The wide range of ingredients and the varying composition of different microalgae species necessitates selective processing of the biomass. The primary objective is to effectively extract high-quality ingredients and simultaneously preserve the technical, functional, nutritional and physiological properties of these products. Within the framework of the Baden-Württemberg Bioeconomy Research Program, the "Microalgae – Integrated Use for Food and Feed" research association is seeking to utilize the different fractions as completely as possible through coupled or cascade use, in order to develop sustainable processes for bioeconomy.

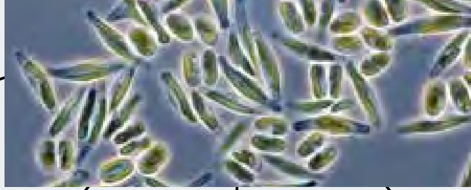
Processing of algae ingredients

Three microalgae strains (*Phaeodactylum tricornutum*, *Chlorella vulgaris* and *Nannochloropsis oceanica*) were selected based on their fundamental differences in size, cell wall assembly and ingredients. A combination of successive extraction processes was used to fractionate both mid- and high-priced ingredients such as EPA and carotenoids as well as the principal fractions that consist of proteins and nonpolar triglycerides sequentially obtained from the microalgal biomass. The processing technique is essentially determined by the chemical character and market specification, such as the required degree of product purity. Further requirements are avoiding, as far as possible, an energy-intensive drying step as well as ensuring gentle extraction that both maintains the functionality and permits the extraction of further cell components.

Selective extraction and scale-up of the procedures

A procedure known as pressurized liquid extraction (PLE) plays a key role; this process allows wet biomass to be extracted using appropriate organic solvents. For this purpose, extraction properties of the selected solvents were examined under pressure with various conditions (e.g. extraction temperature) at Fraunhofer IGB (Fig. 1). In follow-up to optimization of the extraction parameters that has already been carried out at laboratory scale, a scale-up of this PLE procedure to pilot scale is currently being carried out in collaboration with affiliated partners at Hohenheim University.

Extraction with supercritical fluids (SCF) represents an alternative. Cosolvents such as ethanol can be added to the primarily nonpolar supercritical fluids (e.g. carbon dioxide) in order to increase polarity. The different extraction behavior with and without a cosolvent is also specifically utilized for the separation step (cascade extraction) of nonpolar triglycerides and polar lipids such as eicosapentaenoic acid or carotenoids (e.g. fucoxanthin). Fraunhofer CBP offers an opportunity to move this procedure up to pilot scale.



carbohydrates

storage products
- α-(1-4)-glucane, β-(1-3)-glucane
- fructane
- glycerol

up to 50% of dry weight

triacylglycerides

storage lipids
- triacylglycerides with mainly C_{16} to C_{18} fatty acids

up to 70% of dry weight

valuable compounds
- carotenoids, i.e. astaxanthin, fucoxanthin, lutein
- phytosterols (C_{28}, C_{29}), all vitamins and antioxidants
- anti-fungal, -viral and -microbial

from 1–5% each of dry weight

proteins
- proteins with all amino acids
- partly soluble and partly bounded as particulate

up to 50% of dry weight

membrane lipids

glyco- and phospholipids
- up to 40% of fatty acids are poly-unsaturated, i.e. eicosapentaenoic acid (EPA)

up to 7% EPA of dry weight

4

Analysis of the nutritional and technological characteristics of the resulting fractions

In collaboration with the joint project partners, an analysis of the nutritional and technological characteristics of the extracts obtained is simultaneously being carried out; for example, the health-promoting antioxidative and antiproliferative properties and the bioavailability of the ingredients are being investigated. The data obtained will serve as a basis for statutory approval of different microalgae species as well as their extracts for use in human food products.

Outlook

Upon completion of the project, the goal is to have a method matrix for processing algal biomass that can be transferred to the biomass of different algae species that differ in terms of material composition and target fractions. This would be a huge step closer to achieving the objective of using microalgae holistically for nutrition as an important component in the bioeconomy.

1 *Composition and value added of Phaeodactylum biomass.*

2 *Fatty acid extraction from Phaeodactylum tricornutum biomass using PLE.*

3 *Fucoxanthin, extracted from Phaeodactylum tricornutum biomass using PLE.*

4 *Potential microalgal ingredients.*

Contact

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

Felix Derwenskus M. Eng.
Phone +49 711 970-4074
felix.derwenskus@igb.fraunhofer.de

Funding

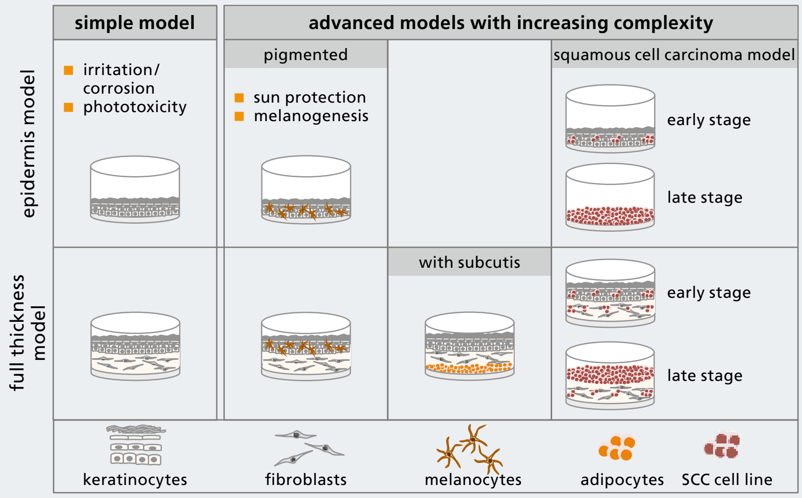
The project is conducted at the Institute of Interfacial Process Engineering and Plasma Technology IGVP, Fraunhofer IGB's partner institute at the University of Stuttgart. We would like to thank the Baden-Württemberg Stiftung and the Ministry of Science, Research and the Arts of the State of Baden-Württemberg for funding the project "Microalgae – Integrated Use for Food and Feed. Partial Project: Development of Cell Disruption and Extraction Processes for the Cascade Utilization of Microalgal Biomass" (Mikroalgen – Integrierte Nutzung für die Ernährung. Teilprojekt Entwicklung von Zellaufschluss- und Extraktionsverfahren zur Kaskadennutzung von Mikroalgenbiomasse) in the Baden-Württemberg Bioeconomy research program, reference no. 7533-10-5-93.

Project partners

Hohenheim University, Institute of Food Science and Biotechnology | Hohenheim University, Institute of Clinical Nutrition | Max-Rubner Institute of Nutrition and Food, Karlsruhe

Further information

www.bioeconomy-research-bw.de/mikroalgen_ziele



1

SKIN MODELS OF VARYING COMPLEXITY FOR R&D AND PRE-CLINICAL STUDIES

Sibylle Thude, Kirstin Linke, Petra Kluger

3D tissue models for substance testing

The Department of Cell and Tissue Engineering is specialized in constructing human three-dimensional tissues. The 3D nature of the scaffolds considerably affects parameters such as metabolic activity, viability, division, morphology and differentiation status and thus, ultimately, the function of the tissue as a test model. After many years of development Fraunhofer IGB has established several 3D human skin equivalents of varying complexity. Depending on integrated cells, complexity increases and therefore different aspects of substance testing in healthy or diseased models can help the development of new therapeutic strategies.

Epidermis and full thickness skin models as a basis

The simple, well stratified epidermis model and the full thickness skin model with matrix embedded fibroblasts are well established *in vitro* skin models which enable the evaluation of biological responses to substances and their formulations. A variety of applications regarding safety and risk assessment, investigations of cell-cell and cell-matrix interactions or differentiation behavior can be performed. Test procedures for the quantification of cytotoxic or phototoxic effects of topically or systemically applied substances have been accredited to support customers in their development of medical devices, cosmetics and dermopharmaceutical products [1, 2].

Pigmented *in vitro* skin model for the investigation of light-induced skin damage

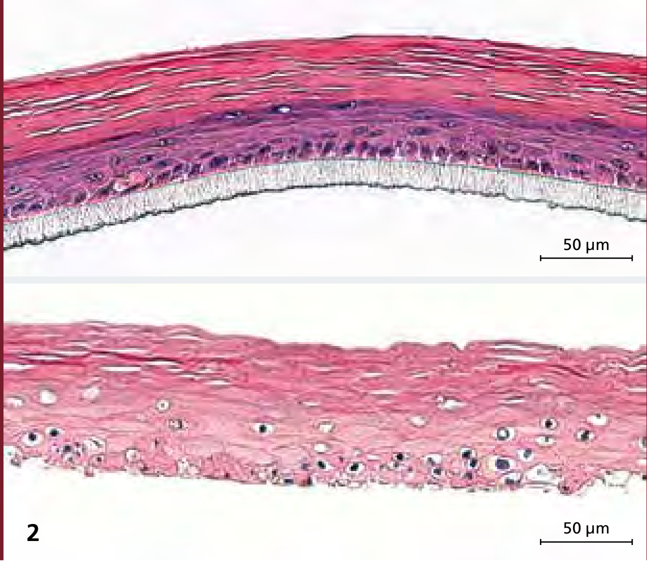
Sunlight has various effects on human health. Several important metabolic processes are only triggered by sunlight. Longtime sun bathing and extended outdoor activities can cause skin irritation, inflammation or even skin cancer due to high radiation dose. Therefore the cosmetic industry focuses not only on the improvement of sunscreens, but also on the development of melanogenic substances, which stimulate melanin production in the skin functioning as a self-protective UV-shield. In addition, anti-oxidative substances are used as radical scavengers to prevent light-induced skin damages and even skin cancer.

Melanocytes are located in hair follicles as well as in the basal layer of the epidermis and serve a protective function in the skin. When exposed to sunlight they synthesize an important UV-absorbing pigment named melanin. This is then distributed to keratinocytes located in the surrounding area of the melanocytes, thus protecting the DNA from UV-light associated damages.

By integrating melanocytes into our *in vitro* skin models (epidermal or full thickness skin model), Fraunhofer IGB can investigate UV-light associated skin damage, analyze sun protective substances and formulations for their melanogenic or anti-oxidative potential. In addition, we can quantify the tanning and whitening effects of solutions after a defined UV-irradiation (UV-A/UV-B or combination) as well as monitor alterations in collagen or elastic fibers caused by aging [3].

In vitro model for human squamous cell carcinoma – a complex diseased model

More than 300,000 new cases of non-melanoma skin cancer (basal cell carcinoma and squamous cell carcinoma) are diagnosed in Germany per year. This increasing number is due to prolonged sun bathing, extended outdoor activities and general exposure to sunlight. Non-melanoma skin cancer



2


3

predominantly occurs in sun-exposed skin areas like the head and neck, forehead, nose, lips and hands with actinic keratosis being the most common form. As a pre-cancerous form (precursor), an invasive squamous cell carcinoma will develop if left untreated. In addition to surgical treatments, numerous non-surgical procedures, including photodynamic therapy (PDT) are available.

By integrating white skin cancer cells (cell line SCC-25) into our well-established three-dimensional skin model simultaneously with healthy keratinocytes in defined ratios, we can mimic early and late stages of squamous cell carcinoma in humans, which are morphologically comparable to the in vivo situation. Using Raman micro-spectroscopy, we are able to non-destructively distinguish healthy keratinocytes from tumor cells.

Outlook

These models are advanced tools to monitor disease progression and allow the investigation of new photosensitizing substances, adapted irradiation protocols with specific light sources and their effects on healthy and diseased cells [4]. In collaboration with the University of Stuttgart, we have also developed a model for melanoma skin cancer.

1 *In vitro skin – from basic to advanced models.*

2 *Effect of phototoxic substance before (top) and after (bottom) UV-A-irradiation (5J/cm²).*

3 *UV-irradiation of pigmented skin models with the BioSUN.*

Contact

Dipl.-Biol. (t.o.) Sibylle Thude
Phone +49 711 970-4152
sibylle.thude@igb.fraunhofer.de

Prof. Dr. rer. nat. Petra Kluger
Phone +49 711 970-4072
petra.kluger@igb.fraunhofer.de

Literature

[1] Biological evaluation of medical devices – Part 5: Tests for *in vitro* cytotoxicity (ISO 10993-5:2009); German version EN ISO 10993-5:2009

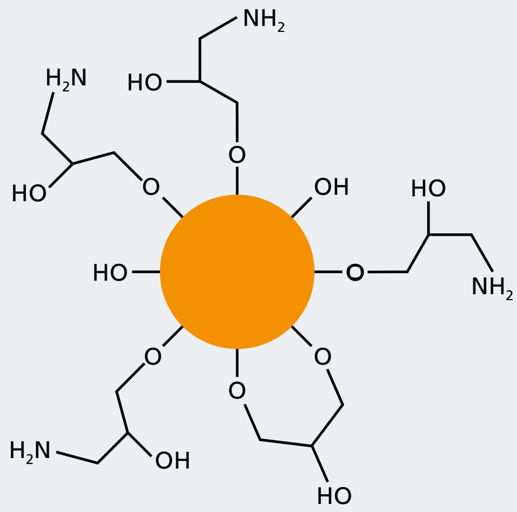
[2] OECD guideline for the testing of chemicals, section 4, Health Effects: *In vitro* 3T3 NRU phototoxicity test (2004). DOI: 10.1787/9789264071162-en

[3] Thude, S.; Kluger, P.; Schenke-Layland, K. (2015) *In vitro*-Hauttestsysteme zur Untersuchung lichtassoziierter Hautschädigung. Biospektrum 02.15, 21. Jahrgang: 172–174. DOI: 10.1007/s12268-015-0557-z. Springer-Verlag.

[4] Brauchle, E.; Johannsen, H.; Nolan, S.; Thude, S.; Schenke-Layland, K. (2013) Design and analysis of a squamous cell carcinoma *in vitro* model system. Biomaterials 30: 7401–7407. DOI:10.1016/j.biomaterials.2013.06.016

Funding

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



1

IRON OXIDE NANOPARTICLES FOR REGENERATIVE MEDICINE

Maria Steinke, Teresa Kilian, Heike Walles

Non-invasive technologies for regenerative medicine

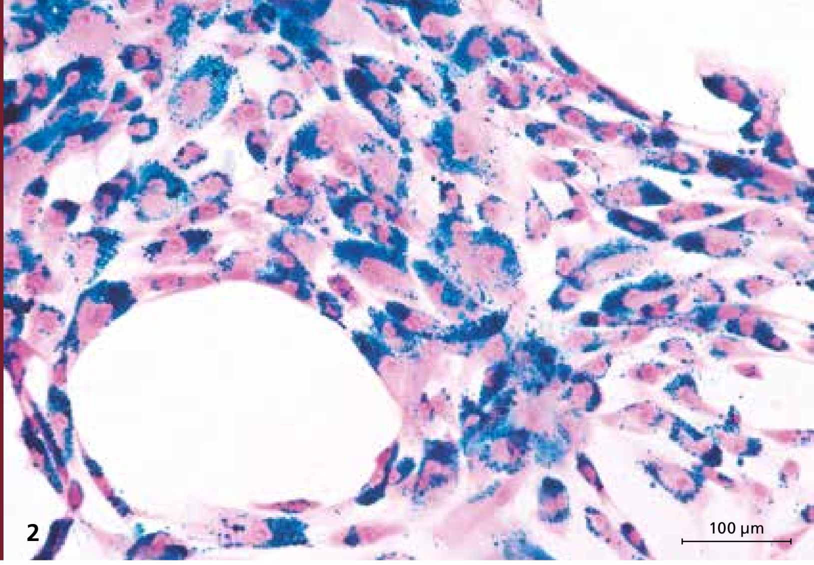
In the research area of regenerative medicine, science focuses on repairing damaged tissue using therapeutic cells, which include mesenchymal stem cells (MSCs). MSCs have a capacity for self-renewal and are capable of differentiating into multiple cell types including osteocytes and chondrocytes. To localize and track stem cells after they have been injected or implanted into the body, they can be labeled with superparamagnetic iron oxide nanoparticles serving as a contrast agent. For non-invasive localization, magnetic resonance imaging (MRI) has been used in both pre-clinical and clinical studies. However, the cellular resolution is often not sufficient with this procedure.

Imaging with magnetic particles

As of late, a new procedure has been available for pre-clinical studies: magnetic particle imaging (MPI). This procedure has a higher temporal and spatial resolution as well as a higher sensitivity than MRI. The use of iron oxide nanoparticles for the non-invasive localization of stem cells is currently limited: Due to a lack of biocompatibility, many particle prototypes fail in the two-dimensional cell culture model. Furthermore, cell labeling often does not last longer than a few days, which makes long-term tracking in the body impossible. As part of the EU-funded project "IDEA – Identification, homing and monitoring of therapeutic cells for regenerative medicine – Identify, Enrich, Accelerate", our goal is to develop iron oxide particles that are biocompatible and suitable for imaging in long-term studies using MPI.

Biocompatible iron oxide nanoparticles

We have succeeded in identifying a particle prototype (M4E) that is internalized by MSCs. M4E particles have a hydrodynamic diameter of 115 nm and consist of an iron oxide core and an amino-functionalized dextran shell (Fig. 1). In *in vitro* cultures, almost 100 percent of the MSCs internalized the M4E particles (Fig. 2). They are passed on to both daughter cells during cell division, which theoretically enables long-term cell tracking. However, the stem cell labeling dramatically decreases within a few days if they are cultured under 2D conditions. If the labeled MSCs are cultured on a three-dimensional scaffold serving as a tissue environment, however, labeled cells can be verified for up to six weeks. Another technology enabling us to track labeled MSCs for up to six weeks is non-invasive magnetic particle spectroscopy, which is based on the same physical principle as MPI. M4E particles do not impact viability, growth or proliferation of MSCs. Furthermore, M4E particles do not trigger any genotoxic effects [1]. Based on these findings, the criteria we defined regarding biocompatibility have been met.



2

Contact

Dr. rer. nat. Maria Steinke
Phone +49 931 31-80720
maria.steinke@igb.fraunhofer.de

Prof. Dr. hum. biol. Heike Walles
Phone +49 931 31-88828
heike.walles@igb.fraunhofer.de

Outlook

The data we generated *in vitro* suggest that the iron oxide nanoparticle prototype M4E is suitable for biocompatible labeling of MSCs and for non-invasive detection using MPI. If stem cells are cultured in a tissue-like 3D environment, labeling lasts for up to five times longer than in conventional 2D cell culture. If we had carried out our study solely in a 2D environment, this would have yielded results that might not have corresponded to the situation *in vivo*. We will verify the *in vitro*/*in vivo* correlation of our data in subsequent animal tests. Furthermore, the 3D scaffold to which the labeled stem cells were applied could be used as an implant for regenerative therapies, in which stem cells can differentiate or migrate to the target tissue.

