Fraunhofer IGB

Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB

We combine biology and engineering

Annual Report 2022/23

70 years of Fraunhofer IGB

The Fraunhofer-Gesellschaft

The Fraunhofer-Gesellschaft, based in Germany, is the world's leading applied research organization. Prioritizing key future-relevant technologies and commercializing its findings in business and industry, it plays a major role in the innovation process. A trailblazer and trendsetter in innovative developments and research excellence, the Fraunhofer-Gesellschaft supports science and industry with inspiring ideas and sustainable scientific and technological solutions and is helping shape our society and our future.

At the Fraunhofer-Gesellschaft, interdisciplinary research teams work with partners from industry and government to turn pioneering ideas into innovative technologies, coordinate and implement system-relevant research projects and strengthen the German and European economies with a commitment to value creation that is based on ethical values. International collaboration with outstanding research partners and companies from around the world brings the Fraunhofer-Gesellschaft into direct contact with the most prominent scientific communities and most influential economic regions.

Founded in 1949, the Fraunhofer-Gesellschaft now operates 76 institutes and research units throughout Germany. Currently around 30,800 employees, predominantly scientists and engineers, work with an annual research budget of about 3.0 billion euros, 2.6 billion euros of which is designated as contract research. Around two thirds of Fraunhofer contract research revenue is generated from industry contracts and publicly funded research projects. The German federal and state governments contribute around another third as base funding, enabling the Fraunhofer institutes to develop solutions now to problems that will drastically impact industry and society in the near future.

The impact of applied research goes far beyond the direct benefits to the client. Fraunhofer institutes strengthen companies' performance and efficiency and promote the acceptance of new technologies within society while also training the future generation of scientists and engineers that the economy so urgently requires.

As a scientific organization, the key to our success is highly motivated employees engaged in cutting-edge research. Fraunhofer therefore offers its researchers the opportunity to undertake independent, creative and, at the same time, targeted work. We help our employees develop professional and personal skills that will enable them to take up positions of responsibility within Fraunhofer itself or at universities, within industry and in society at large. Students involved in projects at Fraunhofer institutes have excellent career prospects on account of the practical vocational training they enjoy and the opportunity to interact with contract partners at an early stage in their career.

The Fraunhofer-Gesellschaft is a recognized non-profit organization named after Joseph von Fraunhofer (1787–1826), an illustrious researcher, inventor and entrepreneur hailing from Munich.

Figures as of: March 2023

▸ *www.fraunhofer.de/en*

We combine biology and engineering

Annual Report 2022/23

Contents

Foreword

Dear readers,

2023 is a special year for Fraunhofer IGB because it marks the 70th anniversary of our institute. Looking back, it is clear that the visionary ideas of the IGB often put it ahead of its time – as a pioneer in the development of sustainable technologies. The IGB was, for example, already researching biogas when the 1970s oil crisis occurred. Similarly, we have long been pursuing the approach of recycling waste and valuable wastewater ingredients with a view to creating closed material cycles. With our applied research in the area of sustainable chemical products and our innovative concepts for the health sector, we are constantly breaking new ground and are making valuable contributions for our society.

These approaches and new technologies are delivering the tools that we need to play our part in overcoming global crises for the good of people and the environment – by creating solutions to safeguard raw materials, food supplies and clean water, and by developing innovative approaches for personalized diagnosis and medicine.

That is precisely what our anniversary campaign called "70 years, 70 voices" is intended to reflect. As part of this, current and former employees, along with our partners from the worlds of politics, business and science, will all get to have their say. In the various articles, you can learn about the topics we are currently researching and how we are helping to develop innovative solutions for the global challenges we face and make them a reality.

You can also get to know our highly committed employees, discovering what drives and motivates them on a daily basis in their pursuit of excellence at the IGB. Allow yourself to be inspired by the diversity of research topics and the creative ideas at the institute that personally fill me with fresh enthusiasm for the new and innovative each and every day. And discover what it is that our business partners appreciate about collaborating with the IGB. This Annual Report contains just a small sample of the 70 voices. Further posts will be released on our website and via our social networking channels over the course of the year. Please do drop by and give them a listen, a read or a watch!

With their focus on innovative solutions for health, sustainable chemicals, the environment and climate protection, the scientific articles in the Annual Report likewise demonstrate how we are consistently pursuing our mission of conducting research to facilitate healthy lives in a livable environment. By way of an example, our new agile "garage projects" made excellent progress in the space of just a few months. Our aim here is to provide a brand-new set of testing systems for the development of veterinary drugs and to develop AI-based algorithms for health applications. Other scientific highlights from the health area include various approaches to pathogen diagnosis and new methods for virus-based therapies.

The oilseed biorefinery that has been constructed at the IGB location in Leuna will officially be inaugurated in May as part of the 10th anniversary symposium at CBP. With this plant, we are opening up new potential for value to be created from rapeseed as a source of human food. Food security also lies at the heart of our projects for exploiting further alternative proteins, e.g., from microalgae. Thanks to the activities being carried out at the IGB branch in Straubing, the use of renewable energies – particularly value creation from CO_2 – has become much more widely visible. The next step will be to implement this on a larger scale.

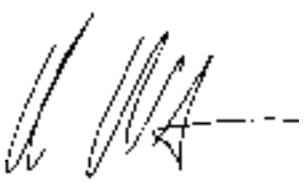
We are also pursuing our vision of combining biology and engineering via five projects that are being sponsored by the Baden-Württemberg Ministry of the Environment and the EU. In these projects, we are linking together processes to create value chains for extracting valuable materials from waste and wastewater. With a view to achieving the UN's "Clean Water" Sustainable Development Goal, we are working on a sunlight-driven technology for destroying problematic micropollutants in wastewater and on new forward osmosis membranes for removing harmful sulfates from groundwater.

The "Circular Bioeconomy for Germany" road map drawn up by the Bioeconomy Strategic Research Field of the Fraunhofer-Gesellschaft with the involvement of ten institutes – including the IGB – has particularly caught the attention of politicians and businesses. The recommended actions were passed on to the German Federal Ministry of Education and Research (BMBF) and the German Federal Ministry for Economic Affairs and Climate Action (BMWK) in November 2022.

I would sincerely like to thank all employees of the institute who are based at the three IGB locations in Stuttgart, Straubing and Leuna. Through their motivation and outstanding dedication, they have played a major part in ensuring another financially successful year for the institute.

I would also like to thank our customers and partners. Despite the challenging international circumstances encountered over the past year and the limitations imposed on us all as a result, they have collaborated with us faithfully and helped to drive forward the transformation of the economy.

I look forward to celebrating a varied and eventful anniversary year with you all, and continuing our fantastic teamwork.



Markus Wolperdinger
Director

Profile

Climate change and the excessive use of global resources are threatening our livelihoods, while at the same time the world's population continues to grow rapidly. In the industrialized countries, an aging society and diseases of civilization are dominating the situation, while infectious diseases are on the rise again worldwide – as the Corona pandemic has shown very recently.

We combine biology and engineering

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

Fraunhofer IGB develops and optimizes processes, technologies and products in three business areas: Health, Sustainable Chemistry, and Environment. In doing so, the institute relies on its unique combination of expertise in biology and the engineering sciences, unparalleled within the Fraunhofer-Gesellschaft. This allows us to design resource-efficient, circular processes based on the approach of bioeconomy and bioinspired, biointegrated and biointelligent solutions, in order to contribute to human welfare, a sustainable economy, and an intact environment.

Our vision: we combine biology and engineering

More than ever, innovative processes and products call for the convergence or constructive interplay of different disciplines in systems approaches. One such systems approach, which the IGB is continuously enhancing, is the bioeconomy. By combining biology and engineering, especially in biotechnology and bioprocess engineering, but also through the genetic engineering of viruses and bacteria, the combination of cell culture and interfacial engineering, or DNA sequencing using bioinformatic algorithms, as well as through the interaction of biological systems with technical materials – the IGB paves the way to new approaches and future-oriented solutions for industrial value creation.

Partnering industry and public authorities – from laboratory to pilot-scale applications

One of the IGB's main goals is to translate its research findings into economically viable, sustainable processes and products for industrial application. Fraunhofer IGB provides its customers and partners with research and development services encompassing the entire material value chain, accompanied by a wide range of analysis and testing services. The ability to deliver end-to-end solutions, from laboratory to pilot-scale applications, and a demonstration of the developed processes, is one of the institute's strong points.

This all-round service makes the IGB a competent partner for industrial companies, small and medium-sized enterprises operating in many different sectors, local authorities and special purpose associations, as well as for EU, federal and state contract research.

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

Advisory board

The Fraunhofer Institutes are counseled by an advisory board whose members are drawn from industry, public authorities, and the scientific community.

Members

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

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

MinR'in Dr. Caroline Liepert
Ministry of Science, Research and the Arts of Baden-Württemberg

Dr. Lorenz Mayr (Chair)
Vector BioPharma AG

MinR'in Andrea Noske
German Federal Ministry of Education and Research (BMBF)

Dr. Dr. h. c. Christian Patermann
Director (ret.) European Commission, MinDirig. (ret.)

Dr. Christian Renz
Ministry of Economic Affairs, Labour and Tourism of Baden-Württemberg

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

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

Dr. Joachim Schulze
JS BioConsulting GmbH

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

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

Dr. Günter Wich
Industrial Biotechnology

Dr. Peter Wolfangel
Robert Bosch GmbH

As of December 31, 2022

Guests

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

Thomas Gerke
Ministry of Science, Energy, Climate Protection and Environment of the Federal State of Saxony-Anhalt

MR Dr. Stefan Wimbauer
Bavarian Ministry of Economic Affairs, Regional Development and Energy

▸ *www.igb.fraunhofer.de/board*

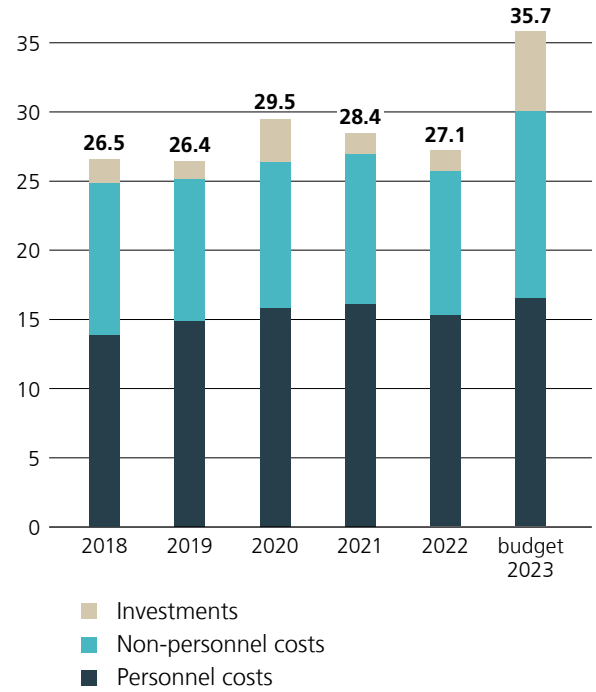
Key figures

Budget of Fraunhofer IGB

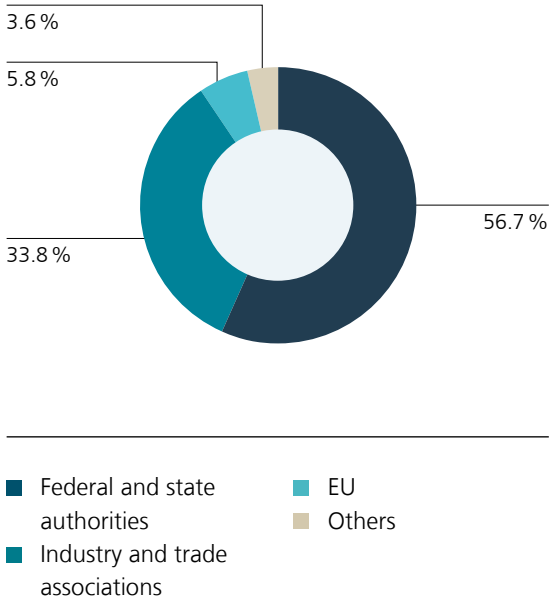
The total budget for 2022 amounted to 27.1 million euros, of which 25.7 million euros was allocated to the operational budget (personnel costs: 15.2 million euros; non-personnel costs: 10.5 million euros). A total of 1.4 million euros was spent on investments.

71.5 percent of the operational budget was financed from Fraunhofer IGB's own revenues generated from contract research projects. 33.8 percent of the institute's revenues came directly from industry.

Development of total budget in million euros



Revenue from contract research 2022



Personnel

Personnel

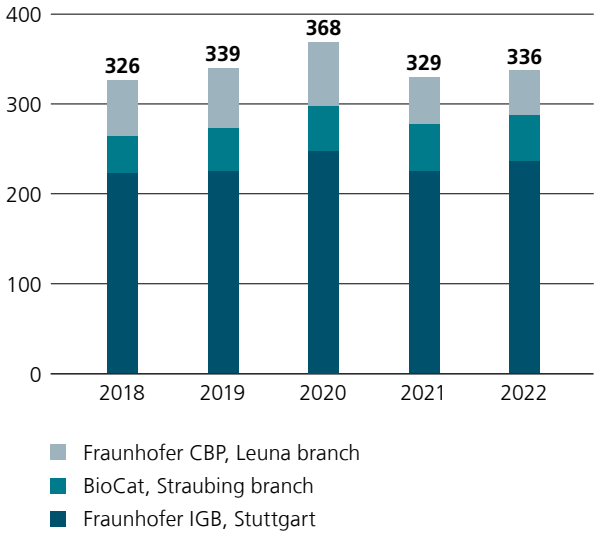
At the end of 2022, Fraunhofer IGB (in Stuttgart and its branches in Straubing, and Leuna) had a staff of 336 of which some 84 percent were scientific or technical employees. Women made up 53 percent of the total.

The close cooperation with the Institute of Interfacial Process Engineering and Plasma Technology IGVP at the University of Stuttgart makes it possible to pursue projects from basic research to application. The IGVP counted a staff of 70 as of December 31, 2022. Women constituted 39 percent of the total.

Cooperation with universities

In addition, we cooperate with the Universities of Hohenheim and Tübingen as well as the Universities of Reutlingen and Esslingen, among others. Due to the connection of our branches in Straubing and Leuna especially to the Technical University of Munich and to the Universities of Leipzig and Halle-Wittenberg, respectively, our scientific network reaches far beyond the Stuttgart region.

Development of staff numbers
(number at year-end)



Number of staff members as of December 31, 2022

	Fraunhofer IGB, including branches	BioCat, Straubing branch	Fraunhofer CBP, Leuna branch
Scientists	79	14	13
Technical staff	90	17	24
Doctoral students	9	3	0
Scholarship holders	2	0	0
Administrative and secretarial staff	43	5	6
Apprentices	12	1	1
Work students /master students /student apprentices	44	1	4
Student research assistants	57	10	1
Total	**336**	**51**	**49**

Organization

Director*

Dr. Markus Wolperdinger
Phone +49 711 970-4410
markus.wolperdinger@
igb.fraunhofer.de

Deputy Director

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

Deputy Director

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

Heads of innovation fields

Bioinspired Chemistry

Dr. Michael Richter
Phone +49 9421 9380-1020
michael.richter@
igb.fraunhofer.de

Sustainable Catalytic Processes

Dr. Arne Roth
Phone +49 9421 9380-1030
arne.roth@igb.fraunhofer.de

Functional Surfaces and Materials

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

Regenerative Resources

Dr. Ulrike Junghans
Phone +49 3461 43-9128
ulrike.junghans@
igb.fraunhofer.de

Industrial Biotechnology

Dr. Grzegorz Kubik
Phone +49 711 970-4102
grzegorz.kubik@
igb.fraunhofer.de

Virus-based Technologies

Prof. Dr. Susanne M. Bailer
Phone +49 711 970-4180
susanne.bailer@
igb.fraunhofer.de

In-vitro Diagnostics

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

Water Technologies and Resource Recovery

Dr.-Ing. Marius Mohr
Phone +49 711 970-4216
marius.mohr@
igb.fraunhofer.de

Membranes

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

Cell and Tissue Technologies

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

Heads of service areas

Technology Scale-up and Transfer

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

Analytics – Stuttgart

Katharina Wasmer M. Sc.
Phone +49 711 940-4037
katharina.wasmer@
igb.fraunhofer.de

Analytics – Leuna

Anett Schlichter B. Sc.
Phone +49 3461 43-9108
anett.schlichter@
igb.fraunhofer.de

Occupational safety

Kai Pusch M. Sc.
Phone +49 711 970-4175
kai.pusch@igb.fraunhofer.de

* Head of Administration (acting)

Heads of business areas

Health

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

Sustainable Chemistry

Dr. Christine Rasche
Phone +49 3461 43-9103
christine.rasche@
igb.fraunhofer.de

Environment and Climate Protection

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

Branches

Fraunhofer Center for Chemical-Biotechnological Processes CBP, Leuna branch

Dipl.-Kfm. Holger Schilaske
Phone +49 3461 43-9120
holger.schilaske@
igb.fraunhofer.de

Bio-, Electro- and Chemocatalysis BioCat, Straubing branch

Dr. Michael Hofer
Phone +49 9421 9380-1010
michael.hofer@
igb.fraunhofer.de

University and political relations

Baden-Württemberg

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

University of Stuttgart

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

Bavaria

Prof. Dr. Volker Sieber
Phone +49 9421 9380-1050
volker.sieber@igb.fraunhofer.de

Saxony-Anhalt

Dr. Christine Rasche
Phone +49 3461 43-9103
christine.rasche@igb.fraunhofer.de

70 years of Fraunhofer IGB

70 years of research for a better future

Unparalleled by any other institute, Fraunhofer IGB is unique in terms of combining biological and biotechnological expertise with bioprocess and interfacial engineering know-how. The convergence of these two dimensions is what enables the institute to bring biological principles to bear on technical applications in the context of interdisciplinary approaches and to establish biobased and bioinspired value chains for a wide range of industries – from laboratory scale to pilot scale. This unique selling point is also the result of the institute's historical development.

One anniversary, lots to celebrate

The IGB was founded as the Institute for Interfacial Physics and Chemistry in 1953 and subsequently taken over by the Fraunhofer-Gesellschaft in 1962. This year, the IGB celebrates its 70th birthday.

In the course of its 70-year history, the institute has acquired a vast array of further expertise and technologies, which remain part of its research scope to this day. The institute has not only been home to membrane research for well over 45 years but also to environmental and bioprocess engineering, with molecular biotechnology and cell technology having taken up residence there almost 30 years ago. For the past 15 years, the institute has been intensifying and expanding its industrial biotechnology activities.

Our institute branch in Leuna called Fraunhofer CBP offers scaling expertise and was officially opened in 2012. We are about to celebrate its 10th birthday in 2023, albeit belatedly. Our institute branch "Bio-, Electro- and Chemocatalysis BioCat," which is based in Straubing and focuses on the use of renewable raw materials and CO_2, was inaugurated at around the same time.

The "Mass Personalization" (Stuttgart) and "Chemical and Biosystems Technology" (Halle-Leipzig region) high-performance centers have been cementing cooperation with the worlds of science and business locally for five years. The discussion surrounding the biological transformation of technology as an enabler of more sustainable value creation has culminated in the establishment of Bioeconomy as a Fraunhofer Strategic Research Field and the founding of the Biointelligence Competence Center in Stuttgart.

At an international level, our cooperation activities with the Hebrew University of Jerusalem and with Stellenbosch University are bearing fruit now that the Fraunhofer Innovation Platforms (FIP) have been set up in Israel and South Africa.

We are thoroughly looking forward to our anniversary activities in 2023!

1976

1987

2010

1953
Founding of Institute for Interfacial Physics and Chemistry

1962
Takeover by Fraunhofer as IGf

1976
IGf becomes IGB

1977 1978

New topics environmental bioprocess technology and interfacial medicine and membranes

1994
First high-load digestion plant

Establishment of LGVT University of Stuttgart (today IGVP)

1998
Junior research teams protein screening systems and biomimetic interfaces

2000
Photobioreactor for microalgae

2007
Market launch of CinnoVex (first biogeneric protein)

2008
Focus on industrial biotechnology

2009
Project groups BioCat in Straubing and CBP in Leuna

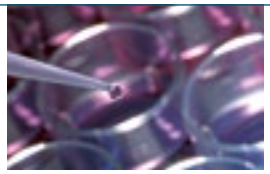
2012

Inauguration of Fraunhofer CBP in Leuna

2018
High-Performance Centers "Mass Personalization" and "Chemical and Biosystems Technology"

Focus on CO_2 and climate technologies

2019
Biointelligence Competence Center



2020
FIP_DD@HUJI, Hebrew University, Israel

FIP-WEF@SU, Stellenbosch University, South Africa

2021
IGB founding member of Fraunhofer Group for Resource Technologies and Bioeconomy

Hydrogen Lab, Leuna

IGB coordinates the EVOBIO project marking the consolidation of Fraunhofer bioeconomy research

70 years, 70 voices

70 years of shaping the future

Events in the anniversary year

- **Official 10-year anniversary symposium of Fraunhofer CBP**
  May 3, 2023, Leuna
- **Event commemorating 70 years of Fraunhofer IGB**
  July 10, 2023, Stuttgart
- **Opening ceremony of the Look@BioEconomy artwork**
  August, Stuttgart

The people at the IGB have always been the key to its scientific and commercial success. The various institute directors have determined what the institute looks like today by steering it in particular strategic directions, which were always informed by the latest economic challenges in each case and the relevant research policy priorities.

Particularly at a research institute whose very lifeblood is innovation, employees that shape the research conducted at the IGB and energetically carry out their tasks with panache, creativity and, above all, personal conviction and motivation are the greatest asset of all. This is the principle that has always been followed and always will be. Through their dedicated efforts, they play a role in developing solutions for the urgent challenges of our age.

That is why we want our employees, former institute directors, and companions and partners from the worlds of research, politics and business to have their say in the course of this anniversary year through our "70 voices" campaign. This will be a time for looking back, looking forward, looking inward and looking outward. In this Annual Report, we have brought together some of these voices for you. They have not only been included on the general pages below but also in the specialist section starting on page 32.

To hear even more of the voices, visit our anniversary website.

▸ *www.igb.fraunhofer.de/70-years*

Greetings from the Chairman of the Advisory Board

Dr. Lorenz Mayr
CEO, Vector BioPharma AG, Basel/Switzerland | Chair of the Advisory Board of Fraunhofer IGB

Dear friends, affiliates and guests of Fraunhofer IGB,
Dear employees of Fraunhofer IGB,

I am addressing you today on behalf of the advisory board and wish to express my sincere gratitude to all employees at the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB for another successful year full of technological, scientific and organizational highlights. Working with purpose, the institute has successfully developed towards its objective: "We combine biology and engineering".

We are currently seeing a number of significant political, economic and environmental changes, both nationally and internationally, and we need to address these challenges in a timely, expeditious, successful and sustained manner in order to secure prosperity for our society in the long term, to further enhance quality of life and to ensure the sustainability of the economy for ourselves and future generations. This requires systematic rethinking of economic processes and significant investment in state-of-the-art technologies, with the aim of quickly and successfully achieving the economic and ecological goals set by society. Every day, we are very much aware of how much technology is intertwined with biology and nature, how these elements depend on each other and how much they can complement and mutually stimulate each other. In my opinion, there is hardly any better place within the whole Fraunhofer Gesellschaft than Fraunhofer IGB with its dedicated people, its advanced technologies and its clear strategy to address these enormous challenges.