Literature

[1] Kilian, T.; Fidler, F.; Kasten, A.; Nietzer, S.; Landgraf, V.; Weiß, K.; Walles, H.; Westphal, F.; Hackenberg, S.; Grüttner, C.; Steinke, M. (2016) Stem cell labelling with iron oxide nanoparticles: impact of 3D culture on cell labelling maintenance. Nanomedicine (Lond) 11(15):1957–70. doi: 10.2217/nnm-2016-0042

Funding

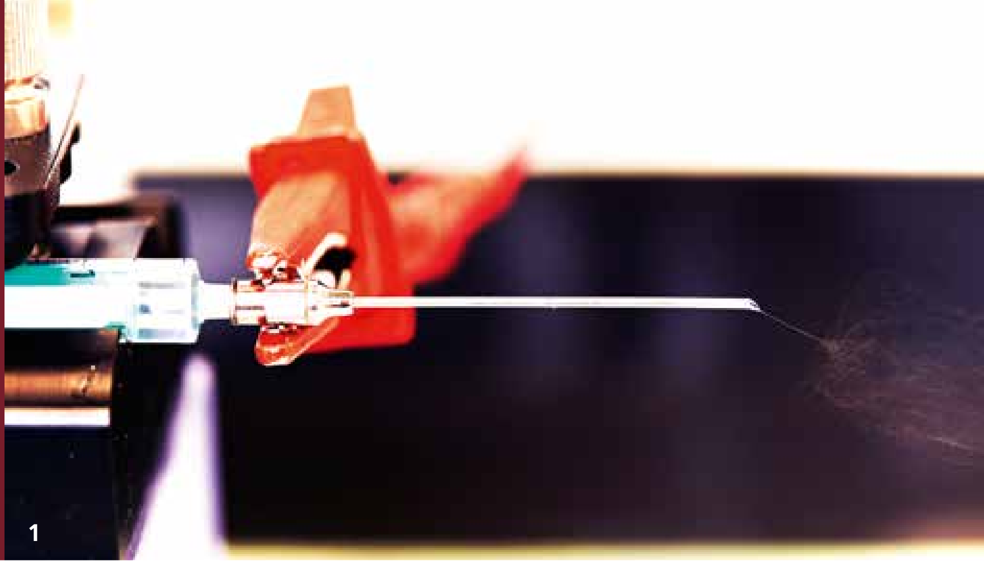
The project "IDEA – Identification, homing and monitoring of therapeutic cells for regenerative medicine – Identify, Enrich, Accelerate" has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 279288.

Project partners

Dr. Florian Fidler, Würzburg | Dr. Cordula Grüttner, Warnemünde | Priv.-Doz. Dr. Stephan Hackenberg, Würzburg | Dr. Annika Kasten, Rostock

1 *Schematic of the particle prototype M4E.*

2 *Prussian blue staining of labeled stem cells. Particles are shown in blue.*



1

ELECTROSPINNING IN REGENERATIVE MEDICINE

Svenja Hinderer, Katja Schenke-Layland

Electrospinning – Functional principle

Electrospinning is a well-known method from the filter and textile industry that is increasingly used in regenerative medicine and medical technology. The process of electrospinning produces a three-dimensional fibrous carrier substrate or membrane. Here, a polymer solution is pumped through a syringe until a drop forms at the tip. By applying a high voltage, a fiber is released from the drop, which moves in circular movements in the direction of the counter electrode, the collector. In this way, the solvent evaporates and dry, arbitrarily oriented fibers in the nanometer to micrometer range are deposited on the collector. Fiber and pore size as well as the fiber morphology can be set and changed via a variety of system and process parameters.

Applications in biomedicine

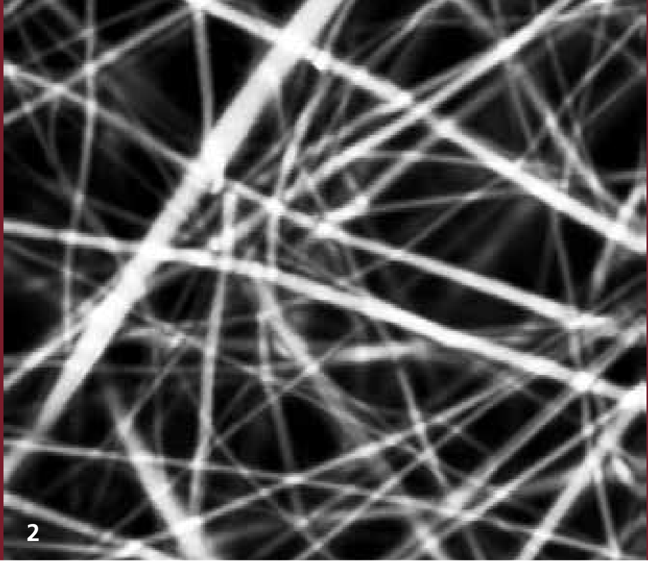
An attractive feature of this technique is that it excellently mimics the fibrous structure of the human extracellular matrix (ECM) [1]. At Fraunhofer IGB, we generate electrospun carrier substrates in various forms for static and dynamic cell culture, differentiation of stem cells, as implants, test systems or as drug delivery systems.

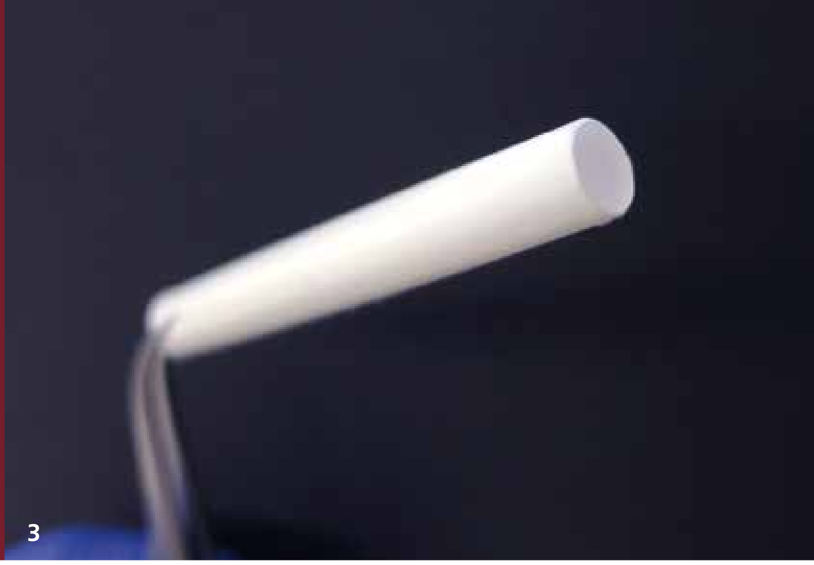
Biomaterials as starting materials

Depending on the future application area and the associated desired functionality of the biomaterial, we use both enzymatically and/or hydrolytically biodegradable as well as non-degradable polymers. We spin natural materials such as collagen, gelatin, hyaluronic acid, fibronectin and smaller ECM molecules (proteoglycans, glycosaminoglycans or growth factors), but also synthetic polymers such as polylactide (PLA), polyurethane (PU), poly-ε-caprolactone (PCL), polyglycolic acid (PGA), polyethylene glycol (PEG), and much more [2]. In addition, we have extensive know-how in the spinning of functional hybrids (PCL-gelatin-decorin, PLA-elastin, PLA-fibronectin), which are mechanically stable and biologically active [3].

The SpinKoll tendon – electrospinning of collagen

Standardized halogenated solvents are used to produce electrospun carrier substrates, which is a critical factor in the spinning of proteins. In the SpinKoll project, type I collagen is to be spun from an acetic acid solution to maintain the collagen structure and functionality after the spinning process. We will increase the mechanical stability of the purely natural material by means of a special layer-by-layer arrangement, resulting in a carrier substrate which can potentially be used as a tendon replacement.





Production of a drug release system

In addition to the manufacture of implants and test systems, we are working on systems that can release drugs, proteins or growth factors over time. A recent example is the encapsulation of glycine-modified diclofenac in a hydrophobic PLA carrier substrate, which is released continuously over 24 hours [4]. The mechanical properties of PLA were not affected by the encapsulation of the drug.

The release experiments showed that approximately 90 percent of the diclofenac is released into the environment. A further release can then only take place via the degradation of the fibers. The drug could be visualized in the fibers via multiphoton microscopy. In addition, we confirmed the biocompatibility of the drug release system using standardized test methods as well as fluorescence endurance microscopy (FLIM) in human fibroblasts. The drug-release system, which is produced by means of electrospinning, is suitable as a wound dressing for the treatment of actinic keratosis.

1 *Electrospinning for the production of fibrous carrier substrates.*

2 *Multiphoton microscopy: electrospun carrier substrate with diclofenac-glycine.*

3 *Tubular electrospun substrate.*

Contact

Dr. rer. nat. Svenja Hinderer
Phone +49 711 970-4196
svenja.hinderer@igb.fraunhofer.de

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

Literature

[1] Hinderer, S. et al. (2016) ECM and ECM-like materials – Biomaterials for applications in regenerative medicine and cancer therapy, Advanced Drug Delivery Reviews 97: 260–269

[2] Hinderer, S. et al. (2014) Bioengineering of a bio-functionalized off-the-shelf heart valve, Biomaterials 35: 2130–2139

[3] Hinderer, S. et al. (2012) Engineering of fibrillar decorin matrices for a tissue-engineered trachea, Biomaterials 33(21): 5259–5266

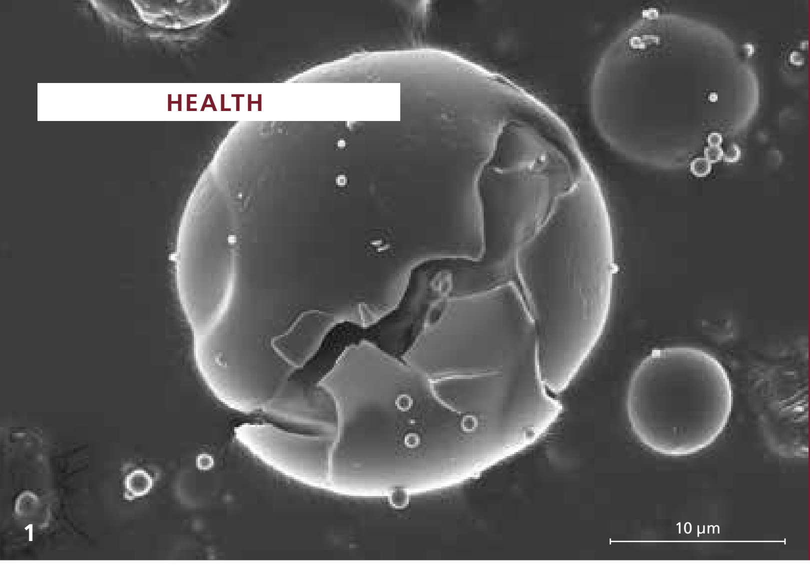
[4] Piccirillo, G. et al. (2016) Electrospun PLA scaffold for a controlled and targeted delivery of a synthetically obtained Diclofenac prodrug to treat actinic keratosis, Acta Biomaterialia: DOI: http://dx.doi.org/10.1016/j.actbio.2016.11.002

Funding

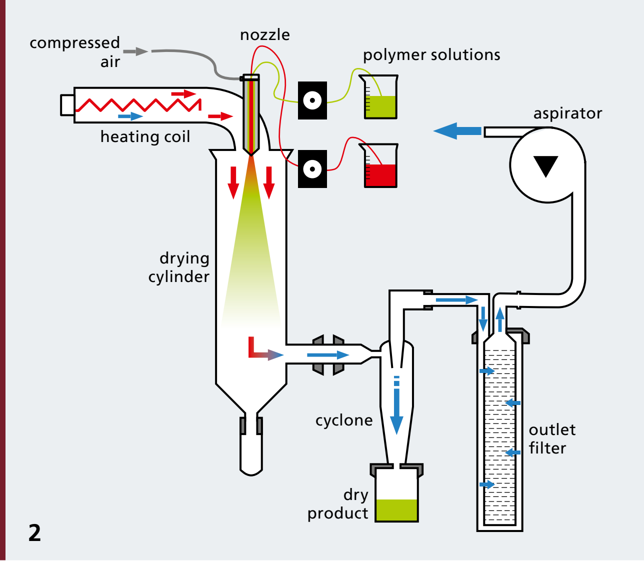
We would like to thank the Fraunhofer-Gesellschaft for funding the “SpinKoll” project as part of the Discover program as well as for funding under the TALENTA speed up program.

Further information and project partners

www.schenke-layland-lab.com



1



2

FUNCTIONAL ENCAPSULATION OF ACTIVE INGREDIENTS BY MEANS OF SPRAY DRYING

Michael Walz, Achim Weber

Encapsulation of active ingredients

Due to several aspects, the encapsulation of active ingredients is of interest to the pharmaceutical and medical technology industry. On the one hand, capsules serve to protect the active ingredients from external influences, for example, gastric juice resistance during oral administration. On the other hand, the treatment of patients can be improved by controlled release. Using a continuous release system leads to lower drug concentrations resulting to fewer side effects. Above all, however, the use and safety of therapy is enhanced compared to conventional methods. An active substance depot can release the active substance over several days to months, avoiding the need for a regular tablet intake, which is considered a great advantage in our era of the aging population.

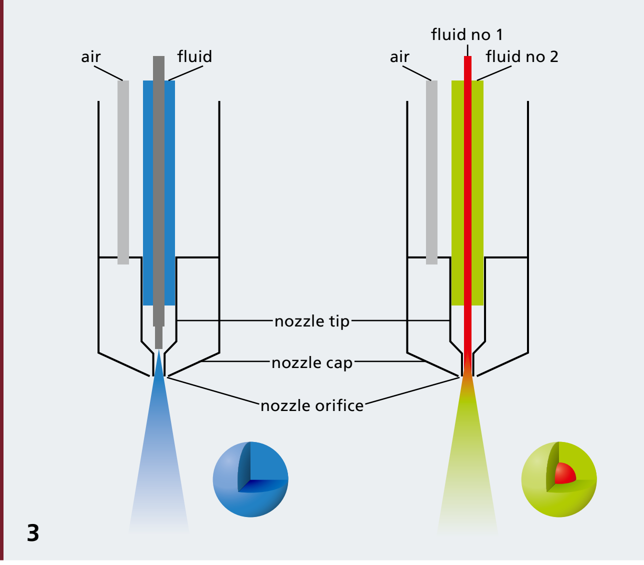
Formulation by means of spray drying

Various aspects such as stability, biocompatibility, cytotoxicity and release behavior must be considered in the formulation of such active ingredient systems. In collaboration with the Institute of Interfacial Engineering and Plasma Technology IGVP of the University of Stuttgart, Fraunhofer IGB is investigating the use of biopolymers from renewable raw materials as a matrix material for active ingredient formulations. As part of a project, inulin was used as a biopolymer in spraying process using a two-fluid and three-fluid nozzle (Fig. 3) for the encapsulation of active ingredients. Inulin was additionally chemically modified in order to investigate the influence on the release properties.

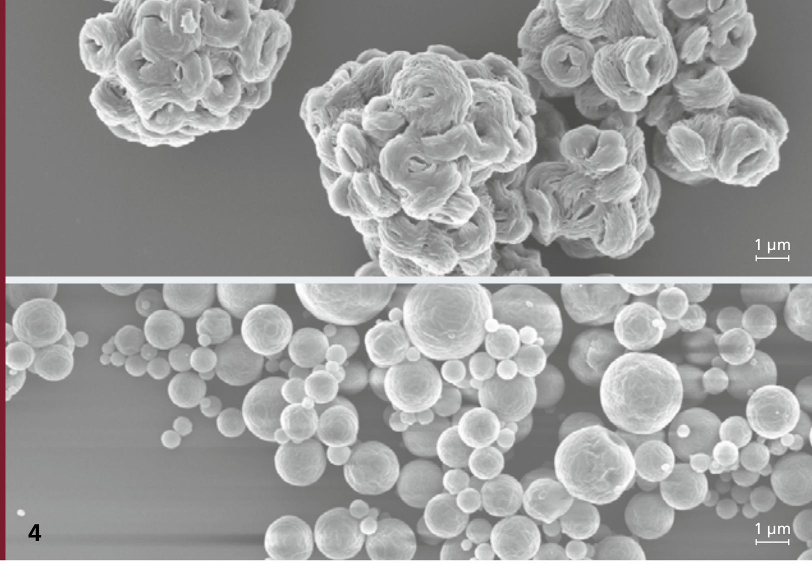
For the production of encapsulated active ingredients in particles, we use, the one-step process of spray drying. A polymer solution in a drying cylinder is atomized into fine droplets by means of compressed gas. The hot gas stream serves to evaporate the solvent, and the resulting particles are separated (Fig. 2). A great advantage is that the application of spray drying does not require any further purification.

Encapsulation using the two-fluid nozzle

The optimal parameters for the spray drying process are determined using the design of experiment. The drying temperature, atomizing gas, pumping speed and the concentration of the polymer solution are varied. Subsequently, various active ingredients are encapsulated, such as dexpanthenol for applications on the skin. For natural inulin, we have observed that the active ingredient is completely released within a few hours. A modification of the biopolymer with acetic acid and propionic anhydride significantly improved the stability of the particles in aqueous solutions (Fig. 4). There was also a prolonged release following the encapsulation of dexpanthenol with these modified inulin derivatives.



3



4

Contact

Michael Walz M. Sc.
Phone +49 711 970-4118
michael.walz@igb.fraunhofer.de

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

Preparation of core-shell particles

Insoluble active ingredients must be converted into stable emulsions or suspensions prior to spray drying. High shear forces and stabilizers are usually required, which cause negative interactions depending on the substance. Therefore, the use of the three-fluid nozzle is investigated in this project (Fig. 3). Two mutually independent component streams can be atomized with a gas stream. In the droplets, mixing occurs due to shear forces and the active ingredient is immobilized in the particle on simultaneous drying [1]. Using different materials, it is also possible to produce core-shell particles (Fig. 1) – the active substance is embedded in a matrix that is coated with a second material. This provides customized solutions for a wide range of applications.

Outlook

In further experiments, various combinations of active ingredients and materials will be prepared and characterized. The encapsulation of nanoparticles using this process is also an interesting application.

Literature

[1] Kašpar, O.; Tokárová, V.; Nyanhongo, G. S.; Gübitz, G.; Štěpánek, F. (2013) Effect of cross-linking method on the activity of spray-dried chitosan microparticles with immobilized laccase, Food Bioproducts Processing 91: 525

Funding

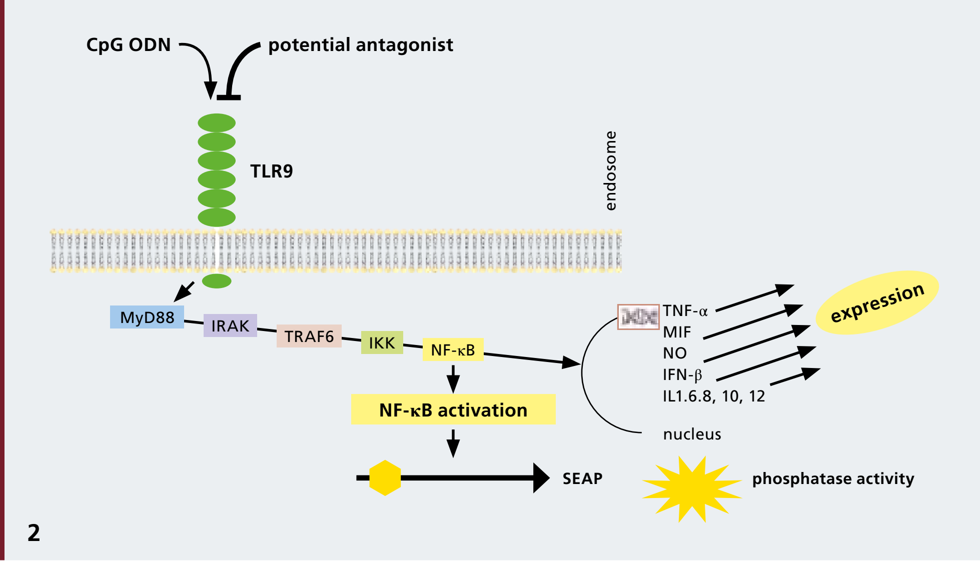
We would like to thank the Konrad Adenauer Foundation for awarding us with a doctorate scholarship.

Project partner

Institute of Interfacial Process Engineering and Plasma Technology IGVP, University of Stuttgart

1 *Core-shell inulin particle, produced by means of a three-fluid nozzle.*
2 *Schematic illustration of the spray drying [1].*
3 *Nozzle design [1].*
4 *Comparison of drug-loaded inulin particles with and without modification.*

1



2

DRUG DISCOVERY AND DELIVERY: FOCUS ON INFECTION, INFLAMMATION AND INNATE IMMUNITY

Steffen Rupp, Anke Burger-Kentischer

Immunomodulators for therapy

Our central objective is to exploit mechanisms of innate immunity in combination with targeted drug delivery for therapy of infections as well as autoimmune and inflammatory diseases. This idea has been fostered by results already achieved in a joint project (ICON project between Fraunhofer IGB and the Hebrew University, IDR) [1, 2]. Based on these results, we aim to design immune-modulatory compounds in order to address infections and inflammatory diseases more effectively. Targeting these compounds directly to the site of infection or inflammation will support the healing process significantly. For infections, stimulating the host's own defense mechanisms should also be effective against pathogens resistant to the current anti-infectives, enhancing "classical" medication efficiently.

As a first target we have identified dermatological disorders such as atopic dermatitis, psoriasis and lupus, since they show involvement of innate immunity, including toll-like receptors (TLRs). Currently, the pipeline for mild-to-moderate psoriasis includes at least 22 investigational topical therapies in various stages of development, including IL-17 antagonizing agents, showing that immune-modulating agents have a high potential as medication. Dermatologic disorders often show a complex interplay between defects in skin barrier function, environmental impact and infectious agents as well as changes in immunity.

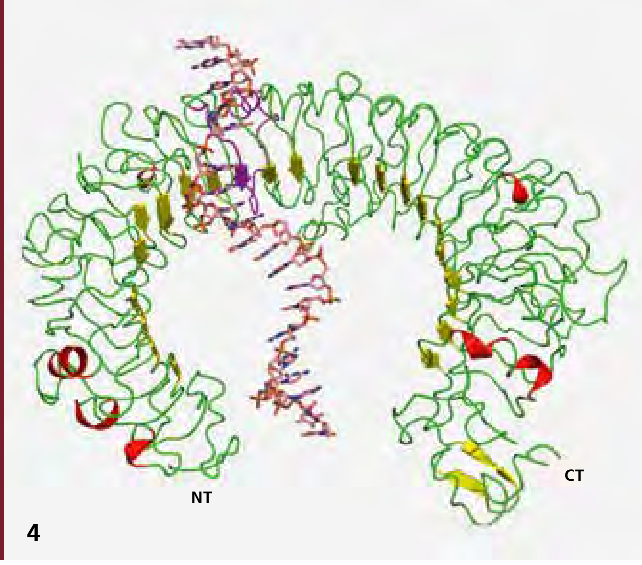
The second focus is to develop novel drugs and targeted nanomedicine to combat fungal infections caused by fungi such as *Candida* spp. and viral infections caused by Herpesviridae. Since innate immunity is an essential part of combating infectious diseases, a combination of drug development, stimulation of innate immunity and targeted formulation of the respective compounds is an ideal approach to combat infections. The first compounds with TLR-modulating activities have been introduced in clinical trials as antiviral agents, indicating the feasibility of this approach.

Drug design and selection

Discovery of novel agonists and antagonists of innate immune receptors (pattern recognition receptors, PRRs) or the molecules downstream in the signaling pathway related to the indicated diseases will be performed as previously described [1] using computational methods by our partner, Hebrew University. For example, for TLRs that have a published set of small molecule agonists/antagonist, models are based on physical and chemical properties of ligands and will serve as filters for scoring and picking top candidates from huge (millions) numbers of commercially available molecules. Modeling and docking is performed in iterations, building on experimental screening results [1, 3]. A library of 200–300 compounds is defined initially and smaller libraries are employed for subsequent screenings for each newly addressed PRR or group of PRRs [1].

Targeted delivery systems

Liposomes (NP) are potent drug delivery systems that protect the drug from degradation, improve its pharmacokinetic properties and deliver a relatively high drug payload. For efficient



NP accumulation at the target site, both long circulation time and efficient particle targeting are critical. True molecular targeting of liposomes can be achieved through ligand linkage to appropriately designed 'stealth' NP by our partners [2]. Targeting will be designed specifically to the indications mentioned above.

In vitro and *in vivo* test systems

Infection models are available for both fungal and viral infections at Fraunhofer IGB [4–6]. These models are used to validate the new immune-modulating compounds as well as the formulations. In a first step, we use cell-based assays [1, 3] to validate the PRR-modulating activity of the compounds identified in silico experimentally (as mentioned above); second, we use complex 3D-tissue models, including components of the immune system [4] to validate both the effect of the IMC on different cell types including immune cells and the formulation in delivering the compounds appropriately. Animal models for further validation of the lead compounds of these indications are available with our partners.

Outlook

With this approach, we aim to combine two central ideas supporting the healing processes in infection and inflammatory diseases: (i) modulating innate immunity by supporting clearance of invading pathogens or ameliorating the (auto)inflammatory process and (ii) targeted delivery of known and novel drugs to infected or pathologically-modified tissues/cells.

1 *Cell-based reporter gene assay in cell-culture plates.*

2 *The cell-based reporter gene assay is a tool to identify lead compounds for drug development.*

3 *Cell culture flasks.*

4 *Structure of the human TLR9 when bound to the antagonist oligodeoxynucleotide (receptor-antagonist-complex).*

Contact

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

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

Literature

[1] Zatsepin, M. et al. (2016) J Chem Inf Model 56: 1835–1846
[2] Ron-Doitch, S. et al. (2016) J Control Release 229: 163–171
[3] Burger-Kentischer, A. et al. (2010) Journal of immunological methods 358: 93–103
[4] Kühbacher, A. et al. (2017) Methods in molecular biology 1508: 439–449
[5] Hogk, I. et al. (2013) Methods in molecular biology 1064; 239–251
[6] Hogk, I. et al. (2013) BioResearch open access 2: 250–257

Funding

We would like to thank the Fraunhofer-Gesellschaft and the Hebrew University for funding the project "Joint Research Hub for Drug Discovery and Delivery" within the ICON program.

Project partners

Gershon Golomb, Amiram Goldblum, Hebrew University, Jerusalem, Israel

1

QUALITY MANAGEMENT SYSTEMS IN PRE-CLINICAL RESEARCH INSTITUTIONS

Marco Metzger, Thorsten Bergmann

Optimizing work and process quality

The Translational Center "Regenerative Therapies for Oncology and Musculosceletal Diseases" (TZKME) is committed to covering the entire value chain in the field of regenerative treatments – from the development to the approval of (biologized) medical products and cell-based transplants. To offer the highest possible quality, the necessary infrastructure based on a quality management system (QM system) is currently being established at the Translational Center.

QM systems are becoming increasingly important in today's corporate world, with the aim of improving work and process quality within companies as well as maintaining and continuously improving the quality of products and services. Depending on individual systems and standards, QM systems comprise different things: They focus on standardizing and optimizing work processes and structures, establishing standards for products and services and ensuring meticulous documentation. One important goal is to maintain and increase customer satisfaction. But the focus is on not only customers, but also employees. QM systems are designed to enhance employees' motivation, ensure their continuous professional development and improve the organization and equipment of their working space.

Quality management pursuant to international standards

Some rudimentary forms of QM systems have a long tradition, going back to the provisions and checks carried out by the guilds in the Middle Ages. With the start of the industrial revolution, these systems started to play an extremely important role as increased production output made the implementation of certain product quality standards ever more necessary.
In general, QM systems comprise the following three fields: Quality planning (defining quality objectives, planning processes and checks); quality scheme (assessing quality standards and identifying appropriate measures if necessary); and quality improvement (optimizing structures and processes).

In 1979, Great Britain introduced the first European Standard for QM systems, the British Standard 5750, which later served as the basis for the DIN EN ISO 9000 and its successor versions. Today, the current DIN EN ISO 9001 (version 2015) [1] is the standard commonly used worldwide in the implementation of QM systems and is applied by most organizations. In some fields, such as the health care sector, the automotive or the pharmaceutical industry, a QM system based on international norms is even a statutory requirement.

Mapping of value chains

The chairs of Tissue Engineering and Regenerative Medicine (TERM) and of Functional Materials in Medicine and Dentistry (FMZ) are both located in the TZKME and run a joint pre-clinical study unit. Their common goal is to cover the entire value chain of regenerative treatments.

This, however, requires the establishment of solid infrastructures that enable efficient, ongoing interdisciplinary cooperation in the fields of research, development, pre-clinical and clinical trials and approval. To this end, the QM system currently in place is to be adapted in line with DIN EN ISO 9001:2015 and certified in the course of 2017.

2

Accredited test laboratories

The FMZ test laboratory has already been accredited under DIN EN ISO 17025:2005 as part of the Translational Center and has been recognized by the Central Authority of the Länder for Health Protection with regard to Medicinal Products and Medical Devices (ZLG). In this laboratory, biological tests of medical products and dental materials (DIN EN ISO 10993-5 and 10993-6, DIN EN ISO 7405) as well as inorganic-analytical test procedures are carried out.

The following biological tests are currently offered:

1. Cell proliferation test after contact with extracts or after direct contact (determination of number of cells)
2. Metabolic activity after contact with extracts or after direct contact (WST-1 assay)
3. Protein synthesis after contact with extracts or after direct contact (Lowry protein assay)
4. Cell damage and lysis after direct contact (agar diffusion test)
5. Determination of local effects after *in vivo* implantation

Good Laboratory Practice

Another strategically important step for covering the entire value chain as mentioned above is the implementation of Good Laboratory Practices (GLP) within the pre-clinical study unit for animal studies. GPL is a statutory requirement for all safety-relevant questions in the context of the pre-clinical development of bioimplants. Building on the existing DIN ISO 10993-6 for the approval-relevant *in vivo* tests of medical products in a small animal model, GLP is to be established at the Translational Center within the next two years.

Contact

Dr. sc. hum. Marco Metzger
Group Manager Implants
Phone +49 931 31-86686
marco.metzger@igb.fraunhofer.de

Thorsten Bergmann
Project manager QM
Phone +49 931 31-82907
thorsten.bergmann@uni-wuerzburg.de

Literature

[1] DIN EN ISO 9001:2015 Quality Management Systems – Requirements (ISO EN ISO 9001:2015, 2015)

Project partners

University Hospital of Würzburg, Chair of Tissue Engineering and Regenerative Medicine (TERM) | University Hospital of Würzburg, Chair of Functional Materials in Medicine and Dentistry (FMZ)

Further information

www.term.ukw.de
www.fmz.uni-wuerzburg.de

1+2 *Coordination and planning carried out by the QM Officer (Thorsten Bergmann, University Hospital of Würzburg) together with the Group Manager Implants (Dr. Marco Metzger, Fraunhofer IGB) to create process chains as part of the implementation of DIN EN ISO 9001 at the TZKME Würzburg.*

1

MICROPHYSIOLOGICAL ORGAN-ON-A-CHIP SYSTEMS AS ALTERNATIVES TO ANIMAL EXPERIMENTS

Julia Rogal, Christopher Probst, Silvia Kolbus-Hernandez, Peter Loskill

Restrictions on drug testing

Drug development is an extremely expensive and time-intensive process. The major reason for the inefficiency of this process is the preclinical drug development requiring large animals or cell lines.

Animal models and cell lines do not only play a key role in pharmaceutical research. They are also used in the cosmetics and chemical industries, as well as in academic basic research. However, even highly developed animal models are not able to replicate the complex human body, particularly human disease. Moreover, they are ethically questionable.

Immortalized cell lines are often of non-human or cancerous tissue origin and are typically cultured in two-dimensional monocultures. The physiological relevance of these cultures compared to human tissue is thereby very limited. Therefore, in many cases, the results obtained from experiments with cell lines or animal experiments do not correctly predict a drug's effect in humans.

Human *in vitro* models instead of animal experiments and cell lines

The discovery of human induced-pluripotent stem cells (hiPS cells) has given scientists the opportunity to overcome many limitations of classical animal models, which is leading to a paradigm shift in the development of personalized and disease-specific model systems. Specifically, the principle of organ-on-a-chip systems has evolved over the past few years from a conceptual idea to a possible alternative for animal models. Science, industry and public authorities now universally recognize the potential of these systems.

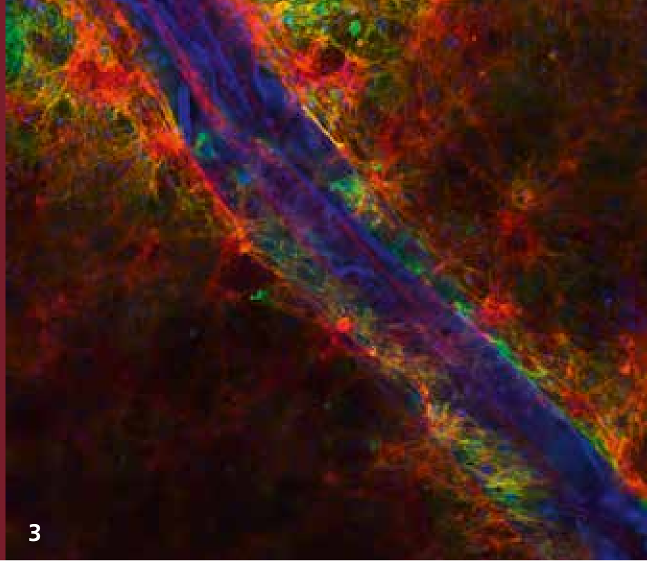
Organ-on-a-chip systems combine the unique features of classical cell assays (human genetic background) and animal models (3D tissue and blood circulation). They make it possible to reduce the need for animal experiments according to the 3R principle (Replace, Reduce, Refine). Furthermore, they improve the translatability of preclinical results to clinical phases and thus make the entire development process more cost-effective, safer and faster.

Basic building blocks of an organ-on-a-chip

In the Attract Group "Organ-on-a-chip", different microphysiological organ-on-a-chip systems, also known as microphysiological systems (MPS), are being developed that replicate the *in vivo* structure and functionality of the respective organs.

The primary component of these systems is the microphysiological environment. For this purpose, technologies from the fields of microfabrication, materials science and microfluidics are used to create structures that physiologically mimic *in vivo* conditions. The use of microfluidics enables the work with physiologically relevant small quantities of liquids and allows for the transfer and removal of soluble factors such as nutrients, drugs or metabolites.

The second important component is the integration of human tissue, which is done by the use of hiPS cells instead of cell lines. By targeted differentiation of hiPS cells, it is possible



to obtain cell types and tissues that have been difficult or impossible to isolate from primary biopsies. hiPS cells can be cryopreserved and expanded, making them far better suited for industrial applications that require reproducible and standardized models. In contrast to embryonic stem cells, the use of hiPS cells is not ethically problematic.

Application

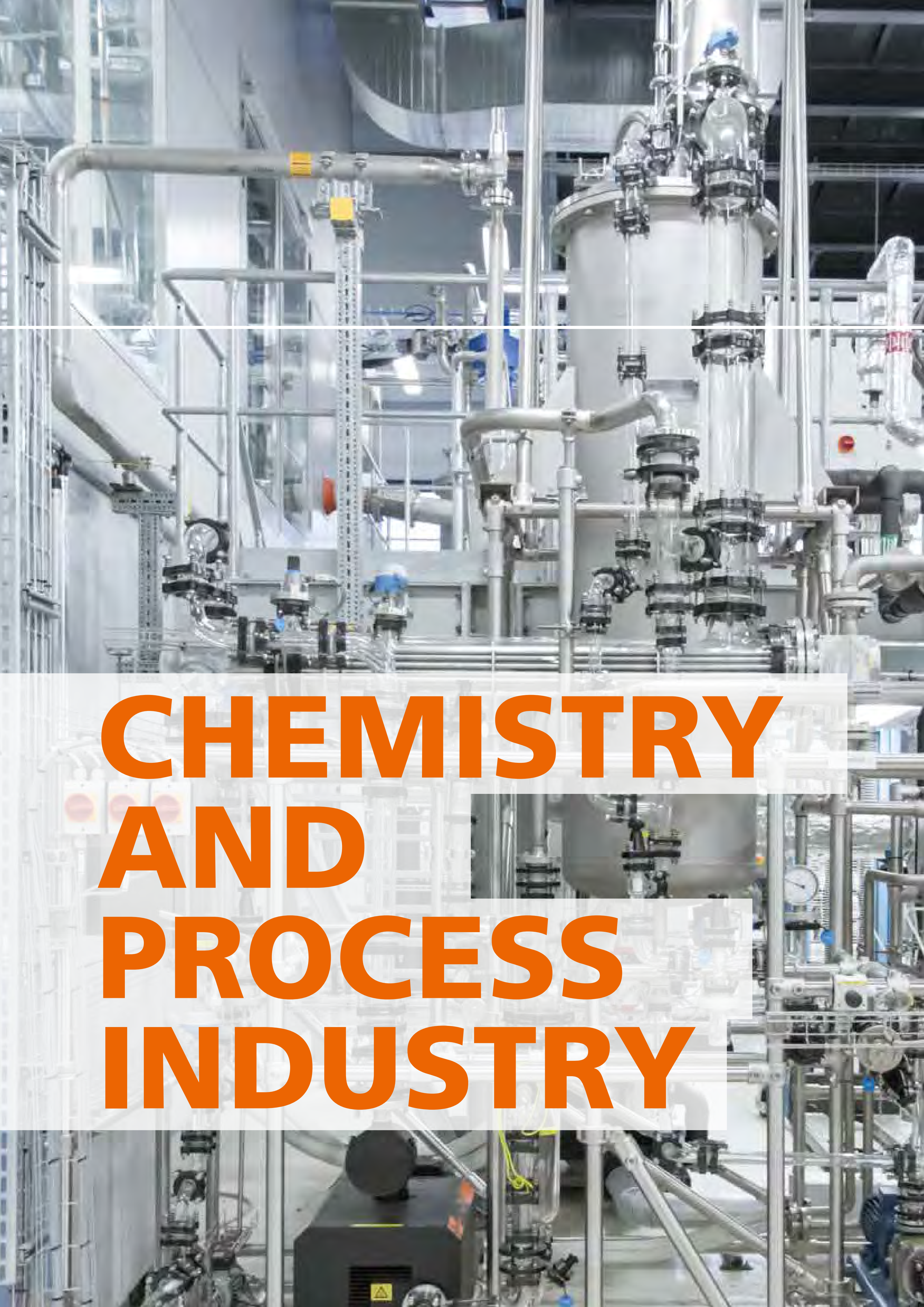
Organ-on-a-chip systems are envisioned to be primarily used for efficacy and toxicity testing during the preclinical screening of drugs. Additional applications exist in almost every area where animal experiments are in use, such as biomedical basic research and the cosmetic industry, where there is a great demand for alternative methods because the EU will ban the import of all cosmetics tested on animals. Another promising field of application is personalized medicine. This area is still immature, but it has great long-term potential.

Contact

Dr. rer. nat. Peter Loskill
Phone +49 711 970-3531
peter.loskill@igb.fraunhofer.de

Funding
We would like to thank the Fraunhofer-Gesellschaft for funding the project "Organ-on-a-chip systems for high-throughput screening" within the Fraunhofer Attract program.