Together with my colleagues at the advisory board and coming from the worlds of business, academia and politics, I have had the pleasure and privilege of accompanying Fraunhofer IGB in its activities throughout the course of the last year. The advisory board was delighted to take on this task, and we have thoroughly enjoyed following theses various innovation projects in the fields of health, sustainable chemistry and environment, bringing our external perspective to the table, attempting to contribute new ideas and establishing new contacts with industry. In discussions with representatives from the various fields of innovation, we have witnessed great enthusiasm by everyone involved for achieving successful results on these highly relevant topics at Fraunhofer IGB and for contributing towards a better future.

I wish Fraunhofer IGB all the best for the future and every success in its activities in combining biology and engineering."

Best regards,
Lorenz Mayr

Prof. Dr. Herwig Brunner
Peter und Traudl Engelhorn Stiftung, CEO | Director of Fraunhofer IGB 1994–2007

Creativity and dedication – with employees at the core

People who have reached the age of 70 might well be showing some signs that their best years are behind them – but that's certainly not the case for Fraunhofer IGB. Far from being in decline, the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB could even be described as a brand whose values are INNOVATIVE, GLOBAL and BIO-FOCUSED.

Throughout all the years that I have experienced the work of Fraunhofer IGB, first on the advisory board, then as institute director (1994–2007), and finally as a guest member of the advisory board, the creativity and dedication of the institute's members have been exemplary. Fraunhofer IGB has foreshadowed Kondratiev waves and enthusiastically implemented them – not just from an idealistic standpoint, but also with new concepts and technologies – all the way to market. Any technological or financial setbacks have always been viewed as an incentive and rectified, even in the face of external resistance.

Within the framework of the pioneering Central Focus Project for Bioprocess Engineering, activities in cell and molecular biotechnology were carried out together with several institutes in the Faculties of Chemistry, Biology and Process Engineering at the University of Stuttgart over a period of eight years. This was funded by the German Federal Ministry of Education and Research and the state of Baden-Württemberg, under my chairmanship from 1994 onwards, and the cooperation among the university institutes themselves and with Fraunhofer IGB was a key factor underpinning the funding. This approach was the secret to the success of the interdisciplinary dialogue that took place, and the joint research and development work that involved companies far beyond Baden-Württemberg.

In addition, an initiative between Fraunhofer IGB and the Stuttgart-Neckar-Alb regional association succeeded in winning the BioRegio contest, which was open to the whole of Germany. As a result, the Neckar-Alb BioRegion was created with the foundation of the BioRegio STERN coordination office. This was the culmination of a vision that made it possible to attract the University of Tübingen as a partner, bringing with it the potential that it offered for medical research.

For Fraunhofer IGB, this resulted in a time of prosperity both for research and in economic terms. Highly qualified gatekeepers were recruited for Fraunhofer IGB (through the formation of two junior research groups) and then became the basis for an integral part of goal-setting and further development. The appointment to the German-Israeli Research Council at the federal level also brought about new networking opportunities and on an international scale.

Today, we can see a clear path on which cell biology, genetic engineering and microbiology of pathogenic bacteria and fungi, together with virology, are being developed toward Fraunhofer IGB and the University of Stuttgart's Institute of Interfacial Process Engineering and Plasma Technology (IGVP) becoming a front-runner in molecular virology. The technologies in the actively promoted and economically significant areas of interfacial science, environmental technology and engineering technology – which have also benefited from synergies in many cases – have become trendsetters. And Fraunhofer IGB, together with the Institute of Interfacial Process Engineering and Plasma Technology at the University of Stuttgart (with which it has been closely associated since 1994), is often viewed with an attempt to imitate its work.

Among all of this, there is one key factor that we must not lose sight of, and that is the employees working at every level. Their commitment to creatively accepting leadership changes, helping to shape them, tapping into new synergies and playing a part in setting new goals has always been and continues to be one of Fraunhofer IGB's real strengths. This is also demonstrated in the close collaboration – through both personnel and technology – that has been established with the Institute of Interfacial Engineering and Plasma Technology IGVP. Simply put, exemplary things have been achieved.

So, here's to IGB – long may it continue!"

Herwig Brunner

Prof. Dr. Thomas Hirth
Karlsruhe Institute of Technology KIT, Vice President Transfer and International Affairs | Director of Fraunhofer IGB 2007–2015

The dawn of industrial biotechnology and the bioeconomy

With my appointment and move to Stuttgart in December 2007, a unique opportunity arose for me to combine basic and applied research at one location, first in the field of industrial biotechnology and later in the bioeconomy.

The conditions for this were very good, as the Fraunhofer-Gesellschaft had recognized the importance of industrial biotechnology as early as 2005 and subsequently developed it as an area for innovation. We have now seen several projects on white biotechnology at Fraunhofer IGB, such as the production of lactic acid from whey. These were initiated by my predecessor Professor Herwig Brunner and his deputy Professor Walter Trösch. At the University of Stuttgart fundamental scientific work on bioprocess technology has been carried out since the 1980s, initially under the leadership of Professor Horst Chmiel and, since 1994, under the direction of Professor Herwig Brunner at the new Institute of Interfacial Process Engineering which I had the privilege of heading in a combined position from 2008 to 2015 and was renamed the Institute of Interfacial Process Engineering and Plasma Technology at the turn of the year 2012/2013.

Building on the strategic process executed in 2008 together with all the employees at Fraunhofer IGB, and with financial support provided by the Fraunhofer-Gesellschaft and the University of Stuttgart within the context of my appointment plus the significant dedication shown by employees at both institutes, we succeeded in developing the subject of industrial biotechnology and closely related topics as a starting point, working with partners from industry and other scientific institutions and firmly anchoring these subjects at both institutes for the long term. On this basis, we then jointly developed the area of the bioeconomy.

I am particularly grateful for the opportunity I was given to be a member of the first Bioeconomy Council of the German federal government and participate in developing the first bioeconomy strategy for Germany. Later, I was also able to help shape the Bioeconomy Baden-Württemberg research program by chairing the steering committee. This generated valuable momentum that has had a decisive and lasting influence on the development of not only Fraunhofer IGB, but also the IGVP. The establishment of the Fraunhofer Center for Chemical-Biotechnological Processes CBP at the Leuna chemical site, which was officially opened in 2012 by then-German Chancellor Angela Merkel, was another major milestone. The activities in Leuna and Stuttgart formed the basis for the success achieved in the German Federal Parliament's Leading Edge Cluster Competition and the launch of the BioEconomy Leading Edge Cluster, which also led to the establishment of bioeconomy companies at the Leuna site.

In addition to bioeconomy matters, which were certainly the central building block of Fraunhofer IGB's strategic development from 2007 to 2015, we also developed and expanded on other topics, such as water treatment and nutrient recovery, membrane processes, electrochemistry, pharmaceutical biotechnology and plasma technology. As a result, Fraunhofer IGB has become a beacon for science that has international visibility and sustainable funding.

When I look back on my time at Fraunhofer IGB today, I do so with gratitude, as I was able to develop and implement important subjects for science and industry together with the employees there. I was also able to ensure that the institute was prepared for the future and, most significantly, give a wealth of young people something to take with them into their professional futures.

I would like to wish Fraunhofer IGB all the very best on the occasion of its 70th birthday and hope it achieves every success in its development along its future path, combining biology, engineering and the development of processes, technologies and products for health, sustainable chemistry, the environment and climate protection."

Thomas Hirth

Dr. Gerd Unkelbach
UPM-Kymmene Oyj,
Director Molecular
Bioproducts R&D

Fraunhofer IGB as a pioneer in the bioeconomy

I am incredibly proud that, for more than ten years, I have been able to contribute initiate and develop Fraunhofer CBP and the strategic direction of Fraunhofer IGB with the result that the institute and its branch in Leuna are now a respected research and development partner in the field of the industrial bioeconomy. Through a team with highly dedicated colleagues and external partners, a strong network of interests has emerged alongside Fraunhofer CBP, even in the early days of the German government's bioeconomy initiative. This has resulted in numerous project activities, particularly in central Germany. In addition to technical success stories, which can be seen in growing industrial activities and in key political decisions, stable alliances have been formed.

The two powerful centers for the development and scaling of processes and new products based on biogenic raw materials and residues, located in Leuna and Straubing, have firmly established their positions and I am convinced that they are on course for a promising future. With the promise to unite the chemical and energy sectors, the excellent breadth of knowledge in the field of environmental research and the expansion of expertise and infrastructure in the areas of power-to-X and circular economy, the institute is set to continue making a major contribution to the sustainable transformation of the economy.

I wish the institute and its two institute branches continued success, and I am sure that the future will see even more results from Fraunhofer IGB's research emerging in society."

Gerd Unkelbach

Prof. Dr. Andrea Büttner
Executive Director of Fraunhofer Institute for Process Engineering and Packaging IVV | Deputy Spokeswoman Fraunhofer Strategic Research Field Bioeconomy | Spokeswoman Fraunhofer Agriculture and Food Industry Alliance

Prof. Dr. Alexander Böker
Director of Fraunhofer Institute for Applied Polymer Research IAP | Spokesman Fraunhofer Strategic Research Field Bioeconomy

Added value through cooperation – shared innovations for a sustainable society

The bioeconomy has the potential for sustainable solutions that simultaneously preserve resources while responding to societal challenges. One of the first Fraunhofer institutes to recognize this was Fraunhofer IGB. Researchers at the three sites in Stuttgart, Leuna and Straubing develop innovative solutions along the entire value chain in a wide variety of application fields – from developing new raw materials to scaling up and producing the final product.

We also pursued this approach in the joint project EVOBIO, which saw Fraunhofer IGB take the lead together with the Fraunhofer IAP and IVV institutes. With the involvement of 15 other Fraunhofer institutes, concepts for sustainable value creation and production processes were developed. Combining their expertise, the Fraunhofer IGB researchers significantly contributed to the development of solutions in the field of biobased materials and wastewater treatment plants of the future. EVOBIO impressively demonstrated that we can make a significant contribution to the bioeconomy through cross-institutional collaboration. Around the same time as this success, in 2020 the Fraunhofer Strategic Research Field (FSF) Bioeconomy was founded and we were appointed as the spokesperson team alongside Markus Wolperdinger. In this endeavor, our aim is to pool and represent all of the expertise Fraunhofer has to offer. Our roadmap "A Circular Bioeconomy for Germany," which was delivered to the German Federal Ministry of Education and Research (BMBF) and Federal Ministry for Economic Affairs and Climate Action (BMWK) in December last year, has already been met with an enthusiastic response at national and international level. This shows once again that the Fraunhofer-Gesellschaft, with its combined areas of expertise, is a strong partner in industrial and political circles when it comes to transitioning to a sustainable economy and way of life.

On behalf of all institutes involved in the FSF Bioeconomy, we would like to wish Fraunhofer IGB all the best for its 70th anniversary and say a huge thank you for the good and reliable cooperation we have enjoyed over the years. Together, we look forward to a future that will further advance a sustainable and circular bioeconomy driven by joint projects and initiatives."

Andrea Büttner and Alexander Böker

Dr. Dr. h.c. Christian Patermann
Director (ret.) European Commission |
MinDirig. (ret.) German Federal Ministry
of Education and Research (BMBF)

The role of Fraunhofer IGB in developing the bioeconomy

My first contact with Fraunhofer IGB dates back to 2005/2006, around the time when European bioeconomy efforts began as part of the preparations for the European Union's 7th Framework Programme for Research and Technology, which started in 2007. A few months after the official launch and publication of the concept behind the Knowledge-Based Bioeconomy (KBBE) in September 2005, with the Charlemagne building in Brussels providing the location for the event, a whole host of institute directors and employees of Fraunhofer institutes contacted me in the Brussels office thanks to involvement from the active local Fraunhofer office. These directors and employees had all been grouped together under the Fraunhofer Group for Life Sciences for a number of years and included Prof. Rainer Fischer from Fraunhofer IME and Prof. Thomas Hirth, at that time still at Fraunhofer ICT in Pfinztal. A major research institution, Fraunhofer was actually the only research institution in Germany at the time that showed interest as an entire entity in helping to shape the KBBE content in the first calls to tender for the 7th Framework Programme. This then changed abruptly between 12 and 15 months later, when the KBBE initiative, endowed with approximately two billion euros, started up as part of the 7th Framework Programme in 2007 under the German presidency. During this time, the now almost legendary Cologne Paper on the future of the bioeconomy for Europe was produced. All the major German research institutions became very actively involved from that point.

Cooperation with Fraunhofer IGB then intensified from 2007 when Thomas Hirth succeeded Herwig Brunner at its head. After my retirement, in 2009 I was successful in having Thomas Hirth appointed as a member of the first German Bioeconomy Council – then called the Bioeconomy Research and Technology Council – as a kind of representative for Fraunhofer. The years that followed saw a rapid boost to the bioeconomy in Germany, at least in the field of research and technology. Fraunhofer IGB has made a unique contribution to this with the founding of BioCat in Straubing and, most importantly, the founding of Fraunhofer CBP in Leuna, which was inaugurated by the German Chancellor in 2012 and marked the very beginnings of the first German commercial biorefinery. The naming of the Halle bioregion as Germany's first bioeconomy excellence cluster felt like the logical next step following on from this work.

But then came more difficult times, which are now thankfully behind us. Under Markus Wolperdinger, Fraunhofer IGB has regained a key technological and scientific position for the development of the bioeconomy, both within Fraunhofer (where the Group for Life Sciences has been partially replaced by the Group for Resource Technologies and Bioeconomy, in which Fraunhofer IGB plays a leading role) and beyond. Markus Wolperdinger has become deputy chairman of the third German Bioeconomy Council, which advises the German federal government, as well as spokesperson for the Bioeconomy Council of the state of Baden-Württemberg.

Besides all these very noteworthy details, there are two things in particular that come to mind when I talk about Fraunhofer IGB.

- The strong and successful role that Fraunhofer IGB has played and continues to play in the EU's funding programs, which is not something that can be taken for granted.
- The fact that Fraunhofer IGB is always several steps ahead in the dynamics of social and economic challenges and the technological response to this:
  - When it comes to the shortage of phosphorus as a raw material, and its potential recovery from sludge and wastewater – We're already on it.
  - What about exploiting the potential of chitin and chitosan from seafood waste? – We're already working on three projects in this area.
  - Upscaling? – Fraunhofer CBP has been doing this for years.

In this way, Fraunhofer IGB has shown commitment and foresight in the work it has done – over almost two decades now – in supporting the necessary changes in the use of raw materials in our economy and on our planet by combining biology and engineering. The war in Ukraine and the Covid pandemic that came before it have made us even more acutely aware of the critical importance of this change in approach than even the climate challenges we have been facing. My 70th birthday wish from an 80-year-old supporter of the institute is to keep up the good work – and shout more about your work in Europe!

Happy birthday!"

Christian Patermann

Prof. Dr.
Oliver F. R. A. Damm
Fraunhofer-Gesellschaft,
Senior Advisor South Africa,
Director FIP-WEF@SU

Fruitful partnership on water, energy and food safety in South Africa

South Africa is the most industrialized country in Africa with sophisticated economic sectors such as mining, manufacturing, information and communication technology, and financial services. However, the country is also facing increasing challenges in the key areas of water and energy supply security, due to the combined influence of climate change, a young and growing population, and ageing infrastructure. To contribute to solving these challenges, the Fraunhofer-Gesellschaft has continuously strengthened its collaboration with Stellenbosch University (SU) in South Africa. In February 2020, the two institutions jointly established the Fraunhofer Innovation Platform for the Water-Energy-Food Nexus at SU (FIP-WEF@SU) where research experts from both institutions jointly develop needs-based technological and cross-sectoral solutions for water, energy and food security. Fraunhofer IGB is a key driver in the FIP, together with three other Fraunhofer institutes (IST, ISE and IOSB).

This unequalled mix of local and international expertise has caught the eye of some of the leading South African utilities and institutions. The largest bulk water utility in Africa, Rand Water, has signed a Memorandum of Understanding with the IGB and FIP-WEF@SU to establish a collaborative relationship in areas of research development and innovation, focusing on key topics like digitalization of the water economy and water security modelling. Similarly, the Ekurhuleni Water Care Company (ERWAT) has worked with Fraunhofer for years and is exploring the reuse of wastewater with the IGB. The IGB is also developing key technologies in the CoalCO_2-X Program, an industry-led 10-year flagship program in South Africa that aims to capture CO_2 and other emissions from industrial flue gases and convert these into saleable commodities.

These notable contributions would not be possible without the energy and passion of our Fraunhofer colleagues. Many congratulations on the 70th anniversary; we look forward to many more years of fruitful partnership."

Oliver F. R. A. Damm

Prof. Dr. Ofra Benny
The Hebrew University of Jerusalem, Institute for Drug Research, The School of Pharmacy | Director FIP_DD@HUJI

Establishing cutting-edge solutions for drug discovery and delivery

The Fraunhofer Innovation Platform for Drug Discovery and Delivery at the Hebrew University in Jerusalem, Israel, (FIP_DD@HUJI) is a joint research institution of Fraunhofer IGB and the Institute for Drug Research of the Hebrew University. The focus of the Innovation Platform is on discovery and validation of new drug candidates compounds for infectious and inflammatory diseases as well as on development of targeted nanoparticle delivery systems. To contribute to solving these challenges, the Fraunhofer-Gesellschaft has continuously strengthened its collaboration with the Hebrew University of Jerusalem in Israel. The current FIP_DD@HUJI is the continuation of the Fraunhofer Project Center for Drug Discovery and Delivery, which started in October 2018. Initial first bilateral projects were started in 2012, showing the long history of our collaboration.

Our collaboration resulted in several joint publications, patents and industry cooperations, enabling significant progress in the basic understanding of mechanisms in infectious disease and immunity as well as its application with several companies, from the pharmaceutical sector to cosmetics. Our ongoing projects involve the development of cutting-edge ex-vivo skin models and novel drug delivery systems.

This would not have been possible without the enthusiasm of our IGB colleagues. Warm greetings on the occasion of the IGB's 70th anniversary; we are very much looking forward to another many years of successful collaboration."

Ofra Benny

Anandi Iyer
Director Fraunhofer Office India

Successful international cooperation: Fraunhofer IGB provides water technology for India

Sustainability has never been more relevant and yet challenging than in today's times. An extremely volatile world is panning out, and the ever-dwindling resources such as water, minerals and fossil fuels are creating an alarming situation. Responsible earth citizens are called upon to play their part in developing innovative solutions for reuse, recycling and restoring the delicate balance between need and greed. The Fraunhofer office in India has been partnering with Fraunhofer IGB in developing exciting initiatives around the topics of the Sustainable Development Goals such as Water, Energy, Mobility, Sustainable Building Technologies and other interventions around circular economy. Whether it's the sustainable neighborhood in Kochi, the Water Innovation Hubs in Coimbatore and Solapur or working with leading industry players to develop waste management and circularity, our colleagues from the IGB have been right at the front of working in multistakeholder formats, identifying the exact problems, developing out-of-the-box solutions and creating models for replication and large scale deployment. It is exactly this solution-driven attitude tempered with scientific acumen that has been the hallmark of our association in India.

We are delighted to continue this journey under the dynamic leadership of Dr. Markus Wolperdinger, supported so excellently by Dr. Marius Mohr and Marc Beckett, and we are excited to work on larger projects such as the world's most sustainable airport or the first Water Technology Center driven by industry in India. Our deep appreciation to our colleagues for their time, energy and passion! Congratulations for the 70 years' anniversary and look forward to an exciting future of innovation and partnership!!«

»There is enough on Mother Earth for every man's need but not for even one man's greed«

Mahatma Gandhi

Anandi Iyer

Dr. Matthias Stier
Variolytics GmbH, CEO

From PhD student to founder

When I started my research in 2015 as a PhD student at Fraunhofer IGB in Stuttgart, I had no idea what would come from this eight years later. My scientific project work first led to a patent, and then came my idea to make the invisible visible with measurement technology and use this as a basis for optimizing processes. Fraunhofer IGB has supported me on this path from the very beginning. With the support of the Fraunhofer Venture program and funding from the German Federal Ministry for Economic Affairs and Energy (BMWi) EXIST program, I founded Variolytics GmbH in 2020. During this time and even beyond this, we have been able to make use of spaces and technical infrastructure at Fraunhofer IGB – without which we could not have developed our first prototypes or tested them for our targeted applications.

Since then, my two co-founders and I have been working in a team of ten on our vision of contributing to a climate-neutral future with our measurement technology. Our patented EmiCo system helps wastewater treatment plant operators to better understand their processes, enabling them to use energy more effectively and reduce environmentally harmful direct emissions.

Variolytics is a prime example of how real products can be developed from research and brought to market.

I can only encourage today's emerging talents at Fraunhofer IGB to take the step towards a spin-off. I hope that my journey to becoming an independent entrepreneur serves as an example of how to successfully make your ideas a reality and achieve the dream of self-employment and independence. Wishing every success to all the future founders out there!"

Matthias Stier

Health

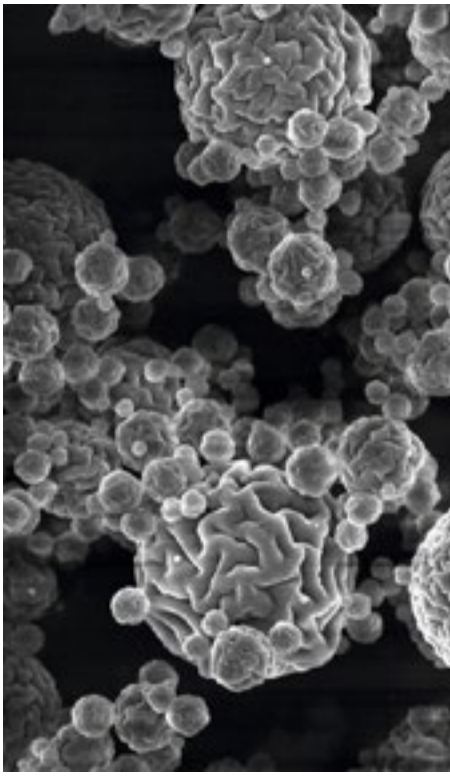
Smart health engineering and enabling technologies for precision medicine

The rapid increase in the acquisition and analysis of genome-wide data of and the enormous potential for cell manipulation have led to the emergence of data-driven diagnostics and fundamentally new therapies, which already enables precision medicine – i.e. health care customized to the needs of the individual patient. At Fraunhofer IGB, our objective is to develop and enhance the enabling technologies required for precision medicine and thereby help to improve the standard of medical care for patients while also reducing the costs of the healthcare system. We see preventive measures, such as curbing resistance development in microorganisms and emergence of zoonoses in the environment, as essential for relieving the burden on the healthcare system. Under the label Circular Health, we are active in this field together with the Fraunhofer Group for Resource Technologies and Bioeconomy.

Fraunhofer IGB is active in the development of

- innovative, nucleic acid-based diagnostic processes, particularly in the field of high-throughput sequencing and data analysis,
- human-based test systems for drug development and personal care,
- viruses, viral vectors and therapeutic viruses as well as processes for their production,
- materials for medical devices as well as
- quality-control systems for medical devices and drug development.