1 *Microphysiological fat-on-a-chip system.*
2 *Fluorescence-stained human adipocytes for fat-on-a-chip systems.*
3 *Humane iPS-derived cardiomyocytes along a microstructured fiber.*



CHEMISTRY AND PROCESS INDUSTRY

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

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

Networking and Cooperation

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

Functional surfaces and materials

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

Fermentation and biocatalysis

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

Biobased chemicals

Fraunhofer IGB has successfully developed fermentation and purification processes, for example, for C2 compounds (ethylene, acetic acid, ethanol) and C3 compounds (propylene, propanol, propanediol, propionic aid, lactic acid) as well as for dicarboxylic acids (malic acid and itaconic acid), amino acids and proteins such as thaumatin or bacteriorhodopsin. Based on renewable resources, algal lipids or biogenic residuals, we have successfully demonstrated new ways to produce basic materials (long-chain dicarboxylic acids, fatty acid epoxides, lactams) for plastics production. We have acknowledged expertise in the microbial production of biosurfactants for use as emulsifiers or detergents.

Biorefinery concepts

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

(Electro)chemical conversion

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

Purification technologies

Substance separation is a key step in many sectors of the chemical and process industry. For upstream processing of raw materials as well as downstream processing of fermentation and synthesis products, Fraunhofer IGB is developing economical procedures and is planning corresponding facilities. The focus is on resource-efficient membrane or electrophysical procedures that simplify multi-stage processing procedures and that are combined, if necessary, with conventional separation methods such as centrifugation, extraction or chromatographic procedures.

1

2

BI-AMIN – PRODUCING AMINES MORE SUSTAINABLY

Fabian Steffler, Volker Sieber

Amines play an important role in the chemical industry. They are manufactured in a wide variety as building blocks for agricultural and pharmaceutical chemicals as well as surfactants, coatings and lubricants. In the BMBF-funded Bi-Amin project, Fraunhofer IGB and its project partners are searching for biotechnical reaction routes and catalysts that can make production more sustainable.

Demand for alternative synthesis routes

Amines are industrially produced based on fossil fuels. The chemical synthesis usually requires high temperatures and pressures. Unfortunately, this has a negative impact on the energy balance of production. In addition, the reactions are usually not enantioselective, which reduces the specific product formation and yield.

Biotechnological process uses renewable resources

In the Bi-Amin project, Fraunhofer IGB's BioCat branch in Straubing is developing a process for the biotechnological production of amines in cooperation with the Technical University of Munich and industrial partners. Biotechnological processes offer the possibility of using various renewable raw materials as substrates instead of fossil resources. In addition, biocatalysts – enzymes that are often derived from microorganisms or plants – work preferably at low temperatures and under ambient pressure, thus under "natural" conditions. This can improve the energy balance of the production process.

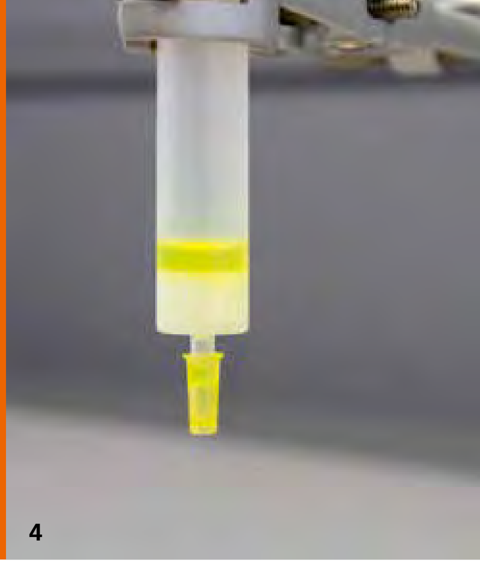
Cell-free biosynthesis as an alternative to fermentation

In contrast to fermentation processes, where usually microorganisms are applied as whole cells, the researchers are planning to use the concept of cell-free biosynthesis for the production of amines. For this, purified specific enzymes are applied which are combined to purely enzymatic reaction cascades. The aim of the project team is to develop such enzymatic reaction routes for the biosynthesis of amines and to scale up this process to the pilot scale.

Outlook

Enzymes should convert renewable raw materials to the desired amines with yields as high as possible. The Straubing branch of Fraunhofer IGB is working on the optimization of suitable enzymes and their production for implementation in the reaction cascades. Another focus of the researchers in Straubing is to develop new methods for processing amines from the cell-free reaction mixtures, as these contribute significantly to the economic efficiency of the biotechnological process.

3



4

Contact

Dr. rer. nat. Fabian Steffler
Phone +49 9421 187-358
fabian.steffler@igb.fraunhofer.de

Prof. Dr. rer. nat. Volker Sieber
Phone +49 9421 187-300
volker.sieber@igb.fraunhofer.de

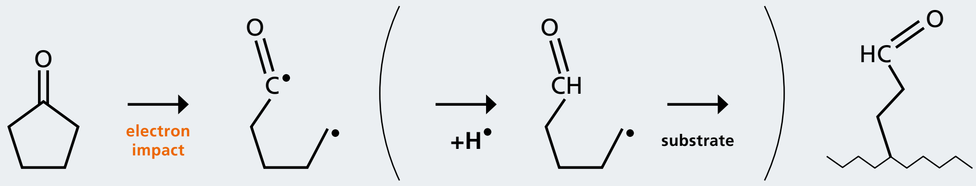
Funding

We would like to thank the German Federal Ministry of Education and Research (BMBF) for funding the project Bi-Amin, promotional reference 031B0071C.

Project partners

TU München | CASCAT GmbH, Straubing

1 *Bioreactor connections for enzyme production.*
2 *Bioreactor intermixing aqueous and gaseous phases.*
3 *Sample fractionation for analysis.*
4 *Protein processing using the example of green fluorescent protein (GFP).*



1

STABLE PLASMA POLYMERS GENERATED BY RING OPENING

Jakob Barz, Bentsian Elkin, Michael Haupt, Christian Oehr

Chemical surface functionalization

Coating by plasma polymerization is an established and widely used process to equip surfaces with specific properties. An example are various oil and water-repellent coatings developed at our institute. In addition to coatings where it essentially comes down to a macroscopic effect, coatings that have specific chemical functional groups and therefore display particular characteristics are also in demand. Chemical functional groups that enable the attachment of various substances to a surface include the amino, epoxide, carboxyl and thiol groups. They can be employed, for example, in the biotechnology sector or in the field of adhesive technology.

Since the conventional methods are not efficient enough and can only be used to a limited extent, Fraunhofer IGB is investigating an alternative plasma process, characterized by surface functionalization by means of ring-opening plasma polymerization.

Initial situation

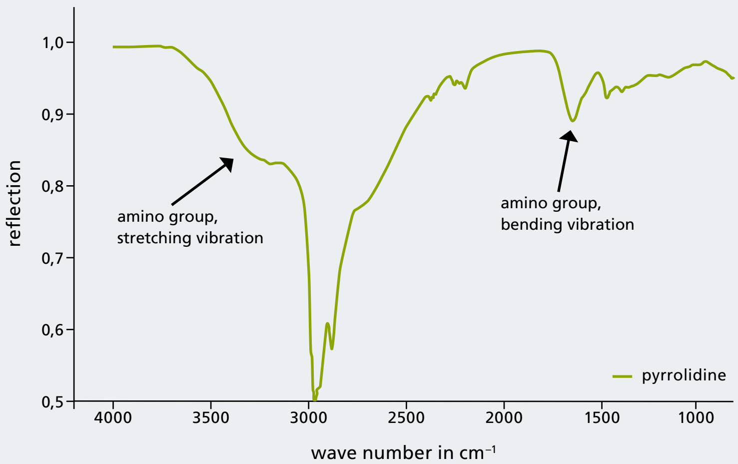
The usual way of producing a chemically functionalized plasma polymer layer is by employing a starting substance (precursor) that already contains the desired functional group. Frequently, a double bond is also included as a "break point". Examples thereof are plasma polymers of allylamine (amino groups) or acrylic acid (carboxyl groups). The problem here is that the energy input from the plasma, which leads to the activation of the target break point, almost equals the energy threshold at which the functional group in the plasma can be destroyed. In order to retain the functional groups, the energy input must therefore be kept as low as possible. However, this also has a negative effect on the degree of polymerization and cross-linking of the generated layer, as well as on the deposition rate. Moreover, the precursors used in this way are toxic and/or unstable owing to their reactivity.

Other methods for the production of functionalized plasma polymer layers, such as grafting or the use of chemically simple gases or gas mixtures, can only be used to a limited extent.

Method

An alternative way of generating functionalized plasma polymers is characterized by the desired chemical function not being present in the starting substance, but rather generated only after plasma has taken effect. Ring-opening polymerization by means of electron impact in plasma generates highly reactive intermediates that contain precursors for the desired chemical function. On the surfaces exposed to the plasma, they form a polymer layer which displays a high density of these functional groups.

An illustrative example of this basic principle is the formation of aldehyde-functionalized layers of cyclopentanone (Fig. 1). The ring is opened (preferably at the bond adjacent to the keto group) by electron impact in the plasma. This generates a biradical, which reacts with a hydrogen atom from the plasma to form an aldehyde-containing radical intermediate and can be incorporated into the growing plasma polymer layer. In an analogous manner, plasma polymers with primary amino groups, hydroxyl groups, thiol groups and further functional layers were also produced at Fraunhofer IGB.



2

The advantage of the method: Since the chemical target functional group is not present in the precursor molecules, particularly gentle plasma conditions are not required in contrast to the conventional method. On the contrary, optimal results are actually achieved at higher energy densities. This leads to additional positive effects such as high deposition rates and/or short process times on the one hand, and highly adherent and stable plasma polymer layers on the other hand.

Results

Plasma polymer layers produced in this way were characterized by different analytical methods such as ellipsometry, FTIR spectroscopy, X-ray photoelectron spectroscopy and chemical derivatization. This allowed us to demonstrate a high density of the desired chemical functions. Furthermore, the layers deposited on different substrates (polymer, metal, ceramic) were tested for stability in various media (alkaline and acidic aqueous solutions, solvents such as alcohols or acetone) and proved to be stable.

Outlook

The generation of plasma polymers via ring opening can be applied in many fields where stable functional layers are required. The coatings can be applied to various materials in many different forms, from solid bodies and films to textiles and fibers. Fraunhofer IGB is thus able to offer its customers customized coatings for their products.

Contact

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

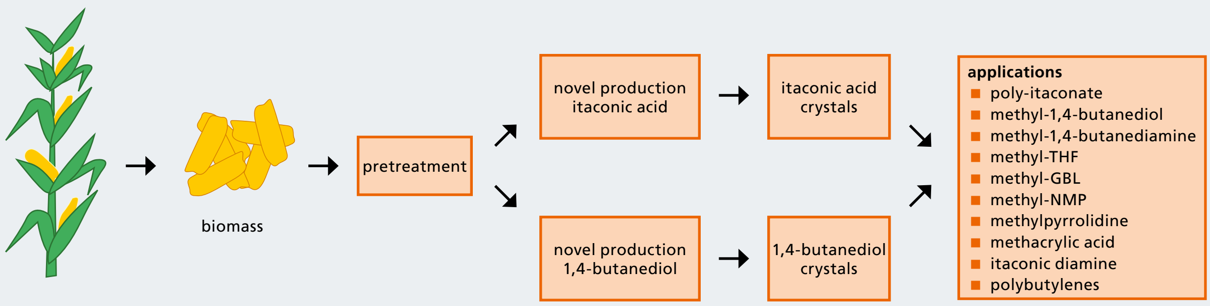
Dr. rer. nat. Michael Haupt
Phone +49 711 970-4028
michael.haupt@igb.fraunhofer.de

Literature

Elkin, B.; Müller, M.; Oehr, C. (2006) Verfahren zur chemischen Funktionalisierung von Oberflächen durch Plasmapolymerisation, DE 102004057155

1 *Reaction scheme of the ring-opening plasma.*

2 *FTIR spectrum of the pyrrolidine plasma polymer.*



1

PRODUCTION OF ITACONIC ACID – FERMENTATIVE PRODUCTION AND SCALE-UP

Katja Patzsch, Andy Leschnik, Georg-Ullrich Geiger, Björn Vater, Susanne Zibek

Initial situation

Europe is preparing for the transition from a fossil fuel-based to a biobased economy. Because of the extensive opportunities and the complexity of the theme, it is expected that this transition will take at least one to two decades. Currently, the initial position of Europe, especially in the biotechnological production of valuable chemicals from renewable biomass, is very good. Thereby, Europe is taking a leading role in researching the field of industrial (white) biotechnology. Furthermore, Europe is distinguished as the leading global position in its chemical and food industry and its advanced logistic infrastructure, too. However, there is an essential requirement for the economic implementation of the research results for industrial processes in order to hold this leading position against faster-acting competing economies.

Project Bio-QED

Against this background, the consortium of the EU-funded Bio-QED project likes to show that biobased (basic) chemicals can be manufactured economically and at the same time in a sustainable manner on an industrial scale. This includes the compilation of all technical and economic key parameters that are required for the investment decision on the first industrial production plants to produce the biobased basic chemicals such as 1,4-butanediol and itaconic acid (Fig. 1).

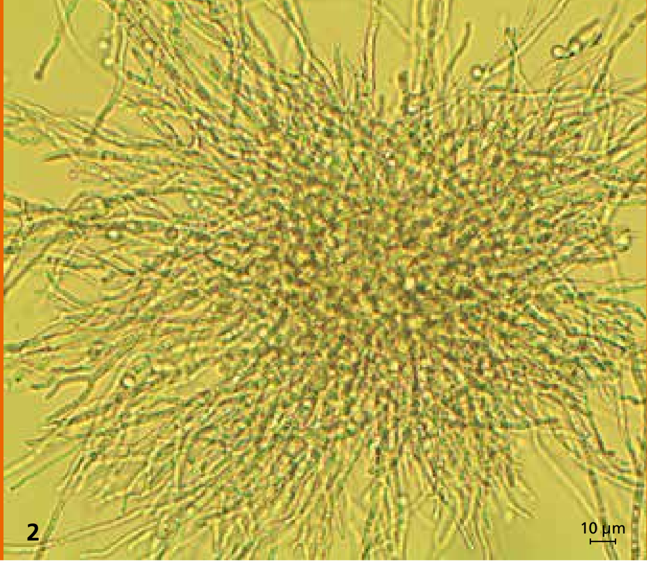
Itaconic acid

Itaconic acid is an important dicarboxylic acid used as a platform chemical; for example, it serves as a co-monomer for the synthesis of emulsion polymers, as a substitute for petrochemically produced acrylic acid or for the production of paints and varnishes and biodegradable polymers in the packaging industry. Itaconic acid is produced biochemically by fermentation of sugar substrates with *Aspergillus terreus* (Fig. 2).

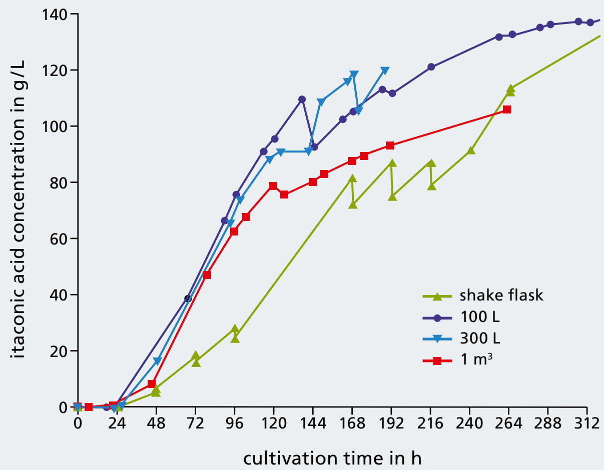
Fermentation of itaconic acid

The Industrial Biotechnology group of Fraunhofer IGB is working on the development of fermentation processes at the laboratory scale. The Bio-QED project examined the extraction of spores from *Aspergillus terreus* for production preparation and achieves a simplified preparation method in which the fungus mycelium no longer needs to be separated from the spores for inoculation. Furthermore, different laboratory parameters such as temperature, salt concentration and the addition of glycerol to spores/spore-mycelia mixtures were investigated. For comparison and in preparation for the industrial scale-up, experiments on the transfer of biomass at a ratio 1 to 10 were carried out.

Furthermore, the group is researching the optimization of itaconic acid production. One focus is the influence of pH on itaconic acid production. In experiments at the scale of shake flasks, a final itaconic acid concentration of 137 g/L with a cultivation period of 14 days (Fig. 3) was reached. This was achieved by increasing pH once the pH had lowered below 1.8. The method is known from literature [1]. Adjustment of pH resulted in an increase of itaconic acid production.



2



3

Scale-up

The scale-up of the fermentation process is being carried out at Fraunhofer CBP. The protocols were transferred to the scales 100 liters, 300 liters and 1 m³ (total volume). The fermentation processes at the 100 liter and 300 liter scales achieved comparable results regarding itaconic acid production and glucose consumption (Fig. 3). The 1 m³ scale resulted in a somewhat lower itaconic acid production since the fungus morphology changes slightly with higher fermentation volume. Whereas *A. terreus* grows in pellet form up to the 300 liter scale, the growth form was more mycelial at the 1 m³ scale. Therefore, we are currently working on adjusting scale-up parameters to ensure consistent morphology of the fungus.

Further work will consider the transfer of the fermentation process to other sugar substrates, an additional scale-up to 10 m³ and the development of product preparation at a pilot scale.

1 *Added value chains of the Bio-QED project.*

2 *Microscope image of the fungus Aspergillus terreus.*

3 *Itaconic acid production at different production scales.*

Contact

Dr.-Ing. Katja Patzsch
Phone +49 3461 43-9104
katja.patzsch@cbp.fraunhofer.de

Dr.-Ing. Susanne Zibek
Phone +49 711 970-4167
susanne.zibek@igb.fraunhofer.de

Literature

[1] Hevekerl, A.; Kuenz, A.; Vorlop, K.-D. (2014) Influence of the pH on the itaconic acid production with *Aspergillus terreus*, Appl Microbiol Biotechnol 98: 10005 – 10012

Funding

The project "Bio-QED – Quod Erat Demonstrandum: Large scale demonstration for the bio-based bulk chemicals BDO and IA aiming at cost reduction and improved sustainability" has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 613941.

Project partners

Novamont, Italy | Mater Biotech, Italy | Cargill, Belgium | TNO, the Netherlands | Itaconix, USA | Lubrizol Advanced Materials S.L., Spain | MiPlast, Croatia | VLCI, the Netherlands | Patentopolis, the Netherlands | nova-Institut für politische und ökologische Innovation GmbH, Germany | Rina Services, Italy

Further information

www.bio-qed.eu


1

BIOINSPIRED FLUOROCARBON-FREE WATER REPELLENT AGENTS FOR TEXTILES

Michael Richter, Christina Faltl, Patricia Huber, Michael Hofer

Environmentally compatible textile equipment

Textile finishing, aiming to provide the textiles with water and dirt repellent properties, usually requires the use of harmful chemicals. Nature-derived water repellent ("hydrophobing") agents are environmentally compatible alternatives. Innovative approaches to the low-pollutant production of water-repellent functional molecules, which are entirely harmless to humans and the environment, are therefore of great importance in the textile industry. For this reason, in collaboration with Hohenstein institutes in Bönnigheim, the BioCat Straubing branch of Fraunhofer IGB is researching the production and application of such bio-inspired water repellent agents.

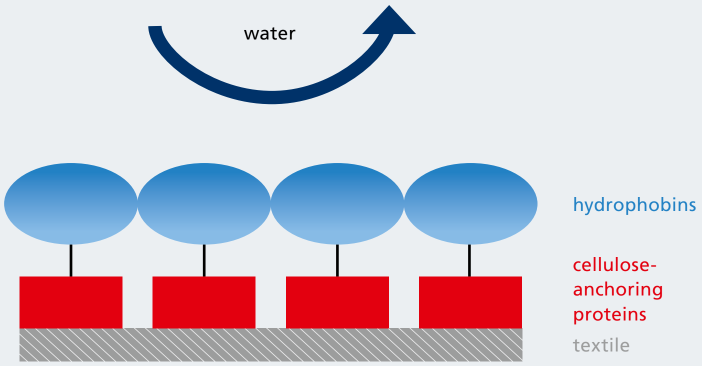
Nature as a role model

The basic concept of the project is borrowed from nature. Agents offering hydrophobic performance are composed of functional proteins and can be produced by biotechnological processes from renewable raw materials. The hydrophobic proteins occur in nature as hydrophobins in fungi, for example. Among other things, they play an important role in affecting the surface tension of water during the formation of aerial mycelia. As amphiphilic proteins, hydrophobins can form very hydrophobic (water-repellent) layers on a material surface by non-covalent interactions, when their hydrophobic part is directed away from the material side.

Proteins from nature are also used to bind the selected hydrophobins specifically in a targeted manner to cellulose-containing textiles; these cellulose-anchoring proteins occur, for example, in natural enzymes such as cellulases. The resulting bi-functional fusion proteins can then be applied to various textiles and should reveal their unique hydrophobic properties there. In a feasibility study, anchoring proteins have already been successfully tested for selective and firm binding to cellulose textiles.

Biological alternative to chemicals

The bio-inspired functional proteins are developed in order to present a sustainable and robust alternative to the perfluorinated and polyfluorinated chemicals used to date in the water-repellent finishing of textiles. They are very controversial due to their manufacturing processes and environmental compatibility, and are subject to growing regulatory pressure. The project covers all necessary work in molecular biology, protein, surface and textile chemistry. It is being supported by a committee composed of representatives of the textile industry and the biotechnology sector. Thus, the basic conditions for the implementation of the project's objectives and industrial feasibility are ideally met from the outset.



2

Contact

Dr. rer. nat. Michael Richter
Phone +49 9421 187-353
michael.richter@igb.fraunhofer.de

Prof. Dr. rer. nat. Volker Sieber
Phone +49 9421 187-300
volker.sieber@igb.fraunhofer.de

Outlook

Target products are outdoor textiles, technical textiles, surgical textiles and antimicrobial textiles, whose fibers are protected against decomposition, for example in the automotive sector. The technology is easily applied to applications in other business fields where functionalization of cellulose plays a role.

Funding

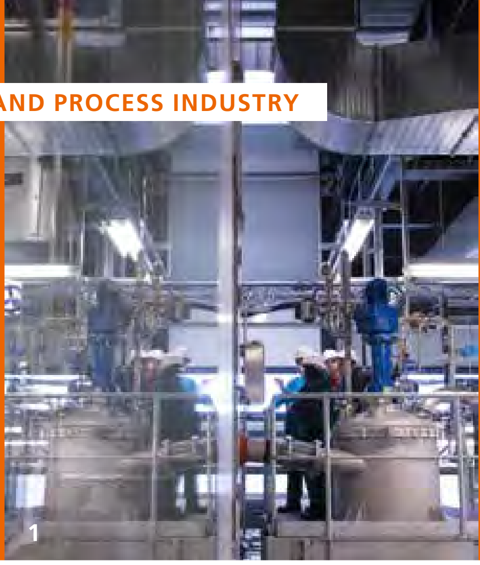
We would like to thank the German Federal Ministry for Economic Affairs and Energy, which is funding the interdisciplinary IGF project no. 18884N of the research association Forschungskuratorium Textil e. V. The funding is provided via the German Federation of Industrial Research Associations (AiF) as part of the industrial collective research program (Industrielle Gemeinschaftsforschung, IGF).

Project partners

Hohenstein Institut für Textilinnovation gGmbH, Bönnigheim | William-Küster Institute of Hygiene, Environment and Medicine, Bönnigheim

1 *Textiles rendered water-repellent.*

2 *Scheme of protein-based textile functionalization.*



CARBOPREC – CARBON FIBERS FROM RENEWABLE RESOURCES

Moritz Leschinsky, Christine Roßberg, Maik Tretbar, Daniela Pufky-Heinrich, Jakob Barz

Background

The demand for high-performance composite materials is increasing in a growing number of industrial applications. This requires new, improved possibilities for the production of carbon fibers. At present, more than 80 percent of the carbon fibers are produced based on polyacrylonitrile (PAN) as the precursor due to its outstanding technical properties. However, this polymer is expensive and available only in a limited amount, which currently limits the use of carbon fibers to a few premium sectors, where the considerable cost can be tolerated in favor of high performance. In order to be able to use carbon fibers in other industries such as automotive engineering or the construction of wind power plants, more lower-priced precursor materials have to be developed.

Approach

The EU project "CARBOPREC" brings together 14 partners from seven countries who are working together to develop two new precursor materials based on renewable raw materials, which are readily available in Europe in the form of lignocellulose, i.e. cellulose and lignin. Carbon nanotubes (CNT) are used as reinforcements in both cases, and new production methods are being developed.

The preparation processes of the precursors are highly dependent on the macro-molecular structure of the raw materials used. Cellulose is isolated from commercially available paper grade pulp in pure form and then spun as a multi-filament in a phosphoric acid-based wet spinning process. Lignin is isolated in pure form from wood by means of organosolv fractionation, compounded with CNT and other polymers, and subsequently spun from the melt as a multi-filament.

The various process stages, from the extraction of raw materials, fiber production, stabilization and carbonization, to the final application in demonstrator components are the subject of the project.

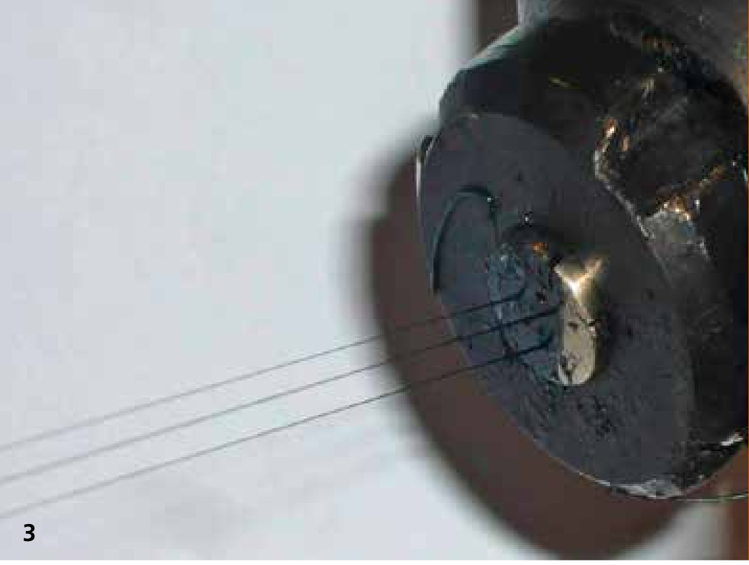
A modified organosolv method optimizes lignin properties

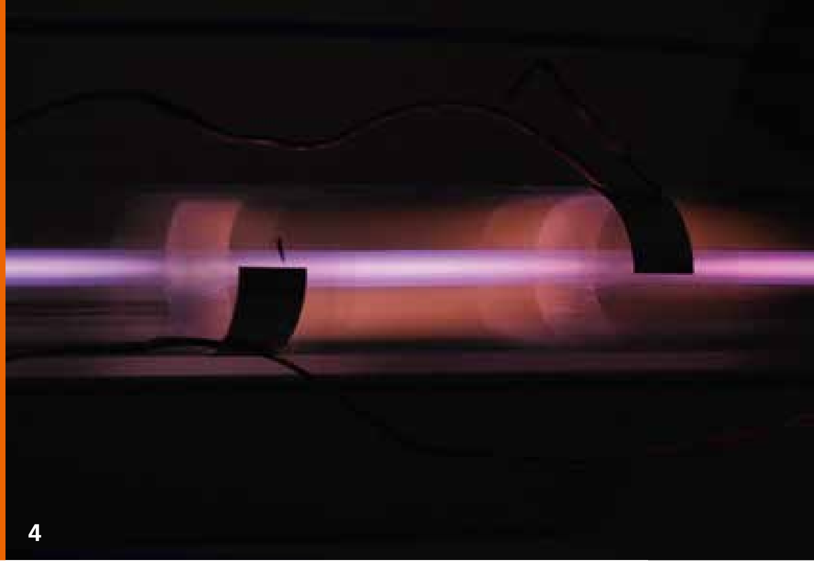
In the project, the Fraunhofer Center for Chemical-Biotechnological Processes CBP plays a leading role in the isolation and property optimization of the raw materials lignin and cellulose. Using organosolv fractionation on pilot scale, established at Fraunhofer IGB's branch in Leuna, optimization of the lignin properties was systematically carried out by varying the process conditions and by selecting various lignocelluloses. Subsequently, more than 150 kilograms of the optimized lignins were produced and handed over to the consortium for the production of demonstrators. The lignins produced in this way display particularly advantageous spinning properties compared with commercially available lignins.

In addition, a cellulose extraction process developed by the University of Hamburg was successfully transferred to the pilot scale in Leuna. This resulted in the production of 120 kilograms of dissolving grade cellulose for the project's wet spinning experiments.

Fiber stabilization by plasma technology

A crucial aspect in the carbonization of lignin fibers is the stabilization of the initially still thermoplastic precursor. To enable this in plasma, a new lignin derivative was developed at Fraunhofer CBP in Leuna, whose functional groups react and cross-link in the plasma. After extensive plasma testing,





carried out in the IGB's Department of Interfacial Engineering and Materials Science, the evidence of reaction was demonstrated, lignin derivatization at Fraunhofer CBP was scaled to the kilogram scale and further optimized. The reaction in plasma leads to a marked increase in the molecular weight in the lignin derivative and thus to the desired cross-linking. In addition to fiber stabilization, which is currently being studied in the project, the approach also offers opportunities in other applications.

Outlook

The materials and processes developed at Fraunhofer CBP and IGB are expected to contribute in a sustainable manner to the development of biobased carbon fibers. In addition, the understanding of the structure-property relationships of lignin gained in the project, as well as the developed and scaled procedures, are also of great value for future developments, applications and projects in the business field of chemical and process industries.

1 *Pilot plant for organosolv fractionation of wood at Fraunhofer CBP in Leuna.*

2 *Filter press for the separation of organosolv-lignin at Fraunhofer CBP.*

3 *Meltspinning of lignin fibers.*

4 *Plasma plug flow tube reactor for material modification.*

Contact

Dr. rer. nat. Moritz Leschinsky
Phone +49 3461 43-9102
moritz.leschinsky@igb.fraunhofer.de

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

Funding

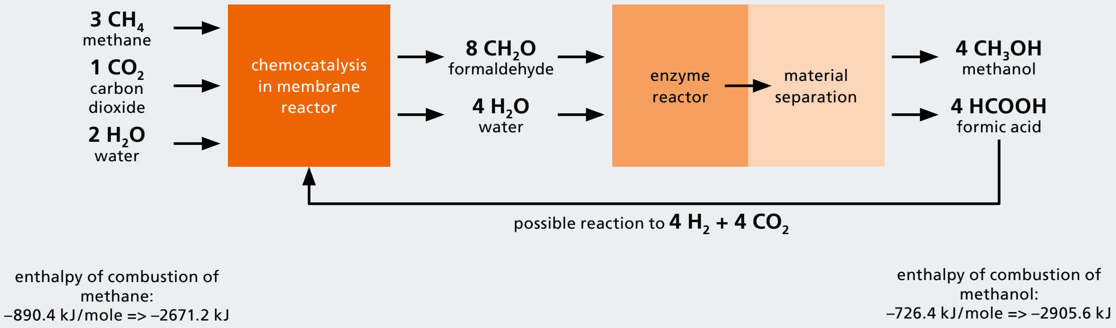
This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 604215.

Project partners

Arkema, Colombes, France | Avana Industries, Budapest, Hungary | Ayming, Asnières-sur-Seine, France | Balakovo Carbon Production LLC, Balakovo, Russia | Canoe, Pessac, France | CETI, Lille, France | CTAG, Pontevedra, Spain | MDP, Terni, Italy | Plastinov, Samazan, France | Renault, Boulogne, France | Sigmatex, Middlewich, Cheshire, United Kingdom | University of Freiburg, Germany | University of Hamburg, Germany

Further information

www.carboprec.eu



1

MATERIAL USE OF METHANE FOR THE PRODUCTION OF PLATFORM CHEMICALS

Matthias Stier, Dieter Bryniok

Alternative use of biogas

Methane is the main component of biogas. Currently, biogas is mainly used as an energy source to produce heat and energy. The energetic use of biogas is efficient if the heat is used judiciously throughout the year – which is not the case for all biogas plants. Therefore, for a long time, research has focused on possibilities for material use of the contained methane. Fraunhofer IGB is making an important contribution to the transition to bio-based production.

Combination of chemocatalytic and enzymatic conversion

In the joint project "ECOX – Enzymatic-chemocatalytic oxidation cascades in the gas phase", foundations for procedures to convert gaseous substrates have been laid in cooperation with the Leibniz Institute for Catalysis LIKAT in Rostock and Martin Luther University in Halle.

Project partner LIKAT has developed a chemical catalyst to convert biogas to formaldehyde [1, 2]. The enzymatic processes necessary for the conversion of formaldehyde were developed by Fraunhofer IGB. Using a formaldehyde dismutase from *Pseudomonas* sp., IGB was able to transform formaldehyde into methanol and formic acid. The formic acid emerging in the enzyme reactor can be used as valuable material or returned into the chemocatalytic process. In addition, use of the procedure to produce methyl formate is a conceivable possibility. This spontaneously occurs in aqueous solution from methanol and formic acid – but so far only at low concentrations. LIKAT hopes to pursue this approach and in the future to also develop chemocatalytic processes for a similar production method for methyl formate.

Development of membrane reactors

Economic conversion of methane to valuable substances in the chemical or pharmaceutical sectors requires specific reactor concepts, for example for membrane bioreactors. These allow the continuous extraction of emerging products from the reaction mixture and thus the combination of production and purification. The aim is an effective recovery of methane by aerobic methanotrophic microorganisms [3].

The substance data characterizing the reactions in the reactor, such as solubility of methane in water at different temperatures and pressures, can be recorded simultaneously with the new foxySPEC mass spectrometer jointly developed by the Fraunhofer ICT and IGB Institutes. The foxySPEC has a modified membrane inlet that makes it possible for the first time to measure simultaneously up to 30 different volatile components in the gas phase as well as in the liquid phase in real time.

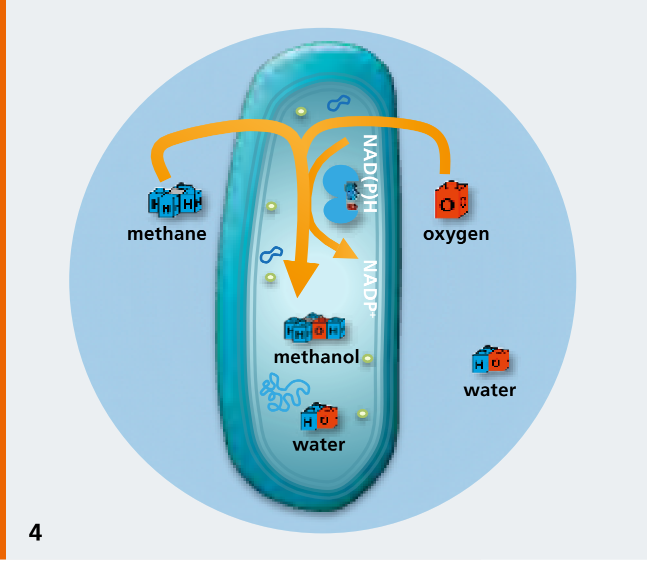
Based on the data so collected, parameters can be derived to optimize the construction of the reactor using a computer-aided simulation. In this way, Fraunhofer IGB is currently developing bioreactors that can be used for all processes of aerobic biotechnical conversion of gaseous substrates.

Automated pilot plant for gas phase reactions

For the process-engineering development of these processes, a fully automated pilot plant for gas phase reactions was designed and built at Fraunhofer IGB in which temperature, pressure and addition of substrate can be precisely controlled. For the ECOX project, IGB integrated the foxySPEC mass spectrometer into the plant. This allowed measurement of the

2

3



4

concentrations of the substrates formaldehyde and methane as well as of the products. Thus, a complete balancing of chemical and biological reactions is reliably possible.

Progress in process development

After successful conversion of methane to the basic chemicals methanol and formic acid, the production of both substances could be further improved in the pilot plant at Fraunhofer IGB. The measurement capabilities of the foxySPEC mass spectrometer proved to be the crucial step. With its help, coupling of the chemocatalytic processes to produce formaldehyde from methane with the enzymatic process was successful.

Outlook

The technical process for the production of methanol and formic acid from biogas is a model for further enzyme-technical processes with gaseous substrates in the gas phase and in combination with chemocatalytic reactions. A promising follow-up approach is the use of methanotrophic bacteria and their key enzyme methane monooxygenase (MMO) for the production of different base chemicals [4]. This represents an important step towards the material use of biogenic materials via intermediate products such as biogas or synthesis gas.

1 *Combined chemocatalytic-enzymatic process for the production of methanol and formic acid from biogas.*
2 *Enzyme pressure reactor.*
3 *Real-time mass spectrometer foxySPEC.*
4 *Methanotrophic bacterium.*

Contact

Dipl.-Ing. Matthias Stier
Phone +49 711 970-4075
matthias.stier@igb.fraunhofer.de

Prof. Dr. Dieter Bryniok
Phone +49 711 970-4211
dieter.bryniok@igb.fraunhofer.de

Literature

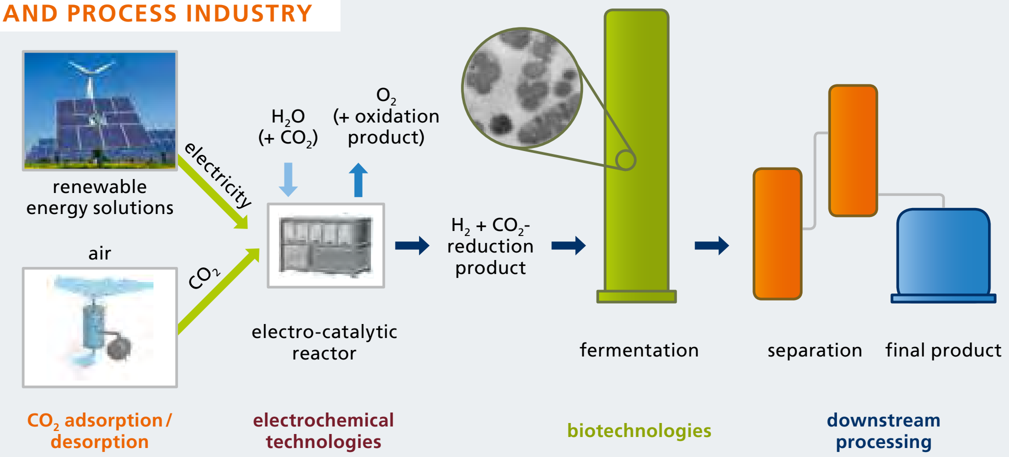
[1] Leibniz-Institut für Katalyse, Zweijahresbericht 2013 und 2014, S. 36–37; available at: www.catalysis.de/institut/oeffentlichkeitsarbeit,accessed on 31st Januar 2017
[2] Nguyen, L. et al. (2006) J. Catal. 237(1): 38–48
[3] Burrows, K. J. et al. (1984) Microbiology 130(12): 3327–3333
[4] Lee, E.-H. et al. (2010) J. Hazard. Mater. 184(1): 313–320

Funding

We would like to thank the German Federal Environmental Foundation (Deutsche Bundesstiftung Umwelt, DBU) for granting of a doctoral sponsorship and the German Federal Ministry of Education and Research (BMBF) for funding of the project "ECOX", promotional reference 031A168A.