Target markets



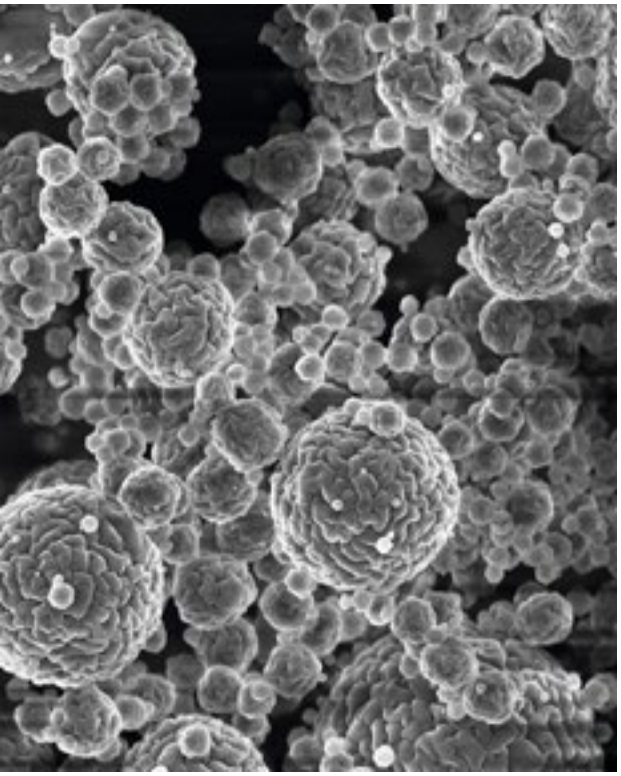
Fraunhofer IGB seeks to partner life science companies, especially in the fields of diagnostics, medical engineering, drug development and personal care.

Diagnostics

Fraunhofer IGB has extensive experience in high-throughput sequencing for the diagnosis of sepsis, endocarditis and intraamniotic infection, pancreatitis and pancreatic cancer and also for microbiome studies. Prospective multicenter research trials have been conducted to validate our diagnostic procedure for sepsis which is available through our spin-off company, Noscendo GmbH.

Drug development and personal care

In the field of drug development, we develop human-based test systems that enable evaluation of the efficacy and side effects of drug candidates at the preclinical stage of research, which cannot be identified reliably on the basis of animal testing. Examples for these test systems are organoid in-vitro systems and three-dimensional multi-cell type in-vitro models including components of the human immune system. Our wealth of experience in molecular cell technology has enabled us to develop highly precise receptor-based assays for drug validation as well as for the evaluation of personal care products. In the cosmetics industry, the need for human-based test systems is particularly high, as the EU has implemented a ban on animal experiments for the testing of new ingredients in personal care products.



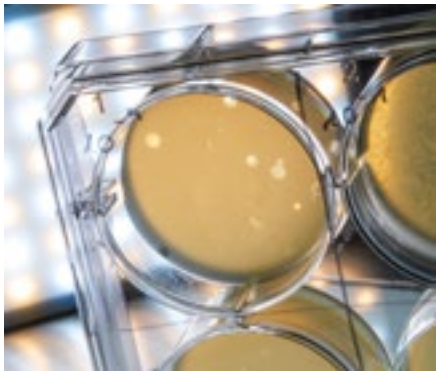
Medical engineering

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

GLP test facility and cleanrooms

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

We also operate cleanrooms (ISO 5) for work in compliance with GMP guidelines.



At Fraunhofer IGB, our many years of experience in virus engineering enable us to develop novel and innovative therapies based on customized viruses for targeted prevention (vaccines) and therapies (oncolytic viruses). Oncolytic viruses were developed based on herpes simplex virus type 1 (HSV-1). In addition, we are developing virus-like particles as vaccines and for targeted drug delivery.

For targeted drug delivery and release, we also formulate active ingredients in, for example, a matrix consisting of biobased polymeric or silicate materials for various applications, including development of an intranasal form of therapy for the treatment of CNS-based diseases.

▸ *www.igb.fraunhofer.de/health*

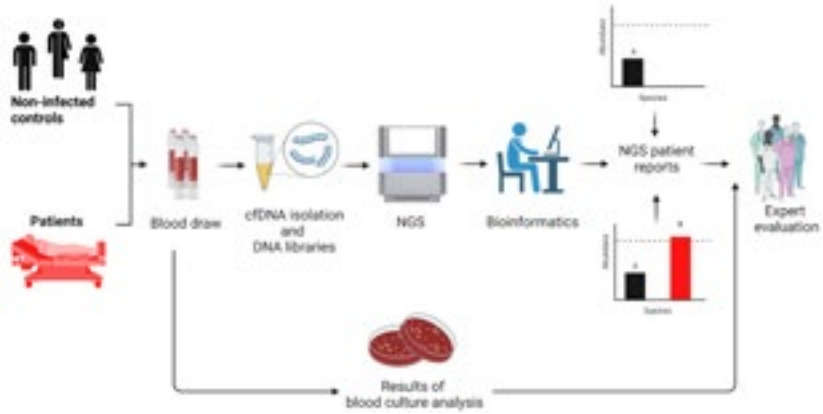
Contact

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

Automated processing of clinical samples for next-generation sequencing diagnosis

Clinical evaluation of NGS-based diagnostics of sepsis pathogens

Sepsis remains one of the main causes of death in intensive care units. It is caused by infections, whereby pathogens – bacteria, viruses, fungi or parasites – spread throughout the body from a local focus of infection via the lymph and the bloodstream, triggering an uncontrolled and overreactive immune response. Rapid treatment with the appropriate antibiotic is critical for the patient's survival. However, it often takes too long to reliably identify the corresponding sepsis pathogen. Furthermore, standard blood culture analysis – which uses microbiological methods to detect microbes – only manages to diagnose a pathogen in less than 30 percent of cases.



Overview of NGS-driven sequencing of cfDNA for sepsis diagnosis (created with BioRender.com)

Here at Fraunhofer IGB, we have developed an innovative process that relies on molecular diagnosis and bioinformatics. Using next-generation sequencing (NGS) in combination with bioinformatic algorithms, this process is able to detect DNA fragments of pathogens in the patient's blood to identify the cause of the sepsis with highest specificity and sensitivity [1–3].

Identification of pathogens using microbial, cell-free DNA

Our approach exploits the fact that the DNA sequences of every pathogen are unique and that cells release DNA in the form of circulating, cell-free fragments (cfDNA) – healthy cells, cancer cells and microorganisms that can be analyzed to identify pathogens. Comparable to liquid biopsy, cfDNA is isolated from blood using a fully automated device which is subsequently sequenced using NGS (Fig. below).

To identify pathogens, the sequences of DNA fragments present within a blood sample – up to 30 million of them – are bioinformatically aligned with known human sequences stored in databases. This comparison reveals that less than one percent of cfDNA originates from microbes rather than from the patient themselves. In the next step, we compare these "reads" precisely with the sequences that are stored in a specially developed database containing genomes of bacteria, viruses, fungi and parasites.

Via a bioinformatic analysis, a SIQ (sepsis indicating quantifier) score is determined for each identified pathogen and compared to the score from non-infected controls to detect lowest levels of contamination. If the SIQ score exceeds a threshold value, the relevant patients are diagnosed as SIQ positive for the respective pathogen [1].

Monocentric clinical study

A monocentric clinical study involving 48 sepsis patients was conducted in collaboration with University Hospital Heidelberg for the purpose of comparing and evaluating the new approach against the standard diagnostic method of blood culture. NGS sequencing of cfDNA performed superior compared to blood culture analysis. An underlying pathogen was detected in only 11 percent of the patients using blood culture analysis. By contrast, NGS diagnosis enabled one or more pathogens to be identified in 71 percent of the patients. Moreover, a jury of independent intensive care physicians judged 96 percent of the SIQ-positive results to be plausible, which would have led to an adapted and more appropriate form of treatment in 53 percent of cases [3].

Contact

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

Multicentric clinical study
To further validate these promising results, "Next GeneSiS" was launched in 2019 – a multicentric clinical study encompassing 500 sepsis patients and 50 healthy subjects at 17 clinics [4]. The clinical value of the NGS-based approach is being evaluated by a committee of independent clinical experts judging on plausibility and possible changes to the treatment of the patients based on the NGS results.

The study data has not yet been published but interim evaluations indicate that the previous results obtained for the NGS approach with regard to sensitivity, specificity and plausibility are now being corroborated in a large, independent patient population.

The Dietmar Hopp Stiftung (Dietmar Hopp Foundation) is sponsoring the multicentric study along with a research project at Essen and Heidelberg University Hospitals, where we are investigating NGS-based diagnosis on seriously ill newborn babies, premature infants and small children [5].

Univ.-Prof. Dr. med. Thorsten Brenner, MHBA
Universitätsklinikum Essen, Clinic Director,
Clinic for Anesthesiology and Intensive Care Medicine

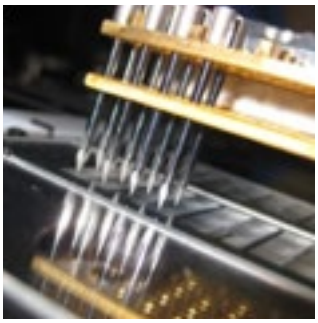
Successful translation into clinical practice

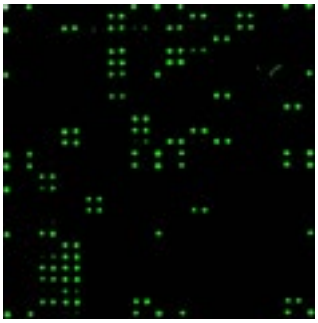
Over eight years ago, we embarked on a journey together with Fraunhofer IGB's In-vitro Diagnostics innovation field, headed by Dr. Kai Sohn, to significantly optimize pathogen diagnostics in patients with sepsis, something that is also commonly known as blood poisoning.

In a multi-step bench-to-bedside approach, technology based on next-generation sequencing (NGS) was further developed from the initial proof of concept to a commercially available diagnostic product that has now become part of clinical routines.

This success story was only possible because scientists from the clinic and researchers from Fraunhofer IGB played an equal part in the project and shared the goal of wanting to improve care for patients with sepsis."

▸ *www.igb.fraunhofer.de/sepsis-study*





above:
In-house production of a prototype for molecular detection of insect pathogens

below:
Detection of pathogens by fluorescence signals

Molecular diagnostics for an automated insect farming

In view of the effects of climate change, the scarcity of arable land and a constantly growing world population, conventional agriculture faces considerable challenges. In order to meet the increasing demand for food, new agricultural systems with more land-efficient forms of production are required. At the same time, it is important to avoid conflicting goals with existing manufacturing methods. In addition, the preservation of the environmental resources air, water, soil and biodiversity as well as the fulfillment of relevant environmental or climate protection goals are of central importance.

Insects as an alternative protein source
The sustainable production of insect proteins as feed for livestock and food for humans represents a globally booming alternative to conventional protein sources such as meat and dairy products. Since January 2018 the EU's Novel Food Regulation has allowed foods made from insects to be marketed in Europe. The first food insect farm in Germany has been in operation since 2019.

However, the production of insects on an industrial scale also promotes the spread of diseases, which can lead to the collapse of insect breeding, production losses and thus serious financial losses. In addition, the insect-based food must be free of human and animal pathogens. A specific and efficient detection system for pathogens in insect farms that is automated, digitized and capable of high-throughput, and that can deliver results promptly and on site, is still missing.

Currently, classic, culture-dependent methods or metagenomic approaches are applied to identify microorganisms in the gut and in the breeding tanks of insects. Both approaches are expensive, time-consuming and tedious, and thus not suitable for daily routine inspections in insect farms.

DNA-based detection of insect pathogens
As part of the Fraunhofer lighthouse project FutureProteins, the IGB is developing an automated monitoring system for insect farming together with the Fraunhofer institutes IME and IVV: For this purpose, a molecular detection system covering the eleven most important insect-associated pathogens is being developed at the IGB. Using insect sample material, DNA signatures of the pathogens are amplified and fluorescently labeled using an isothermal amplification technique. Specific binding to an immobilized probe results in a fluorescent signal that is identified optically and evaluated using a simple matrix. This technique allows for much easier handling than the commonly used PCR applications. In the future, the detection system developed for routine inspection at production sites will be integrated into a partially or fully automated inline system and can ultimately help to minimize the use of antibiotics and promote the resource-saving production of proteins.

Contact

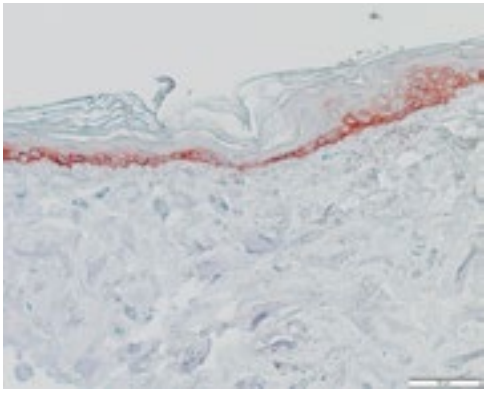
Prof. Dr. Susanne M. Bailer
Phone +49 711 970-4180
susanne.bailer@
igb.fraunhofer.de

Jens Wetschky M. Sc.
Phone +49 711 970-4215
jens.wetschky@
igb.fraunhofer.de

▸ *www.igb.fraunhofer.de/en/futureproteins*

WowWowSkin – in-vitro canine skin equivalents for veterinary therapeutics testing

Due to the large amounts of money spent on treatments in the companion animal sector, the global veterinary medicines market is a steadily growing market, with an estimated value of US$18.5 billion for 2021 [1]. However, compared to human medicine, the market for veterinary medicines is poorly regulated. Therapeutics are used in this context even without prior testing for efficacy, often with minimal or no evaluated benefit. In addition, human therapeutics are often applied to animals, although pharmacodynamics and toxicological effects differ, sometimes significantly, on a species-specific basis. Therefore, species-specific testing is increasingly required for efficacy and risk assessment of veterinary therapeutics. In order to avoid controversial animal experiments at the same time, in-vitro test methods are suitable for this purpose.



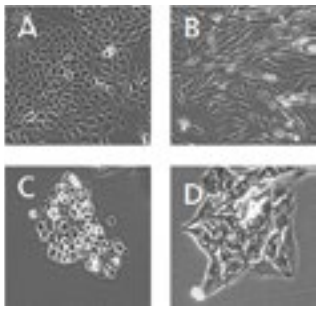
Canine skin, immunohistochemical staining of CK14 (scale bar equals 100 µm)

Standardized testing of therapeutics and care products for dogs

Dermatological problems of pets, especially dogs, are among the most frequently occurring diseases in veterinary clinics. In the WowWowSkin project, the IGB is therefore developing an in-vitro model for canine skin (see Fig. left-hand side) in order to be able to test therapeutic agents and care products for dogs in a standardized manner. To this end, (1) primary cells are isolated from canine skin biopsies, (2) are genetically immortalized, and finally (3) used to construct canine full-thickness skin equivalents (see Fig. right-hand side). The isolation of primary cells and their immortalization as well as the establishment of in-vitro skin models has been successfully performed with human material for decades in the innovation field Cell and Tissue Technologies. Based on this expertise, essential steps were adapted and optimized for the isolation of primary cells from canine biopsies. Primary canine keratinocytes, fibroblasts, endothelial cells and melanocytes were successfully isolated and expanded. These primary canine cells were immortalized by stable transfection with suitable plasmids to finally establish in-vitro epidermis, dermis, and full-thickness skin models.

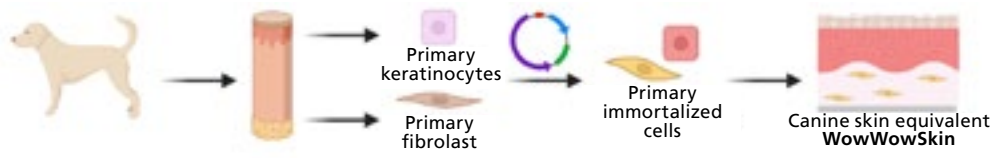
Reproducible complex canine skin model

The final canine full-thickness skin model, consisting of different immortalized cell types, is characterized on the one hand by a high donor-independent reproducibility and on the other hand by its cellular complexity. With the development of a canine in-vitro skin model, the internally funded garage project WowWowSkin enables the IGB to enter a new strategic field of animal in-vitro skin models, addressing the testing of veterinary therapeutics, especially for the treatment of zoonotic skin diseases, of grooming products as well as of flea and tick prevention products.



Isolated, primary cells of canine skin: A) keratinocytes; B) fibroblasts, C) endothelial cells, D) melanocytes

▸ *www.igb.fraunhofer.de/en/wowwowskin*



WowWowSkin workflow: isolation of primary cells from canine skin biopsies, immortalization and establishment of canine 3D in-vitro skin equivalents (Created with BioRender.com)

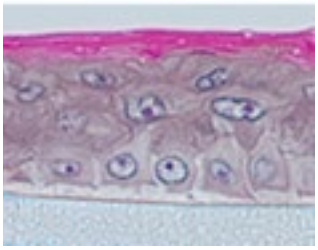
Contact

Dr.-Ing. Christina Kohl
Phone +49 711 970-4183
christina.kohl@
igb.fraunhofer.de

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

Cell stress of the skin: novel in-vitro skin models for the detection of stress signaling pathways – reporter skin

Epidermis model



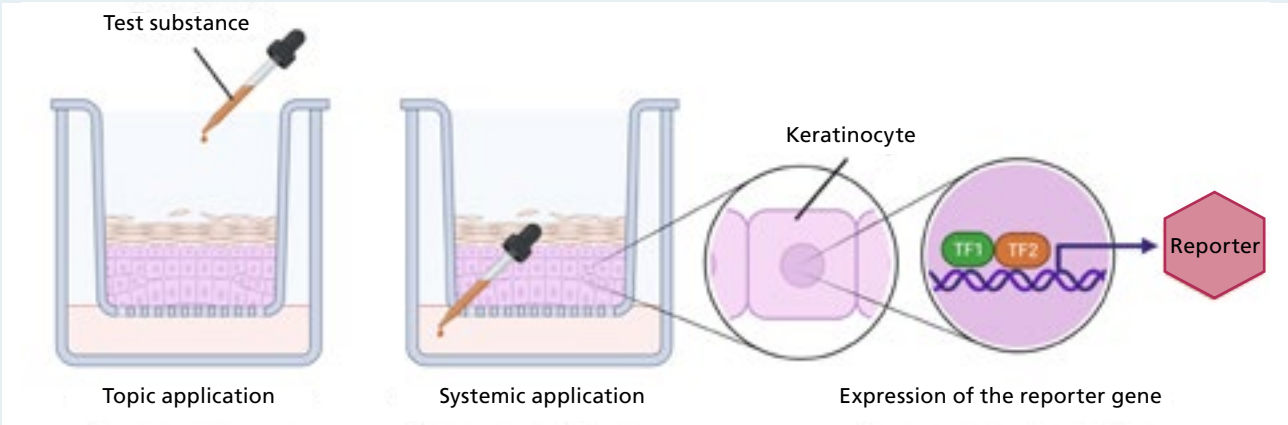
Cross-section through a 3D in-vitro reporter skin model. The epidermis with the cornified layer (pink) is cultured on a support membrane (green).

Standardized testing of substances for safety assessment

Cosmetic and medical ingredients are subjected to risk assessment prior to their approval to guarantee consumer safety of preparations. Ethical, regulatory and scientific reasons have led to the development of Next Generation Risk Assessment (NGRA), a hypothesis-driven, modern and, most importantly, animal-free risk assessment. Consequently, there is an urgent need for in-vivo mimicking in-vitro alternatives to replace previous tests for the safety assessment of substances.

Reproducible, in-vivo mimicking in-vitro reporter skin models

The organotypic reporter skin models are based on human primary, immortalized keratinocytes, which guarantees a high donor-independent reproducibility. The activation of a specific cellular stress signaling pathway in these primary immortalized keratinocytes can be read out rapidly and easily by using a reporter protein that has been stably integrated into the genome via a reporter construct. These reporter keratinocytes form a multi-layered epidermis in-vitro. Analysis of the epidermis demonstrated a full physiological skin barrier function as well as a unique match of characteristic differentiation markers of the models with native human skin.



Schematic representation of the principle of the 3D in-vitro reporter skin models. TF = transcription factor (Created with BioRender.com)

At Fraunhofer IGB, we have established a set of in-vitro 3D reporter skin models (Burger-Kentischer et al., in-vitro 3D reporter skin model, EP 2 041 172) that represent the complex physiology of the skin, including the intact skin barrier. These reporter skin models can be used to determine the toxicological potential of a substance as well as to specifically and rapidly read out the activation of various cellular stress signaling pathways by the test substance in the same model. Thus, these models considerably outperform the test systems available on the market in terms of applicability and relevance.

To date, various reporter skin models are available for testing skin stress, which assess parameters such as inflammatory responses in the skin. Test substances can be applied both systemically and topically to the reporter skin models. This allows to investigate the skin penetration of a substance in addition to the skin stress potential and cytotoxicity.

Contact

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

Service and application areas
With our patented reporter skin models we offer a modern perspective to screen ingredients of preparations potentially coming into contact with the skin for their skin stress potential in a state-of-the-art in-vitro test system. The reporter skin model set can be used to investigate potentially inflammatory allergy and stress of the endoplasmatic reticulum inducing factors. Upon customer request, the reporter test system can be extended to additional cellular signaling pathways and can also be applied to other organs.

Dr. Anke Burger-Kentischer
Head of Innovation Field Cell and Tissue Technologies

Reporter skin allows cell stress to be measured visually in a living model

The safety of new chemical substances to humans must be demonstrated before they can be launched on the market in the form of ingredients in cosmetics, cleaning agents, clothing or industrial chemicals. For example, in-vitro tissue models can replace animal testing in this context. However, substance testing with skin models has so far proven to be tedious, non-specific and non-standardized. To determine whether a substance damages skin cells, various cells have to be cultivated and expanded and sections of the tissue model have to be prepared and compared with controls under the microscope.

It was my goal to establish a model that allows to create a rapidly and accurate result when testing different chemicals. The solution is our patented reporter skin, which we have developed and optimized through years of research. By genetically modifying skin cells, we can now use different reporter skin models to distinguish between major cell stress responses such as inflammation, oxidative stress or stress of the endoplasmatic reticulum. This method visualizes whether a substance for cosmetics or new chemicals damages human skin cells thanks to a reporter gene activated via the cellular signal cascade, allowing for quick and easy identification. For this, only culture medium has to be taken and the results can also be quantified.

My next goal is to get our model approved by regulatory authorities!"

www.igb.fraunhofer.de/reporter-skin

KinVOid – kinetic analysis of virotherapy in the 3D organoid model

Virotherapies are currently experiencing an enormous boom and will be of central importance in the future. Viruses and viral vectors are already being used in cell and gene therapy, as well as oncolytic viruses in cancer therapy, but the many possible applications of virotherapy are far from exhausted. Currently, the data from the preclinical studies of virotherapy are only of limited significance, since up to now mainly 2D cell systems have been used for their analysis. These 2D systems do not adequately reflect the complex in-vivo situation in terms of efficacy, safety and dosage [1]. Furthermore, the "one size fits all" principle still applies to virotherapy, which hinders effective personalized use.

Meaningful tests using organoids

Organoids represent innovative, preclinical 3D test systems for virotherapy, which will even enable personalized tests in the future through the use of patient material (patient-derived organoids). With KinVOid, the first steps were taken towards the development of a simple, inexpensive and mass-market platform procedure for testing therapeutic viruses. Based on a herpesviral infection of neuronal organoids as a model, the kinetics of viral infection of (tumor) organoids will be determined using an inline proteome analysis in combination with viral detection methods.

Virus analysis in the infection model

As part of this project, the cultivation of neuronal organoids and an infection model adapted to them could be established in cooperation with Fraunhofer IPA. This includes determining an appropriate amount of virus for infection and the duration of infection. The organoids could be examined microscopically for morphological changes and the viability could be monitored several days after infection. The investigation of the organoid-based infection model was also expanded to include a novel virus analysis using mass spectroscopy. This enabled pioneering investigations into the kinetic penetration of organoids with therapeutic viruses.