Further information

www.foxyspec.fraunhofer.de



1

PRODUCTION OF CHEMICALS FROM CO_2

Tobias Gärtner, Lénárd-Istvan Csepei, Luciana Vieira, Fabian Steffler, Thomas Michael Scherer, Siegfried Egner, Volker Sieber

Baseline situation and project goal

In the coming decades, the use of CO_2 as a source of carbon for the production of key chemicals by direct use of renewable energy will become strategically important. The advantage of this process is that not only are greenhouse gas emissions reduced, but CO_2-neutral compounds are generated as well. CO_2 sources from fermentation processes (e.g. alcoholic fermentation in breweries or distilleries) are generally available. Their CO_2 content is high. However, only CO_2 recovery from the air or exhaust gas streams will provide a significant CO_2 share of the future need for the CO_2-to-chemicals processes [1]. A further necessity is the use of renewable energy sources or chemical reduction equivalents such as hydrogen. These are usually decentralized under today's conditions, which is in line with the power-to-gas technology [2]. Therefore, the project "Cost-effective CO_2 conversion into chemicals via combination of Capture, ELectrochemical and BIochemical CONversion technologies – CELBICON" aims at new CO_2-to-chemicals technologies, which (a) have a modular design and a scalability for decentralized use, (b) high material and energy efficiency, (c) low investment and operating costs, and (d) high robustness with simultaneous variability (Fig. 1).

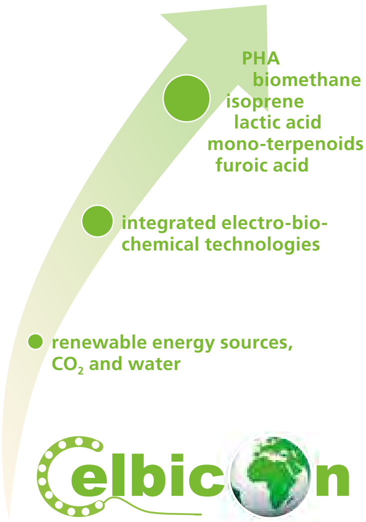
Technology platform

The project, launched in March 2016, involves a high-pressure and a low-pressure process line. Fraunhofer IGB is developing a technology platform for the low-pressure line. An energy and resource-efficient integrated process is being developed to produce high-quality chemicals such as isoprene or lactic acid from atmospheric CO_2 by combining electrochemical and biotechnological catalysis (Fig. 2). In the electrochemical step, the CO_2 provided by Climeworks AG is converted into a mixture of water-soluble C1 intermediates such as formate, formaldehyde or methanol using a gas diffusion cathode. At the same time, the process water of the fermentation is reprocessed at the anode. The C1 intermediates of the cathode reaction are converted directly into isoprene and/or monoterpenes and lactic acid via an integrated fermentation process. In addition to the innovative combination of electrochemical and biotechnological procedural steps, the integration of the reactors into one system and the associated heat and material flow management are also being investigated for the development of the technology platform.

Catalysts for electrochemical conversion of CO_2

A key step for CO_2 activation in the low-pressure process line is the development of a gas diffusion electrode and its integration into an electrochemical cell, in cooperation with Gaskatel GmbH. Firstly, mass transport via phase boundaries and multiple-electron transfer have to be optimized to CO_2, and, secondly, suitable catalysts have to be developed in order to minimize the energy input in the conversion of H_2O and CO_2 to C1 intermediates. Since the start of the project, Fraunhofer IGB has already produced and characterized a large number of catalysts using various preparation methods. Inter alia, copper-based catalysts are used and also tested under continuous process conditions. For the simultaneous process water treatment, the use of boron-doped diamond electrodes is tested, which ensures an ideal hydroxyl radical production, thus enabling an effective process water treatment.

2



Fermentative conversion of C1 intermediates

In the domain of fermentative conversion of C1 intermediates, Fraunhofer IGB focuses on *Methylobacterium* species for the production of isoprene and monoterpenes, and on *Lactobacillus* species for the production of lactic acid. In order to adapt the strains to the C1 substrate, various variants of the biocatalysts are investigated by means of screening methods. The corresponding fermentation processes are optimized by varying the process parameters. Subsequently, the processing of the fermentation products in the context of the entire heat and material flow management is further developed and integrated into the technology platform.

Outlook

The development of the central issue of a technology platform with a combination of CO_2 recovery from the air, electrochemical fixation in water-soluble C1 intermediates and subsequent fermentative preparation of basic chemicals such as isoprene and fine chemicals such as lactic acid is still in its early stage. Nevertheless, this concept provides access to a CO_2-neutral chemical production, which can redefine today's chemical industry.

1 *Presentation of the process chain in the Celbicon project.*

2 *The Celbicon approach allows for a wide range of products.*

Contact

Dr. rer. nat. Tobias Gärtner
Phone +49 9421 187-352
tobias.gaertner@igb.fraunhofer.de

Prof. Dr. rer. nat. Volker Sieber
Phone +49 9421 187-300
volker.sieber@igb.fraunhofer.de

Literature

[1] Wurzbacher, J.A.; Gebald, C.; Steinfeld, A. (2011) Energy Environ. Sci. 4: 3584
[2] http://www.powertogas.info/ retrieved in December 2016

Funding

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no 679050.

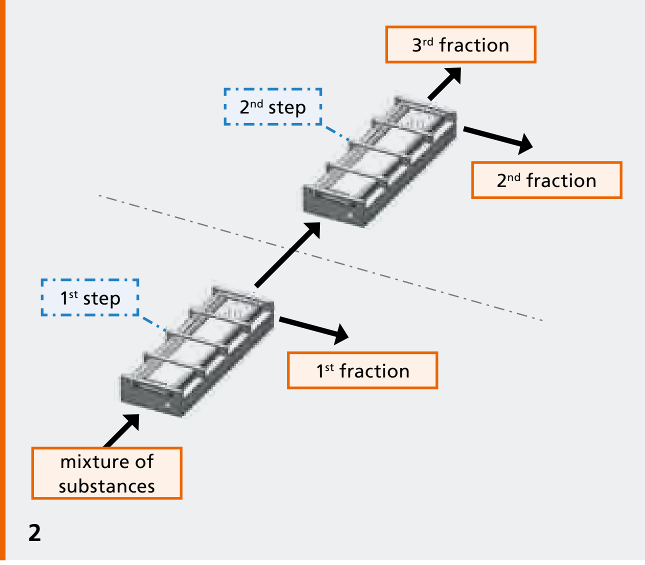
Project partners

Politecnico di Torino, Italy | Delft University of Technology, the Netherlands | Karlsruhe Institute of Technology KIT, Germany | University of Montpellier, France | Agencia Estatal Consejo Superior de Investigaciones Cientificas, Madrid, Spain | Avantium Chemicals BV, Amsterdam, the Netherlands | Climeworks AG, Zürich, Switzerland | Gaskatel GmbH, Kassel, Germany | Gensoric GmbH, Rostock, Germany | Hysytech S.R.L., Turin, Italy | Krajete GmbH, Linz, Austria | M.T.M. SRL, Cherasco, Italy

Further information

http://cordis.europa.eu/project/rcn/200178_en.html


1



2

FREE FLOW ELECTROPHORESIS – DEVELOPMENTS FOR INDUSTRIAL IMPLEMENTATION

Lea König, Maximilian Kotzur, Thomas Scherer

Separating substances in an electrical field

Free flow electrophoresis (FFE) is a continuous process that originally comes from the field of analytics. Its purpose is the selective separation or fractionation of a mixture of dissolved or suspended components that carry a charge. Numerous classes of substances can be addressed with FFE. These range from metal ions such as gold by way of organic substances and proteins to cell organelles and particulate matter. The application possibilities are therefore extremely varied. But FFE has other advantages such as excellent yields or extremely high selectivity and purity with a relatively low use of chemicals. Processes based on the previous technologies such as chromatography or extraction are often very complex and/or require numerous steps and the intensive use of chemicals to achieve a comparable product quality. Fraunhofer IGB is working on developments that will make it possible to use the FFE process on an industrial scale.

Operating principle

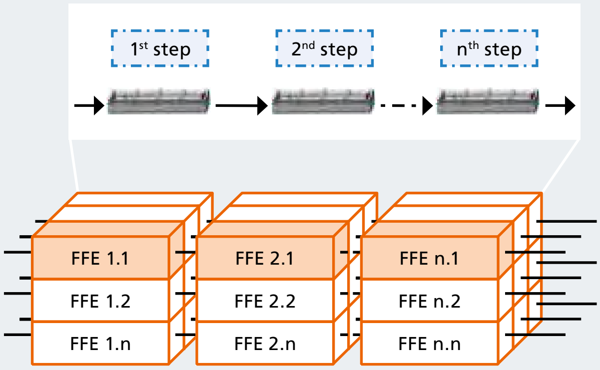
In the FFE process the substances to be separated are fed directly into a buffer flow which continues through the process chamber as a laminar flow. The electrical field perpendicular to the direction of flow subjects the charged substances to a deflective force and these migrate along the field lines. The migration direction (to the anode or cathode) and speed of a substance depend on the substance-specific, electrophoretic mobility (symbol μ). As a result, different substances undergo different deflections across their direction of flow and can be separated into different fractions at a discharge grille.

Challenges

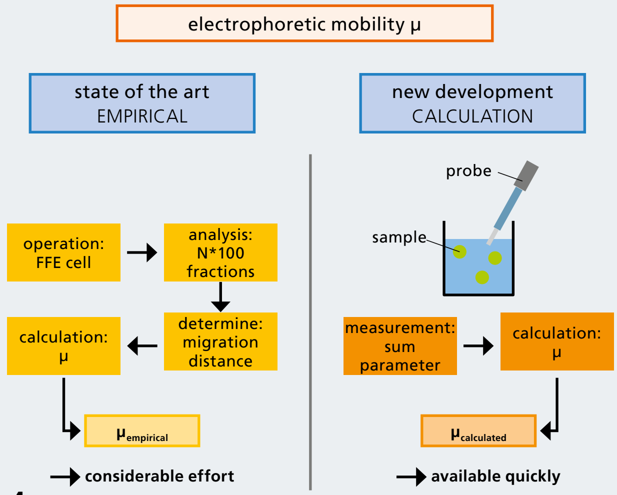
The electrophoretic mobility of a substance depends on a variety of parameters that cannot all be directly determined. The mobility can only be determined empirically in an FFE cell (Fig. 1) with considerable effort (Fig. 4, left). The following steps are necessary: operation of the FFE cell, analysis of numerous fractions, determining the migration distance of the product fraction and, on the basis of this distance, calculation of the electrophoretic mobility. For industrial implementation, however, knowledge of the mobility is fundamental for process planning and dimensioning as well as for the design of systems. In addition to this, further decisive process parameters such as dwell time or electric field strength have to be determined and optimized.

Development strategy

Among other things, the electrophoretic mobility largely depends on the charge and size of a substance. The lanthanoids are especially similar to one another as regards these characteristics. That is why Fraunhofer IGB uses them as a benchmark to identify decisive parameters for the design of the process and the plant. In addition, a method for calculating the electrophoretic mobility on the basis of *ex situ* measurements of a sum parameter (outside the FFE cell) was developed at Fraunhofer IGB (Fig. 4, right). This method makes it possible to determine this crucial process parameter with very little effort and to use it for process planning and dimensioning, and also for the design of systems.



3



4

Available FFE cells from the field of analytics have fixed sizes. Using the conventional method of solving customer-specific separation problems, the process parameters are adapted to the separation problem; the limitations of the FFE cell remain unchanged. This frequently reduces the efficiency of the separation process and/or the product quality. The approach adopted by Fraunhofer IGB combines the process and plant design in order to eliminate these disadvantages. If a separation problem cannot be solved by varying those process parameters that do not negatively influence the product quality, the FFE cell can be adapted to solve the separation problem.

This modification has further advantages. The separation chamber is always designed to exactly the required width. As a result, the energy consumption is reduced because the electric voltage drop decreases through the FFE cell. Also, the FFE cell throughput can be increased and the process media consumption as well as the material costs for the FFE cell can be reduced. By setting up sequential FFE cells that operate on the 0/1 principle (Fig. 2), Fraunhofer IGB optimizes the efficiency of an FFE system in terms of the use of chemicals, energy and the separation performance. Parallelization (Fig. 3) further increases the throughput and permits simple operation of the FFE system.

Applications

Free flow electrophoresis offers numerous industrial application possibilities such as in the production and recovery of precious metals (both in mining and in recycling), in downstream processing, in diagnostics and in the production of pharmaceuticals.

Contact

Dr. rer. nat. Thomas Scherer
Phone +49 711 970-4091
thomas.scherer@igb.fraunhofer.de

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

Funding

The work was conducted within the Fraunhofer Lighthouse project "Critical Rare Earths". The Fraunhofer-Gesellschaft intends to strengthen Germany as a business location by rapidly transforming original scientific ideas into marketable products through its Lighthouse Project initiative.

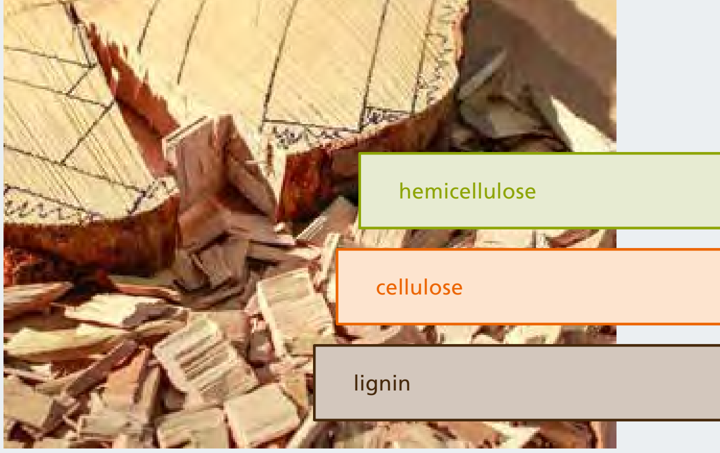
Project partners

Fraunhofer Institutes IWMS, IWM, IWU, IWKS, IGB, IFAM, ISI and LBF

Further information

www.seltene-erden.fraunhofer.de

1 *FFE laboratory setup.*
2 *Sequential 0/1 principle.*
3 *Parallelization of a FFE cell sequence.*
4 *Method developed for calculating the electrophoretic mobility μ.*



woody biomass (waste material / co-products)

1

KOMBICHEM^{PRO} – FINE AND PLATFORM CHEMICALS MADE OF WOOD

Gerd Unkelbach, Moritz Leschinsky, Katja Patzsch, Daniela Pufky-Heinrich, Susanne Zibek

The aim of the joint project KomBiChem^{Pro} is to combine various development activities for the material use of lignocellulose-containing biomass in an integrated biorefinery concept. The most important aspect is the production of marketable products using robust processes and efficient process management in order to ensure broad applicability and competitiveness against petrochemically produced materials and chemicals.

On the basis of the work of the partners involved, the subprocesses are combined at one location, mapped in sufficient dimensions and accounted. This is the only way to obtain reliable statements on the entire value chain from raw material processing and conversion to product separation. The engineering data as well as the material and energy flows allow conclusions to be drawn about the scalability of the processes and make it possible to fully exploit the potential of process integration.

Chemical pulp from organosolv digestion

The basis of the project is the physico-chemical digestion of wood with alcohol-water mixtures (organosolv process), making it possible to obtain all three main components of lignocellulose (i.e. cellulose, hemicellulose, and lignin). As an alternative to the production of glucose, the production of fibers and chemical pulp with this process is another economically viable option [1]. However, the investigations by Peter and Höglinger contain considerable potential for optimization, especially with regard to the process conditions during pulping and bleaching. The quality and possible applications of lignin or hemicelluloses were also ignored. Therefore, the Fraunhofer Center for Chemical-Biotechnological Processes CBP has adapted the pulping parameters to meet the necessary requirements for yield and purity of cellulose, but also of other products.

Chemical conversion of hemicellulose and lignin

The profitable value added from hemicellulose is still an important prerequisite for the economic viability of a lignocellulose biorefinery, in addition to the utilization of lignin. The German Biomass Research Center (DBFZ) was able to show that a conversion of hemicellulose to biogas is possible with high yields. However, higher-quality material use is more economically viable.

Hydrothermal processes are well-suited for conversion of aqueous systems (the hemicellulose fraction in this case), since water is simultaneously a solvent and a reaction partner in these processes [2, 3, 4]. The aim is to select the conditions so that sugars or furans can be selectively recovered from the hemicellulose fraction. In subsequent processing steps, they can then be separated as starting materials for fermentation or as basic chemicals.

The investigations on the reaction patterns of real hemicellulose fractions carried out at the DBFZ laid the foundations for scaling up to the mini-plant scale at Fraunhofer CBP. In recent months, process windows were identified for the target products.

To increase the value, the organosolv lignins obtained by fractionation is converted into phenol fractions by base-catalyzed depolymerization, also under hydrothermal conditions. The process established at Fraunhofer CBP is further improved

with regard to product selectivity as well as on energy- and material efficiency. In the future, a central issue will be further development of the separation and purification steps, in order to optimize the process with regard to technical feasibility, overall efficiency and profitability.

Fermentative production of malic acid and xylonic acid

In addition to the hydrothermal reaction, biocatalytic processes are also suitable for the conversion of pentoses and hexoses. There is a growing market for malic acid as it is used as a flavoring agent or for preservation of foodstuff. It also displays a potential as a polymer building block or in printing inks. The use of xylonic acid is also versatile, e.g. as a precursor for polyesters or hydrogels. The Industrial Biotechnology group at Fraunhofer IGB is developing fermentation processes for both products. In the second project phase, fermentation is carried out up to the 1-m^3-scale in Leuna. Significant improvements have already been made in the laboratory development for the fermentative production of malic acid, achieving higher yields than with the state of the art.

Outlook

In addition to the economic assessment of the experiments carried out at Fraunhofer CBP, DBFZ will work out an ecological assessment of the advantages and disadvantages of this biorefinery concept in order to overcome the latter. Further pilot-scale tests also enable the production of sample quantities for application characterization and determination of product specifications.

1 *Schematic concept of the joint project KomBiChem^{Pro}.*

Contact

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

Literature

[1] Peter, W.; Höglinger, O. (1986) Lenzinger Berichte, Heft 61: 12 – 16

[2] Bouvier, J. M.; Gelus, M.; Maugendre, S. (1988) Wood Liquefaction – An Overview. Appl Energy 30(2): 85 – 98.

[3] Garrote, G.; Dominguez, H.; Parajo, J. C. (1999) Hydrothermal processing of lignocellulosic materials. Holz als Roh- und Werkstoff 57: 191 – 202

[4] Carvalheiro, F.; Duarte, L. C.; Girio, F.M. (2008) Hemicellulose biorefineries: a review on biomass pretreatments. J Sci Ind Res 67: 849 – 864

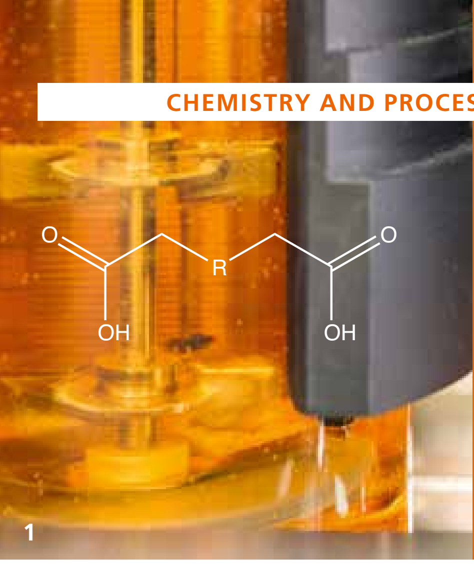
Funding

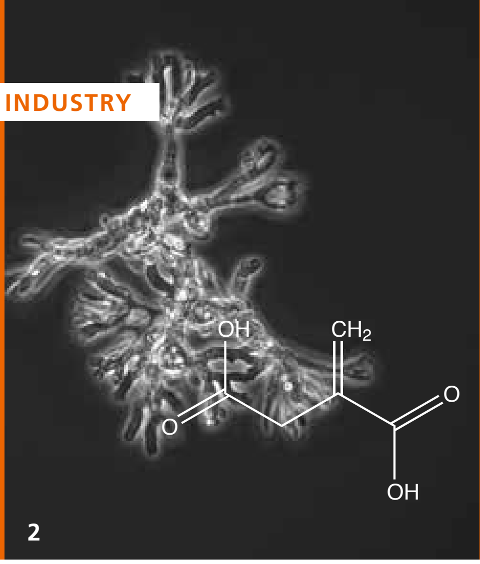
We would like to thank the German Federal Ministry of Education and Research (BMBF) and the Project Management Jülich (PTJ) for funding the project "KomBiChemPro", promotional reference 031B0083A.

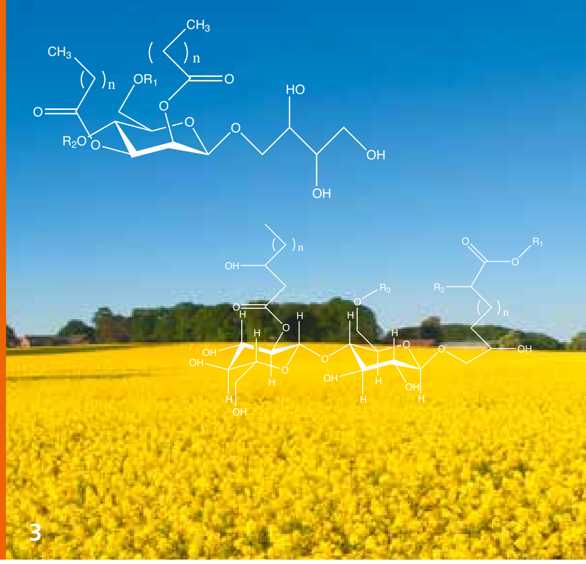
Project partners

Deutsches Biomasseforschungszentrum gemeinnützige GmbH, Leipzig | Thünen Institute of Wood Research, Hamburg* | Max Planck Institute for Dynamics of Complex Technical Systems, Magdeburg* | Universität Leipzig*

* These partners are subcontractors of Fraunhofer CBP







MICROBIAL PRODUCTION OF BASIC CHEMICALS AND SCALE-UP OF FERMENTATION PROCESSES

Susanne Zibek, Björn Vater, Georg Geiger

Industrial biotechnology – alternative for chemistry

Two advantages of microbiological production of basic chemicals are mild reaction conditions and high specificity; in addition, the multitude of different microorganisms means that product diversity is nearly inexhaustible. Thus, products difficult to acquire through chemical synthesis can also be produced. Moreover, microbial production allows the use of substrates based on renewable raw materials. Therefore, it offers alternative solutions for chemicals based on fossil resources.

Development from biocatalyst to purified product

The Industrial Biotechnology group of Fraunhofer IGB is developing processes for the production of platform chemicals using renewable resources. The main focus is on establishing, optimizing and scaling of bioconversion processes in which biogenic resources are converted to basic chemicals either by microorganisms (bacteria, yeast or fungal culture) or by enzymes. Our range of services includes selection and optimization of biocatalysts, development of suitable conversion processes on a laboratory scale and their transfer into pilot or up to m^3-scale. Within process development, we look at all relevant parameters such as temperature, pO_2, OUR, CER and RQ or composition of the medium and establish perfectly adjusted mineral salt media and feeding strategies (repeated-batch, fed-batch or continuous culture management). On the basis of a statistical evaluation of all process parameters, we first transfer the optimal process from the shake flask to the fermenter (scale-over) and then into technical and pilot scale (scale-up). In addition, the downstream processing of products is enhanced.

We are researching and optimizing a wide range of fermentative processes for the production of basic chemicals such as organic acids or dicarboxylic acid with great application potential, for example as building blocks for polymers or plasticizers.

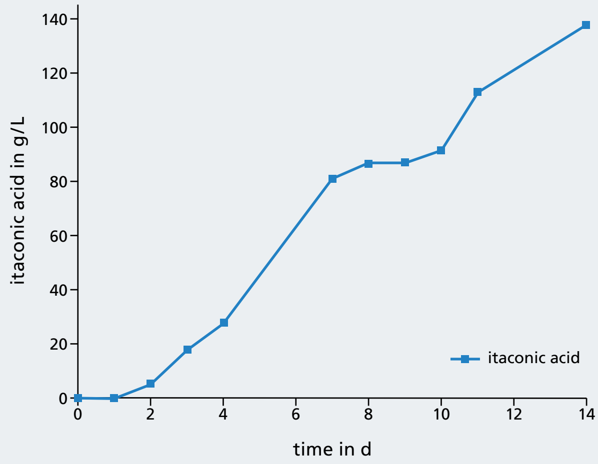
Furan dicarboxylic acid

During the development of a furan dicarboxylic acid (FDCA) production process, we were able to successfully establish whole cell catalysis with *Pseudomonas putida* by adding hydroxymethylfurfural from biomass containing lignocellulose. In the laboratory, we were able to achieve a yield of more than 80 percent at a concentration up to 20 g/L FDCA through precise reaction control. The subsequent scale-up was carried out in model experiments with scalable reactors or fermenters in the laboratory. The dimensionless key figures selected in these experiments allowed us to adapt the processes to the larger scale of a pilot plant.

Long-chain dicarboxylic acids

For long-chain dicarboxylic acids from oils, our processes were optimized in order to simplify subsequent purification. Thus, we were able to increase the biomass concentration to c_x = 21 g/L dry biomass and the product formation rate to up to r_P = 0.44 g/L/h using a process with exponential supplementary feeding rate. A maximum product concentration of $c_P \cong$ 100 g/L was achieved for 1,18-octadec-9-enoic acid.

4



5

Malic and itaconic acid

Fungal systems have proven to be particularly advantageous for the microbial production of malic acid and itaconic acid. Our research on fermentation development for the production of malic acid from C5 sugars of hemicellulose fractions is one example of the use of fungi. We establish biotechnological production of malic acid with *Aspergillus* strains that have the GRAS (Generally Recognized as Safe) status, an approval designation of the US FDA (Food and Drug Administration) indicating the safety of a substance as food additive. By using product process optimization we were able to increase product concentration by a factor of 1.5 compared to what is reported in the literature.

The fermentative production process of itaconic acid dates back to 1932, at that time using *Aspergillus itaconicus*. Now, the *Aspergillus terreus* strain is primarily used. We were able to yield 137 g/L itaconic acid using *A. terreus* for biotechnological applications.

Biosurfactants

Fraunhofer IGB has many years of expertise in the microbial production of biosurfactants. Different smut fungi of the genera *Ustilago* sp. and *Pseudozyma* sp. naturally secret the biosurfactants mannosylerythritol lipid (MEL) and cellobiose lipid (CL), which can be extracted from the culture medium. Application studies for different MEL and CL variants showed a broad application potential – as detergents, emulsifiers and active ingredients in cosmetics, crop protection products and for technical applications. Currently, we achieve product concentrations of 30 g/L for CL and 100 g/L for MEL by optimizing the production process.

Contact

Dr.-Ing. Susanne Zibek
Phone +49 711 970-4167
susanne.zibek@igb.fraunhofer.de

Funding

The projects "BioQED – Quod Erat Demonstrandum: Large scale demonstration for the bio-based bulk chemicals BDO and IA aiming at cost reduction and improved sustainability" and "BioConSepT" have received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 613941 and grant agreement no 289194, respectively.

Furthermore, we would like to thank the German Federal Ministry of Education and Research (BMBF) and the Baden-Württemberg-Stiftung for funding the project "KomBiChem^{Pro}", promotional reference 031B0083A, and the German Federal Ministry of Food and Agriculture (BMEL), represented by the Agency for Renewable Resources (Fachagentur Nachwachsende Rohstoffe e. V., FNR) for funding the CLIB 2021 (Cluster Industrielle Biotechnologie e. V.) project "PolyTe", promotional reference 22012608.

1 *Production of different long-chain dicarboxylic acids from fatty acids or second generation oils.*

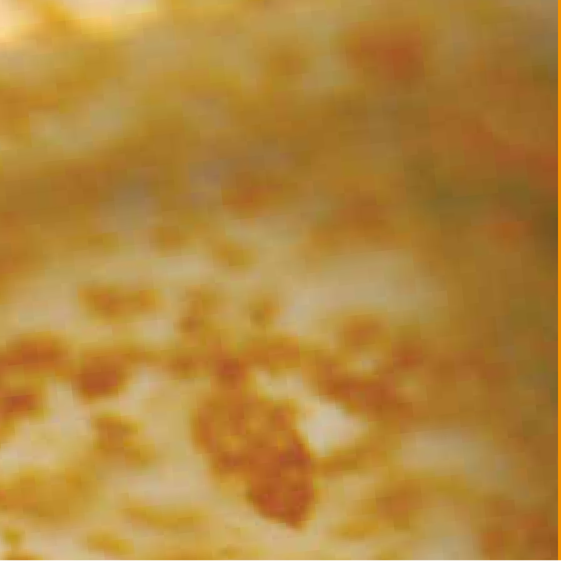
2 *Aspergillus terreus in the production phase of itaconic acid production.*

3 *Production of different MEL and CL variants from renewable raw material oils.*

4 *Fermentative production of L-malic acid.*

5 *Course of itaconic acid production with Aspergillus terreus. Concentrations of 137 g/L can be achieved at shake flask scale through process optimization.*

ENVIRON-MENT AND ENERGY



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

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

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

Networking and cooperation

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

Water and wastewater technologies

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

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

Water monitoring

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

(Re)processing of raw and residual materials

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

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

Energy conversion and storage

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

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

Bioenergy

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

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

1

RECONCILING INTERESTS IN THE COMPANY USING STAKEHOLDER INTERACTION ANALYSIS

Birgit Haller, Jan Iden, Ursula Schließmann

Assessment of sustainability

Resource and energy efficiency are generally important objectives in the development and application of new products and technologies. However, the contribution made by companies to sustainable development also involves other factors. For example, the working conditions in production and the impact of a location on its surrounding environment play a part in this. Yet the evaluation of a product in the early phases of development is a laborious task, especially as the necessary data is often not yet available.

Stakeholder Interaction Analysis identifies hot spots

In order to identify and evaluate so-called hot spots – fields of action that urgently need to be addressed – at this early stage, Fraunhofer UMSICHT and Fraunhofer IGB have developed an instrument called Stakeholder Interaction Analysis (SHIA). The goal of SHIA is – by taking into account the interests of the relevant stakeholder groups – to market socially acceptable products and processes, which make a greater contribution to sustainable development. The aim is to enable the company to find a transparent way of dealing with opportunities and risks through a change of perspective and dialog.

To develop SHIA, the Fraunhofer Institutes IGB and UMSICHT made use of their experience with methods and standards of sustainability assessment and reporting. Existing instruments were compared over a period of three years, and new dialog-oriented, production-related approaches were developed and tested. Finally, these were translated into a tool that can be easily implemented in various branches of industry and areas of application.

Implementation and evaluation tools

SHIA is intended mainly for small and medium-sized manufacturing companies, and focuses on processes of change in production or in future location development.

The Fraunhofer experts advise and support companies in the following steps:

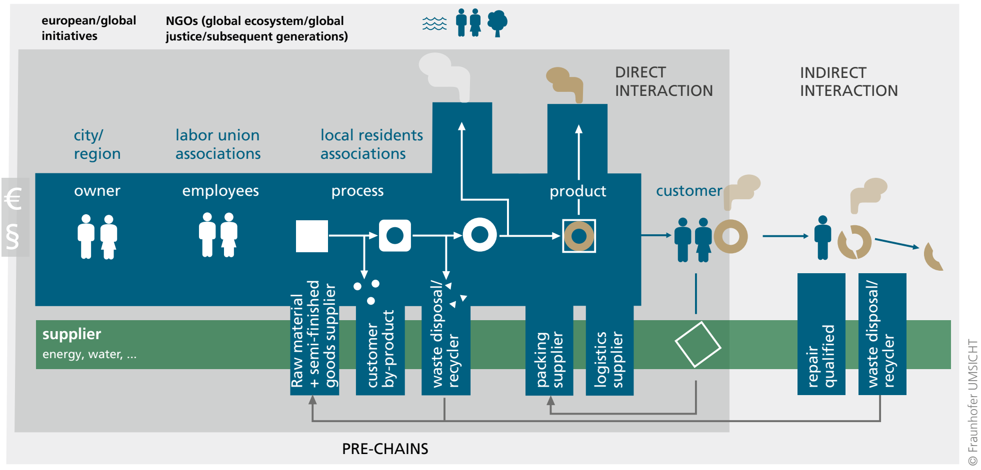
(a) self-assessment of relevant fields of impact in the product development process,
(b) identifying the stakeholders concerned,
(c) identifying the interests of the stakeholders,
(d) assessment of the implementation status in the company.

Fields of impact include in their scope the economic, ecological and social effects of production at the location, also aspects of the product lifecycle as well as the supply chain or disposal and recycling routes.

The full service range comprises phases of dialog, investigations and analysis, as well as expert advice, and makes use of a modular system with various tools:

- The key component is the systematic analysis of the fields of impact, stakeholders and their interests using an interview guideline and an evaluation matrix.
- A criticality tool to assess the influence of a stakeholder group on the planned production process: the stakeholders are evaluated on the basis of the criteria ability to achieve aims and organizational capability.
- A knowledge database of stakeholder interests and examples of good practice in the form of a wiki platform: typical stakeholder interests serve to classify interview results.

STAKEHOLDER ALONG THE PRODUCT LIFE CYCLE



2

Over 300 examples from manufacturing companies provide support in developing recommendations for action.

- A dialog tool for planning communication with various stakeholder groups.

The dialog with representatives of the company and, if necessary, with selected stakeholders as well as the use of expert knowledge and the results of investigations are the basis for the systematic description of hot spots in the company, possible conflicts of interest and for the feasibility of improvement measures as well as recommendations for action on the basis of examples of good practice. Building on this, a communication concept is developed to achieve a closer involvement of the various stakeholders. The concept also serves as a basis for presenting the SHIA results in the company or to customers.

Lighthouse project E³ Production

SHIA was developed in the Lighthouse project "E³ Production", in which a total of 12 Fraunhofer Institutes were involved. The intensive networking between the institutes provides an interface to the technological developments they are working on. The efficiency of the technology, the emissions neutrality of the factory and the involvement of people are placed in a new context by the E³ concept. Solutions for challenges facing production technology result specifically from the consistent use of newly created synergies of efficient technologies and facilities, new thinking about logistics and factories and a deliberate, future-oriented integration of people in the world of production.

Contact

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

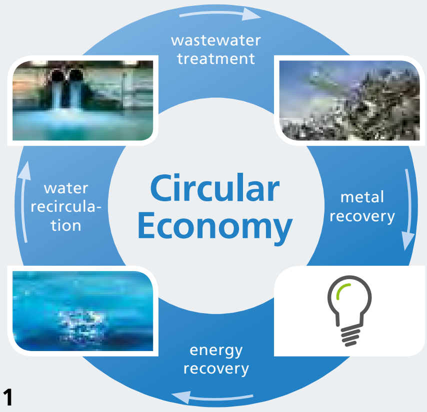
Funding
The work was conducted within the Fraunhofer Lighthouse project "E³ Production". The Fraunhofer-Gesellschaft aims to strengthen Germany as a business location by rapidly transforming original scientific ideas into marketable products through its Lighthouse Project initiative.

Project partners
Fraunhofer Institutes FIT, IBP, ICT, IFF, ILT, IML, IPK, IPA, IPT, UMSICHT and IWU

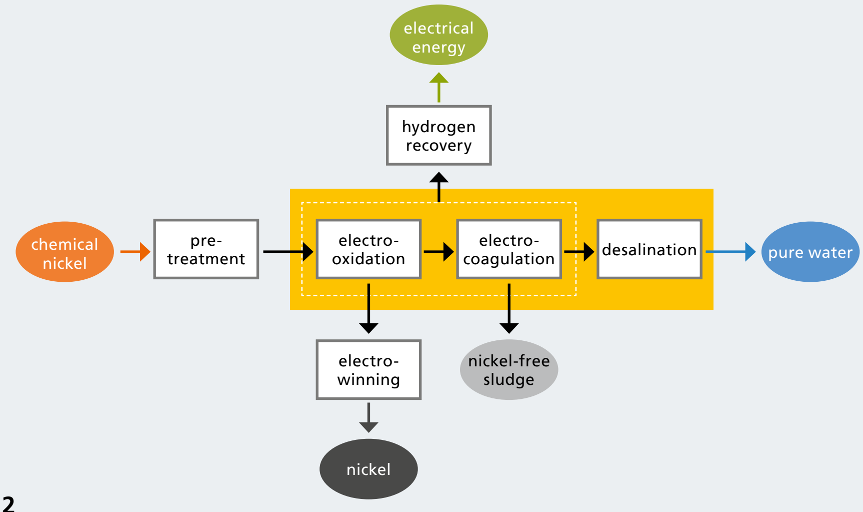
Further information
www.stakeholder-interaktion.de
www.e3-produktion.de

1 *Impact fields and stakeholders are determined in talks with company representatives.*

2 *The stakeholder structure of a manufacturing company.*



1



2

IMPROVEMENT OF PRODUCTION EFFICIENCY IN ELECTROPLATING FACILITIES BY ELECTRO-CHEMICAL TREATMENT OF PROCESS WATER

Maximilian Kotzur

Initial situation

The metalworking industry is of great importance for the German and European economy, and in this sector of industry, electroplating plays a key role [1]. A significant use of resources is required at the same time combined with release of large quantities of hazardous wastewater and waste material to maintain this position. In Europe alone the surface treatment industry consumes more than 100 million m^3 of fresh water annually and, in doing so, produces more than 300,000 tons of toxic waste [2].

This indicates the need for clearly defined economic and ecological objectives in the electroplating sector [1]:

- Reduced need for chemicals
- Effluent-efficient mode of plating operation
- Total return of recyclable materials to the production process
- Minimization of energy consumption
- Reduction of the disposal costs and avoidance of waste, thus increasing production efficiency

The ECOWAMA concept

The EU-funded project ECOWAMA addresses these aims and combines the energy- and cost-efficient treatment of wastewater with the recovery of recyclable materials (metal) as well as the recirculation of treated process water into operation of the electroplating facility. By the efficient use of resources this closed-loop approach, which goes beyond the state-of-the-art technology used at many electroplating facilities, the development supports the efforts of the European Union to achieve a circular economy (Fig. 1).