As a result, a workflow for further studies based on the organoid model for personalized oncolytic virotherapies was established, which can be used for other areas of theranostics, i.e. diagnostics for a precise therapy. An automated mass spectrometric analysis of the virus infection in the model also enables patient-specific therapy, in which the amount of active ingredient and the therapeutic strategy can be adjusted with little effort.

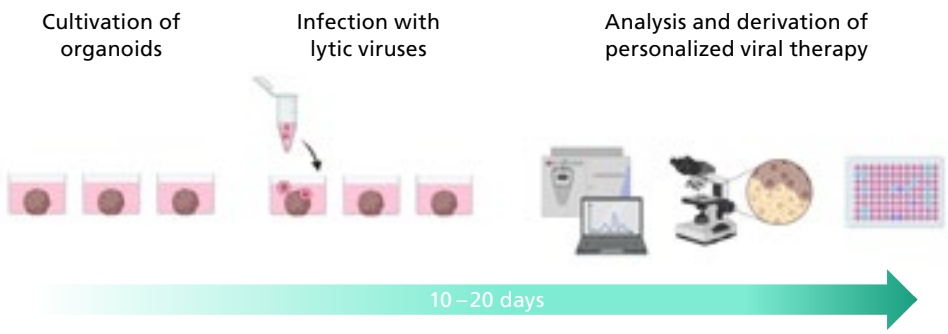
▸ *www.igb.fraunhofer.de/en/kinvoid*

Contact

Prof. Dr. Susanne M. Bailer
Phone +49 711 970-4180
susanne.bailer@
igb.fraunhofer.de

Gabriele Vacun M. Sc.
Phone +49 711 970-4193
gabriele.vacun@
igb.fraunhofer.de

Karina Epting M. Sc.
Phone +49 711 970-4180
karina.epting@
igb.fraunhofer.de



Time course of the infection model with subsequent virus analysis (mass spectrometry, viability, titer determination)

BioProS – biointelligent sensor for the measurement of viral activity

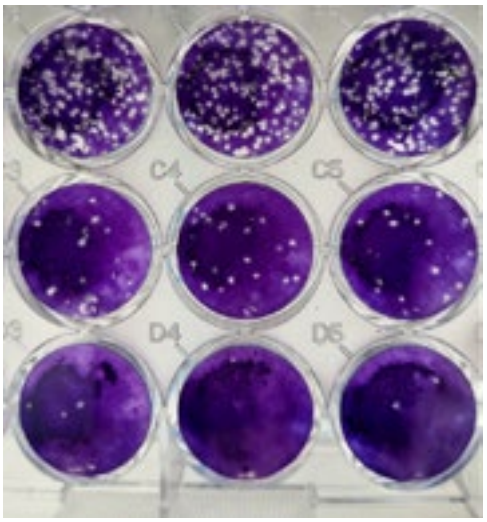
Viruses and viral vectors represent a new class of therapies that have enormous potential to treat or even cure previously inadequate or untreatable diseases such as genetic defects or cancer. Viruses are complex biopharmaceuticals whose properties are fundamentally different from conventional drugs. In order to make them more clinically available, developments for their efficient biotechnological production are required.

Platform technology oncolytic viruses
Such a therapeutic virus was established in the innovation field of virus-based technologies at Fraunhofer IGB through genetic engineering in order to establish a platform technology for oncolytic virotherapy. This patent-pending technology is now ready for modular functionalization for a combined virus-immunotherapy of tumors. In the TheraVision project coordinated by Prof. Bailer (IGB) and further involving the Fraunhofer institutes IZI, ITEM, ISC, and ITWM, functionalized viruses were developed on the basis of this platform technology. The resulting viruses were demonstrated to be safe and to destroy tumor cells of the non-small cell lung carcinoma (NSCLC) in a targeted manner while delivering a potent therapeutic cargo to tumor cells.

Determination of virus activity in real time
A strong trend in the development and application of virus-based therapies for cell, gene and virotherapy can be observed worldwide. The first applied virus products convince with high effectiveness and tolerability, the increasing number of clinical studies makes it likely that further viral therapies will be approved. In order to cover future requirements of viral therapeutics and thus, accelerate their translation into clinical usage, digitized and automated processes are needed to increase the yield of high-quality virus and thus reduce the costs per dose.

The EU project BioProS that started in 2022 under the coordination of Fraunhofer IPA, therefore aims to develop a continuous and real-time capable sensor technology for the detection of virus activity and to combine this as a platform technology with other analytes. Several disciplines (virology, engineering, data science, manufacturing experts) combine their skills to transform the production process of viruses and provide virus products that meet the highest quality requirements.

Aim: personalized production
The combination of optical sensor technology and cell- as well as affinity-based measurement techniques enables bio-hybrid monitoring of viral infection cycles at real-time during production. The bio-intelligent production of the viruses enables personalized production, which is used by various partners in the form of a platform technology and ensures a sustainable and robust production process through new quality control strategies.



Virus activity test for determining the number of infectious virus particles

▸ *www.igb.fraunhofer.de/en/biopros*

Contact

Prof. Dr. Susanne M. Bailer
Phone +49 711 970-4180
susanne.bailer@
igb.fraunhofer.de

Nathalie Metzler M. Sc.
Phone +49 711 970-4221
nathalie.metzler@
igb.fraunhofer.de

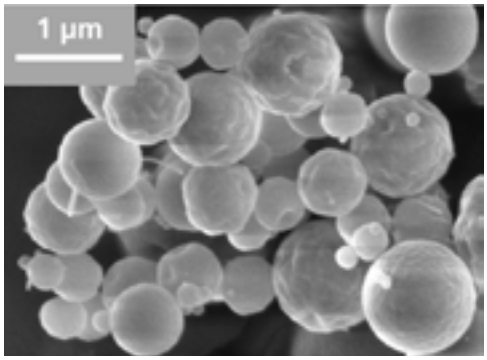
Formulations for intranasal administration of CNS-active biopharmaceuticals

Effective drugs for the treatment of diseases of the central nervous system (CNS) – in addition to multiple sclerosis (MS) these can be the consequences of a stroke, neuro-degenerative diseases or tumors – do exist. However, the blood-brain barrier (BBB), which protects the brain as the body's control center, makes it difficult for therapeutic biomolecules to pass through. This can be remedied by nose-to-brain transport via the olfactory nerve, which allows the direct passage of therapeutic antibodies into the CNS [1].

For patients, this innovative form of therapy may provide a less burdensome treatment available to patients, as fewer side effects can be expected and the drug can be administered at longer intervals and without the need for hospitalization.

Novel gel patch for nose-to-brain transport

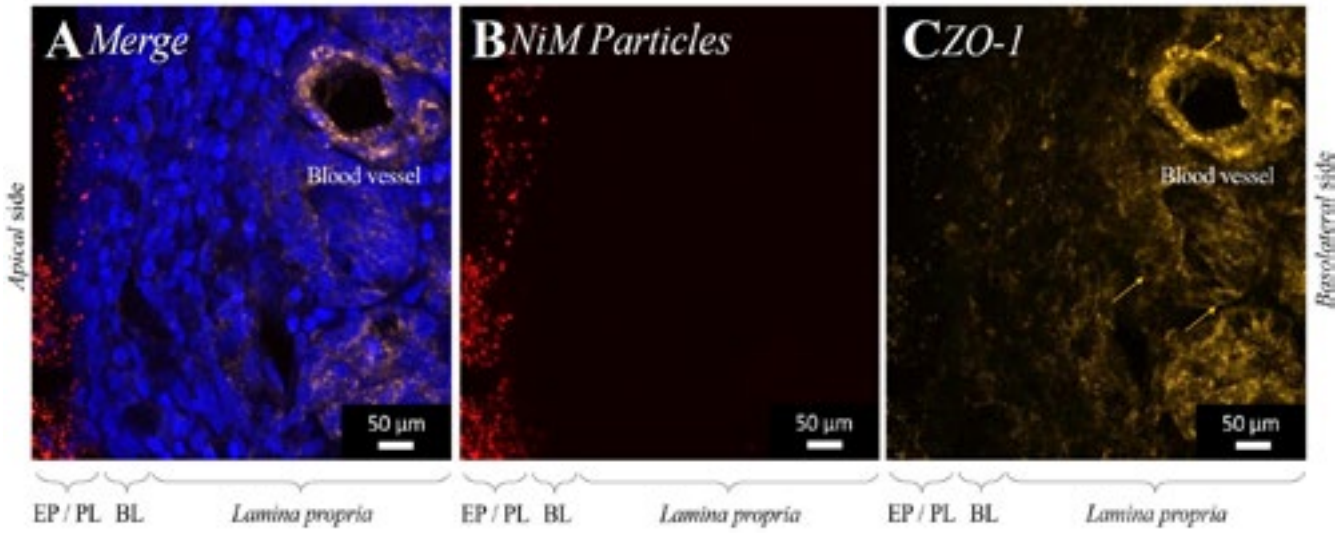
The new therapy form developed in the EU project N2B-Patch consists of different components: the active ingredient itself, a formulation containing the active ingredient, a hydrogel as a carrier material and a suitable applicator for insertion of the gel patch. The active ingredient contained in the gel patch is released over a longer period of time. The patch dissolves and does not need to be removed again. For a long-term treatment, a new patch will be applied.



Scanning electron microscope (SEM) image of spray-dried chitosan particles, magnification 25,000 X

Formulation of the active ingredient

Fraunhofer IGB developed the final formulation of the clinical antibody and was involved in the development of the incorporation process into the gel. The active ingredients, monoclonal antibodies (mAbs), were encapsulated in chitosan as matrix material by spray drying. This process allowed us to achieve high encapsulation efficiencies of up to 90 percent while maintaining the bioactivity and structural integrity of the drug. The storage stability of the formulation at room temperature is up to four weeks. In experiments with



The application of chitosan particles (NiM) causes an opening of the tight junctions in the olfactory mucosa and enables a paracellular transport.

porcine epithelium, it was shown that tight junctions opened 15 minutes after ex-vivo application of the formulation to porcine olfactory mucosa when chitosan was used as the capsule material [2]. Preclinical proof-of-concept studies in minipigs showed a controlled release profile of the patch and demonstrated CNS bioavailability.

Outlook

Basic research also goes beyond this specific project, as part of the Marie Skłodowska Curie Network "Bio2Brain" coordinated by Fraunhofer IGB. Young scientists from all over the world are involved in this network.

Here, Fraunhofer IGB has developed a formulation with high encapsulation efficiency that is storage stable at room temperature and whose production can be transferred to industrial scale. This represents a promising new system for improving the formulation of biologics and the associated therapeutic challenges, and may be used in the future (with and without gel patches) as a potential platform technology for other CNS diseases such as stroke and Alzheimer's – or even for certain cancers.

▸ *www.igb.fraunhofer.de/en/n2b-patch*

Contact

Dr. Carmen Gruber-Traub
Phone +49 711 970-4034
carmen.gruber-traub@
igb.fraunhofer.de

70

Collaboration with innovation partner opens up new horizons

Dr. Nazende Günday-Türeli
MyBiotech GmbH, CTO

My first encounter with Fraunhofer IGB was in the context of the N2B-patch research project. Our goal was to develop an intranasal application platform for biopharmaceuticals as an innovative galenical formulation for the treatment of multiple sclerosis. Now we are joint partners in the Bio2Brain network, which runs a research and education program for training young scientists in the development of novel technologies with the aim of efficiently delivering biopharmaceuticals intranasally to the brain.

For me, the cooperation with Fraunhofer IGB means working together with amazing colleagues in a trusting and uncomplicated setting – that's also highly professional. This is why Fraunhofer IGB is a reliable partner for us in applied innovation collaborations. Cooperative interdisciplinary work also enables us to fix our sights on joint partnerships in other R&D and innovation topics that we would not be able to tackle alone. As a result, it also offers opportunities for further projects that can lead to new horizons."

Nanogel biosensors for fast and safe pathogen diagnostics

Who doesn't know it? The throat is scratchy, a feeling of listlessness spreads. Have you been infected with Corona? You can quickly check this at home using rapid antigen tests – but the accuracy of these tests leaves a lot to be desired. Many infections remain undetected, and false positive results can also occur. For reliable detection, a PCR test is indispensable, but this is both much more expensive and more time-consuming.

Fast and reliable results

A network of researchers from the Fraunhofer Institute for Production Technology IPT, the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB and the Fraunhofer Center for Manufacturing Innovation CMI in Boston (USA) now wants to change this. The three institutes are jointly developing the Pathogen Analyzer SECURIGEL (Fig. below left) and combine the advantages of antigen and PCR tests: speed and accuracy.

Amplification at constant temperature

To amplify the genetic material, the institutes use a different method than the PCR test. The result is now available after about 30 minutes. The core of the technology is the encapsulation and on-chip storage of pathogen-specific diagnostics using RT-LAMP (reverse transcription loop-mediated isothermal amplification) in a patented, printable hydrogel (Fig. below center). The reaction for amplifying the viral RNA takes place at a constant temperature of 62 °C – the heating and cooling of the sample liquid required in PCR is not necessary.

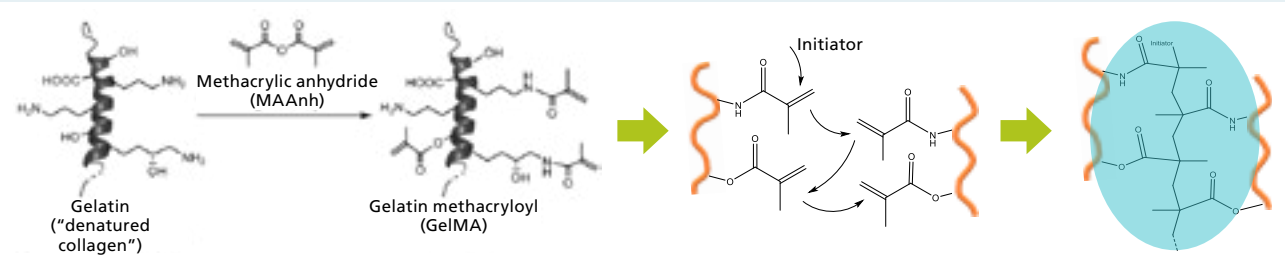
Multiplexing by hydrogel

For this purpose, we at Fraunhofer IGB and Fraunhofer CMI have printed numerous small hydrogel droplets on a test chip similar in size to a rapid antigen test (Fig. below center). These biogel nanosensors are arranged in 1500 individual 500 pL spots, with 500 additional spots each for simultaneous positive and negative controls, which increases the accuracy and reliability of the results. The hydrogel was optimized at Fraunhofer IGB for the adhesion of the droplets to the chip surface and the reaction for a correct test result. Accordingly, our hydrogel (Fig. below right and above right) is characterized by five features: Spatial multiplexing capability, lower detection limits, on-chip storage of reagents, longer shelf life and scalability. The key advantage of our approach is a simplified sample preparation and discretization – i.e. obtaining finitely many ("discrete") data from a continuous flow of information – of RT-LAMP to significantly reduce false positives.

left:
Test station to read out the chips, © Fraunhofer IPT

center:
CAD drawing of a test chips, © Fraunhofer IPT

right:
Hydrogel



Schematic drawing of hydrogel

Parallel detection of multiple pathogens
On the one hand, such a multiplexing approach increases reliability; on the other hand, it makes it possible to detect up to twelve different types of viruses simultaneously with one sampling and one chip. Since we developed the system as a modular system, it can be quickly adapted to new pathogens and thus new situations.

▸ *www.igb.fraunhofer.de/en/omnitest*

Contact

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

Sustainable chemistry

Development, scaling and optimization of processes for the production of sustainable chemicals, fuels and materials from biogenic raw/residual materials or CO_2

Faced with environmental regulations, international competition and new legislation, the chemical industry and its downstream industries have to continuously improve their production processes. The business area Sustainable Chemistry provides solutions which are not only economic but also more ecological according to the model of a circular economy. Our prime objective is to develop highly efficient conversion processes – in terms of both energy and resources – based on renewable raw materials, residues or CO_2, coupled with intelligent solutions for downstream processing. Supplemented by the bioinspired production of new polymer materials, functionalization by means of different technologies and the material and biological characterization, complete process cycles can be demonstrated up to pilot scale.

Fraunhofer IGB is active in the development of

- pretreatment and fractionation processes of raw materials,
- industrial biotechnology processes for selectively converting materials by means of enzymatic or fermentation processes,
- chemocatalytic, electrochemical and electrobiological processes and their combination with biotechnological processes,
- power-to-X-to-Y cascade processes for the utilization of regenerative produced redox equivalents in synthesis processes, e.g. for using CO_2,
- bioinspired synthesis routes for the production of fine and specialty chemicals, polymers, and functional materials,
- membranes for efficient gas separation, e.g. for CO_2 capture and storage, or for membrane reactors as well as
- customized thin films and functionalized surfaces.

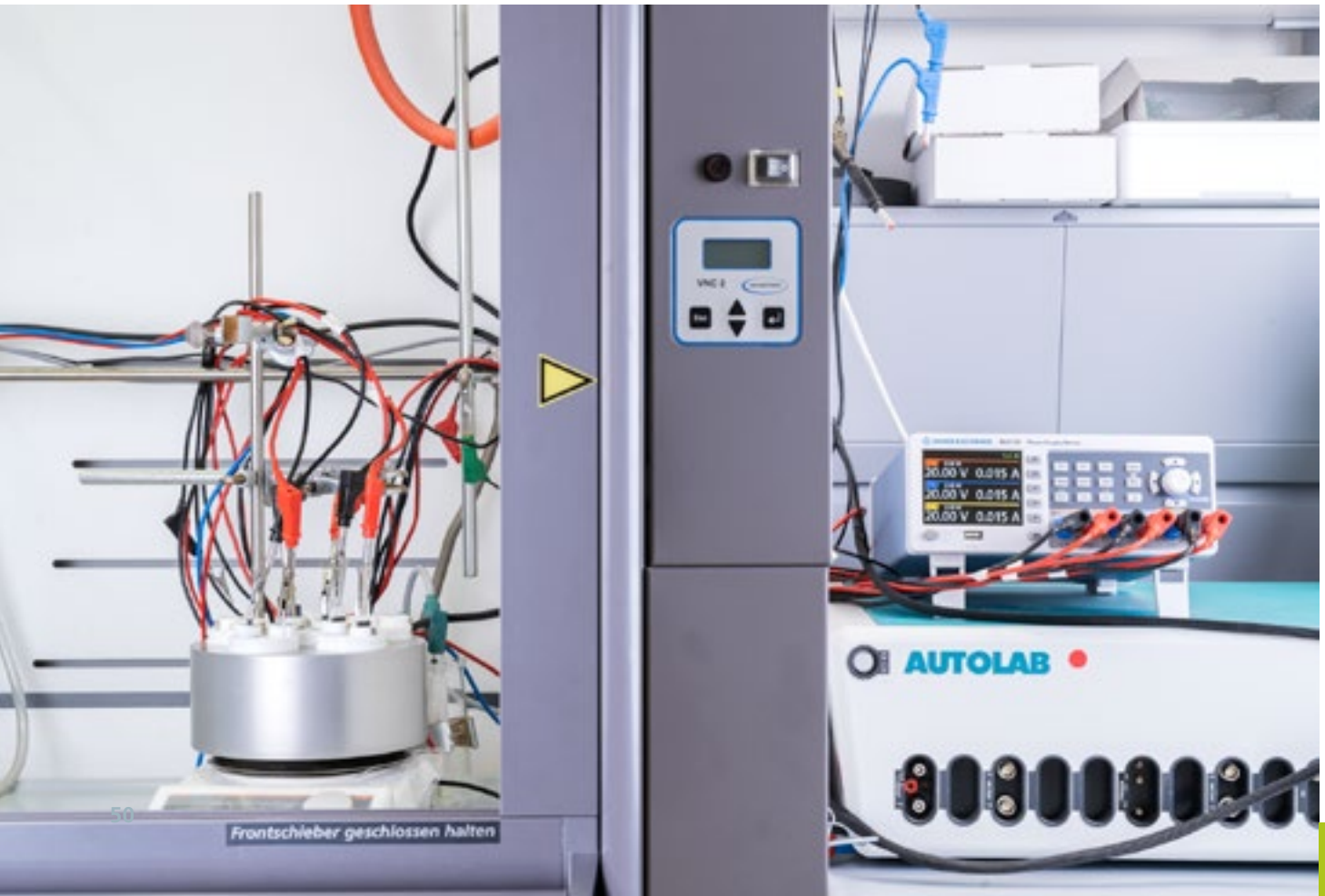
Fraunhofer IGB is helping to drive the transformation of the process industry, especially in the chemicals sector, and contributes to all four segments of the bioeconomy: food, animal feed, sustainable chemical products and bioenergy (see business area Environment and Climate Protection).

Target markets

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

Fine and specialty chemicals

In general, industrial biotechnology approaches provide access to many different substance groups in this segment. The institute has decades of expertise in the identification, modification and cultivation of microorganisms or the use of enzymes, which, coupled with know-how and technologies from the field of interfacial engineering, enable new products and applications. Examples of particularly interesting product groups are surface-active substances such as surfactants or biobased coating systems. We also focus on synthesis, downstream processing and characterization of substances and materials for which an interaction with biological systems plays an essential role. Examples here include additives for agriculture such as plant boosters made of microalgae, which positively impact cell growth in agricultural crops.



Biopolymers and biobased polymers

We also develop biopolymers for use as packaging for foodstuffs or for medicinal products (see Health business area). By using advanced coatings or the special functionality of biobased monomers, we are able to create new properties for materials. Examples here include the transparent Caramid-polyamides that Fraunhofer IGB has developed from terpenes. Based on renewable raw materials such as sugar, plant or animal based lipids or chitin, we have also been able to demonstrate methods of synthesizing monomers for the production of polymers, e.g. from short- and long-chain dicarboxylic acids and fatty acid epoxides. The fractionation of plant raw materials and residues is another way of directly utilizing nature's synthesis potential. At Fraunhofer IGB, these pretreatment methods are (further) developed and, if necessary, further conditioning and functionalization are added.

Ingredients for food and animal feed

New extraction and fermentation processes offer access to a wide range of products for the food and feed industry from resources that have been insufficiently tapped to date. These include, for example, alternative proteins from plants, insects or microalgae, but also (modified) carbohydrates. Further functional ingredients can also be obtained from microorganisms and microalgae or via new fractionation technologies from by-products from the agricultural and food industries. Due to their antioxidant, immunostimulant or antimicrobial properties, they are suitable for use in animal feed or as food supplements. For this purpose, we develop cultivation methods and product-friendly separation processes, for example for extraction and purification.

Technologies for the material use of CO_2

The ready availability of renewable electrical energy means that the chemical and energy sectors will increasingly merge in the future as the redox equivalents needed for product synthesis based on CO_2 as feedstock can directly be coupled with in power-to-X processes. Developments on electrochemical catalysts, electrode materials, membranes and finally entire systems are taking place at the institute, as well as the coupling of these technologies with additional synthesis processes. In this way, complex molecular structures can be generated elegantly from the electrochemically produced C_1-derivatives methanol, formic acid or formaldehyde using biotechnological processes. This power-to-X-to-Y concept, defined at the institute, has already been successfully demonstrated in the EU project Celbicon or within the ongoing Fraunhofer-internal lighthouse project ShapID.

▸ *www.igb.fraunhofer.de/sustainable-chemistry*

Contact

Dr. Christine Rasche
Phone +49 3461 43-9103
christine.rasche@
igb.fraunhofer.de

Rapeseed as a source of vegetable protein

Rapeseed is a much sought-after raw material. High-quality rapeseed oil is the most popular type of oil in German kitchens and some of the protein-rich residues that remain after the oil has been extracted are used as animal feed. However, rapeseed processing methods rely on high pressures and temperatures – resulting in denaturation of the proteins – as well as chemicals that pollute the environment and are sometimes toxic. These include hexane or special petroleum-based solvents that are used to extract the rapeseed oil. Consequently, the added-value potential of this process has been basically exhausted.

De-hulling system

Pilot plant for a mild EthaNa process

The mild EthaNa process represents an alternative approach. It is performed at ambient pressure and temperatures of no more than 70 °C, uses ethanol instead of hexane or petroleum-based solvents and is capable of processing de-hulled rapeseed. In the EthaNa project funded by the German Federal Ministry of Food and Agriculture (BMEL), eleven partners collaborated on investigating the novel process under the joint coordination of Fraunhofer CBP and B+B Engineering GmbH. The Fraunhofer Institute for Interfacial Engineering and Biotechnology, the Fraunhofer Institute for Process Engineering and Packaging, the IFF's Research Institute of Feed Technology, the Institute of Industrial Production at the Karlsruhe Institute of Technology, C. Thywissen GmbH, AVA Anhaltinische Verfahrens- und Anlagentechnik GmbH, MICCRA GmbH, VetterTec GmbH and tti Magdeburg GmbH were also involved. On completion of the project, in 2022 a pilot plant – consisting of a de-hulling system and an extraction system – was built and put into operation at Fraunhofer CBP in Leuna.

EthaNa: improved oil quality, valuable by-products

The research has revealed that the oil is displaced from the kernel during the EthaNa process rather than being extracted in the usual manner. Consequently, the rapeseed oil obtained in this way is of higher quality than oil produced using conventional methods. In addition, the rapeseed concentrate is rich in nutritious proteins and contains significantly fewer hulls. The hull fraction is an additional product that can, for instance, be used to manufacture insulating materials. Moreover, valuable molecules such as sinapinic acid or phospholipids dissolve in ethanol and can be used in the cosmetic or pharmaceutical industries. Strategies for separating and processing these molecules are subject of current research work.

Rapeseed concentrate with native proteins

The mild conditions of the EthaNa process lead to a rapeseed concentrate that is rich in high-quality, non-denatured proteins. Together with our partners, we are researching how this can be utilized as a source of protein for food production as part of the Like-A-Pro project that has recently been launched with the sponsorship of the EU.

Stirrer and storage tanks for rapeseed pulping and conditioning

Decanter for separating suspended particles

In the course of the project, the EthaNa® plant is further optimized in terms of oil separation, the size of the rapeseeds is correlated with the quantity of oil released and a countercurrent process is established for ethanol extraction.

In addition, efforts are being made to establish new cooperations for expanding the range of raw materials that can be processed with the EthaNa® plant. Some promising candidates in this regard are sunflower seeds, beechnuts or residual products such as coffee grounds or hemp seeds.

- *www.cbp.fraunhofer.de/en/ethana*
- *www.cbp.fraunhofer.de/en/like-a-pro*

Contact

Dr. Robert Hartmann
Phone +49 3461 43-9111
robert.hartmann@
igb.fraunhofer.de

Fraunhofer CBP as a research partner for transferring new processes to industrial applications

Bringing new, innovative processes to traditional industries, such as refining vegetable oils and fats, is often a challenge. That is why it is especially productive for small companies such as B+B Engineering to work together with research partners like Fraunhofer IGB. We started working with Fraunhofer IGB in Stuttgart on extracting bioactive minor components from vegetable oil back in 2013 – and this cooperative endeavor with a focus on solutions has now led to another joint project. When dedicated, creative people work together, progressive approaches to established processes can emerge. One example of this was produced a few years ago at a dinner during the Tutzing Symposium, when the concept of the EthaNa® plant was planned out on the back of a napkin. Since then, the idea underpinning mild ethanolic extraction of oilseeds has been further developed thanks to an excellent partnership with Fraunhofer CBP, and a pilot plant has been established. This will enable advancements in plant-based biorefineries, workarounds for previous limitations in sustainability, and more innovations."

Dr. Jeannette Hollien
B+B Engineering GmbH, Managing Director

Wood as a raw material for pharmaceutical products

Our project partner HV-Polysaccharides GmbH & Co. KG has developed a hydrothermal aqueous extraction process of beechwood which produces the polysaccharide xylan in a higher quality than ever before thanks to special process control. Thus xylan is suitable for use as a raw material in the manufacture of active pharmaceutical ingredients.

From gram to kilogram
To ensure full utilization of the beechwood material, in the XyloSolv project the aqueous xylan extraction was combined with the Organosolv process, an ethanolic pulping of lignocellulose producing high-quality lignin and pulp.

We implemented the sequential extraction at the pilot plants of Fraunhofer CBP for the first time. Individual process steps were optimized to enable the high-yield production of products without any variations in quality. The extraction processes, which have been developed and optimized jointly by all the partners involved, are resource-efficient and environmentally friendly. According to analyses, both the xylan and the organosolv lignin are of high purity, making them suitable for pharmaceutical, cosmetic or food applications.

From kilogram to metric ton
The technical feasibility of the overall combined process was evaluated by our project partner Glatt Ingenieurtechnik GmbH. This evaluation was then used as a basis for drawing up a production plant concept. The subsequent techno-economic assessment revealed that the xylan production costs lie within the range of the current market prices for pharmaceutical xylan.

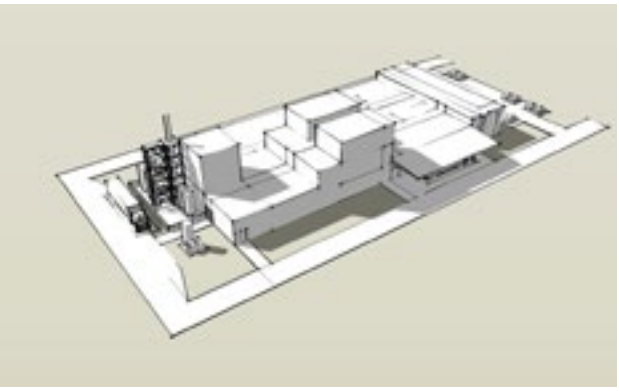
However, the costs of producing Organosolv lignin are relatively high due to the planned production scale of a few metric tons only, thereby ruling out its use in material applications. Alternatively, Organosolv lignin might be utilized in high-end pharmaceutical or cosmetic products, where the high purity would justify the high price. Given that lignin has never been used in large quantities in pharmaceutical or cosmetic applications, future projects are to be undertaken to investigate this option in collaboration with our partners from science and industry.

left:
Laboratory extraction of xylan

right:
The Fraunhofer CBP pilot plant is capable of processing up to 90 kilograms of wood per batch, resulting in a few kilograms of xylan.

Contact

Dr. Ireen Gebauer
Phone +49 3461 43-9133
ireen.gebauer@
igb.fraunhofer.de



This is how a production plant might look like.

Irrespective of this, HV-Polysaccharides GmbH & Co. KG is striving to implement the key results of the collaboration with Fraunhofer CBP in a commercial xylan production plant, which is scheduled to go into operation in 2025.

▸ *www.cbp.fraunhofer.de/en/xylosolv*

Dr. Holger Wondraczek
HV-Polysaccharides GmbH & Co. KG, Managing Director

A solid foundation for process development – with Fraunhofer CBP

HV-Polysaccharides distributes tailor-made polysaccharides for pharmaceutical applications. The company's achievements have included designing a process for extracting xylan from beech wood that makes it possible to adjust the properties required for pharmaceutical applications with precision. This approach also dispenses with the use of otherwise common chemicals. Since our very beginnings, we have been seeking out partners who can help us develop our process so that we can achieve greater technological and economic maturity. With this in mind, we got in touch with Dr. Christine Rasche and Dr. Moritz Leschinsky (now at UPM Biochemicals) from Fraunhofer CBP and piloted our process at the facilities there in order to create product quantities beyond the scale possible in the lab and gain experience in scaling up.

Relatively quickly, the trusting, uncomplicated cooperation that we found resulted in the idea of combining our process for xylan extraction with Organosolv fractionation developed at Fraunhofer CBP. In order to map the full complexity of this kind of a process development, the company Glatt Ingenieurtechnik from the Weimar/Dresden area was brought in. With funding from the Fachagentur für Nachwachsende Rohstoffe (German Agency for Renewable Resources), this consortium has now successfully developed the XyloSolv process, which enables the main components of beech wood to be used holistically.

Building on the success of our cooperation, we are now planning to create our own biomass fractionation plants and hope to start production in 2025. Should new ideas for a development in this area or a similar one arise in the future, Fraunhofer CBP would certainly be my first port of call to flesh out a project."

A project that combines base-catalyzed and oxidative depolymerization of lignin – KoBaOx

Cleaving solution after base-catalyzed depolymerization

Lignin is the only renewable resource that offers the potential for extracting large quantities of aromatic molecules of the kind that are essential for producing many platform chemicals and materials, for example. When lignin is produced using the Kraft process for making paper pulp, the heterogeneity, high molar mass and low functionality essentially prove a major hindrance for many applications. Using base-catalyzed (BCD) or oxidative depolymerization to cleave the lignin molecule is one way of overcoming these restrictions. Depending on how the process is controlled, this enables the molar mass and heterogeneity to be reduced while also generating new functionalities.

Base-catalyzed depolymerization reduces heterogeneity, oxidation increases functionality

In the BCD process, lignin is depolymerized into phenolic monomers, oligomers and various by-products. Using the kind of continuous BCD technique that is available at Fraunhofer CBP, the weight-average and number-average molecular weights of commercial Kraft lignin can, for example, be reduced by approximately 70 and 50 percent respectively. By contrast, oxidation only enables a slight decrease in the weight-average and number-average molecular weights of Kraft lignin to be achieved because it is often the case that only the side chains of the lignin get oxidized. However, the upside of oxidation is that it allows the introduction of highly reactive carboxyl groups.

Combining the advantages of both processes

Thus, KoBaOx aims to sequentially combine base-catalyzed lignin depolymerization (BCD) with alkaline oxidation involving hydrogen peroxide. In this way, innovative carboxylated lignin derivatives can be produced for use in various applications – such as thermoplastics. Two synthesis routes are being explored within this context: i) oxidation of the lignin with subsequent BCD, ii) implementation of the processes the other way round as an alternative. Both possibilities lead to advantages and disadvantages from a process technology perspective and these are to be compared in the course of the study.

For instance, linking the two processes (oxidative and base-catalyzed depolymerization of lignin) eliminates processing steps that would otherwise have to be performed on the cleaving solutions obtained. In addition, membrane technology is likewise to be used as a means of reducing the number of processing steps and chemicals involved. The innovative carboxylated lignin derivatives with a low molar mass could potentially offer improved water solubility, thereby facilitating film applications. If these aims are achieved, it will open up a new source of high-quality products for the bioeconomy.

▸ *www.cbp.fraunhofer.de/en/kobaox*

Contact

Dr. Kerstin Thiele
Phone +49 3461 43-9127
kerstin.thiele@
igb.fraunhofer.de

SynLink – synthesizing fuels for mobile applications

The SynLink research project deals with the production of renewable fuels, such as methanol or long-chain hydrocarbons. This means considering the entire value chain from both a technical and an economic perspective – from production of the synthesis gas using renewable electrical energy and carbon dioxide, and its subsequent chemocatalytic conversion into fuel, right through to practical application tests on cars and trucks – and demonstrating that a technology readiness level (TRL) of 5–6 has been achieved. Within the project, Fraunhofer CBP was tasked with carrying out long-term experiments for methanol production on a pilot scale with a TRL of 5–6.

Upstream rack of the pilot plant for synthesizing methanol from synthesis gas

Producing methanol from synthesis gas

After a methanol plant had been engineered and set up on a laboratory scale at the CBP, the temperature (250 – 270 °C), pressure (50 – 90 bar gauge) and gas hourly space velocity (GHSV; 8,000 – 30,000 h^{-1}) were varied to determine the optimum process parameters while using an industrial catalyst.

During this process, the synthesis gas was converted into a methanol-water mixture using a plug flow reactor and an industrial catalyst. Any non-converted synthesis gas was separated by a separator and fed back to the reactant flow. As the process parameters were varied, their influence on the conversion process was examined, long-term tests were carried out in relation to catalyst stability and the results of the experiments were compared with the simulations that were being conducted in parallel with the process.

The results of the experiments demonstrated that the conversion rate could be increased up to 44 percent by raising the pressure. In contrast, increasing the GHSV led to a reduction in the conversion rate. This can be explained by the shorter contact time with the catalyst. Within the investigated temperature range, the temperature was not found to have any influence on the conversion rate. The results from the simulations were comparable to those from the laboratory-scale experiments.

Piloting the methanol process

After the methanol synthesis had been established on a laboratory scale, a pilot plant was rebuilt in order to be able to carry out the methanol process on a pilot-plant scale and then put into operation. The operating point was scaled to the highest conversion rate and the plant was operated on a long-term basis with subsequent rectification of the methanol-water mixture. The conversion rate and purity of the methanol produced in the pilot plant were similar to those achieved in the laboratory experiment.

For the subsequent practical application tests on the cars and trucks, the methanol produced from the synthesis gas was used as a fuel in both blended and pure form. Given that no standard has yet been drawn up for using methanol as a fuel, possible requirements for the product were defined on the basis of DIN 51625 "Automotive fuels – Ethanol fuel – Requirements and test methods."

Methanol synthesis on behalf of customers

Following the successful completion of the project, Fraunhofer CBP now has the expertise required to carry out methanol synthesis on behalf of interested companies and organizations on both a laboratory and a pilot scale.

▸ *www.cbp.fraunhofer.de/en/synlink*

Contact

Robert Röver M. Eng.
Phone +49 3461 43-9125
robert.roever@
igb.fraunhofer.de

Dr. Ulrike Junghans
Phone +49 3461 43-9128
ulrike.junghans@
igb.fraunhofer.de

above:
The FuTuReS project investigated under which conditions and for which applications the cultivation of microalgae is currently already economically viable.

below:
When using the diatom Phaeodactylum tricornutum to produce the carotenoid fucoxanthin, it can pay to use artificial LED lighting to cultivate the algae.

An economic and ecological study of microalgae cultivation – the FuTuReS project

Microalgae can be grown in closed cultivation systems called photobioreactors. In addition to light and carbon dioxide (CO_2), these single-celled organisms need nutrients such as nitrogen and phosphorus to grow. Microalgae biomass can contain various valuable compounds. Which ones are produced and in what concentrations depends on the cultivation conditions, e.g., the nutrient supply, and – above all – the choice of microalgae species. Various algae species can be used to produce pigments, omega-3 fatty acids or proteins that are suitable for use in the food or cosmetic industry.

In the FuTuReS research project funded by the German Federal Ministry of Food and Agriculture (BMEL), researchers from Fraunhofer IGB, the University of Hohenheim and the Karlsruhe Institute of Technology (KIT) investigated under which conditions and for which applications the cultivation of microalgae is currently already economically viable in Germany.

Process data from microalgae production and extraction of valuable compounds

Therefore different pilot-scale cultivation scenarios were compared for the first time: cultivation of microalgae in photobioreactors outdoors or in greenhouses using sunlight versus indoor cultivation in photobioreactors using artificial illumination. For this comparison, the single-celled diatom *Phaeodactylum tricornutum*, which can also be grown effectively under central European climatic conditions, was used. The research focused on the production of the pigment fucoxanthin, eicosapentaenoic acid (an omega-3 fatty acid, abbreviated to EPA) and proteins, as well as the associated value creation

Higher biomass yield with artificial lighting

The process data generated by the cultivation processes was used in a techno-economic analysis and life-cycle assessment conducted at the University of Hohenheim. The results revealed that, in Germany, continuous artificial lighting with energy-saving LEDs offers advantages over outdoor cultivation using sunlight (which, of course, is not continuous).

Regarding the produced valuable compounds, the researchers were able to show that cultivating microalgae to obtain high-cost products such as fucoxanthin and EPA can be an economically worthwhile pursuit. However, no further increase in profitability can be achieved by additionally extracting proteins because proteins are already globally available at relatively low prices.

Lower costs through automation

The results of the project directly affected the further work of the working group at Fraunhofer IGB. Reducing the costs of microalgae cultivation, e.g., by automating processes or introducing new lighting and reactor concepts, remains in its focus. Furthermore, we are looking for partners who are interested in putting the research results into practice outside of the research context.

Contact

Konstantin Frick M. Sc.
Phone +49 711 970-4074
konstantin.frick@
igb.fraunhofer.de

▸ *www.igb.fraunhofer.de/en/futures*

InBiRa – the insect biorefinery: from the recycling of residual and waste materials to the manufacture of chemical products

The InBiRa project is the first ever example of an insect biorefinery being built as a pilot plant that converts organic residual materials and waste into new products that are usable in a technical context. The project is being funded by the Baden-Württemberg Ministry of the Environment, Climate Protection and the Energy Sector in conjunction with the European Union, and is being coordinated by Fraunhofer IGB.

The larvae of the black soldier fly are the key to the approach that is being adopted for the insect biorefinery. The larvae of this fly feed on spoiled food, biowaste from restaurants and organic waste containers, and convert these into biomass as they develop. The insect biomass is rich in fats, proteins and chitin, which can be used to make new secondary products.

Insect biorefinery pilot plant for the technical utilization of all fractions

The first step is to process the waste and residual material flows so that they can be efficiently utilized by the insect larvae. During primary refining, the insect larvae that have been reared on the waste and residual materials are separated into fat and protein fractions, with a residual fraction left over. For the purpose of converting the three fractions into higher quality products (secondary refining), the project partners are developing specific process steps in each case.

The aim is to plan and construct a complete large-scale pilot plant at Fraunhofer IGB in Stuttgart. Here it will be possible to carry out and evaluate the relevant process steps – from the fattening of the larvae, the separation of the fat and protein fractions and their refinement through to the completed end product – on a pilot scale.

Secondary refining to create fuels, cosmetics, cleaning agents, plastics and plant fertilizers

Following chemical or enzymatic conversion, the fat fraction can be turned into lubricants, fuels, biosurfactants or soaps for care and cleaning products (secondary refining). The key advantage here is that the raw fat of the black soldier fly contains a high proportion of lauric acid, giving it a fatty acid composition similar to that of coconut or palm kernel oil and thereby providing a local alternative to tropical oils.

The protein fraction can be used to make wood adhesives, binding agents, paper coatings or packaging films. Hydrolyzed protein can also be used in cosmetic or care products.

Even the residual materials generated by rearing and processing the insect larvae are to be utilized. The residual substrate primarily contains cellulose, insect excrement or larval molting products. This is to be investigated from the perspective of fermenting it into biogas, recovering nutrients for making fertilizers and isolating chitin or chitosan.

Marketability and holistic assessment

The InBiRa project is investigating the production feasibility and marketability of various products obtained from the refined insect larvae of the black soldier fly by working in close cooperation with potential user groups. Furthermore, the entire production process is undergoing a comprehensive sustainability assessment and environmental audit.

above:
The larvae of the black soldier fly convert organic waste into biomass.

below:
Extracted insect fat

▸ *www.igb.fraunhofer.de/en/inbira*

Contact

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

Trends from industry in scaling bioprocesses

The Bioprocess Scaling working group at Fraunhofer CBP in Leuna has again made a significant contribution to the introduction of new biotechnological processes in industry, as it has done for the past ten years. In particular, it supports start-ups as well as small and medium-sized enterprises in the implementation of their projects by providing equipment and know-how for the scaling and optimization of fermentation processes and the associated downstream processes. Within this framework, a total of 23 fermentations were carried out on behalf of industrial customers in 2022, four of which were on a 1000-liter scale and thirteen on a 10,000-liter scale.

Pilot plant for industrial biotechnology at Fraunhofer CBP in Leuna

Fraunhofer CBP – an internationally valued partner for optimizing and scaling up biotechnological processes

As in the previous year, a particular focus of research performance was on supporting start-ups, which was particularly strong this year (around 90 percent of industrial contracts). The working group enjoys broad international visibility and an excellent reputation, so that in 2022 we were once again able to support young and highly innovative companies from all over the world in particular with our services. Overall, we provided 20 percent of our contract research services to German companies, 30 percent to companies from other European countries and 50 percent from outside Europe.

Broad product portfolio in bulk and fine chemicals and proteins

The projects were commissioned by a variety of industries, with a particularly large proportion of contract research focused on the field of fine chemicals, especially the fermentative production of dyes (48 percent). However, interest in the development of fermentative processes for the production of alternative proteins also continues unabated, and in 2022 we again worked on two research projects in the field of fermentative milk protein production. The third major pillar of projects in 2022 was the development and scaling of processes for the production of materials or monomers for the plastics industry.

All in all, we look back on a successful and diverse year 2022 and are looking forward to the continuation of some exciting projects on the one hand, but also to new exciting topics. We would like to express our sincere thanks for the great work done by the team; without each and every one of them, the contribution we make to the biotechnology industry would not be possible.

Contact

Dr. Grzegorz Kubik
Phone +49 711 970-4102
grzegorz.kubik@
igb.fraunhofer.de

▸ *www.cbp.fraunhofer.de/biotechnology*

Conversion of CO_2 from South African coal-fired power plants using green ammonia

As a signatory of the COP21 Paris Climate Agreement, South Africa has committed to reduce its CO_2 greenhouse gas emissions in all its industry sectors. In the Integrated Resource Plan 2019 [1] the Ministry of Mineral Resources and Energy set out ramping up the renewable energy production in parallel with decommissioning several fossil power plants.

Challenges in South Africa

In order to meet the high energy demand, some of the fossil-fired power sources covering the base-load will still play significant role in the energy supply even beyond 2030. Coal-fired plants in energy-, cement- and paper manufacturing sectors emit large quantities of greenhouse gas CO_2 while the NO_x, SO_x, and particulate matter cause severe health issues especially in the industrialized regions. Intensified agricultural activities in the last two decades boosted the demand for fertilizers. As domestic production lags behind due to aging infrastructure, South Africa imports more than 60 percent of the used nitrogen fertilizers [2].

South African-German program for climate protection

The South African Department of Science and Innovation (DSI) CoalCO_2-X™ program, which is cofunded by the German Federal Ministry of Education and Research (BMBF), envisions decreasing the environmental footprint of hard-to-abate sectors, establishing circular economy processes by utilization of captured gases as raw material and finally, integrating renewable ammonia synthesis as key enabler for decarbonization of (agro)chemical and energy sectors.

Making flue gas usable

One part of the CoalCO_2-X™ program is financed by the DSI of Republic of South Africa. Managed by EPCM Global Engineering, the first part of the program targets demonstrating the patented CPPE multipollutant capture and conversion technology at a scale of 300 m^3/h for the removal of CO_2, NO_x and particulate matter from coal combustion flue gas at one of the production sites of PPC Cement SA and the conversion of CO_2 into ammonium bicarbonate. Process development aims turning the captured gases into an unprecedented variety of products: synthetic Diesel fuel, marketable commodity chemicals such as ammonium bicarbonate, potassium carbonate, nitric acid and sulfuric acid, respectively. The multinational fertilizer company Omnia Holdings developed a marketable fertilizer formulation using converted inorganic salts.

Synthesis of green ammonia

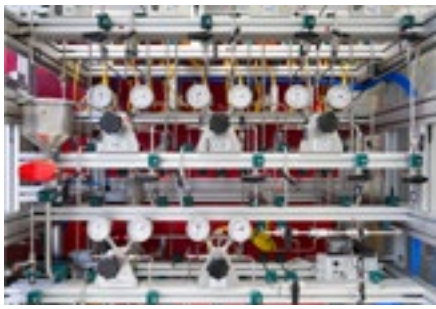
The second part of the project is financed by the German BMBF. Managed by Fraunhofer IGB, this part focuses on piloting the renewable ammonia synthesis on the 1 kg/h scale in a low-pressure Haber Bosch reactor using electrolytic hydrogen produced at the premises of HySA (Hydrogen South Africa). Besides technical development and optimization of the process for intermittent operation, economic analysis will be carried out to support the upscaling efforts on renewable ammonia synthesis.

Using sulfuric acid obtained from the flue gas the produced ammonia will be further transformed into ammonium sulfate, a marketable commodity chemical and valuable fertilizer. Thus, the renewable hydrogen and ammonia is a link of key importance between the technologies developed within the program.

Industry partners sought for scale-up

Further phases of the CoalCO_2-X™ program aim at upscaling of these technologies. Suitable industrial partners will be identified in South Africa and Germany to join the program. This will allow the South African economy, heavily dependent on coal, to use coal as a bridging technology in the most environmentally friendly way possible until the complete transition to a renewable energy and raw materials base.

▸ *www.igb.fraunhofer.de/en/coalco2x*



above:
Screening unit for optimizing ammonia synthesis

below:
CPPE CO_2 multipollutant carbon capture and conversion pilot plant operating at the coal-fired PPC Dwaalboom Cement Factory in South Africa

Contact

Dr. Lénárd-István Csepei
Phone +49 9421 9380-1003
lenard-istvan.csepei@
igb.fraunhofer.de

Tape2Grape – biobased and biodegradable grafting tape for fruit growing and agriculture

In commercial fruit and agricultural production, grafting of woody plants plays an important role. For the grafting process, grafting tapes are often used to close the "open wound" on the tree and promote the growing together. As consumables, commercially available grafting tapes are mainly made from petrochemical raw materials, end up as plastic in the soil, where they do not degrade or do so just very slowly. Tape2Grape provides an environmentally friendly alternative: It is biobased on the one hand and biodegradable on the other, so it does not pollute the environment.

Functional alternative to commercial grafting tapes

By specifically selecting the starting polymers and ingredients used, we at Fraunhofer IGB are producing a multifunctional, biobased and biodegradable grafting tape in the Tape2Grape project funded by the German Federal Ministry of Education and Research (BMBF). The aim is to control the mechanical and plant-healing properties of the tape via the functionalities of the starting materials. By using antibacterial, antiviral and antifungal components integrated into the material to form a "bioinspired artificial bark," the woody plant will be actively supported in the healing process by preventing infection with pathogens at the open tree wound. An individual fertilizing finishing of the grafting band, adapted to the location and the plant, is also being investigated.

Advantages: degradable, bioactive, adaptable

Tape2Grape represents an economic and environmental added value in both commercial and organic fruit production. The grafting tape is made of biobased polymers and can be equipped with bioactive substances. Due to the biodegradability, the tape can remain in the growing area after grafting and decompose, as it is not harmful to the environment compared to microplastic residues in competing products. The novel Tape2Grape grafting tape can also be customized for specific requirements, for example, equipped with fertilizer

Targeted selection of starting materials to control the properties of the tape

Contact

Manuela Kaiser
Phone +49 9421 9380-1009
manuela.kaiser@
igb.fraunhofer.de

Claudia Falcke M. Eng.
Phone +49 9421 9380-1011
claudia.falcke@
igb.fraunhofer.de

ingredients. In this way, further significant benefits such as soil improvement can be achieved as a side effect when it rots on site.

Manuela Kaiser
Chemistry lab technician
Fraunhofer IGB,
BioCat, Straubing branch

Taking inspiration from the garden in a project

The idea for Tape2Grape came to me in my garden at home. During a grafting attempt on a hazel bush, the commercial grafting tape we were using grew inwards, resulting in some of it unfortunately remaining in the environment as plastic residue. It was at this point that I thought, "Surely there must be a more eco-friendly way." The answer was to produce a biobased, biodegradable tape. During further discussions with my colleagues, we also came upon the idea of introducing additives to the grafting tape to really round off the project concept.

As part of the day-to-day project work, I collaborate with colleagues on formula development and the tape's biological properties. We produce initial prototypes, analyze them, and expose them to environmental influences in order to test the stability of the materials.

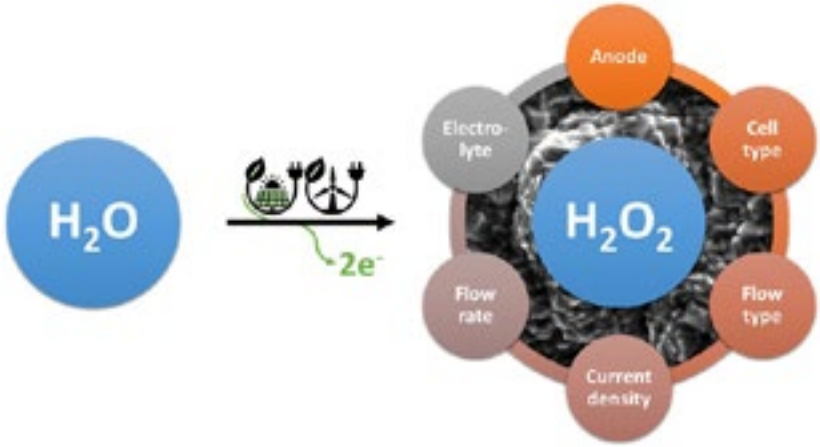
It's a great pleasure to be working on this project – and I find a huge source of motivation in the prospect of Tape2Grape becoming available on the market in a few years' time."

www.igb.fraunhofer.de/en/tape2grape

Biobased grafting tape: protects grafted woody plants and rots over time

Electrochemical production of H_2O_2 – further development in large-scale international project

Hydrogen peroxide (H_2O_2) is an oxidant widely used in the chemical industry. It is considered environmentally friendly as it releases only water and oxygen upon decomposition. At present, 95 percent of the world's annual H_2O_2 production of about 5.5 million tons is based on the anthraquinone process – a costly method and impractical for routine on-site application at a small scale. Alternatively, H_2O_2 can be synthesized electrochemically via oxygen (O_2) reduction or water (H_2O) oxidation, which is cost-efficient and applicable on both large and small scales.



Various parameters have to be considered and optimized for the production of H_2O_2 via anodic oxidation [2].

Successful anodic oxidation in continuous flow cell

As part of the EU-funded CO_2EXIDE project, researchers at Fraunhofer IGB have already developed a process for two electron ($2e^-$) H_2O oxidation to H_2O_2. Various carbon-based materials, including carbon paper, boron-doped diamond, and graphite bipolar plate, have been investigated as anodes in the electrochemical synthesis of H_2O_2 at high current densities in a continuous flow. Broad range of operating parameters, including the electrolyte concentration, pH, and the presence of a chemical stabilizer, substantially increases the selectivity towards H_2O_2 generation using optimized parameters [1 – 3].

Further development and demonstration

The new European project POWER2HYPE, funded through EU's Horizon Europe program and coordinated by Fraunhofer IGB, aims to establish a sustainable route for H_2O_2 production.

An innovative custom-made electrolyzer will be used to produce H_2O_2 at both the cathode and anode, using air and water as feedstock and renewable energy as the sole energy source. The researchers at Fraunhofer IGB will be working together with the partners to electrochemically produce H_2O_2 in high concentrations (from 20 to 99 wt.%). In this way, electrosynthesized H_2O_2 can be used for a wide range of applications, from sanitation, bleaching, to niche markets such as a propulsion fuel.

Contact

Dhananjai Pangotra M. Sc.
Phone +49 9421 9380-1104
dhananjai.pangotra@
igb.fraunhofer.de

- *www.igb.fraunhofer.de/en/co2exide*
- *www.igb.fraunhofer.de/en/power2hype*

Roll-to-roll coating and structuring

Functional surfaces provide new properties to products and materials and thus open up new areas of application. At Fraunhofer IGB, we develop functional coatings with water-, oil- and dirt-repellent properties. Barrier coatings against oxygen, water vapor and various chemicals can also be produced.

Multiple roll-to-roll process combinations
With our technical equipment, we are able to finish web materials such as films, nonwovens or textiles using wet-chemical and gas-phase processes in roll-to-roll (R2R) processes, and to combine different coating procedures. In addition, we offer processes for surface structuring, which can also be carried out in R2R. As an example, films are first structured in the roll-to-roll process via hot embossing processes and then provided with ultra-thin plasma coatings to obtain e.g. superhydrophobic and ice-repellent surfaces.

Process development: from batch to R2R processes
We develop the desired equipment and transfer the processes to an R2R process on our plants. Compared to the finishing of films in small format, various conditions have to be taken into account for continuous treatment.

Foil structuring by means of hot embossing
At Fraunhofer IGB, we primarily use hot embossing for surface structuring, both in small format and R2R. The optimum process parameters (temperature, heating and cooling profile, embossing pressure) depend on the polymer properties and are adapted in each case. Depending on the temperature and holding time at high pressure, we achieve structure heights of between 10 µm and 40 µm in the foil in the R2R process.

Structuring of small-format foils
When hot embossing small-format foils, we work with a hot press that transfers the desired structure to the foil via an embossing stamp. With the hot press, different temperature levels can be used to achieve an optimum result. Transferring this process one-to-one to R2R would, if at all, only be feasible with immense technical effort and would hardly cover costs.

Scale-up of structuring to R2R process
The small-format hot stamping die is the equivalent of a calender in R2R processes. The roller temperature, pressing and throughput speed can be set accordingly for optimum process control. Infrared or hot air are used for fast temperature control outside the calender. The parameter window in which R2R can work with foils depends on the material and, e.g. in the case of composite films with adhesive coating, on the foil structure. We already take these considerations into account in the early-stage development on a laboratory scale.

left:
Continuous finishing of foils in customized plasma chamber

right:
Icing test chamber for measuring wetting properties and investigating ice formation

R2R process development

- Material-independent (textiles, plastic films, etc.)
- Individual on customer request
  - With or without structuring
  - With or without coating
  - Combination of structure and coating
- Accompanying analysis (e.g. measurement of static and dynamic contact angle, determination of surface energy, chemical surface composition)
- Internal resistance tests (e.g. sand erosion)
- Scale-up from batch to R2R process

Plasma coating

When plasma processes are transferred to R2R, possible outgassing of the web material must be taken into account. This mainly concerns the gas flow in the chemically highly reactive plasma zone. The electrical power input, the travel speed of the foil and other process parameters are adjusted so that the coating can be applied with the best possible layer quality at the highest possible throughput.

Results

In the example of water- and ice-repellent films, we were able to increase the static water contact angle of the polyurethane foil used via structuring methods from approx. 75° to up to 135°. An additional plasma coating on the pre-structured polyurethane foil made it possible to further increase the water contact angle to a total of around 160° and thus to obtain a superhydrophobic surface that qualitatively matches the laboratory-scale results.

Equipment

- Customized plasma chamber PINK V340-GKM
- Low pressure fiber treatment system
- Continuous structuring (SC24 Coatema)
- Combined facility for plasma and wet chemistry

Applications

- Anti-icing films, e.g. on self-adhesive and erosion-resistant PU foils
- Barrier layers against oxygen, water vapor, e.g. on packaging foils
- Protective coatings, e.g. anti-corrosion, anti-scratch, anti-slip

www.igb.fraunhofer.de/en/r2r

Coatema plant: R2R structuring by means of calender unit

Contact

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

Dr.-Ing. Georg Umlauf
Phone +49 711 970-4142
georg.umlauf@
igb.fraunhofer.de

r2r@igb.fraunhofer.de

Dr.-Ing. Georg Umlauf
Innovation Field Functional Surfaces and Materials

We develop processes to give surfaces new functions

At Fraunhofer IGB, my work focuses on a classic issue in interfacial engineering: coatings on surfaces and materials. These aren't just any layers – they're functional and ultra-thin ones in the nanometer range. Functional means that we can equip surfaces of a wide variety of materials with specific desired properties, tailored to the project in question. The technology we use to achieve this include low pressure plasmas, which can be used to deposit extremely fine coatings from a surrounding gas phase.

For large formats, we draw on roll-to-roll processes (or R2R for short) that enable us to process and make use of films or non-wovens over large areas. For example, we can apply a water-repellent layer without losing the original properties of the films (such as UV resistance or impact strength).

What excites me most about my work at Fraunhofer IGB is the combination of basic and applied research. This allows me to follow the progress of a project from the initial idea to the final implementation with our clients."

70

Environment and climate protection

Sustainable water and resource management for industry, municipal government and agriculture

The Environment and Climate Protection business area develops systemic solutions in integrated environmental protection and for the energy transition of industry, cities and regional authorities, both in Germany and abroad. Our activities in this field comprise the development of new concepts and processes as well as specific solutions and products. Our aim is to achieve the greatest possible efficiency in the use of resources by taking into account the ideas of a circular economy and climate neutrality as well as an assessment of sustainability.

Fraunhofer IGB is active in the development of

- innovations and solutions in water and wastewater treatment as well as water management,
- processes for generating biogas and biohydrogen from organic waste and residues,
- solutions that recover and reclaim nutrients and valuable substances from wastewater, organic waste and residues,
- processes for gentle drying of various organic raw and residual materials,
- torrefaction of organic waste fractions to produce soil conditioners,
- separation processes on the molecular and atomic level for the recovery of precious metals, and rare earth compounds,
- humidifier membranes for water management in fuel cells and polymer electrolyte membranes (PEM) for electrolyzers,
- membranes for efficient gas separation, e.g. for CO_2 capture and storage, or for membrane reactors (e.g. syngas production) as well as
- tailored surfaces and particles for environmental applications such as adsorption of pollutants.

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

Target markets

Smart infrastructure for smart cities

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

Production and treatment of drinking water

Water vapor in the atmosphere is a source of high-quality drinking or process water. Current research at Fraunhofer IGB is focusing on the use of efficient adsorption systems that capture atmospheric water and, when required, release this as water for drinking and other purposes. Further developments focus on the removal of micropollutants by means of advanced oxidation processes (AOP) and membrane adsorbers.

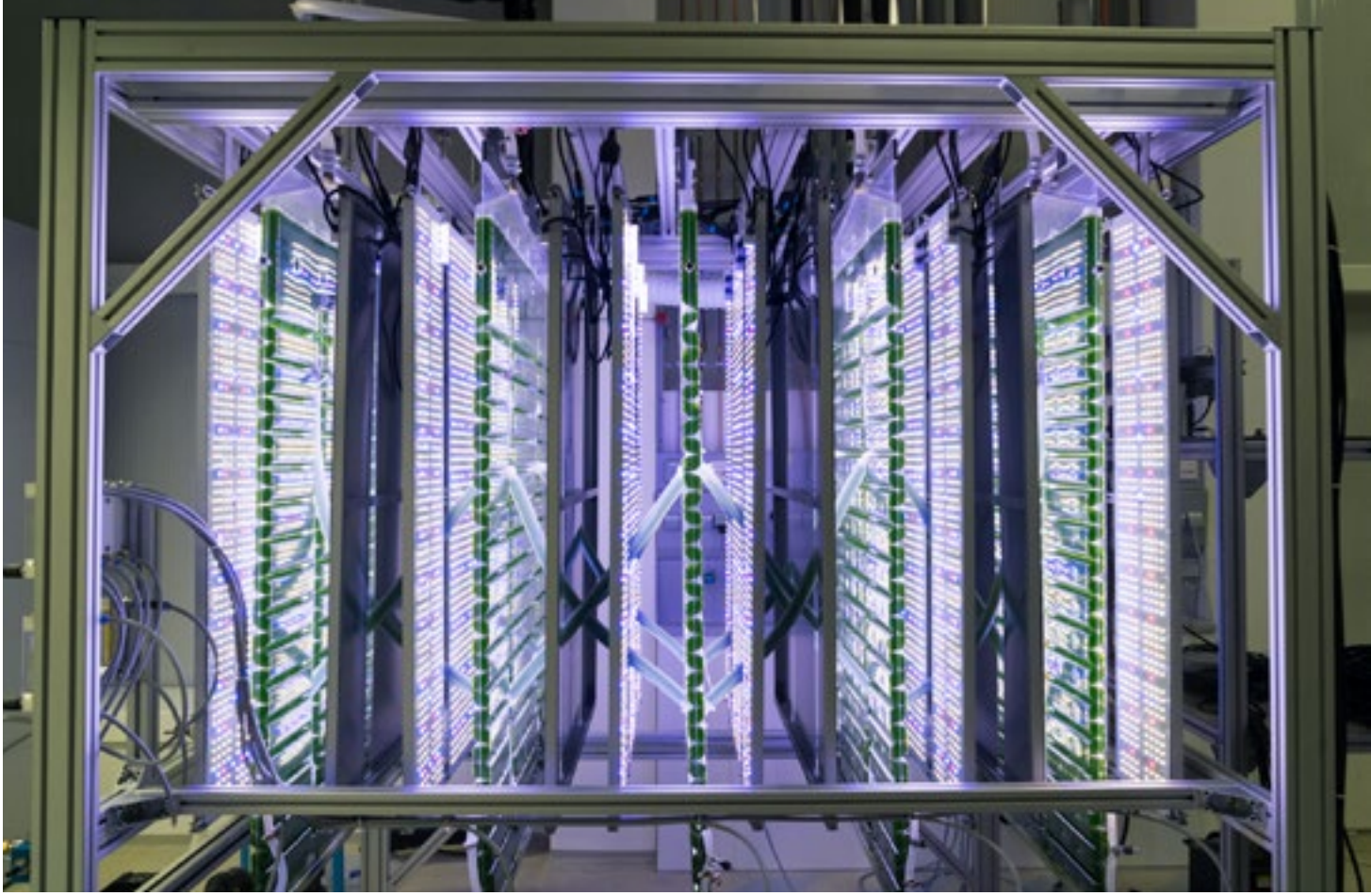
We have many years of expertise in the investigation of bacterial contamination and in the determination of the efficacy of individual disinfection steps. We specialize in the identification of bacteria, viruses and fungi as well as in the analysis of biofilms and how to reduce or avoid them in technical systems.

Treatment of process water, wastewater and sludge

Based on our many years of experience in this field, the IGB offers both biological and physico-chemical methods and solutions for wastewater treatment and sludge conditioning for industry and municipalities. A particular focus is on the design of new wastewater treatment plant concepts for a "wastewater treatment plant of the future" that not only treat wastewater in compliance with the regulations, but can also generate additional value at the same time – via the production of energy sources and products such as e.g. fertilizers to biostimulants for agriculture. Another key topic is water reuse, which will become increasingly important in the future. Our portfolio also includes customized membranes, filters and adsorbents, which will play an important role in the growing future markets for water and wastewater treatment systems.

Water monitoring

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



Energy transition and sustainable mobility

As one key source of regenerative and dispatchable energy, biogas is becoming increasingly important for the energy transition. Our method of high-load digestion for the efficient production of biogas from sewage sludge has already been implemented at a number of municipal wastewater treatment plants. We also develop specific solutions for the conversion of biowaste and biogenic residues to produce biogas or biohydrogen.

In order to produce and use green hydrogen, high-performance membranes are needed across a wide range of applications. The IGB develops membranes for the provision of pure water for electrolysis, for the electrochemical splitting of water in polymer electrolyte membrane (PEM) electrolyzers and for reconversion to electricity by means of PEM fuel cells as well as for moisture management in the fuel cell and the separation of H_2-containing gas mixtures.

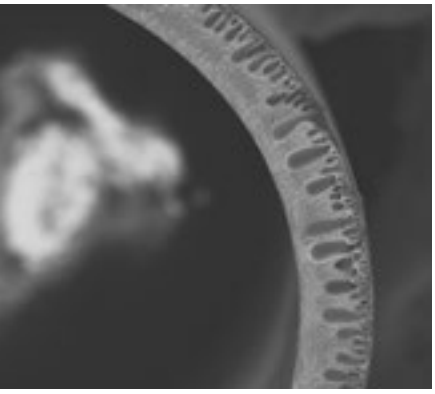
Secondary resources, raw materials and water reuse

With its development in biotech and physico-chemical processes for recovering valuable materials and nutrients (P, N) from sewage and other sources of waste as well as for the reuse of treated wastewater, Fraunhofer IGB makes important contributions towards the establishment of a sustainable bioeconomy inspired by the natural cycles of materials. One example is our ePhos® system, an electrochemical process for the recovery of phosphorus from wastewater rich in phosphates. Its efficiency has been demonstrated at the pilot plant scale. Other approaches include new and improved technologies for the production of hydrogen from industrial residual streams, which can be coupled with algae biotechnology processes for utilizing carbon dioxide (carbon capture and utilization, CCU) from industrial and agricultural sources.

▸ *www.igb.fraunhofer.de/environment-and-climate-protection*

Contact

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



SEM image of a cellulose acetate hollow fiber membrane for forward osmosis

SULFAMOS – sulfate depletion from opencast lignite mine using forward osmosis

One of the late effects of lignite mining in Germany is the large-scale iron and sulfate contamination of ground and surface waters. In the case of Lusatia, this not only affects the region itself, but all waterworks using the Spree water, i.e. also Frankfurt/Oder and Berlin. The situation is similar in the Leipzig area and in the future also in the Lower Rhine Bay.

Regeneration of waters with membranes

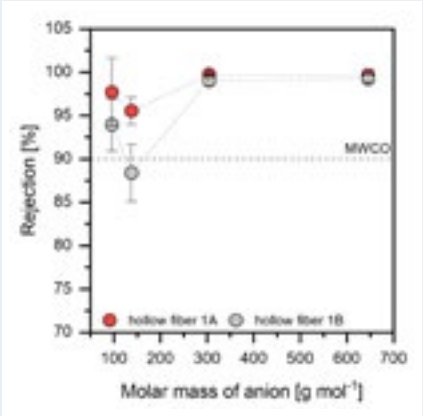
The first objective of the SULFAMOS project is to develop and demonstrate a process based on continuous forward osmosis to remove sulfate from wastewater, surface water and groundwater so that they can be used as irrigation and drinking water. At the same time, the construction industry will lack the raw material gypsum in the future, which has so far been produced in the flue gas desulfurization plants of lignite-fired power plants. The second goal is therefore to make the sulfate precipitated in the form of gypsum usable as a raw material.

Submersible modules with customized hollow fiber membranes

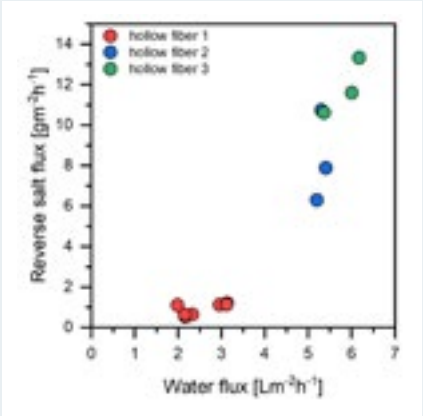
The task of the IGB in the project is to develop a forward osmosis membrane tailored for this application. For this purpose, hollow fibers based on cellulose acetate were developed, which carry the separation layer not on the inside but on the outside (see Fig. left-hand side) and were processed from a green solvent [1]. This allows the hollow fiber membranes to be used directly for treatment in the water in the form of submersible modules.

The hollow fibers have a high retention for sulfate (molar mass 96.06 g/mol) in nanofiltration (Fig. below left). In forward osmosis, water flux and inverse salt flux can be adjusted by spinning conditions of the hollow fibers (Fig. below right). Meanwhile, these hollow fibers can be reproducibly fabricated at 100-meter scale and provided to partners for field testing. In the future, the potential of these membranes for energy production will also be investigated [2].

▸ *www.igb.fraunhofer.de/en/sulfamos*



Retention of CA-HF that were post-treated differently



Inverse salt flux as a function of water flux for different membranes

Contact

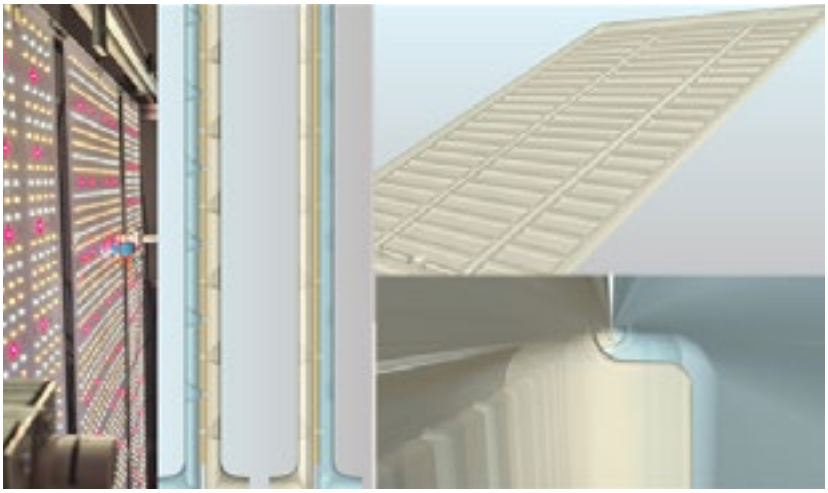
Dr. Tobias Götz
Phone +49 711 970-4176
tobias.goetz@
igb.fraunhofer.de

Phyt-O-mat – development of a modular photobioreactor prototype with an artificial light source

The major advantage of flat-panel photobioreactors is that they distribute large amounts of light to all algae cells thanks to their high surface-to-volume ratio. Thorough mixing of the reactor volume increases this effect due to light integration. In comparison to other established systems, this leads to maximum biomass and product productivity, depending on which strain of algae is being cultivated [1]. Up until now, algae has mainly been cultivated outdoors, which involves heavily fluctuating light and temperature conditions. Even if the most advanced flat-panel reactor systems are selected, this method still only allows low space-time yields to be achieved. Another factor hindering widespread use of the systems is the immaturity of the technology. Particularly when it comes to enabling rapid, modular scaling and commercialization of the technology, the investment and operating costs will need to be brought down significantly first.

Higher productivity thanks to artificial lighting

Artificial light sources for photobioreactors are gaining currency as an alternative means of supplying algae with photons [2]. The LED industry has made major strides in efficiency over recent years and small mass-produced SMD chips are coming down rapidly in price. In turn, this is increasingly allowing industrial algae photobioreactors to be operated all year round regardless of the weather conditions and with a consistent level of product quality. Within this context, the electricity costs make up approximately 80 to 90 percent of the operating costs, with the cooling of the systems playing only a secondary role. Up until now, approximately 150 kWh of energy per kilogram of algae biomass has always been required for single-stage processes in industrial applications [3]. Initial laboratory results for artificial light sources are showing an improved energy input of approximately 80 to 100 kWh per kilogram of algae biomass coupled with a further significant increase in productivity compared to the volatile sunlight associated with outdoor systems.



Prototype development: specifically adapted LED lighting and CAD design drawings

Modular stack reactor with LED lighting

The Phyt-O-mat project aims to bring about a further reduction in the energy input per kilogram of algae biomass. With a view to achieving this aim, a new reactor prototype is being built. In addition to utilizing the light more effectively, this will enable the creation of a cost-effective reactor platform with modular scalability that can be used to good advantage within the process industry according to the algae strain, market and product involved. The aspects being incorporated into the concept not only include minimal downtime thanks to quick cleaning and the flexible handling of such plants, but also requirements such as the need for thorough mixing and beneficial temperature control during operation.

The key element here is the use of an innovative stack structure for the photobioreactors. When the yields of these systems are compared with agricultural production, according to our calculations the extremely compact design means that the same quantity of biomass can be produced within the space of just a few square meters as on a whole hectare of land using sunlight [3]. Assuming that electricity from renewable energy sources (such as photovoltaics) is used for systems of this kind in the future, we already have the evidence to show that – depending on the product – cost-effective operation is possible. Thus, the Phyt-O-mat project represents the key to further expanding the boundaries of cost-effectiveness and feasibility within the area of algae biotechnology.

▸ *www.igb.fraunhofer.de/en/phytomat*

Contact

Dipl.-Ing. Gordon Brinitzer
Phone +49 711 970-4101
gordon.brinitzer@
igb.fraunhofer.de

Green wastewater treatment plants applying photocatalysis for micropollutant removal

As a precautionary measure and due to new limit values for micropollutants [1, 2], numerous wastewater treatment plants are currently upgraded to include a so-called fourth treatment stage. After mechanical, biological and chemical treatment, this stage aims to remove the remaining residues of pharmaceuticals, pesticides or industrial chemicals. However, the processes predominantly used, ozonation and activated carbon adsorption, are quite energy-intensive.

Energy-efficient technology for the degradation of trace substances

A potentially more energy-efficient and, in terms of carbon footprint, more favorable method is sunlight-driven photocatalytic pollutant oxidation. In the research project CatMemReac, funded by the German Ministry of Education and Research (BMBF), reactors with high-power LED arrays and titanium dioxide-coated nickel foams are being tested for the photocatalytic degradation of pollutants (Fig. below). At Fraunhofer IGB, new, tailor-made photoreactors have already been designed and characterized in terms of reaction engineering in order to gain access to dimensionless process parameters (Fig. right-hand side). On this basis, the performance of different systems can already be objectively compared on a laboratory scale, allowing an optimized concept for scale-up.

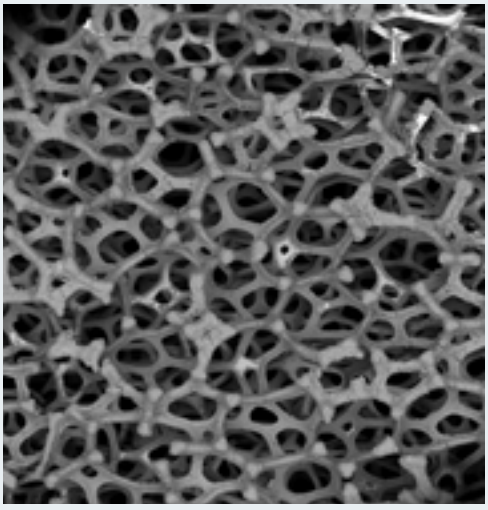
Investigations on photocatalytic processes

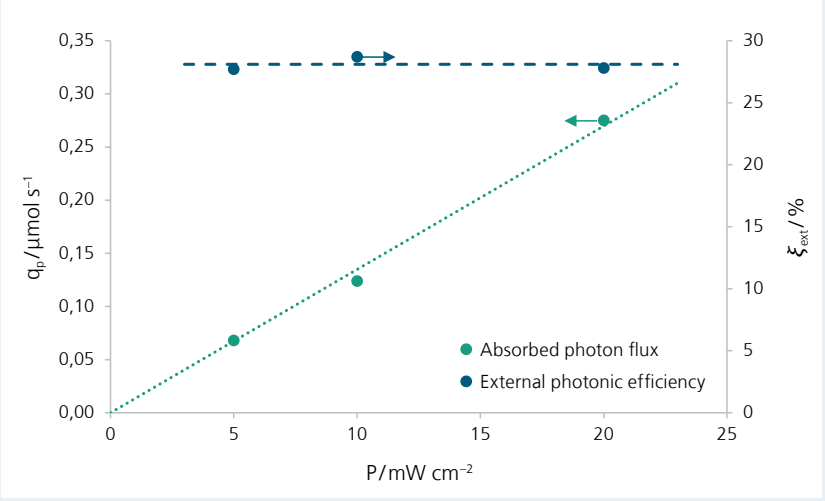
Necessary tools for the understanding and systematic optimization of photocatalytic processes are actinometry and the determination of the oxidation potential by free radicals. The experimental design and execution of these measurements are performed at the IGB. The external photonic efficiency and quantum yield parameters can be used to model the maximum possible treatment performance.

Actinometry is a chemical measurement technique to determine the photon flux available in the reaction volume including wavelength resolution. [3] It can be used to model kinetics, select catalysts with higher efficiency, and perform process simulations for optimization. [4, 5]

The determination of the scavenging potential quantifies the next step in the purification process by measuring the concentration of radicals that can attack and destroy the molecular structure of micropollutants. Combined with actinometry, efficiency sinks can thus be found and eliminated.

Titanium dioxide-coated nickel foams (left) are activated by high-power LEDs. This promises higher available photon fluxes and efficiencies (right), improving the carbon footprint.





Demonstration and evaluation at a wastewater treatment plant in Israel

In the CatMemReac project, photochemical reactor characterization on a laboratory scale was successfully completed. The next step will be the construction of a pilot-scale demonstrator plant for use in an on-site wastewater treatment plant in Israel in early 2023. The experimental data collected from this pilot application will be used to conduct a life cycle analysis (LCA) with a focus on the CO_2 balance. This implicitly deduces to what extent greenhouse gas emissions can be saved by implementing photocatalytic wastewater treatment as a fourth treatment stage compared to the state of the art.

Parallel to the construction of the demonstrator, further parameters effecting treatment efficiency are being investigated. These include e.g., the influence of the pore size of the nickel foam, the irradiation time and intensity in the reaction chamber, as well as the degradation efficiency as a function of the water and trace substance matrix.

Treatment of sample wastewater from customers

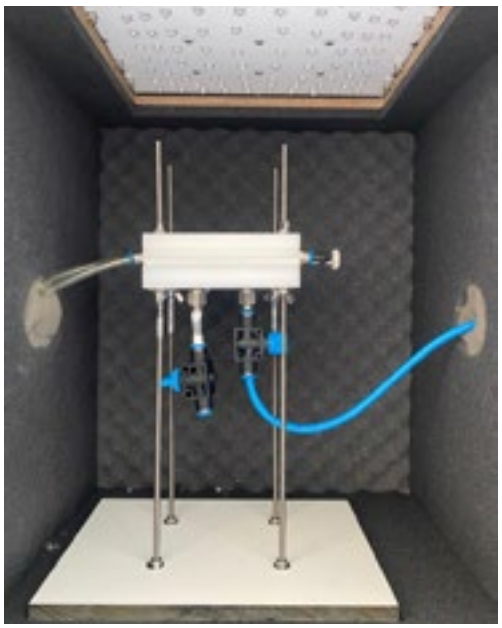
Energy efficiency in the treatment of wastewater is not only of elementary importance for municipal wastewater treatment plants with regard to economic efficiency, but also for all companies in which polluted water is produced.

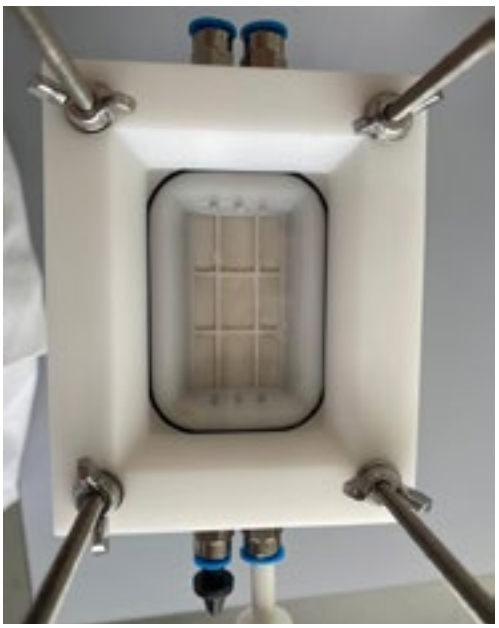
When deciding on the right technology to suit individual customer needs, the IGB can offer technology- and company-independent support. Energy demand, treatment time and method efficiency can be evaluated in laboratory tests with sample wastewater from customers to derive a recommendation on the appropriate treatment process. Furthermore, Fraunhofer IGB offers the determination of the oxidation potential and the available photon flux in a plant as service measurements.

▸ *www.igb.fraunhofer.de/en/catmemreac*

Dr. Benjamin Wriedt
Innovation Field Water Technologies and Resource Recovery

"Energy-efficient water purification based on sunlight: In water purification, photocatalysis has three key advantages: it does not require any toxic chemicals, pollutants are broken down instead of simply being bound and the necessary electricity can be drawn entirely from renewable energy sources."





Reactor setup inside the irradiation chamber and view in irradiation direction (without nickel foam – which is flowed through from bottom to top)

Contact

Dr. Benjamin Wriedt
Phone +49 711 970-4008
benjamin.wriedt@
igb.fraunhofer.de

Biobased flocculant for the purification of agro-industrial wastewater

Purification performance of functionalized chitosan using the example of rinsing water from red wine production

Wastewater from wine and olive oil production processes contains a complex organic load that poses major challenges for wastewater treatment plants due to peak loads during the harvesting season. For example, phenolic compounds contained in the wastewater are toxic to microorganisms in wastewater treatment plants, resulting in extended aeration times and thus increased energy consumption for the process.

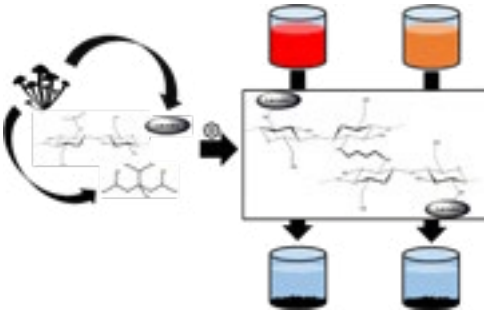
In primary treatment stage, flocculants can help to remove suspended solids and particles as well as impurities adhering to them. Flocculants promote the formation of larger "flocs" that sink to the bottom or float on the surface. Usually, polymers containing metal ions or synthetic polymers are used here. Since their residues are not biodegradable, the resulting sludge must be disposed of at great expense. Highly technical solutions are often too costly and complex due to the strong seasonal fluctuations. Flocculants capable of both reducing seasonally increased loads of wastewater and oxidizing phenolic compounds may offer an alternative to overcome the aforementioned challenges.

New flocculant: biobased, functional, customizable

In the Fraunhofer-funded project "La ChiPur", we at the IGB have developed a biobased and functionalized flocculant which can be used to efficiently purify seasonal wastewater.

The completely biobased technology, which uses chitosan as a matrix and the enzyme laccase, exhibits a flocculation performance that is comparable to conventionally used metal salt-containing (iron, aluminum salts) or synthetic polymers (e.g. polyethylenimine) for complex, seasonal agro-industrial wastewater. In addition to its flocculation properties, the flocculant developed in "La ChiPur" can also oxidize phenols, reducing toxicity to microorganisms in the aeration tank and ultimately reducing energy use. Further advantages are offered by the specific adjustment of the composition depending on the application and load.

For producers of agricultural products, such as wineries or olive mill operators, as well as for wastewater treatment plant operators, the sustainable flocculant opens up new



Functionalization of chitosan for the purification of seasonally generated wastewater

opportunities for action to respond to seasonally specific requirements for wastewater treatment. In addition to the savings in energy for aeration of the activated sludge tank, savings in sewage sludge disposal can be expected. The use of locally produced recyclables from food production ensures a sustainable supply – without the dependencies of complex international supply chains.

Partners sought for further development

Based on the first promising results, we want to further optimize our product with SMEs that sell or produce flocculants, as well as companies that produce waste containing chitosan, e.g. mushroom growers or biotechnology companies.

Currently, the focus is on the German market. However, the Mediterranean region (e.g. olive mills) is also being investigated as part of the project. In the long term, we aim to open up further international markets (wastewater from the textile industry) and applications (drinking water extraction).

▸ *www.igb.fraunhofer.de/en/lachipur*

Contact

Dr.-Ing. Thomas Hahn
Phone +49 711 970-4159
thomas.hahn@
igb.fraunhofer.de

Diego Eufracio Lucio M. Sc.
Phone +49 711 970-4124
diego.eufracio.lucio@
igb.fraunhofer.de

Marc Beckett M. Sc.
Phone +49 711 970-4086
marc.beckett@
igb.fraunhofer.de

"urban BioEconomyLab," a living lab that is guiding cities toward a sustainable bioeconomy

Many people and institutions are involved in driving the transformation toward a sustainable circular bioeconomy in the German state of Baden-Württemberg. The "urban BioEconomyLab" project funded by the Baden-Württemberg Ministry of the Environment, Climate Protection and the Energy Sector focuses on industrial and urban material cycles. Within this context, Fraunhofer IGB is adapting methodological and problem-solving approaches, and structuring concrete implementation proposals, in order to make bioeconomy processes, materials and products a reality within urban and industrial settings.

The project focuses on three example metropolitan areas: Stuttgart, Mannheim/Rhein-Neckar and Karlsruhe. It is intended to support the aims of the "Landesstrategie Nachhaltige Bioökonomie Baden-Württemberg" (the "Baden-Württemberg state strategy for a sustainable bioeconomy") and its implementation.

Data collection for relevant sectors

Morgenstadt City Lab® (Morgenstadt = city of the future) has already proven to be a successful method of identifying priority measures for sustainable urban development. Now, Fraunhofer IGB is seeking to develop it further into something called the BioEconomyLab method.

Indicators available from public sources (many of which can also be accessed online) and potential fields of action have been collected for the Stuttgart region and reduced to a data set characteristic of this region that contains less than 100 individual values.

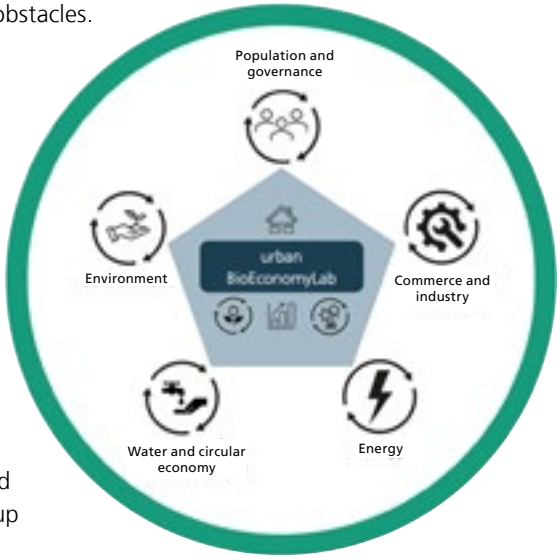
The Stuttgart region is to serve as a model region for transforming the economic system in urban and industrial zones into one that is sustainable and bioeconomy-based.

Semi-structured interviews have been conducted within the Stuttgart region to ask representatives from the sectors of

a) population and governance,
b) commerce and industry,
c) energy,
d) water and circular economy, and
e) the environment

about their experience and insights regarding the bioeconomy transformation within the region, particularly in relation to transformation drives and obstacles.

The next step building on this preliminary work is a workshop to gather and discuss concrete proposals for making bioeconomy processes, materials and products a reality within urban and industrial settings. On this basis, a road map, including concrete recommended actions and measures, will be drawn up for the Stuttgart region.



Urban and industrial sectors according to the BioEconomyLab method

Pilot regions to serve as a transformation model

On February 13, 2023, a networking event was held at Fraunhofer IGB in Stuttgart for stakeholders in the urban and industrial bioeconomy in Baden-Württemberg, thereby laying the foundation for long-term and productive cooperation between them.

In 2023 and 2024, the plan is to build on the BioEconomyLab method developed on the basis of the Stuttgart region by conducting similar surveys and workshops for the regions around Mannheim and Karlsruhe with the aim of identifying priority measures to encourage the bioeconomy transformation of the economic system.

▸ *www.igb.fraunhofer.de/urban-bioeconomylab*

Contact

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

Mounting for nature inspired wastewater treatment at the Government Higher Secondary School in Kochi

Water management in India

Since 2017, Fraunhofer IGB has been cooperating with India in the field of water management. We have succeeded in establishing many good relationships with Indian partners. Together we have produced promising results which lay the foundation for our continued engagement in India. With its large population and strong economic growth, India is an important partner in many global challenges and cooperation in research and development is a key to sustainable development of the country – with potentials also for German partners.

Strategic water management needed
Within the "Smart Water Future India" project (2017–2019), funded by the German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV), we assessed the water management situation in the South Indian city of Coimbatore, on which basis we derived recommendations for decision-makers in the city. Together with the local stakeholders, we developed a concept to foster and deepen the Indo-German cooperation on water – the Water Innovation Hubs. At the same time, we conducted a feasibility study on joint water projects with the City of Solapur in Maharashtra. The study was conducted on behalf of Umwelttechnik BW who support the state partnership between Baden-Württemberg and Maharashtra. Workshops were organized in both cities to discuss the challenges for water supply and sanitation. One result of this was that a strategic approach has been lacking so far, but that data is needed for this, which is not always available.

Pilots for successful Water Innovation Hubs
In Germany, the IGB also participated in the Regional Forum India of the German Water Partnership initiative and networked with companies that are already active in the field of water management in India or want to get involved in the future. In the currently running AQUA-Hub project (BMUV, 2020–2023), Water Innovation Hubs are now being piloted in the two cities of Coimbatore and Solapur, where German technology is being used to monitor water quality and quantity. These examples show how Indo-German cooperation benefits both sides. In September 2022, Umwelttechnik BW and the IGB organized a delegation visit to Solapur where the first results could already be presented.

Actions for sustainable neighborhoods
As part of the "Morgenstadt Global Smart Cities MGI" project, funded by the German Federal Ministry for Economic Affairs and Climate Action (BMWK) within the International Climate Protection Initiative (IKI), the IGB has been active in Kochi (Kerala) since 2019. Until now, a comprehensive city analysis, a strategy development report as well as proposed measures have already documented and handed to the local stakeholders. Currently, a pilot implementation of measures for an integrated sustainable city district is in progress, in which PV systems, green infrastructure and nature inspired wastewater treatment are being implemented in a state school as well as in the adjacent city district. These measures were discussed and prepared at a workshop in April 2022 with the stakeholders concerned.

A clear signal of the importance of cooperation with India for the IGB were two trips by the institute's director, Dr. Markus Wolperdinger, before (March 2020) and immediately after (April 2022) the pandemic-related travel restrictions. One focus of the trips was in particular on initiating projects directly with Indian industries, for example with the infrastructure company Larsen & Toubro (L&T) and the operator of the airport in Bangalore. Further trips to India are also planned for 2023. One project that is being driven forward together with companies from the German Water Partnership network is the construction of a demonstration sewage treatment plant, which is to be modernized with German technology and turn wastewater into reusable service water.

▸ *www.igb.fraunhofer.de/water-management-india*

Contact

Dr.-Ing. Marius Mohr
Phone +49 711 970-4216
marius.mohr@
igb.fraunhofer.de

Marc Beckett M.Sc.
Phone +49 711 970-4086
marc.beckett@
igb.fraunhofer.de

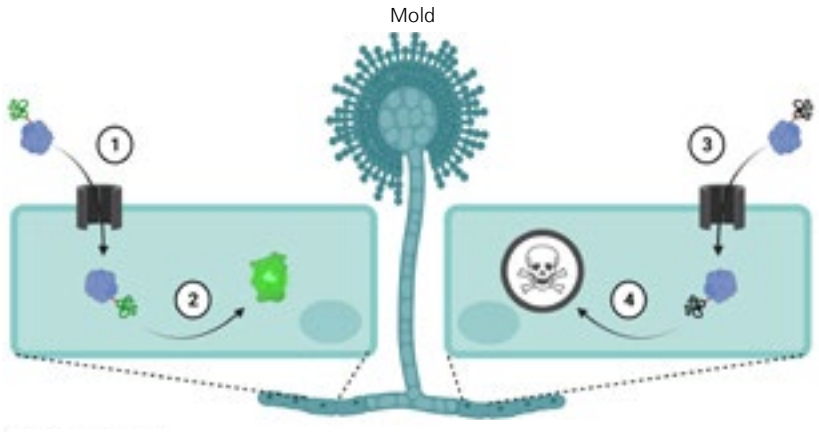
RiboZid – mRNA as biobased fungicide to control phytopathogenic fungi

Fungal diseases of crops are widespread and cause about 20 percent of crop losses worldwide. Climate change and monocultures further promote the spread of fungal diseases. Until now, mainly chemicals are used to protect plants against phytopathogenic fungi which however leads to pesticide accumulation in soil, groundwater, plant foods and consequently, also in humans and animals. Pesticide residues pose a constant invisible threat to human health, particularly through hormone-like substances that can impair fertility and increase cancer risks.

Compatible pesticide alternative

The RiboZid project aims to develop an alternative to pesticides known to be harmful to health and the environment and to create a solution that is compatible and sustainable for human beings and the environment, while at the same time, food supply and health of the world's growing population is ensured.

The RiboZid approach is based on the hypothesis that plant-damaging fungi can be effectively controlled by incorporating an mRNA as a biobased plant protection agent. The objective is therefore to develop an mRNA, whose protein product selectively combats the fungus but does not affect the plant. Taken up by the fungal cell, the mRNA information is translated into a protein that has a lethal effect on the fungus but does not affect plants, humans and animals. Like the human cell with corona mRNA vaccine, the fungal cell itself forms the protein product after absorbing the mRNA, which in this case, however, leads to the death of the plant pest.



Proof of concept:
uptake of the mRNA and expression of the reporter gene

Transfer of mRNA technology
to a suicide gene

graphic created with BioRender.com

Proof of concept with reporter mRNA

The ascomycete *Aspergillus niger* has been selected as the test organism. This mold fungus is ubiquitous in the soil and often leads to the spoilage of plants and food due to the rapid spread of airborne spores. To establish the method, a reporter mRNA is first designed that encodes the fluorescent protein mNeonGreen, a small, monomeric, yellow-green fluorescent protein that can easily be detected microscopically and spectrophotometrically. The mRNA is generated by in-vitro transcription and applied to cultures of *A. niger*. If translation takes place after uptake of the mRNA, the cells of *A. niger* glow with green-yellow color due to the produced reporter protein (Fig. left). Subsequently, the same procedure will be applied to the suicidal mRNA. If translation is successful, the fungal cell is killed by the toxic protein product (Fig. right).

▸ *www.igb.fraunhofer.de/en/ribozid*

Contact

Prof. Dr. Susanne M. Bailer
Phone +49 711 970-4180
susanne.bailer@
igb.fraunhofer.de

Dr. Dagmar Rother
Phone +49 711 970-4193
dagmar.rother@
igb.fraunhofer.de

above:
NFT system with Arduino control at JKUAT

below left:
Hydroponic cultivation of kale at the IGB pilot plant facility

below right:
Greenhouse with PV module at JKUAT

NexusHub – resource-efficient system solution for food and energy security in rural areas

Hydroponic plant cultivation is a water-, nutrient- and space-efficient way to produce fresh food. Usually, mineral nutrient salts are used for this purpose, which are easy to dose and can also be adjusted depending on the plant and growth stage. However, these nutrient salts are expensive to purchase and not always available. Particularly in arid and rural regions of Kenya, where food shortages and crop failures due to drought have occurred over the past years, farmers face major challenges in terms of water shortages as well as severe price fluctuations of fertilizers. In addition, many communities in rural Kenya have no or very limited access to energy.

Thanks to solar power: decentralized and sustainable system solution
The aim of the NexusHub project, which is funded by the Fraunhofer-Zukunftsstiftung (Fraunhofer Future Foundation), is to develop a decentralized system solution powered by photovoltaics (PV) that can be deployed to contribute to energy and food security in rural regions of Kenya. Among other things, mineral fertilizer is to be replaced by organic-based fertilizer from locally available and processed waste materials. PV systems provide the electricity required for processing the organic waste materials and for cultivating market-relevant products (coriander, kale) in the hydroponic system. Surplus electricity can additionally be used for other productive activities.

Nutrient solution through combined processing of residual materials
In NexusHub, we are investigating various organic resources (plant and animal residues) and processing steps for their suitability to produce a hydroponic nutrient solution for coriander and kale. The residues are first anaerobically digested for several days and then biologically treated in a sequencing batch reactor (SBR). These processes are designed to ensure conversion to nutrients in a plant-available form. Subsequently, the effect of the produced nutrient solution on plant growth is tested in the NFT system (nutrient film technique).

Energy self-sufficient due to photovoltaics
To operate the processing and planting systems, a PV-based energy generation and storage system is being developed by Fraunhofer ICT. An overreaching Arduino control system, developed by the Jomo Kenyatta University of Agriculture and Technology (JKUAT) controls the individual components on the basis of data collected by sensors. The developed system makes it possible to generate energy and food in remote regions year-round in a sustainable and resource-efficient manner. In addition to the system in Germany, a demonstrator was also developed in Nairobi.

Scale-up according to demand: for small and large scale applications
The system can be scaled at different levels. Thus, the process is suitable for subsistence farming, small cooperatives as well as large-scale commercial cultivation. At the prototypes in Stuttgart and in Nairobi, we are currently working on process optimizations for the generation of the nutrient solution as well as energy management. In the next step, we aim to scale up and implement the system in a village community in rural Kenya.

▸ *www.igb.fraunhofer.de/en/nexushub*

Contact

Dr. Lukas Kriem
Phone +49 711 970-4212
lukas.kriem@
igb.fraunhofer.de

Marc Beckett M. Sc.
Phone +49 711 970-4086
marc.beckett@
igb.fraunhofer.de

Dr. (Eng.) Evan Murimi
Dr. (Eng.) Rehema Ndeda
Department of Mechatronic Engineering, Jomo Kenyatta University of Agriculture and Technology

Solving the twin problem of waste treatment and food security

The collaboration between the Jomo Kenyatta University of Agriculture and Technology (JKUAT) and Fraunhofer IGB started upon our choice to cooperate with Fraunhofer ICT on renewable energy projects. Immediately after the first discussions on the envisioned research topics, the IGB was introduced to us to work together on the NexusHub project.

As leading researchers on the Kenyan side, we are very happy having the opportunity now to visit our German colleagues Lukas Kriem and Marc Beckett here at Fraunhofer IGB in Stuttgart. This knowledge transfer is so important for us because the idea of using wastewater treatment technologies for the production of organic nutrient solutions for plant cultivation is primarily being implemented at the IGB's and JKUAT's facilities. Besides that, working together with the IGB colleagues is an invaluable experience. Both Lukas and Marc have been very helpful in facilitating us to not only carry out research at the IGB, but also have a good stay in Stuttgart. We could repeat this!

The most valuable result: An SBR (sequencing batch reactor) system can be used for developing nutrients for hydroponic systems from wastewater. In the Kenyan context, implementing this could solve the twin problem of waste treatment and food security."

70

Publications

Dissertations

Beck, A.
Development and characterization of fermentation processes for the production of mannosylerythritol lipid (MEL) biosurfactants,
University of Stuttgart

Bosson, K. N.
Proton-conducting membranes for the artificial leaf,
University of Stuttgart

Derwenskus, I.
Entwicklung eines Verfahrens zur Herstellung von Propylenoxid und Phenol mittels Ganzzellbiokatalyse unter Nutzung der Methan-Monooxygenase des Organismus *Methylosinus trichosporium* OB3b,
University of Stuttgart
http://dx.doi.org/10.18419/opus-12351

Götz, T.
Untersuchungen zur Herstellung von Hydrogelen mit spezifischer Ladungsdichte über Thiol-Michael-Additionen,
University of Stuttgart

Kriem, L.
The use of confocal raman microscopy for the evaluation of in-vitro biofilm model structures,
University of Stuttgart

Mazen, A. E.
Investigations and technical development of adsorption thermal energy storage systems with simulation and different control strategies,
University of Stuttgart
http://dx.doi.org/10.18419/opus-12442

Spindler, L.
Entwicklung und Charakterisierung einer partikulären biobasierten Wirkstoffformulierung zur kontrollierten Freisetzung an der *Regio olfactoria*,
University of Stuttgart

At a glance

7 Dissertations
60 Academic theses
75 Teaching activities
45 Articles in scientific journals
40 Conference presentations
5 Book articles
23 Newly granted patents

▸ *www.igb.fraunhofer.de/publications*

References

Health

Page 36/37, Clinical evaluation of NGS-based diagnostics of sepsis pathogens

[1] Grumaz, S.; Stevens, P.; Grumaz, C.; Decker, S. O.; Weigand, M. A.; Hofer, S.; Brenner, T.; von Haeseler, A.; Sohn, K. (2016) Next-generation sequencing diagnostics of bacteremia in septic patients, Genome Medicine 8: 73, DOI: 10.1186/s13073-016-0326-8
https://publica.fraunhofer.de/entities/publication/d939a200-1cb7-4956-91aa-a8ada5d9b729/details

[2] Decker, S. O.; Sigl, A.; Grumaz, C.; Stevens, P.; Vainshtein, Y.; Zimmermann, S.; Weigand, M. A.; Hofer, S.; Sohn, K.; Brenner, T. (2017) Immune-response patterns and next generation sequencing diagnostics for the detection of mycoses in patients with septic shock – results of a combined clinical and experimental investigation, International Journal of Molecular Sciences 18(18), DOI: 10.3390/ijms18081796
https://publica.fraunhofer.de/entities/publication/ce481ab2-fed6-471c-99ed-466b272e5882/details

[3] Grumaz, S.; Grumaz, C.; Vainshtein, Y.; Stevens, P.; Glanz, K.; Decker, S. O.; Hofer, S.; Weigand, M. A.; Brenner, T., Sohn K. (2019) Enhanced performance of next-generation sequencing diagnostics compared with standard of care microbiological diagnostics in patients suffering from septic shock, Critical Care Medicine 47(5): e394–e402, DOI: 10.1097/CCM.0000000000003658
https://publica.fraunhofer.de/entities/publication/9e1f-f59c-1a85-4af9-bab2-efb04aa83117/details

[4] Brenner, T.; Decker, S. O.; Grumaz, S.; Stevens, P.; Bruckner, T.; Schmoch, T.; Pletz, M. W.; Bracht, H.; Hofer, S.; Marx, G.; Weigand, M.A.; Sohn, K.; TIFOnet Critical Care Trials Group (2018) Next-generation sequencing diagnostics of bacteremia in sepsis (Next GeneSiS-Trial): Study protocol of a prospective, observational, noninterventional, multicenter, clinical trial, Medicine 97(6): e9868, DOI: 10.1097/MD.0000000000009868
https://publica.fraunhofer.de/entities/publication/e7d2bb-cd-72d8-40b1-90b4-d0833fc4d7cd/details

[5] Schmoch, T.; Westhoff, J.H.; Decker, S.O.; Skarabis, A.; Hoffmann, G.F.; Dohna-Schwake, C.; Felderhoff-Müser, U.; Skolik, C.; Feisst, M.; Klose, C.; Bruckner, T.; Luntz, S.; Weigand, M.A.; Sohn, K.; Brenner, T. (2021) Next-generation sequencing diagnostics of bacteremia in pediatric sepsis, Medicine 100(25): e26403, DOI: 10.1097/MD.0000000000026403
https://publica.fraunhofer.de/entities/publication/3af8f11b-096b-41e6-895d-010c1524aa7f/details

Page 39, WowWowSkin – In-vitro canine skin equivalents for veterinary therapeutics testing

[1] MarketsandMarketsTM (2021) Companion animal pharmaceuticals market, Report Code MD 7870, https://www.marketsandmarkets.com/Market-Reports/companion-animal-pharmaceutical-market-252218886.html und https://www.bft-online.de/der-verband/tierarzneimittelmarkt (retrieved March 17, 2022)

Page 42, KinVOid – Kinetic analysis of virotherapy in the 3D organoid model

[1] D´Aiuto, L. et al. (2019) Modeling herpes simplex virus 1 infections in human central nervous system neuronal cells using two- and three-dimensional cultures derived from induced pluripotent stem cells, Journal of Virology 93(9), DOI: 10.1128/JVI.00111-19

Page 44/45, Formulations for intranasal administration of CNS-active biopharmaceuticals

[1] Stützle, M.; Flamm, J.; Carle, S.; Schindowski, K. (2015) Nose-to-brain delivery of insulin for Alzheimer's disease, ADMET and DMPK 3(3), DOI: 10.5599/admet.3.3.184

[2] Spindler, L. M. et al. (2021) Nano-in-micro-particles consisting of PLGA, nanoparticles embedded in chitosan microparticles via spray drying enhances their uptake in the olfactory mucosa, Frontiers in Pharmacology 12, DOI: 10.3389/fphar.2021.732954,
https://publica.fraunhofer.de/entities/publication/bb0bf06e-6077-4cf1-b65f-f3d8d98ed970/details

Sustainable chemistry

Page 61, Conversion of CO_2 from South African coal-fired power plants using green ammonia

[1] Integrated Resource Plan 2019, Department of Energy, Republic of South Africa, http://www.energy.gov.za/IRP/2019/IRP-2019.pdf (retrieved January 26, 2023)
[2] South African fertilizers market analysis report 2019, Department of Agriculture, Forestry and Fisheries, Republic of South Africa

Page 64, Electrochemical production of H_2O_2 – Further development in large-scale international project

[1] Pangotra, D.; Csepei, L. I.; Roth, A.; Ponce de León, C.; Sieber, V.; Vieira, L. (2022) Anodic production of hydrogen peroxide using commercial carbon materials, Applied Catalysis B: Environmental 303, DOI: 10.1016/j.apcatb.2021.120848 https://publica.fraunhofer.de/entities/publication/2705a16d-539c-403c-908a-f957299f1054/details
[2] Pangotra, D.; Csepei, L. I.; Roth, A.; Sieber, V.; Vieira, L. (2022) Anodic generation of hydrogen peroxide in continuous flow, Green Chemistry 24: 7931–7940, DOI: 10.1039/d2gc02575b
[Abb.] Reproduziert aus Green Chemistry 24, 7931–7940, mit Genehmigung der Royal Society of Chemistry
[3] Pangotra, D.; Roth, A.; Sieber, V.; Vieira, L. (2023) Electrochemical water oxidation to hydrogen peroxide on bipolar plates, ACS Sustainable Chemistry & Engineering, DOI: 10.1021/acssuschemeng.2c06314

Environment and climate protection

Page 72, SULFAMOS – Sulfate depletion from opencast lignite mine using forward osmosis

[1] Götz, T.; Achenbach, B.; Schiestel, T. (2023) Cellulose acetate hollow fiber membranes for forward osmosis prepared using a novel annealing procedure and the green solvent Agnique® AMD 3 L, Journal of Applied Polymer Science (submitted)
[2] Touati, K.; Tadeo, F.; Hänel, C.; Schiestel, T. (2015) Effect of the operating temperature on hydrodynamics and membrane parameters in pressure retarded osmosis, Desalination and Water Treatment 57(23), DOI: 10.1080/19443994.2015.1039600 https://publica.fraunhofer.de/entities/publication/ad8442b0-754d-4339-846c-23cc3902fb4f/details

Page 73, Phyt-O-mat – Development of a modular photobioreactor prototype with an artificial light source

[1] Cuaresma, M.; Janssen, M.; Vilchez, C.; Wijffels, R. H. (2009) Productivity of Chlorella sorokiniana in a short light-path (SLP) panel photobioreactor under high irradiance. Biotechnology and Bioengineering 104(2), DOI: 10.1002/bit.22394
[2] Pruvost, J.; Le Borgne, F.; Artu, A.; Cornet, J.-F.; Legrand, J. (2016) Industrial photobioreactors and scale-up concepts, Elsevier Advances Chemical Engineering 48: 257–310, DOI: 10.1016/bs.ache.2015.11.002
[3] Tzachor, A. (2019) Catalyzing Innovation. The future of feed: Integrating technologies to decouple feed production from environmental impacts, Industrial Biotechnology 15(2): 52–62, DOI: 10.1089/ind.2019.29162.atz

Page 74, Green wastewater treatment plants applying photocatalysis for micropollutant removal

[1] Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL concerning urban wastewater treatment (recast), European Commission, 2022; 26.10.2022 COM (2022) 541 final, ANNEXES 1 to 8
[2] Verordnung des UVEK zur Überprüfung des Reinigungseffekts von Massnahmen zur Elimination von organischen Spurenstoffen bei Abwasserreinigungsanlagen, Das Eidgenössische Departement für Umwelt, Verkehr, Energie und Kommunikation (UVEK), from November 3, 2016 (As of December 1, 2016), 814.201.231
[3] Wriedt, B.; Ziegenbalg, D. (2018) Experimental determination of photon fluxes in multilayer capillary photoreactors, ChemPhotoChem 2(10), DOI: 10.1002/cptc.201800106
[4] Wriedt, B.; Ziegenbalg, D. (2020) Adapting actinometry procedures for use in intensified photoreactors, Chemie Ingenieur Technik 92(9)
[5] Wriedt, B.; Ziegenbalg, D. (2021) Application limits of the ferrioxalate actinometer, ChemPhotoChem 5(10), DOI: 10.1002/cptc.202100122

Editorial notes

Editorial team
Dipl.-Wirt.-Ing. (FH) Antje Hetebrüg,
Dipl.-Betriebswirt (DHBW) Jan Müller M. A.,
Dipl.-Des. Thaya Schroeder M. Sc. (pictures),
Dr. Claudia Vorbeck
and the scientists referred to as authors
or contact persons.

Layout and production
Dipl.-Des. Thaya Schroeder M. Sc.
Lisa Kern M. A.

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

Photo acknowledgments
B+B Engineering: page 53
Bayerl, Günther: cover
Budde, Till: page 25
EPCM Global: page 61
Ernsting, Thomas: cover
Fogel, Walter: page 65
Genisher, Nimrod: page 29
Hackl, Andreas: page 25
Karlsruhe Institute of Technology (KIT): page 22
Kleinbach, Frank: pages 7, 12/13, 41
Masur, Claudia: page 12/13
Michalke, Norbert: cover, page 60
Müller, Bernd: cover, pages 34, 35, 36
Müller, Marc: pages 12/13, 62
privat: pages 19, 26, 28, 45, 55
Royal Society of Chemistry: page 64
Shutterstock: pages 33, 49, 69, 77
Variolytics GmbH: page 31

All other photographs and figures

Information

You can find further information on the internet

Competencies
www.igb.fraunhofer.de/competencies

Analytical and testing services
www.igb.fraunhofer.de/analytics

Laboratories, plants and technical equipment
www.igb.fraunhofer.de/equipment

Cooperation and network
www.igb.fraunhofer.de/network

Publications
www.igb.fraunhofer.de/publications

Current events
www.igb.fraunhofer.de/en/events

Press releases
www.igb.fraunhofer.de/press

Newsletter subscription
www.igb.fraunhofer.de/en/newsletter

... or follow us on our social media channels

Facebook
www.facebook.com/FraunhoferIGB

Instagram
www.instagram.com/fraunhoferigb

YouTube
www.youtube.com/FraunhoferIGB

Twitter
www.twitter.com/FraunhoferIGB

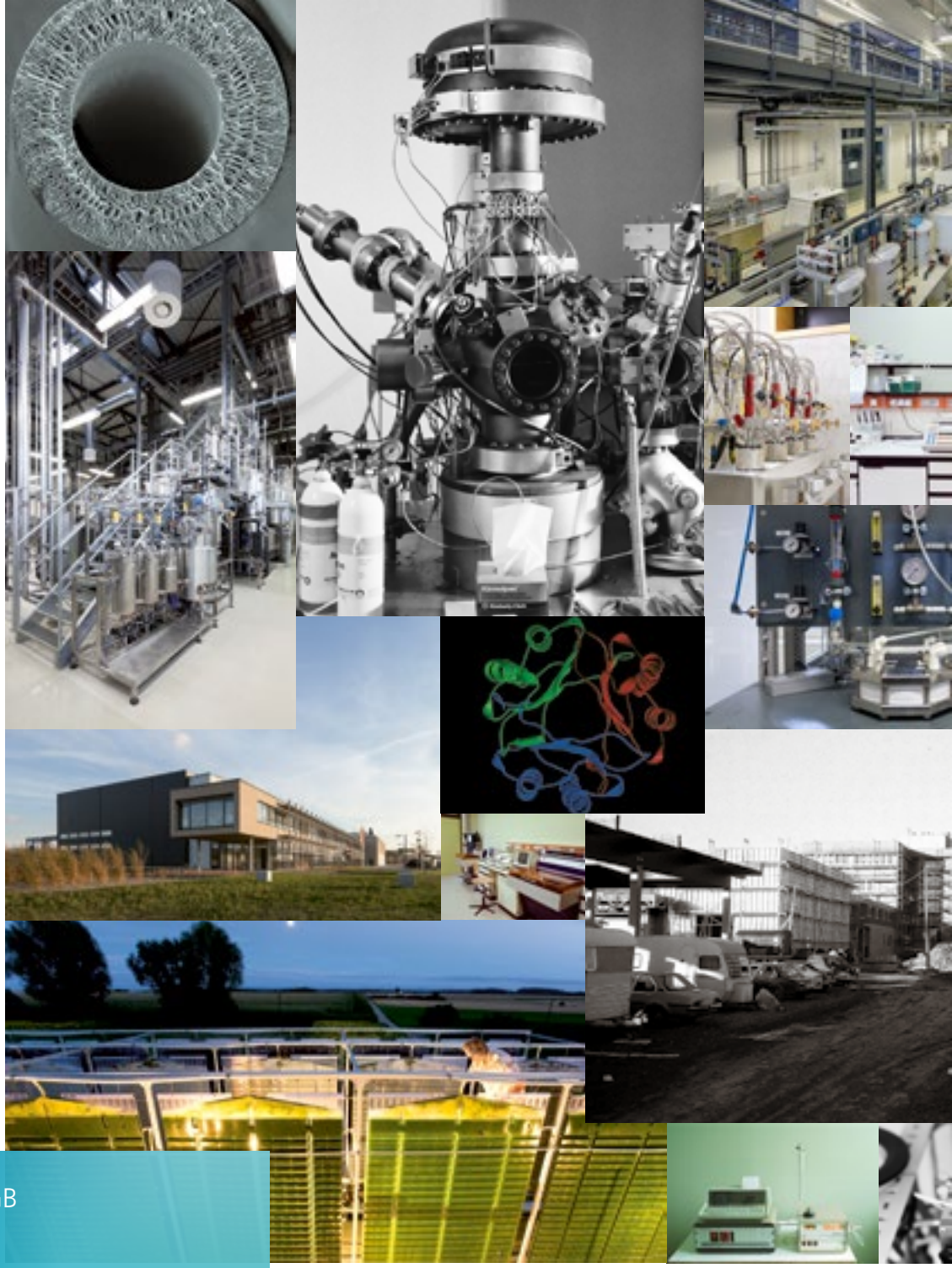
LinkedIn
www.linkedin.com/company/fraunhofer-igb

Fraunhofer Institute
for Interfacial Engineering
and Biotechnology IGB

Nobelstrasse 12
70569 Stuttgart
Germany

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

▸ *www.igb.fraunhofer.de*



70 years of Fraunhofer IGB

The IGB was founded as the Institute for Interfacial Physics and Chemistry in 1953. This year, the IGB celebrates its 70th birthday. In the course of its 70-year history, the institute has acquired a vast array of further expertise and technologies, which remain part of its research scope and the vision of combining biology and engineering to this day.

▸ *www.igb.fraunhofer.de/70-years*