ECOWAMA pilot plant

The core of the pilot plant built for the project consists of the processes of electrooxidation and electrocoagulation based on electrochemical and electrophysical principles, and also a new thermal multistage humidification-dehumidification process. These are used for the oxidation and precipitation of the components that are relevant both for disposal and for desalination (Fig. 2). These process steps are supplemented by the electrolytic recovery of nickel (electrowinning) and a preliminary cleaning of the process water by means of pulsed electric fields to remove fats and oils. Within the scope of ECOWAMA it was possible to show that hydrogen, which is a by-product of the electrochemical process water treatment, can be fed into a fuel cell via a suitable gas cleaning step and converted into electrical energy.

Demonstration

The ECOWAMA pilot plant was demonstrated in a facility for plastic electroplating. The chemical (electroless) nickel plating of plastic parts is a widespread application in this area. These nickel-phosphorus layers are characterized by high corrosion resistance, very good wear and hardness properties, and above all they can also be used for geometrically highly sophisticated parts. The coating layers are mainly used in the automotive, telecommunications and plastics sectors and also in the chemical industry [1].

However, due to the formation of undesirable by-products the treatment of the depleted chemical nickel baths and the rinse water associated with them presents a major challenge. The

3

4

reason for this is the reducing agent used, as a rule sodium hypophosphite. This cannot be directly precipitated due to its good solubility; it is thus a major problem for a downstream municipal sewage treatment plant. For this reason electroplating facilities have to find large sums of money for disposal by external companies that then generally incinerate the wastewater. In order to avoid this, in the ECOWAMA plant the hypophosphite present in the chemical nickel bath is specifically oxidized in the electrooxidation unit to form a precipitable phosphorus compound. Boron-doped diamond electrodes, which exhibited the best oxidation characteristics in all the trials, are used for this purpose.

Results

Numerous short- and long-term trials with depleted chemical nickel baths confirmed the complete decomposition of the hypophosphite and the substantial decomposition of the phosphite. In a further step more than 98 percent of the easily precipitable phosphate produced was in each case separated by means of electrocoagulation (Fig. 3). In the treatment of the waste and process water from the electrolytic nickel plating an electric conductivity of 12 µS/cm was achieved, enabling a complete return of the water to the appropriate process baths. Metallic nickel with a purity of over 99.9 percent was obtained from the concentrate by means of galvanic deposition; it can therefore be reused for coating purposes.

Outlook – further applications

The robust and modular design of the ECOWAMA pilot plant enables the use of individual process units for further applications in the treatment of process water. The principal market here consists of other types of waste and process water in the surface treatment industry, followed by special applications in the chemical industry that require strong, chemical-free oxidation.

Contact

Dipl.-Ing. Maximilian Kotzur
Phone +49 711 970-4097
maximilian.kotzur@igb.fraunhofer.de

Dr. rer. nat. Thomas Scherer
Phone +49 711 970-4091
thomas.scherer@igb.fraunhofer.de

Literature

[1] Kanani, Nasser (2009) Galvanotechnik – Grundlagen, Verfahren und Praxis einer Schlüsseltechnologie: 16–18

[2] European Commission (2006) Integrated Pollution Prevention and Control – Reference Document on Best Available Techniques for the Surface Treatment of Metals and Plastics: 164ff

Funding

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 308432.

Project partners and further information

www.ecowama.eu

1 *Principle of the circular economy in the ECOWAMA project.*
2 *Diagram of the ECOWAMA process.*
3 *ECOWAMA modules: electrooxidation (front), electrocoagulation (rear).*
4 *Coated workpiece.*

1

MoGeSoWa – INCREASING ENERGY EFFICIENCY BY MEANS OF SORPTION HEAT STORAGE

Simone Mack, Siegfried Egner

Increasing energy efficiency

In order to meet the global climate protection targets, attention is now being focused on increasing the degree of utilization of fossil and regenerative primary energy. Here heat storage systems play a key role in storing excess heat, thus making it possible to balance out the mismatch in time between the supply and demand for heat, e.g. in industrial processes or building technology applications. In 2010 more than 57 percent of the gross energy consumption and accordingly 38 percent of the primary energy requirement in Germany (5408 petajoules ~ 1500 terawatt hours) was used for heating and cooling [1, 2].

Use of waste heat

On the other hand, large quantities of waste heat currently remain unused in the energy sector, trade and industry. It is estimated that the waste heat utilization potential from industrial plants in Germany is only 132 to 282 terawatt hours per year (475 – 1015 petajoules) [1, 2]. Sorption heat storage systems are a promising solution. They offer clear advantages as regards storage densities, minimization of heat losses and available temperature levels. Compared with the currently available hot water storage heaters, three to six times higher storage densities with up to 240 watt hours per kilogram of storage material can be achieved, making possible considerably more compact systems. Additionally, the working temperatures for charging (80 – 300°C) and discharging (> 100°C) are more flexible. Since the energy is not stored as sensible heat, no thermal losses occur over the storage period. This enables both short-term (days to weeks) and also long-term storage (several months). The aim of the project "MoGeSoWa" is to develop a high-performance, cost-efficient and modular heat storage system so as to convert sorption heat storage into an industry-compatible application. To achieve this, the economic field of application of the technology is to be extended to the temperature range of significantly below 110°C by means of the systematic development of new composite adsorbents.

Approach

With sorption heat storage, energy is stored in the form of a chemical-physical potential. Heat is released in a subsequent reversible interaction between a porous solid and a fluid, which is also called an adsorption process. This enables it to be used when and where it is required. In order to realize the project objectives, an integrated approach was adopted consisting of material, component and process developments and production-optimized construction. In the initial phase of the project several innovative approaches relating to the three areas were developed and tested in the lab and on a pilot plant scale. In the second phase of the project the results were combined in a pilot plant and tested under near real-life conditions.

Trial operation in an apartment house

In the subsequent demonstration phase the modular heat storage unit developed by Fraunhofer IGB was tested for several months under real conditions. The demonstration of the sorption modular heat storage system was conducted over several months in an apartment house with more than 70 residential units; the aim was to increase the energy efficiency of a combined heat and power (CHP) plant. For this purpose excess heat from a mini-CHP unit with an power of 20 $kW_{electric}$ and 40 $kW_{thermal}$ was stored in order to make the thermal energy available when required for heating the building and thus

to reduce the primary energy consumption. The development of the composite adsorbents made possible a reduction of the charging temperature from > 120°C to 80°C. In addition, the optimized design of the overall process significantly increases the specific power from 120 W/kg to 269 W/kg.

Utilizing the cooling effect

A further advantage of the system is the additional possibility of exploiting the cooling effect. When the hygroscopic zeolite binds water vapor in its pores (and heat is released in the process), heat is removed from the water tank by means of vaporization and can then be used for cooling purposes.

Outlook

In addition to the building technology applications for water heating, heating and cooling, due to the modular design the system can be adapted flexibly to other applications, for example industrial uses. For potential end users the new heat storage technology provides economic and process engineering advantages that result from an increase in energy efficiency and savings in energy costs.

1 *Zeolite bed in the test reactor.*

2 *Modular storage unit for testing purposes.*

Contact

Dr.-Ing. Simone Mack
Phone +49 711 970-3539
simone.mack@igb.fraunhofer.de

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

Literature

[1] EEFA; Bestimmung des »Bruttoendenergieverbrauchs« nach den Vorschriften der EU-RL/2009/28/EG auf Basis der Daten der AG-Energiebilanzen (Kurzstudie im Auftrag des BMWi); Münster, Berlin, Nov. 2011

[2] AG-Energiebilanzen e. V. (AGEB)

Funding

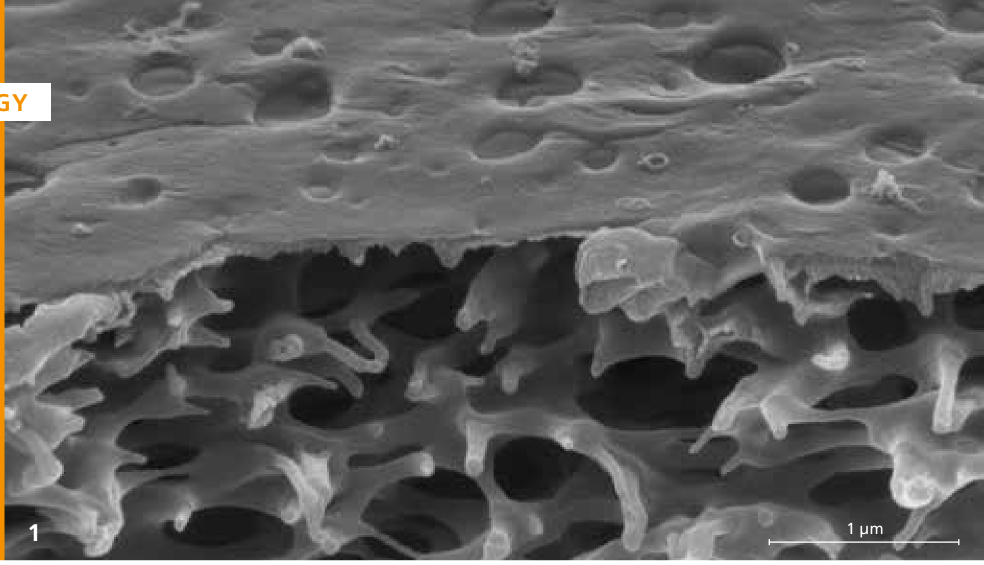
We would like to thank the German Federal Ministry of Economics and Technology (BMWi) for funding the project "MoGeSoWa – Development of a modular, self-contained, sorption heat storage system to increase the energy efficiency of combined heat and power plants", promotional reference 03ESP259E.

Project partners

ZeoSys GmbH, Berlin | Fraunhofer Institutes IVI, IKTS and IWU | B&O Gebäudetechnik GmbH & Co. KG, Berlin | KKI GmbH, Osterburken | Pneumatik Berlin GmbH, Berlin

Further information

http://forschung-energiespeicher.info/projektschau/gesamtliste/projekt-einzelansicht//Sorptiver_Waermespeicher_fuer_die_Industrie/
http://www.zeosys.de/index.php?page=projekte/mogesowa



1

USE OF MEMBRANES FOR PROCESSING BIOBUTANOL BY OSMOSIS

Christopher Hänel, Thomas Schiestel

The need for energy-optimized processing

Replacing fossil fuels with renewable energy sources is absolutely essential in the long term. Apart from the economic factors involved, the breakthrough of biofuels depends on the CO_2 and energy balances. For second-generation fuels produced by fermentation such as butanol, the energy balances still have to be significantly improved to make them competitive and environmentally compatible [1]. Yet the downstream processing required is an energy-intensive step and therefore also cost-intensive.

The aim is to develop a process that enables dehydration of the product flow with a significantly reduced energy input by means of the combined use of optimized gas stripping and an osmosis-driven membrane process. The use of forward osmosis to recover ethanol has already been described [2]. So far, no studies are known for butanol, which only requires concentration to 7.3 percent by weight, at which point a phase separation occurs.

New forward osmosis membranes

In the joint project "Innovative Process Combination for the Downstream Processing of Biobutanol" it was the task of Fraunhofer IGB to develop suitable membranes and a membrane process for the concentration of biobutanol. Tests were carried out on various commercial reverse osmosis membranes and the institute's own membranes for forward osmosis (FO), both on a cellulose acetate base (CA) and also thin-film composite membranes (TFC) [3 – 5]. The membranes were examined with a view to their water permeation as well as the butanol and salt retention. The feed solution used was an aqueous butanol solution with 5.7 percent by weight. The draw solution used was an aqueous NaCl solution with a concentration of 300 g/L NaCl.

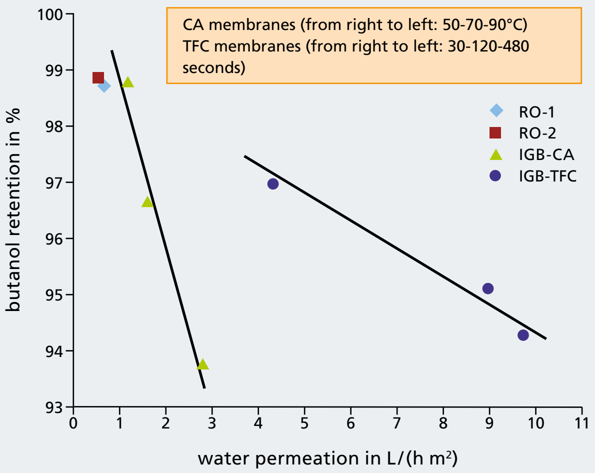
Best separation performance

The CA membrane was applied to a woven-type fabric with a doctor blade, is 60 µm thick and has a distinct asymmetrical structure with a very thin separating layer (approx. 100 nm). The matrix of the TFC membrane is a 110 µm thick microfiltration membrane with a pore size of 100 nm (Fig. 1).

With the CA membranes, the separation performance can be controlled via the temperature of the heating bath. The higher the temperature, the lower the water flow and the greater the butanol retention. At 90°C the CA membranes exhibit the same butanol retention as commercial reverse osmosis membranes, while the water flow of 1.23 L/(h m^2) is 75 percent higher (Fig. 2).

With the TFC membranes the separation performance can be controlled via the reaction time of the surface polymerization. For example, a reaction time of 480 seconds results in membranes with a water flow of 4.35 L/(h m^2) and a butanol retention of 97 percent. A further variable that was used to compare the membranes was the ratio of water to butanol flow. In the case of the commercial membranes this was in the region of 20, with the best CA membranes 40 was measured and with the best TFC membranes 60 was achieved (Fig. 2).

Subsequently the membranes were transferred for 500 hours to an ABE solution (26 g/L acetone, 80 g/L butanol, 22 g/L ethanol). Generally speaking, the membranes were stable in this solution. Over time, however, the water flow continuously



2

3

grew by 30 percent and the passage of butanol increased by a maximum of 55 percent.

Excellent water flow, rapid phase separation

Subsequently tests were carried out to optimize process parameters. Depending on the flow velocity, for example permeations of 12 L/(h m^2) were measured for TFC membranes; in this case the water/butanol ratio was 30. The best commercial reverse osmosis membranes exhibited a water flux of 1.8 L/(h m^2) with a water/butanol ratio of 22.

Using these results, the time to the occurrence of the phase separation were estimated in each particular case. The result was a time of 42 hours for the best commercial membrane. In comparison, a time of four hours was estimated with the best TFC membrane. No phase separation was observed in experiments with the commercial membranes over a period of up to five days. However, with the best TFC membranes a clear phase separation was apparent after six hours.

Outlook

In summary, it can be stated that it is technically possible with forward osmosis to concentrate butanol solutions to such an extent that a phase separation occurs. The production of membranes will now be transferred to a larger scale (Fig. 3). The feasibility of the overall process is then to be demonstrated on a pilot plant scale.

Contact

Christopher Hänel
Phone +49 711 970-4125
christopher.haenel@igb.fraunhofer.de

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

Literatur

[1] Qureshi, N. et al. (2000) Renewable Energy 22: 557–564
[2] Zhang, X. et al. (2013) Chemical Engineering Journal 232: 397–404
[3] Kunst, B. et al. (1970). Journal of Applied Polymer Science 14(10): 2559–2568
[4] Touati, K. et al. (2015) Desalination 365: 182–195
[5] Jin, H. et al. (2015) RSC Adv. 5: 79774–79782

Funding

We would like to thank the German Federal Ministry of Food and Agriculture (BMEL) for funding the project "Innovative Process Combination for the Downstream Processing of Biobutanol", promotional reference 22032014.

Project partner

Institute of Environmental Process Engineering, University of Bremen

1 *TFC membrane under the electron microscope.*
2 *Forward osmosis tests in a stirred cell.*
3 *Flat membrane coating plant.*

FURTHER DATA AND FACTS 2016

331 Publications

4 Book articles

77 Posters

126 Journals papers

124 Oral presentations

388 Applied patents in total

48 Patents granted in 2016

15 New patent applications

14 Inventions

120 Academic theses

51 Master theses

36 Bachelor theses

13 Internship reports

7 Dissertations

2 Diploma theses

11 Student research studies

4 Excursions

122 Teaching activities

34 Practical courses, exercises

34 Seminars

50 Lectures

1288 Followers on Twitter

37 Press releases and research news

494 Press clippings

1648 Followers on LinkedIn

166 Committee memberships

26 Trade fairs and events

82 Strategic cooperations

Detailed information
www.igb.fraunhofer.de/data

INFORMATION SERVICE

Would you like to receive further information?
We would be happy to inform you!

Please mark the relevant fields on this page and
and send us per fax or post:

Periodicals

- ☐ Annual Report
- ☐ Online newsletter

Topic-specific brochures and product leaflets

- ☐ Health
- ☐ Chemistry and Process Industry
- ☐ Environment and Energy

Sender

Name, First Name, Title

Company/Department

Street/P. O. Box

Postal code, City, Country

Phone

Fax

E-mail

Fraunhofer Institute
for Interfacial Engineering
and Biotechnology IGB
Press and Public Relations
Nobelstrasse 12
70569 Stuttgart | Germany

Phone +49 711 970-4150
Fax +49 711 970-4200
info@igb.fraunhofer.de
www.igb.fraunhofer.de

Visit our online ordering service and download area:
www.igb.fraunhofer.de/publications

EDITORIAL NOTES

EDITORIAL TEAM
Dipl.-Wirt.-Ing. (FH) Antje Hetebrüg,
Jan Müller M. A.,
Dipl.-Des. Thaya Schroeder (picture),
Dr. Claudia Vorbeck
and the scientists referred to as authors or contact persons.

LAYOUT AND PRODUCTION
Dipl.-Des. Thaya Schroeder

PRINTING
Fraunhofer Verlag, Mediendienstleistungen,
Stuttgart, Germany

EDITORIAL ADDRESS
Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB
Dr. Claudia Vorbeck
Nobelstraße 12, 70569 Stuttgart, Germany

This annual report was printed climate neutral with mineral oil-free inks. The paper used is 100% recycled and FSC-certified, as well as awarded the EU Ecolabel AT/11/002 and the Blue Angel.

TRANSLATIONS, PROOFREADING
Dr. Stuart Amor, Stuttgart, Germany
Sherrie Blackman-Linse, Greußenheim, Germany
Textworks Translations, Manchester, UK
Dr. Sabine Wacker | Wacker Translation, Aichwald, Germany

PHOTO ACKNOWLEDGMENTS
Altmann, Jürgen: page 7
Baden-Württemberg: Connected e. V.: page 29
Canoe: page 79
Doering, Sven: page 78
Fogel, Walter: pages 13, 34, 42
Fotolia: pages 88, 97
iStockphoto: page 76
Krötz, Rafael: pages 37, 46, 84
Michalke, Norbert: pages 23, 27, 35, 39, 87
Müller, Bernd: pages 60, 61, 64
Shutterstock: pages 19, 20, 24, 25, 26, 83, 87, 94

Fraunhofer CBP closes the gap between the lab and industrial implementation: By making infrastructure and plants available, the center makes it possible for cooperation partners from research and industry to scale up biotechnological and chemical processes right up to production-relevant dimensions and to accelerate process developments.

Fraunhofer Institute
for Interfacial Engineering
and Biotechnology IGB
Nobelstrasse 12
70569 Stuttgart
Germany

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

Stay in contact: