Fraunhofer IGB

Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB

We combine biology and engineering

Annual Report 2021/22

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. It is a trailblazer and trendsetter in innovative developments and research excellence. The Fraunhofer-Gesellschaft supports research and industry with inspiring ideas and sustainable scientific and technological solutions and is helping shape our society and our future.

The Fraunhofer-Gesellschaft's interdisciplinary research teams turn original ideas into innovations together with contracting industry and public sector partners, coordinate and complete essential key research policy projects and strengthen the German and European economy with ethical value creation. International collaborative partnerships with outstanding research partners and businesses all over the world provide for direct dialogue with the most prominent scientific communities and most dominant economic regions.

Founded in 1949, the Fraunhofer-Gesellschaft currently operates 76 institutes and research units throughout Germany. Over 30,000 employees, predominantly scientists and engineers, work with an annual research budget of €2.9 billion. Fraunhofer generates €2.5 billion of this from contract research. Industry contracts and publicly funded research projects account for around two thirds of that. The federal and state governments contribute around another third as base funding, enabling institutes to develop solutions now to problems that will become crucial to industry and society in the near future.

The impact of applied research goes far beyond its direct benefits to clients: Fraunhofer institutes enhance businesses' performance, improve social acceptance of advanced technology and educate and train the urgently needed next generation of research scientists and engineers.

Highly motivated employees up on cutting-edge research constitute the most important success factor for us as a research organization. Fraunhofer consequently provides opportunities for independent, creative and goal-driven work and thus for professional and personal development, qualifying individuals for challenging positions at our institutes, at higher education institutions, in industry and in society. Practical training and early contacts with clients open outstanding opportunities for students to find jobs and experience growth in business and industry.

The prestigious nonprofit Fraunhofer-Gesellschaft's namesake is Munich scholar Joseph von Fraunhofer (1787–1826). He enjoyed equal success as a researcher, inventor and entrepreneur.

Figures as of: January 2022

▸ *www.fraunhofer.de/en.html*

We combine biology and engineering

Annual Report 2021/22

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Foreword

Dear readers,

Over the course of another year marked by the shadows of the pandemic and its ramifications, we have all had to find entirely new solutions to deal with the challenges brought by the coronavirus. And once again, the outstanding ability to combine biotechnology research with process engineering expertise has proved to be a key factor here.

Just like the vaccine manufacturers, we at Fraunhofer IGB have put our know-how to work and developed tools to address these new challenges. For example, in the Healthy Air Initiative of the state of Baden-Württemberg, we helped to develop new methods for detecting viruses in aerosols. To read more about our contribution, take a look at the "Highlights" section (page 16) and the report on "Aerosol-carried viruses – Production, capturing and analysis" (page 34).

We have also conducted extensive research to find ways of increasing our PCR testing capacity to meet demand. One promising development is a procedure for detecting SARS-CoV-2 based on the high-throughput sequencing method developed at the IGB. In this procedure, a single diagnostic approach is being used for a pool of samples from thousands of people. Using an innovative "molecular barcode," the results from sequencing can be directly assigned to individual samples from the pool. The benefits in terms of time and efficiency are incredible.

However, we have more on our plate than just the pandemic, since the issue of climate change also calls for fast progress in technology. In a wide range of projects – such as CO_2EXIDE (page 54) – we are investigating ways of using CO_2 as raw material for innovative conversion processes and to manufacture sustainable products. One of these novel solutions, which was developed under the collaboration program between Fraunhofer and Max Planck Society, brought our vision of combining biology and engineering to life in a particularly impressive way. In this project, the team in Straubing and their partners have successfully fixed CO_2 in a redox-active hydrogel for the first time, by means of electro-biocatalytic reduction (page 46).

One of the outstanding events of the year was the launch of the Hydrogen Lab Leuna, an electrolysis plant that we constructed in collaboration with the Fraunhofer Institute for Microstructure of Materials and Systems IMWS (headquartered at Fraunhofer IWES) (page 17). Now, for the first time, the Fraunhofer Center for Chemical-Biotechnological Processes CBP, our institute branch in Leuna, will be able to test the production of chemical components from green hydrogen under real life conditions of fluctuating energy generation in a chemical park.

For an outstanding example of fruitful collaboration between the institutes of the Fraunhofer Strategic Research Field Bioeconomy, we need look no further than the new Fraunhofer lighthouse project, SUBI²MA, headed by the Fraunhofer Institute for Applied Polymer Research IAP. Our BioCat institute branch in Straubing will make a substantial contribution to the transformation of the plastics industry by providing "caramides" – our patented polyamides made from terpenes.

We can also look back on a successful year from a financial perspective. The IGB has succeeded in continuing the institute's positive development even under the challenging conditions of the pandemic, and as publicly funded project activities have increased, so too has our recruitment of new, highly qualified staff. The high proportion of female employees, at 51 percent, is also to be commended. Similarly, I would like to call attention to the various successful initiatives we have implemented at the IGB to promote our employees' development and ensure equal opportunities for men and women (page 14).

I would like to express my sincere thanks to all employees of the institute at the Stuttgart, Straubing and Leuna sites for their extraordinary commitment, particularly under the difficult conditions of the past year.

I would also like to thank all our customers and partners who have worked so closely and trustingly with us, never shying away from exploring new opportunities and allowing us to ultimately succeed in reaching our goals together.

I look forward to further opportunities for exciting collaborations and innovations, and hope that this Annual Report will also play its part.

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*

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

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

As of December 31, 2021

▸ *www.igb.fraunhofer.de/board*

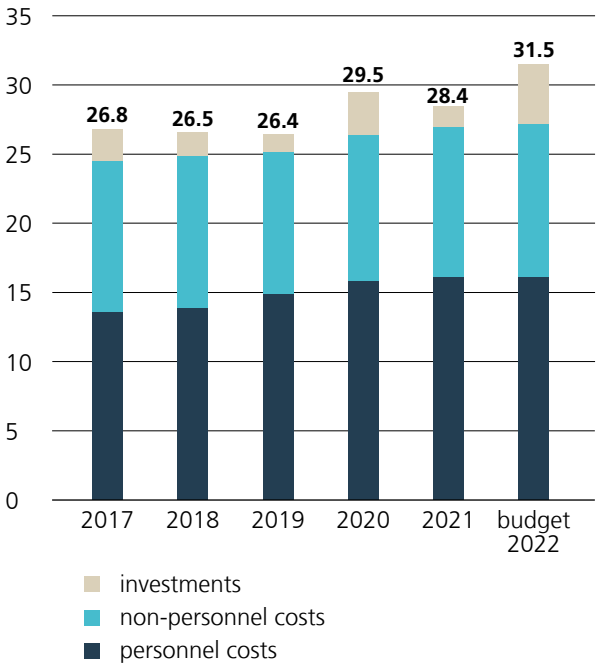
Key figures

Budget of Fraunhofer IGB

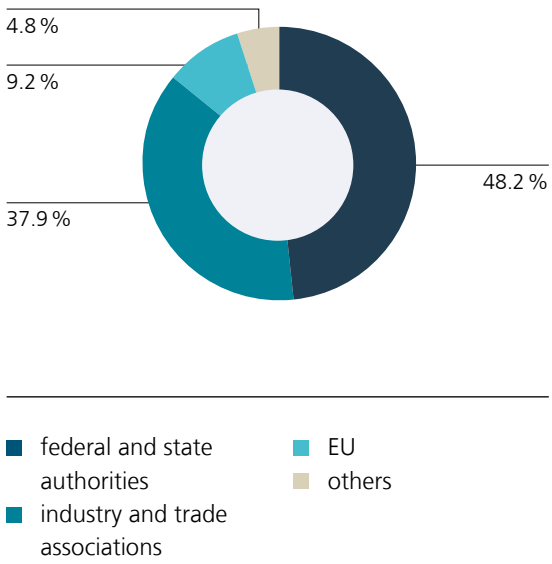
The total budget for 2021 amounted to 28.4 million euros, of which 26.9 million euros was allocated to the operational budget (personnel costs: 16.1 million euros; non-personnel costs: 10.8 million euros). A total of 1.5 million euros was spent on investments.

71.2 percent of the operational budget was financed from Fraunhofer IGB's own revenues generated from contract research projects. 37.9 percent of the institute's revenues came directly from industry.

Development of total budget in million euros



Revenue from contract research 2021



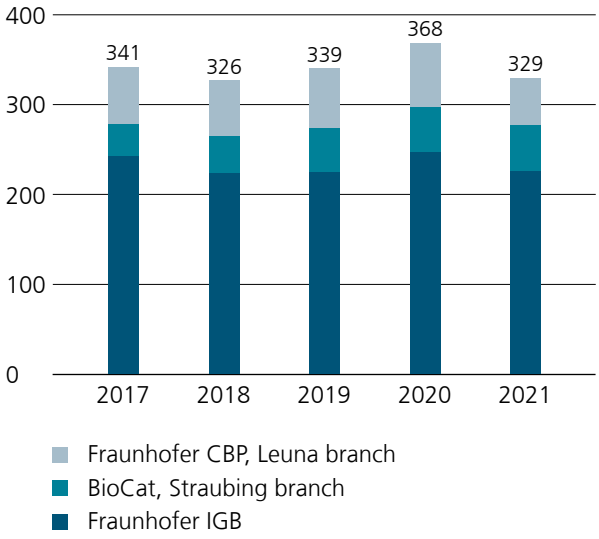
Personnel

At the end of 2021, Fraunhofer IGB (in Stuttgart and its branches in Straubing, and Leuna) had a staff of 329 of which some 81 percent were scientific or technical employees. Women made up 51 percent of the total.

Cultural diversity has been practiced at the institute and its branches for many years: 29 staff members, for example, come from 18 different countries outside Germany.

The close cooperation with the Institute of Interfacial Process Engineering and Plasma Technology IGVP at the University of Stuttgart, which is also partially housed in the Fraunhofer IGB premises, makes it possible tu pursue projects from basic research to application. The IGVP counted a staff of 53 as of December 31, 2021, predominantly scientists and doctoral students as well as technical staff and student research assistants. Women constituted 28 percent of the total.

Development of staff numbers
(number at year-end)



Number of staff members as of December 31, 2021

	Fraunhofer IGB, including branches	BioCat, Straubing branch	Fraunhofer CBP, Leuna branch
Scientists	83	14	13
Technical staff	95	20	27
Doctoral students	8	3	1
Scholarship holders	2	0	0
Administrative and secretarial staff	49	4	6
Apprentices	13	1	1
Work students /Master students /student apprentices	34	1	1
Student research assistants	45	9	3
Total	**329**	**52**	**52**

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Equal opportunities at Fraunhofer IGB

Fraunhofer IGB is among the Fraunhofer Institutes that employ the highest proportion of women – more than 50 percent of the workforce is female. This figure is high not only in management but also in roles in the field of science and engineering.

At Fraunhofer IGB and CBP, we make every effort to structure our daily working life in such a way as to promote equal opportunities, which is demonstrated in the new initiatives we have established for employees, for example.

Establishing new pathways for careers

Women@Work format casts a spotlight on women and their work
As part of the new portrait series Women@Work female colleagues from all areas of work, such as science, engineering, management and administration, are introducing themselves in their own, personal way. This presentation provides them with visibility and direct contacts, thus strengthening their internal network right from the start, and creates long-term role models for future female employees at Fraunhofer. We also want to send a clear signal to our female applicants.

The new initiative not only provides information about the exciting business areas in which these women work but also draws attention to their other areas of interest and capabilities, which are not normally, or only rarely, seen in day-to-day activities. In this way, we provide a holistic image of the colleagues and showcase their development potential on a very personal level. Anchor points for their career paths can be identified at an early stage and can be integrated into strategic HR development.






Gender equality is a key company objective
At the company level, we also support the objectives for implementing equal opportunities at the Fraunhofer-Gesellschaft and therefore contribute within the policy framework to the development and structural anchoring of strategies aimed at increasing the visibility of women.

To develop individual objectives and suitable strategies for our institute on the basis of an analysis of the status quo, we regularly participate in the support program established by the Fraunhofer headquarters to promote equal opportunities within the institutes. The benefit of this is twofold: We can share our own tools and experiences with other institutes and, in return, benefit from new perspectives, taking away examples of best practice that we can implement in our work.

Concept "Successful double"
To support the successfully established Women@Work initiative and to develop additional concepts in the area of equal opportunities, a team comprising the equal opportunities officers, a female HR developer and a female scientist came up with the project "Successful double." At the end of 2021, the Fraunhofer-Gesellschaft approved funding for the concept as part of the internal program to support diversity measures within the institutes.

The concept focuses on the development of specific ideas for implementing shared management positions. For this purpose, the equality team will prepare, implement and consolidate different initiatives and workshops for women.

We are thus addressing the needs of future female employees, thereby gaining a competitive edge for attracting and recruiting outstanding specialists in order to secure the long-term success of our work.

Initiatives and programs

- Girls' Day
- Fraunhofer Talent School
- Career advancement for women through the TALENTA program
- Parent-child office
- Women@Work
- Project "Successful double"

▸ *www.igb.fraunhofer.de/equal-opportunities*

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Highlights 2021

Projects

Initiative of the Baden-Württemberg State Ministry of Economic Affairs, Labour and Tourism

Healthy Air Initiative – Testing ventilation systems to protect against COVID-19

As coronavirus SARS-CoV-2 is transmitted through the air, research over the course of the pandemic was focused on ventilation and air cleaning systems to prevent the further spread of the pathogen. In particular, researchers concentrated on developing hygiene and ventilation solutions that could reduce viral transmission through aerosols. To investigate this problem, a joint research team from Fraunhofer IBP, IGB and IPA based in Stuttgart established a new advisory center for healthy indoor air quality, funded by the Baden-Württemberg State Ministry for Economic Affairs, Labor and Tourism. As part of the Healthy Air Initiative, Fraunhofer IGB has established a method for analyzing airborne viruses in terms of their activity and quantity. This new method is designed to identify important adjustments to be made to air purification systems and virus inactivation processes.

▸ *www.igb.fraunhofer.de/en/hai*

Fraunhofer lighthouse project

FutureProteins – Agricultural systems for resilient and sustainable production of high-quality food protein

The demand for high-quality protein for the global food supply is enormous. Yet, there is a serious danger that this need will not be met, resulting in shortages. This issue is becoming increasingly urgent as a result of climate change and associated extreme weather conditions, for example. Rising contamination levels in soil and water through the use of fertilizers and pesticides in agriculture are also a factor here. The current objective is therefore to develop new protein sources that are sustainable and can act as mass-scale alternatives to animal source foods. This is where the FutureProteins Fraunhofer lighthouse project comes in. As part of this project, six Fraunhofer Institutes are working to develop new cultivation systems and processes to extract nutrient-rich proteins from selected plants, insects, fungi and algae for use in new products.

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

Fraunhofer pools expertise on hydrogen

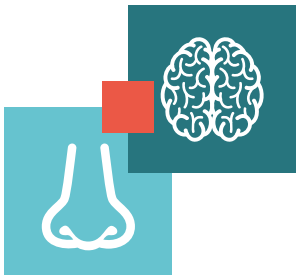
Producing green hydrogen – Hydrogen Lab in Leuna commences operations

Green hydrogen plays a key role in creating a sustainable supply of raw materials for industry while also helping to achieve climate targets. The new Fraunhofer Hydrogen Lab in Leuna commenced operations in 2021. It is the first pilot facility for testing and scaling the necessary electrolysis systems that is fully integrated into a chemical production site. The partners involved, including Fraunhofer CBP, the Leuna branch of Fraunhofer IGB, want to use the Hydrogen Lab to help hydrogen technologies achieve a breakthrough in the market. As the driving force behind the initiative, the Fraunhofer-Gesellschaft intends to use this research unit to expand and further accelerate its hydrogen projects in northern and eastern Germany and create a range of pilot facilities that are unique on the global market and cover the entire value chain of the hydrogen economy.

▸ *www.cbp.fraunhofer.de/en/hydrogenlableuna*

above:
Test environment of the "Healthy Air Initiative" at the Fraunhofer Campus Stuttgart.

below:
On May 21, 2021, the Fraunhofer Hydrogen Lab Leuna was put into operation.



EU project for treating multiple sclerosis

N2B-patch – Careful delivery of biopharmaceuticals via the nose

A promising approach to treating conditions affecting the central nervous system such as multiple sclerosis is to deliver active substances directly to the brain through the nose. The problem here is that although the blood-brain barrier in the human body acts as a highly effective protective structure for the brain, it not only holds back pathogens – it also makes it difficult for therapeutic molecules to pass through. To solve this problem, an international consortium of researchers coordinated by Fraunhofer IGB as part of the EU's N2B-patch project have spent the last four and a half years developing an innovative system that will help circumvent this barrier. In June 2021, the solutions developed during the project were presented at an international closing symposium held online.

- *www.igb.fraunhofer.de/en/n2bpatch*

Initiative for producing personalized products

High-Performance Center Mass Personalization – Second phase of funding completed successfully

Products can be both individualized and mass-produced – it doesn't have to be one or the other. At the High-Performance Center "Mass Personalization," researchers from four Stuttgart-based Fraunhofer Institutes are working with eight institutes of the University of Stuttgart as well as partners from industry to develop new methods for manufacturing customized products for the mass market. The high-performance center is funded by the State of Baden-Württemberg and the Fraunhofer-Gesellschaft. The first pilot phase ended in 2021, which coincided with the end of the second funding phase. In an especially positive development, the number of industry partners increased from an initial 22 to 69, and the expected revenue from industry projects was significantly exceeded once again.

- *www.igb.fraunhofer.de/en/lzmp*

Bioeconomy European Regional Development Fund (ERDF)

EU and Baden-Württemberg funding for five Fraunhofer IGB biorefinery projects

With support from the European Regional Development Fund ERDF, the Baden-Württemberg Ministry for the Environment, Climate Protection and the Energy Sector is funding new research projects, which started at the end of October 2021, as part of its "Bio-Ab-Cycling" initiative – a bioeconomy funding program for extracting raw materials from waste and wastewater at biorefineries. The IGB is involved in all five of the funded biorefinery projects, and is the coordinating partner in three of them. The BW2Pro biowaste refinery, for example, will process one ton of biowaste per day into high-quality products and raw materials. The establishment of an insect-based biorefinery for producing proteins, fats and chitosan from waste streams is being funded as part of the InBiRa project. In the KoalAplan project, researchers are investigating how municipal wastewater can be used as a source of ammonium nitrate, hydrogen and bioplastics. The RoKKa project is looking at using sewage sludge as a source of raw materials to create a wastewater biorefinery as well as improving the carbon footprint of wastewater treatment plants. In the SmartBioH2-BW project, biohydrogen and other products are generated from industrial wastewater and residual material streams by means of two combined biotechnological processes.

- *www.igb.fraunhofer.de/en/bw2pro*
- *www.igb.fraunhofer.de/en/inbira*
- *www.igb.fraunhofer.de/en/koalaplan*
- *www.igb.fraunhofer.de/en/rokka*
- *www.igb.fraunhofer.de/en/smartbioh2bw*

Dialogue with the public

Biological transformation, biointelligence and the bioeconomy

Researchers at Fraunhofer IGB are striving to combine biology and engineering in a wide range of projects, with the aim of using natural principles to achieve sustainable value creation. Now, the IGB is bringing its research into the public eye and engaging in dialogue through a variety of channels – not least the Science Year for Bioeconomy.

As the term "biological transformation" suggests, biobased technologies have the potential to bring about enormous transformations in technology and society. This term also serves to define the scope of research at Fraunhofer – namely the increasing application of materials, structures and principles from natural life in technology, all with the goal of sustainable value creation.

The focal point for research at Fraunhofer IGB is the bioeconomy, an independent field within the wider domain of biological transformation. After all, the bioeconomy cannot be classified as just a technology or field of application; instead, it should be viewed as a systemic approach to achieving a biobased economy. Instead of fossil fuels, the bioeconomy relies on renewable raw materials and the use of waste and residues and CO_2. In order to produce base substances, materials and products from these biobased resources, it is necessary to develop processes that are centered on biology, but where engineering, especially process engineering, plays an essential role. If information technology is added to the mix, the resulting "biointelligent" solutions open up even more possibilities for efficient value creation.

Multimedia communication with the public

For the biological transformation to succeed, there must be an open discussion about the opportunities, risks and challenges it presents in both the political and the public spheres. In 2021, Fraunhofer IGB ran various initiatives and campaigns aimed at ensuring that its important research was accessible to the wider public.

The core element of this effort is a blog on biointelligence, created in collaboration with the Fraunhofer Institute for Manufacturing Engineering and Automation IPA. As a cross-institute research discussion platform, the blog is a first for the Fraunhofer-Gesellschaft. The blog's content has also been supplemented through other channels – both virtually, through related social media campaigns, and in the real world, through a series of lectures held in collaboration with the Württemberg State Library. Another key initiative was the Bild der Wissenschaft magazine's special edition on biointelligence, released at the end of March 2021.

Blogging breathes life into "dusty theories"

The biointelligence blog was launched on March 30, 2021 at www.biointelligenz.de. Since then, scientists have used the blog to communicate in a direct, authentic and creative way, bringing visibility to their research and expertise. The bloggers present new research topics, ideas and innovations, and in so doing, they create new trends and help to set the public agenda. As it helps make the experts behind the theories visible, the blog serves a meeting place for the world of research and potential partners from industry and politics.

Biointelligence blog

(as of: March 1, 2022)

- Six participating institutes (IPA, IGB, UMSICHT, IBP, NMI, IPT)
- 35 authors, of which 12 are from the IGB
- 49 blog posts, of which 19 are from the IGB
- IGB blog post series "Geld verdienen mit CO_2" (Earning money with CO_2)

▸ *www.biointelligenz.de*

Lecture series with the Württemberg State Library

Likewise, when teaming up for a collaborative lecture series on biointelligence, Fraunhofer, the Biointelligence Competence Center and the Württemberg State Library (WLB) intended to take public discourse into account. Over the course of a year, scientists from the IGB gave interested members of the public an insight into the world of biointelligent research. Insofar as the pandemic restrictions allowed, the lectures were held in a hybrid format, with an on-site audience in the State Library and an online audience watching the live stream.

Science Year 2020|21 – Bioeconomy

In their search for solutions to the pressing challenges of our time, researchers from the IGB are concentrating on the field of bioeconomy in particular. The German Science Year 2020|21 – Bioeconomy initiative provided the institute with various platforms for drawing public attention to its research and expertise.

- *www.igb.fraunhofer.de/bioeconomy*

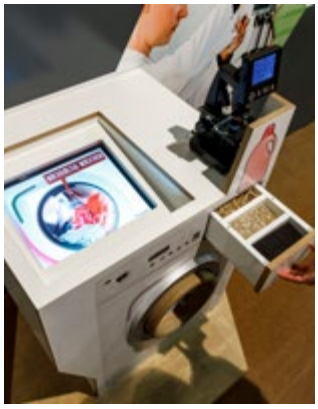
above:
Most of the presentations in the Biointelligence lecture series could take place in a hybrid way.

below:
The IGB contributions at the WLB were kicked off by Institute Director Dr. Markus Wolperdinger on July 20, 2021, with a lecture on the bioeconomy.

Putting the spotlight on biosurfactants: All aboard the MS Wissenschaft

An exhibit on biosurfactants by the IGB was included among the interactive exhibits on board the MS Wissenschaft, which traveled to over 50 cities across two summers during the Science Year Bioeconomy initiative. For the many members of the public and the more than 3000 schoolchildren that came to see the exhibition ship, these visits were a particularly special experience given the ongoing pandemic. In accompanying online content, Dr. Susanne Zibek and doctoral student Amira Oraby demonstrated how science and research can contribute to the development of a sustainable bioeconomy.

- *www.igb.fraunhofer.de/ms-science*



Taking over the Science Year Instagram page

For two days in August 2021, Fraunhofer IGB featured multimedia stories showcasing the institute's bioeconomy research on the Instagram channel of the Science Year Bioeconomy initiative. Through short videos, quizzes and animated statements, they showcased the ideas that inspire researchers at the IGB, as well as the solutions they are developing for the sustainable use of resources. The Instagram takeover allowed the institute to reach a large number of young people with an interest in science. Lisa Kern, digital media manager at Fraunhofer IGB, received first prize at the 2021 Fraunhofer Communications Awards for this initiative.

Discussion and dialogue at NaturFutur

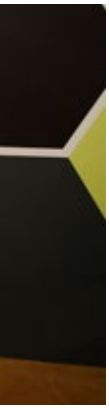
As the Science Year drew to an end, experts from the IGB appeared as guests at various events in connection with the exhibition "NaturFutur – Experience the Bioeconomy" in the Museum für Naturkunde, Berlin. On November 18, 2021, Dr. Grzegorz Kubik, head of Industrial Biotechnology innovation field, took part in a round table discussion on precision fermentation, where he spoke about the diverse areas of application for biotechnological production processes, e.g. in the food industry or the chemical sector.

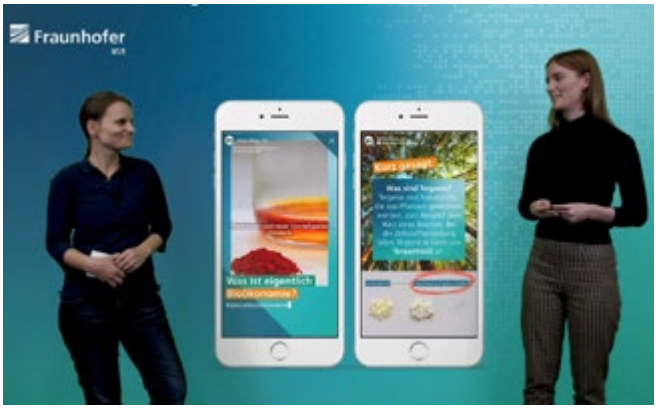
On December 3, 2021, institute director Dr. Markus Wolperdinger came to Berlin to represent the national Bioeconomy Council as its vice chairperson in a question and answer session. "The bioeconomy offers enormous potential for sustainable solutions that could help us to conserve resources and live healthier lives, while at the same time creating prosperity," said Dr. Wolperdinger.

left:
How biosurfactants are produced at the IGB was shown by the institute on the MS Wissenschaft with an interactive exhibit.

center:
The bioeconomy research of the IGB was the focus of the Instagram takeover. Antje Hetebrüg and Lisa Kern (from left) at the Fraunhofer Communication Award ceremony.

right:
Dr. Grzegorz Kubik from the IGB was invited as an expert on precision fermentation for a round table discussion at the Museum für Naturkunde, Berlin.





Brief interview: Chemical analytics

Reliable analytics are the basis of research and product development. In addition to supporting internal research projects, the "Central Analytics" working group at Fraunhofer IGB supports companies from a wide variety of industries. We asked Gabriele Beck-Schwadorf, head of the Stuttgart-based central analytics group, to explain.

What makes your analytical services and expertise attractive to customers?

We are a research laboratory that focuses on method development and our staff is specially qualified for the field of analytics. This enables us to work out individual solutions for each request in consultation with the customer. We use a very wide range of analyses and methods, which allows us to offer specialized analytical techniques such as inorganic nanoparticle analysis.

In order to offer our customers additional quality assurance and to emphasize our expertise, we have DIN EN ISO/IEC 17025:2018 accreditation for selected testing methods. We can also draw on many years of experience.

What can you offer that other analytics labs cannot?

One of our strengths is developing and validating analysis methods for specific problems. Here, the measuring methods must also be adapted to the respective matrix. To find an answer to a specific question, we often have to combine different analytical methods.

What kinds of analytical services does the Chemical Analytics working group at the IGB provide?

We can draw on an extensive range of analysis types and methods to meet the many different internal and external requests we receive. Our instrumental analytics portfolio covers chromatographic and mass spectrometric methods for both the organic and the inorganic fields.

Who are your customers and what kind of requests do you typically receive?

Our customer base extends across many industries, for example health, pharmaceuticals, food, chemicals, construction, water and electrical engineering. As a result, our analysis portfolio covers a large number of fields. The requests we receive from these customers often relate to quality and production control, but also to environmental compatibility tests for building materials, environmental analytics, and analyses of nanoparticles or process media.

Equipment

Organic analysis
- For volatile compounds:
  - Gas chromatography (GC)
  - GC/MS with different sample preparation techniques (headspace, SPME, pyrolysis)
- For non-volatile compounds:
  - HPLC and UHPLC
  - UHPLC-MS
- For ionic compounds:
  - Ion chromatography (IC) with suppressor technology (organic acids, anions)
  - High-performance anion exchange chromatography with pulsed amperometric detection (HPAE-PAD) (mono-, di- and polysaccharides)

Inorganic elemental analysis
- TripleQuad ICP-MS
- ICP-OES
- Various digestion systems

What recurring challenges do you face?

Our goal is always to satisfy the customer and offer individual solutions for their respective problems and questions.

What are your expectations for the future?

Increasingly, decisions in the health sector, in companies and in politics are made on the basis of analytical data. At present, due to the pandemic, we are seeing this every day, and environmental issues are similar. That is why analytics will be a fundamentally important field in the future, as well.

After all, instrumental analysis is affected by trends like miniaturization, automation and the digital transformation as much as every other sector. What's more, these new developments will lead to higher selectivity, efficiency, accuracy and resolution, which will also reinforce the importance of analytics.

▸ *www.igb.fraunhofer.de/chemical-analytics*

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Successful research transfer with Fraunhofer IGB spin-off Variolytics

Transferring technological innovations to industry and society is the primary mission of the Fraunhofer-Gesellschaft. It enables small and medium-sized enterprises as well as large companies to benefit from our diverse range of research services, the results of joint research and development projects and the licensing of Fraunhofer technologies. Spin-offs from Fraunhofer Institutes are another important route for ensuring the rapid and efficient transfer of research findings to new products and services.

Fraunhofer: A hothouse for start-ups

In March 2020, Variolytics, the latest spin-off from Fraunhofer IGB, took its first step toward independence by setting up as a separate GmbH. Variolytics' work with Fraunhofer IGB in recent years clearly demonstrates the role of spin-offs in ensuring the successful transfer of research findings. Variolytics GmbH develops and distributes measuring devices for real-time analysis of substances. Dr. Matthias Stier, a process engineer and current CEO of Variolytics, developed the core technology for the start-up's innovative analysis platform as part of his scientific research work at Fraunhofer IGB.

"We and our project partners were in need of a measuring technology that was capable of detecting and identifying not just gas but also dissolved substances with a high degree of sensitivity," Stier remembers. It was as they applied for a patent for the technology that the idea to establish a company, based on this technology, began to take hold. Supported by the institute and the entire Fraunhofer network, Stier showed great enthusiasm in developing this idea. In 2020, Variolytics was awarded the audience prize at the CyberOne Hightech Award event, while in November 2021, mayor of Stuttgart Frank Nopper honored the early-stage company with the special prize for start-ups at the "Stuttgarter Innovationspreis" award ceremony.

The Variolytics founders at Fraunhofer IGB: Stephan Scherle, Dr.-Ing. Matthias Stier, Johann Barlach, Steffen Görner (from left).

Support right from the start

"Having the expert knowledge needed to transform a technological idea into a practical solution is not in itself a sufficient basis for founding a company," Stier knows. This is why the Fraunhofer-Gesellschaft supports spin-offs from its institutes in a variety of different ways – from training in entrepreneurial thinking, to networking with other founders and venture capitalists. With responsibility for spin-off and investment management, Fraunhofer Venture supports future Fraunhofer founders by providing incubator and accelerator programs and by bringing partners together. In 2017, Fraunhofer IGB researcher Stier met business economist Johann Barlach at one of these Fraunhofer incubator programs. "From our very first exchange at this speed networking event, Matthias had me convinced of the merits of his business idea. We quickly came to an agreement and began preparing a business plan," recalls Barlach, now CFO at Variolytics.

Armed with a business plan, they began their search for investors. To ensure a degree of financial independence during this phase, Stier and Barlach were supported by the Fraunhofer IGB institute management team in applying for funding from the EXIST program for university-based business start-ups, which is run by the German Federal Ministry for Economic Affairs and Climate Action. Their application was approved in August 2019. "This funding of just over 1.6 million euros was a real breakthrough for us, as it meant we could work over the next two years on developing the technology for commercialization and settling some unresolved issues concerning the spin-off itself," says Stier.

It all comes down to the contract

Institute Director Dr. Markus Wolperdinger firmly believes that "timely, trusted communication between the research institute and the founder is crucial to the success of a spin-off – as is, of course, the shared goal to drive the project forward." As in any good collaboration, it's also important that both parties benefit from the project. "The research unit has already invested significantly in the spin-off idea – from the cost of running individual projects to patent fees and operating expenses," explains Director Markus Wolperdinger. As is common practice, this investment during the incubation phase is recouped by the research institute from future revenues earned from licensing agreements or from shareholdings in the spin-off companies. "Especially at the beginning, start-ups such as ourselves are not in a position to invest big sums in our businesses. The only way for founders like us to access investment capital is through our own shares," Stier explains, giving the spin-off's perspective on things.

"With a healthy measure of instinct, and a willingness to compromise on both sides, we were able to create a win-win situation and strike a balance between the future financial viability of the spin-off and the future revenues of the research unit," says Dr. Wolperdinger, who also worked in another technology start-up during the early stages of his career. "For us as founders, negotiating license terms as early as possible is crucial as it allows us to communicate clearly with potential investors down the line. This aspect of our collaboration with Fraunhofer IGB went very smoothly," adds Stier.

Infrastructure and network – A valuable resource

Right up until the extended EXIST grant expired at the end of 2021, Stier and his Variolytics colleagues were able use the facilities and infrastructure at Fraunhofer IGB, which gave them the opportunity to focus on setting up the business. "Without the institute's exceptional technical infrastructure, we would not have been able to develop our initial prototypes, validate where they could be applied in the way described in the business plan or test the market," says Stier.

"I'm really happy we were able to give Variolytics the opportunity to develop the technology and provide the infrastructure and business expertise they needed to support their journey to market launch – and in so doing, transfer our Fraunhofer technology into the innovative products and services of a newly established company," says the institute director. "It's clear that our commitment is paying off as we now have another joint research proposal that will consolidate our collaboration even further."

In the laboratories at Fraunhofer IGB, Variolytics was able to perform the measurements to validate its award-winning emission control system for wastewater treatment plants.

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

Variolytics GmbH

Variolytics GmbH develops innovative measuring devices. Since the start of 2021, it has been based in the STEP Stuttgart Engineering Park, not far from the Fraunhofer campus. The start-up's innovative analysis platform makes substances visible in real-time. It uses smart control technology to efficiently monitor wastewater treatment as well as biotechnological and chemical production processes.

▸ *www.variolytics.com*

Fraunhofer IGB, a strong player in the Fraunhofer-Gesellschaft

An important factor in the success of Fraunhofer IGB is its strong integration within the Fraunhofer-Gesellschaft. Thanks to the intensive collaboration in Fraunhofer Groups, lead-market-oriented alliances, strategic research fields and diverse collaborative projects, progress is also being made across disciplines in the development of innovative and sustainable products.

Founding member of the Resource Technologies and Bioeconomy group

The vision of the Fraunhofer Group for Resource Technologies and Bioeconomy is the protection and sustainable use of resources. The Group's research projects therefore focus on ensuring the nutrition and health of the global population (the WHO's "One Health" approach), managing global resources in a sustainable manner, creating circular systems and reducing climate-damaging emissions as well as developing technological requirements for the sustainable production of materials and products. To achieve this goal, the Group's member institutes are developing technological, systematic and circular solutions both for responsible resource and energy management and climate protection.

The Group's founding members are the Fraunhofer Institutes UMSICHT, IGB, IVV and IME. Since the end of 2021, Fraunhofer IAP and Fraunhofer IWKS have been participating as guest institutes. The Group is led by Prof. Eckhard Weidner, UMSICHT (chair) and Dr. Markus Wolperdinger, Fraunhofer IGB (deputy chair).

Guest member of Fraunhofer Group for Materials and Components

The expertise within the Group for Materials and Components – MATERIALS covers the entire value chain, from materials development and manufacturing processes to evaluating operational behavior. Its mission is motivated by a drive to use its expertise in areas ranging from fundamental materials science to system solutions for materials technology in order to create new innovations for customer and partner markets. These innovations are based on the member institutes' multiscale expertise in materials all along the industrial value chain.

Fraunhofer Strategic Research Field (FSF) Bioeconomy

The Fraunhofer Strategic Research Fields bring together the scientific excellence that exists across Fraunhofer while also setting the strategic agenda within Germany and Europe. They focus their research on their core areas of expertise and look for solutions to challenges currently facing society as a whole. Fraunhofer aims to achieve a position of scientific leadership by focusing on a number of cross-sector impact goals: affordable health care, successful energy transition, security and a resilient society, digitalized value creation and a fully circular economy.

Fraunhofer IGB is active in the FSF Bioeconomy (as a founding member) and participates in the FSF Resource Efficiency and Climate Technologies (as a member of the strategy board).

Within the FSF Bioeconomy, Fraunhofer IGB is working with Fraunhofer Institutes UMSICHT, IME, IAP, IVV and WKI to develop recyclable and competitive products with new and improved functionality. They are also contributing to a low-pollutant, low-emission production model and in doing so, they are creating value and safeguarding prosperity without causing harm to the environment. The FSF Bioeconomy focuses on biobased, machine-enabled, functional and recyclable materials; water as a resource; food and animal feed as well as chemistry and biotechnology. The spokespersons for the FSF Bioeconomy are Dr. Markus Wolperdinger (Fraunhofer IGB) and Prof. Alexander Böker (Fraunhofer IAP).

Fraunhofer lead markets – Strategic customer segments

The identified lead markets allow the Fraunhofer-Gesellschaft to provide industry customers with access to a range of sector-specific services. Through innovations, they help achieve a global competitive advantage for Germany while safeguarding the technological sovereignty of Germany and Europe and generating sustainable value creation for society. The services offered for lead markets are primarily designed and coordinated by the lead-market-oriented Fraunhofer Alliances. The Fraunhofer IGB research portfolio addresses the following four lead markets.

- Lead Market Chemical Industry
- Lead Market Energy Sector
- Lead Market Agriculture and Food Industry
- Lead Market Healthcare Sector

High-Performance Centers

High-Performance centers provide a single location where Fraunhofer Institutes, universities and higher education institutes work together with enterprises and stakeholders from civil society to investigate specific research topics. By offering practical infrastructure, vocational training programs and expertise, they bring partners together and ideas to the market.

The **High-Performance Center Mass Personalization (LZMP)** in Stuttgart is focusing on the question of how products can be tailored to individual needs while being produced in a cost-efficient way. The joint strategic initiative between the University of Stuttgart, the Fraunhofer-Gesellschaft and their industry partners drives interdisciplinary solutions with the aim of significantly increasing the added value of products and services for users, thus helping companies gain a competitive advantage.

▸ *www.masspersonalization.de*

The **High-Performance Center for Chemical and Biosystems Technology CBS** in the Halle-Leipzig region is the go-to contact when it comes to achieving resource conservation through efficient use of energy and materials and the transition from unidirectional processes to circular processes. The center focuses on polymer- and biopolymer-based material systems, holistic drug preparations, sustainable interfacial chemistry and physics and CO_2-neutral carbon and hydrogen conversion. By addressing issues in relation to sector coupling or dealing with business and regulatory risks, the CBS has developed into an interdisciplinary think tank for Chemistry 4.0.

▸ *www.chemie-bio-systemtechnik.de*

▸ *www.igb.fraunhofer.de/network*

Health

Smart health engineering and enabling technologies for precision medicine

The rapid increase in the acquisition and analysis of genome-wide data and the enormous potential for cell manipulation have led to the emergence of data-driven diagnostics and fundamentally new therapies, which already enables precision medicine – i.e. health care customized to the needs of the individual patient. At Fraunhofer IGB, our objective is to develop and enhance the enabling technologies required for precision medicine and thereby help improve the standard of medical care for patients while also reducing the costs of the healthcare system.

Fraunhofer IGB is active in the development of

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

Target markets

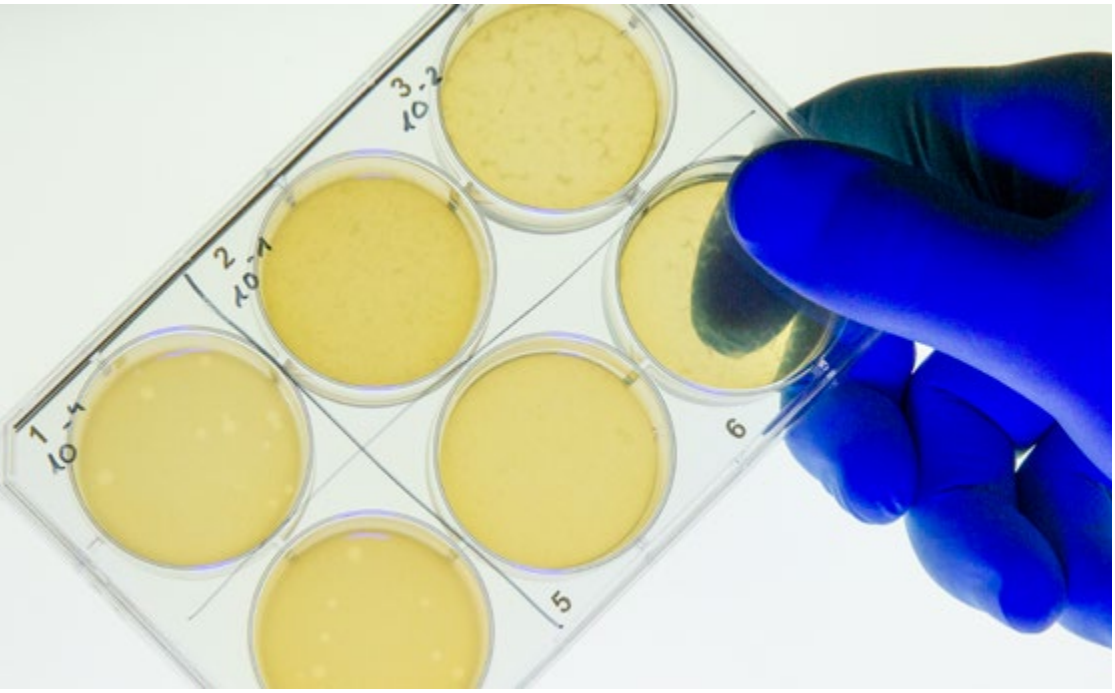
Fraunhofer IGB seeks to partner life science companies, especially in the fields of diagnostics, medical engineering and drug development.

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

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 would otherwise be impossible 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 immune system. Our wealth of experience in molecular cell technology has enabled us to develop highly precise receptor-based assays for drug validation and production cell lines for biologics.



At Fraunhofer IGB, our many years of experience in virus engineering enable us to develop novel and innovative therapies based on customized viruses for targeted prevention (vaccines) and therapies (oncolytic viruses). 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.

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.

www.igb.fraunhofer.de/health

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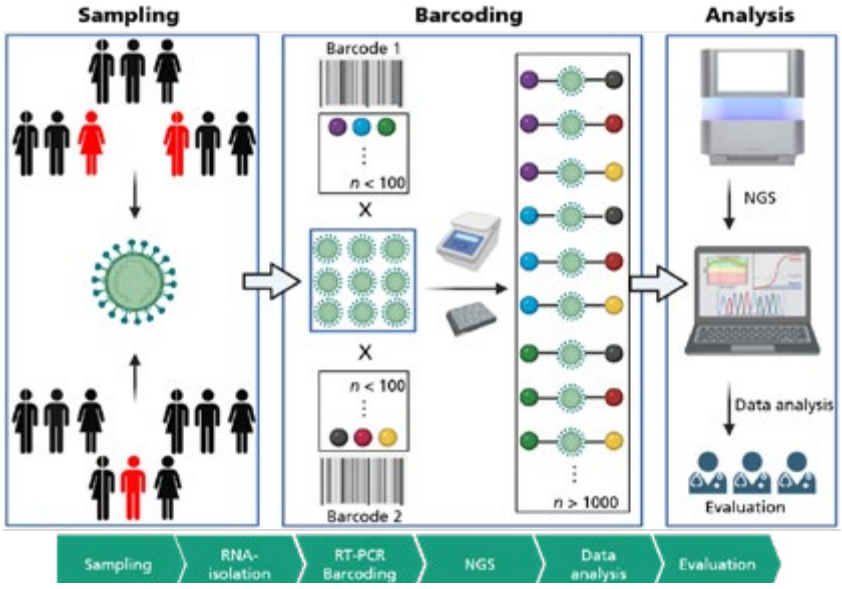
CoV-2-KomET – High-throughput diagnostics of respiratory diseases such as SARS-CoV-2

According to the Robert Koch Institute, approximately 14.75 million SARS-CoV-2 infections have been detected in Germany to date [1], with a higher number of unreported cases suspected. However, the currently used diagnostic methods of reverse transcription of viral nucleic acids followed by quantitative polymerase chain reaction, widely known as PCR tests, are limited in terms of sample throughput. In addition, infections with other seasonal respiratory diseases such as influenza or RSV (respiratory syncytial virus), are also increasing [2], which would need to be analyzed simultaneously in the best possible way.



Procedure of CoV-2-KomET, starting with sample collection to molecular barcoding in RT-PCR, analysis and evaluation of results. Created with BioRender.

Area-wide testing by high-throughput diagnostics

Therefore, in order to be able to offer area-wide PCR testing with regard to the current Omikron variant, sample throughput must be significantly increased. In collaboration with the Fraunhofer Institutes for Cell Therapy and Immunology IZI, and Production Technology and Automation IPA, we at Fraunhofer IGB have developed a new method for high-throughput diagnostics of SARS-CoV-2 and validated it on clinical samples as part of the Fraunhofer CoV-2-KomET project. This combines reverse transcription and amplification of specific viral sequences (RT-PCR) with the high-throughput capability of modern sequencing technologies. In order to analyze thousands of patients simultaneously, samples are labeled with specific oligonucleotides – also known as "molecular barcodes" – in the RT-PCR step, which allows a unique assignment to the patient (Fig.).

First validation of the approach

CoV-2-KomET was successfully tested on a total of 672 clinical samples and achieved a specificity of over 89 percent and a sensitivity of over 87 percent in comparison to standard PCR tests. The diagnostic value of CoV-2-KomET, determined by the "area under the curve (AUC)," of 94 percent also demonstrates the potential of this approach, which will be subject to further evaluation and improvement in the future. In addition to the pure SARS-CoV-2 high-throughput detection, a "respiratory panel" was successfully established on 41 synthetic samples, allowing the detection of SARS-CoV-2 as well as Influenza A/B down to a detection limit of 10 copies/µL.

Outlook

CoV-2-KomET, as a diagnostic approach based on high-throughput sequencing of viral nucleic acids, represents a promising and alternative method for pandemics and infection outbreaks. Not only could sample throughput be increased with this approach, but scalability could also reduce the potential costs per test. Furthermore, by changing the design of the specific viral sequences, it is possible to respond to new variants within a few weeks. The project will be continued with the industrial partner LMV Laboratories, with a special focus on improving and expanding the respiratory panel to simultaneously test patients for SARS-CoV-2, influenza and RSV within one sample.

▸ *www.igb.fraunhofer.de/en/cov2komet*

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Investigation of the inhalation toxicological effects of face masks

The requirements for medical face masks, such as filtration efficiency, breathability and biocompatibility, and the corresponding test methods are defined by legal test guidelines. The official standard for evaluating medical devices (DIN EN 10993) addresses biological effects, such as toxicity, irritation and allergy, resulting only from the medical device/material coming into contact with the skin or bodily fluids. Breathing through masks can trigger adverse respiratory toxicological effects caused by airborne substances that are released from the masks and then enter the lungs – even at very low concentration levels in the inhaled air. This can lead to long-term irritation or inflammation of the airways and even to allergies or asthma. A standard for evaluating airborne exposure in terms of respiratory toxicology does not exist.

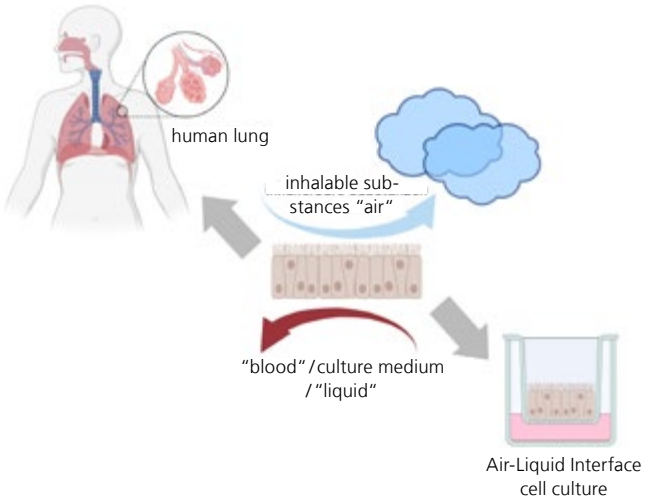
Culture and exposure system for investigating airborne substances

Based on a culture and exposure system for airborne test substances patented by Fraunhofer ITEM, a unique in-vitro test battery to investigate the biological respiratory effects of face masks has been developed. The P.R.I.T.® ExpoCube® facilitates the exposure of cells at the air-liquid interface (air-liquid interface (ALI) cultures) (Fig.). This enables relevant endpoints of respiratory toxicological mechanisms to be investigated.

Reporter cell lines for identification of allergy- and asthma-inducing effects

In addition to using commercial cell lines to evaluate toxic and/or irritative effects, our researchers in the Cell and Tissue Technologies innovation field have developed indicator cell lines, which can be used to study effects that result in the development of allergies and asthma. The basis for this are indicator cell lines (patented by Fraunhofer IGB – EP 2 041 172 B1) using human receptors from the innate immune system that are responsible for activating the immune system (toll-like receptors, TLR). TLR-activation of the reporter cells leads to reporter gene expression via intracellular signaling pathways. Receptor activation can be directly quantified via the reporter protein, in this case a secreted alkaline phosphatase (SEAP), by means of a color change reaction following the addition of a suitable substrate.

To be able to use the cells cultured under submerged conditions to investigate airborne substances for the first time, they were successfully adapted to the conditions of ALI cultivation. To complete the in-vitro test system, suitable vaporizable substances were also identified as positive controls as part of a screening procedure.



Applying the exposure principle to the in-vitro test situation. (Graphic made with BioRender).

Demonstration of the functionality of the test system using a model contaminant

The functionality of the test system was successfully demonstrated through the use of formaldehyde as a model contaminant, supporting the potential application of the test system in the development of wearer-optimized protective masks suitable for daily use as part of the research project TOPAS-COVID19. On the basis of available limit values, a realistic test situation was successfully recreated not only conceptually but also in the quantitatively relevant concentration range of potential filter contaminants.

▸ *www.igb.fraunhofer.de/en/topas*

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Aerosol-carried viruses – Production, capturing and analysis

The SARS-CoV-2 pandemic revealed large gaps in the knowledge of aerosol-borne viruses, raising fundamental questions regarding their spread in enclosed rooms, the preventive measures of protective masks up to air filters and the efficiency of inactivation processes of air purifiers. The innovation field of Virus-based Technologies has established a comprehensive and adaptable workflow to address these questions.

Setup of the aerosolization chamber for the defined investigation of airborne bacterial and viral pathogens up to safety level 2. Additional devices can be integrated for targeted investigations such as the disinfection efficiency of UV-C radiation for airborne pathogens.

Model systems using "harmless" viruses
To establish a test system, several viruses were considered as surrogates for SARS-CoV-2. The decision was made for bacteriophage Phi6, which is similar to SARS-CoV-2 with regard to its morphological characteristics like viral envelope and RNA genome content, but is neither harmful to animals nor to humans. Propagation of Phi6 is performed on specific host bacteria. To ensure a maximum yield from Phi6 propagation as required for testing, a scaled production process based on a liquid culture was established. In parallel, we use the human coronavirus 229E (HCoV-229E), a common and widespread cold virus, as additional surrogate virus for specific queries.

Activity tests for detection of infectious viral particles
To record the presence and/or infectivity of surrogate viruses, detection methods for active, infectious viral particles and for total viral genome counts were established. Virus activity is detected via phage plaque assay, allowing detection of lytic spots on a bacterial lawn (so called plaques) that correspond to the number of active, infectious viral particles, which is used for quantification. In addition, a Phi6-specific RT-qPCR approach was established to record all viral particles, present in active or inactive state, on the genomic level. This serves as both, a reference for the degree of inactivation and for virus depletion.

Aerosolization chamber used as closed test environment
An aerosolization chamber was developed to facilitate closed aerosolization and analysis of surrogate and infectious airborne viruses. For aerosolization procedures, viruses are formulated in an appropriate medium and filled in an aerosol generator hooked up to the chamber. A sampling procedure for aerosolized viruses was established using swabs, allowing the sampling of infectious viruses for further analysis.

Analysis of inactivation processes to customer order
These tools enable us to use a comprehensive and flexible workflow for all kinds of requests in terms of airborne viruses. In addition to burning issues like virus inactivation using UV-C irradiation, we are preparing for future challenges and are already expanding our testing capabilities for aerosols containing fungal spores and bacteria.

▸ *www.igb.fraunhofer.de/aerosol-borne-viruses*

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3D in-vitro model to validate immune receptors as targets for the treatment of psoriasis

Psoriasis is a chronic autoimmune disease that affects about two percent of the population worldwide [1]. The disease manifests itself in the form of inflamed and scaly skin areas accompanied by itching and pain. Current psoriasis treatments include systemically acting biologics such as monoclonal antibodies and topically applied hydrocortisone-containing ointments. Often, these therapeutic options are associated with side effects, in some cases severe, or patients do not respond to them.

To identify molecular targets for specific immunomodulatory treatment, in-vitro models are required that represent the pathological hallmarks of human psoriatic skin. These models must be valid, reproducible, and thus suitable for larger test series. In research, mainly mouse models are used, whose relevance is very limited due to their low transferability to humans. Alternatively, models based on patient biopsies are employed, which are not suitable for drug screening due to limited availability of the starting material.

Novel 3D psoriasis skin model

The innovation field Cell and Tissue Technologies of Fraunhofer IGB has successfully established a completely novel 3D psoriasis skin model that circumvents these problems. The basis for the model are human immortalized keratinocytes, which are differentiated in vitro into a multilayered epidermis. By overexpression of the psoriasis-associated transcription factor STAT3 in these keratinocytes, co-cultivation of the epidermis model with in vitro activated T cells and the specific addition of pro-inflammatory cytokines, the psoriasis-typical inflammatory response was successfully mimicked in the models. A comparison with patient biopsies demonstrated the correlation of psoriasis markers in the in-vitro model.

Validation of Toll-like receptors as targets

This model was used to validate receptors of the innate immune system, so-called Toll-like receptors (TLR), as new therapy option for psoriasis. For this purpose, TLR agonists – molecules that activate TLR – were tested with the new psoriasis model and after addition of these agonists the expression of typical psoriasis markers was detected. Finally, a psoriasis model in which TLR2 was knocked-out in keratinocytes showed a significantly reduced expression of psoriasis markers after addition of TLR2 agonists.

Cross-section through a 3D in-vitro psoriasis model. The disturbed keratinization (pink) and thickening (acanthosis) of the epidermis are typical for the disease.

Outlook

With the new human 3D in-vitro psoriasis model established at the IGB, Toll-like receptors could be validated as a target for the treatment of psoriasis for the first time. In a next step, molecules with TLR inhibitory activity will be evaluated as potential drugs.

The human 3D in-vitro psoriasis model is perfectly suited for testing new immunomodulatory molecules and has the advantage of being adaptable for other inflammatory skin diseases, such as atopic dermatitis.

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

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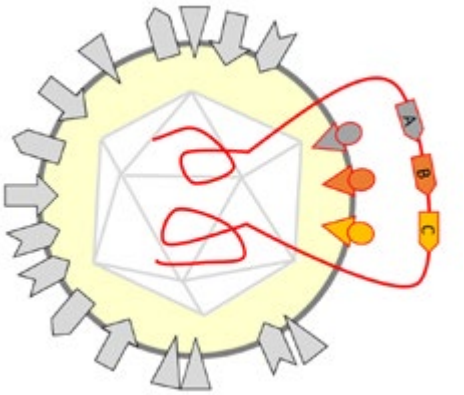
Programming of biointelligent viruses for therapeutic applications

Viruses can penetrate cells in a targeted manner, thereby anchoring biological information and even strengthening their effect through viral reproduction. These natural properties of viruses can be used and expanded in many ways through genetic engineering. Such programmable viruses have enormous potential to be used as platform technology for various therapeutic purposes, e.g. as vectors for cell and gene therapy or as vaccine carriers.



Graphic depiction of a programmed oncolytic HSV-1 virion with inserted transgenes (A, B, C).

Oncolytic viruses (OV) represent a separate class of gene therapies that are increasingly gaining focus as innovative cancer therapies both as monotherapy or combination therapy. Viruses can be engineered into highly specific drug carriers through genetic modification: The resulting OVs develop their effect through specific detection and destruction of tumor cells. In addition, they can recruit and activate tumor-infiltrating immune cells to include the immune system in fighting the tumor. Thereby, a long-lasting in-situ tumor vaccination can be achieved.

Facilitated integration of transgenes into the platform vector

In the innovation field Virus-based Technologies, a proprietary platform vector based on herpes simplex virus 1 (HSV-1) was established as part of the MAVO TheraVision project using bacterial artificial chromosome technology. This engineering platform, for which a patent application has been submitted, enables modular programming of the HSV-1 genome by facilitating the integration of transgenes. Combined with the possibility of high-capacity engineering, this platform vector is therefore ideally suitable as a research tool. Further modifications with the aim of inactivating the neurotoxicity of HSV-1 resulted in an attenuated vector that significantly reduces viral load in the brain of mice compared to the original vector and thus allows safe application.

Suitability for tumor vaccination demonstrated

As a proof of principle, we have already implemented several transgenes in different combinations into the platform vector. Among others, this made it possible to optimize the targeting of the TheraVision virus to tumor cells. In addition, virus-encoded immune checkpoint inhibitors bind the receptors of the immune system and are consequently functional. Finally, diverse foreign antigens that may contribute to tumor vaccination, could be expressed in a virus-mediated manner.

Platform technology for the facilitated development of tailored therapeutic viruses

Overall, the basis for a combined virus immunotherapy was created which enables an effective, safe and sustainable destruction of tumors as well as metastases and at the same time minimizes the risk of systemic side effects. In parallel to virus engineering, a GMP-compliant production process and complex preclinical test systems including human tumor and immune cells have been established by Fraunhofer partner institutes.

Thus, a broadly applicable platform technology for the simplified development of tailored therapeutic viruses is available.

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

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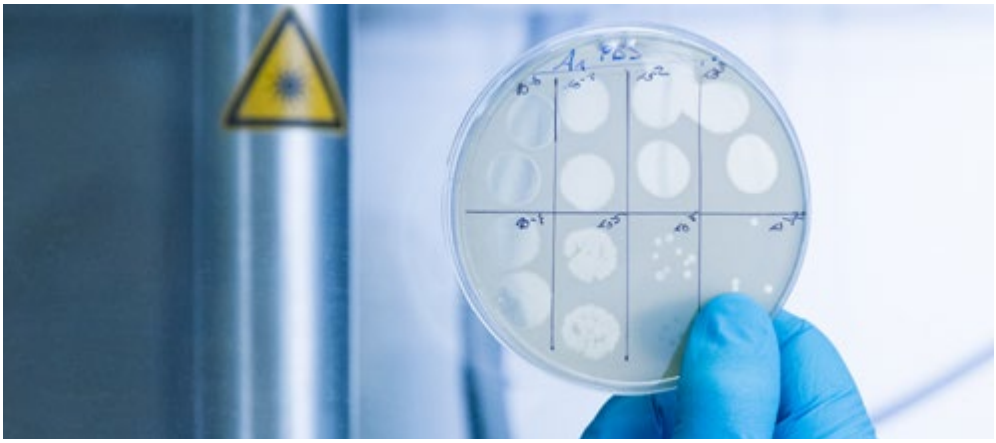
Bacteriophages – Viruses with future potential

Bacteriophages (phages for short) are naturally occurring viruses which can only infect bacteria and destroy them specifically by cell lysis. This property makes them a non-hazardous but very efficient tool for humans, animals and plants with many potential applications in distinct areas. Furthermore, bacteriophages represent natural vehicles for the transfer of genetic material, which can lead to the genetic modification of infected bacteria and thus be exploited for targeted utilization. The innovation field Virus-based Technologies sets the main focus on specific usage of bacteriophages as a customized tool for medicine and bioeconomy.

Phages as multifunctional tool

In the field of bioeconomy, bacteria are used for the production of chemical products from renewable raw materials or residual waste that serve as an alternative to fossil resources. Bacteriophages can be used to specifically modify metabolic processes leading to enhanced or altered production of the desired products, termed "metabolic engineering." Especially for bacteria which cannot be targeted by commonly used genetic engineering methods, bacteriophages display an attractive tool to circumvent this problem. To address this issue, sampling and characterization of bacteriophages against a wide variety of bacteria will be performed, followed by the establishment of a phage collection for storage allowing subsequent usage.



Active phage particles destroy bacteria and form lytic zones (plaques) on a bacterial lawn.

Phages as alternative to antibiotics

Due to the rapid rise of antibiotic-resistant (AMR) bacteria worldwide (see WHO priority pathogen list), the calls for alternative therapeutic options are increasing. This is even more pronounced by a recent analysis performed by the WHO´s AMR division dealing with antibacterial agents in preclinical development [1] which now lists also bacteriophages and phage-derived peptides. In the future, bacteriophages might play an important role in the medical field as putative substitutes for antibiotics, being already successfully applied in some Eastern European countries (e.g. Georgia). Furthermore, huge potential is seen for applications in the food- and agricultural industry, for example to ensure the hygienization of food products or to reduce the usage of antibiotics in animal farming.

Additionally, we are able to use bacteriophages successfully as surrogates, i.e. model viruses, for SARS-CoV-2 to answer questions regarding the effect of protective masks and filters or to evaluate disinfection methods such as irradiation using UV-C. This is described in more detail in the section "Aerosol-carried viruses – Production, capturing, analysis."

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

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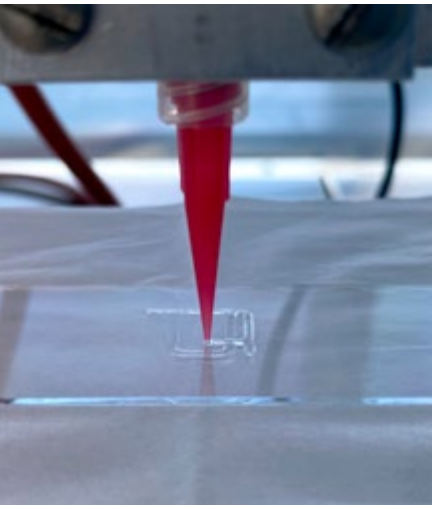

3D printing of crosslinkable bio-inks developed at Fraunhofer IGB.

SOP bioprinting

When it comes to closing the implant supply gap, the most promising solution lies in 3D bioprinting. This is an additive manufacturing process that prints living cells in a biocompatible substrate, layer by layer, into stable, well-defined 3D constructs. These 3D-printed structures are currently the subject of research and development in the diverse fields of regenerative medicine and tissue engineering, and are also becoming increasingly important in industrial applications.

Reproducibility through standardization

When it comes to the transition to industrial applications, criteria such as accuracy of shape and reproducibility of products generated by additive manufacturing are of crucial importance. The considerable diversity of the printer systems available on the market and the current low level of standardization of available biomaterials for manufacturing bio-inks lead to a "data jungle," where it is difficult to establish any universal criteria for materials and processes that would allow 3D bioprinting to be carried out in a targeted and results-based way.

Round robin test for a standard operating procedure (SOP)

To solve these challenges, the Karlsruhe Institute of Technology (KIT) invited 13 renowned partners, selected on the basis of their published expertise in this field, to participate in a round robin test as part of the SOP_BioPrint project. These trials are normally used for quality assurance or to validate measuring and testing procedures. Standard operating procedures (SOPs) give precise descriptions of manufacturing or testing procedures to ensure that the results are always reproducible, and therefore comparable, regardless of the manufacturer or test laboratory that carries them out.

The SOP_BioPrint project therefore investigated the extent to which it is possible to print reproducible and comparable structures with standardized bio-inks in different locations and on different devices, but with the same parameters. To get around the variances that arise from preparing inks at the locations with different 3D bioprinters, partners supplied two bio-inks in addition to one commercially available bio-ink.

Fraunhofer IGB not only participated in this round robin test, but also supplied a gelatin-based crosslinkable bio-ink for all the partners involved. This meant that the IGB bio-ink was one of the three bio-inks investigated in the round robin test. As well as the material (modified gelatins, radical starter, buffer), we also supplied the round robin partners with an SOP for the modification and formulation of the bio-inks. This SOP allowed all those taking part to produce and use bio-inks with identical chemical and physical properties.

Methacrylated gelatin according to standardized modification process

This involvement in the round robin test led to the creation of the first standardized manufacturing procedure for a gelatin-based bio-ink developed at Fraunhofer IGB. Here, the now standardized modification of gelatin with methacrylic anhydride stands out as a simple and cost-effective strategy for integrating photopolymerizable groups into the biopolymer.

The resulting methacrylated gelatin derivatives can crosslink covalently through photo-induced radical polymerization. In this way, they form a versatile matrix that can be used to produce tissue analogs ranging from blood vessels, cartilage, ligaments, tendons and bones to fatty tissue and heart tissue [1].

As well as the biological advantages, another important feature is the ability to use chemically crosslinkable gelatin-based hydrogels in bioprinting to establish mechanical stiffness. Methacrylation also allows the rheological behavior of the gelatin to be controlled so that it becomes fluid at room temperature. This provides a high degree of control over the hydrogel design in 3D bioprinting.

▸ *www.igb.fraunhofer.de/en/sop-bioprint*

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Campus UV-C: Optimization and testing of UV-C disinfection technologies for small and medium-sized enterprises

UV-C radiation is becoming increasingly established as an effective sterilization technology and is being used to an ever greater extent in everyday situations. The "Competence Center for the Assessment of Products with Ultraviolet Sterilization – CAmPUS UV-C" has gathered and broadened the UV-C expertise of three Fraunhofer institutes, the IGB, IBP and IPA, in a service platform offering specialized development, testing and consulting for small and medium-sized enterprises (SMEs).

The unique selling point of the "KMU akut" cluster is the comprehensive support offered to SMEs, from the first product or application idea to the design stage, and all the way through to the execution and testing of new systems. The cluster's combined expertise in UV-C radiation, microbiology and material characterization means that it can provide access to specialist knowledge that is not yet available on the market.

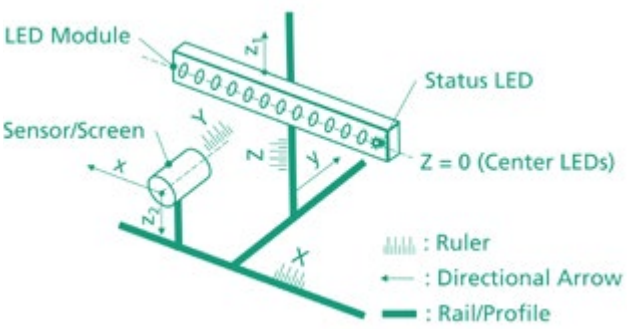
At Fraunhofer IGB, the innovation fields Functional Surfaces and Materials (topics: material characterization and radiation measurements) and Water Technologies and Resource Recovery (topic: microbiology) worked together closely to investigate different UV-C technologies in terms of their physical properties as well as their sterilization performance.

Crystallization phase: Initiation of the first projects

In the crystallization phase, the specific fields of application and the range of services of the Fraunhofer Institutes were defined and communicated. Through the cluster, more than 20 SME contacts were established and independent crystallization projects were set up with five SMEs. On this basis, feasibility studies and validation projects were conducted with the partners in order to realize methods and tools for simulation and evaluation with practical relevance.

Validation phase: Implementation of the projects

In the validation phase, the crystallization projects were put into practice in case studies and in different testing and optimization procedures. The implementation of UV technologies in a "supermarket" customer journey was used as an example. This focused on using innovative UV technologies for a thoroughly innovative purpose: sterilization at key locations in a supermarket, such as the checkout payment systems.



Schematic test setup for UV LEDs with calibrated UV-C measurement technology (sensor).

Feasibility phase: Test benches demonstrate effective sterilization

In the last phase of the project, individual applications were selected on the basis of validated decision-making criteria and ultimately validated and scientifically monitored in the supermarket use case. In this phase, functional prototypes of test benches for material testing were set up and characterized at Fraunhofer IGB, and procedures were established to assess radiation effectiveness while also taking into account material degradation. Various hygiene consultations were also offered and the biological effectiveness of UV sterilization was demonstrated using microbiological methods. The results were used as a basis for recommendations and optimizations of the respective technologies for the SMEs in order to increase customer safety, performance and the effectiveness of sterilization.

▸ *www.igb.fraunhofer.de/en/campus-uvc*

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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 Sustainable Chemistry business area 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 material and biological characterization, complete value-added cycles can be demonstrated up to pilot scale.

Fraunhofer IGB is active in the development of

- pretreatment and fractionation processes for raw materials,
- industrial biotechnology processes for selectively converting materials by means of enzymatic or fermentation processes,
- chemocatalytic, electrochemical and electrobiological processes and their combination with biotechnological processes,
- power-to-X processes for the utilization of regenerative produced redox equivalents in synthesis processes, e.g. for using CO_2,
- membranes for efficient gas separation, e.g. for CO_2 capture and storage or for catalytic reaction processes (e.g. syngas production) as well as
- customized thin films and functionalized surfaces.

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

Target markets

Fraunhofer IGB is a partner for industries 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 provides access to many different substance groups in this segment. The institute has decades of expertise in 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 the synthesis and characterization of substances and materials for which an interaction with biological systems plays an essential role. Examples here include additives for agriculture such as plant boosters made of microalgae, which positively impact cell growth in agricultural crops.

Biopolymers and biobased polymers

We also develop biopolymers for use as packaging for foodstuffs or for medicinal products (see Health business area). By using advanced coatings or the special functionality of biobased monomers, we are able to create new properties for materials. Examples here include the transparent Caramid-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.

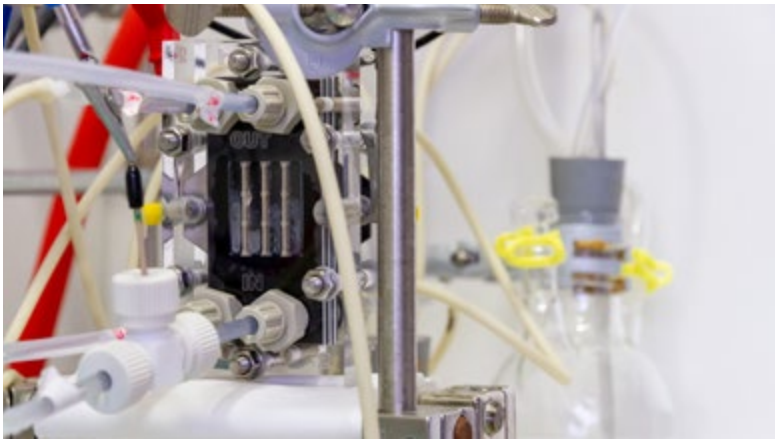
Ingredients for food and animal feed

Functional ingredients made of microorganisms, microalgae or by new fractionation technologies of byproducts from agricultural and food industries can be used in animal feed or as food supplement, due to their antioxidant, immunostimulant or antimicrobial properties. The same applies for certain byproducts from agricultural and food industries. For this purpose, we develop cultivation methods and product-friendly separation methods for extraction and purification. In addition, we develop new physical processes to stabilize and preserve sensitive products like food, active ingredients, drugs or plant extracts.

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 the synthesis based on CO_2 as feedstock can directly be utilized in power-to-X processes. Developments on electrochemical catalysts, electrode materials 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 C1-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.

The ongoing expansion of the Hydrogen Lab Leuna by the Hy2Chem scaling platform for syntheses with regenerative hydrogen and their integration into Fraunhofer CBP will also enable future technology developments in this area up to demonstration scale.



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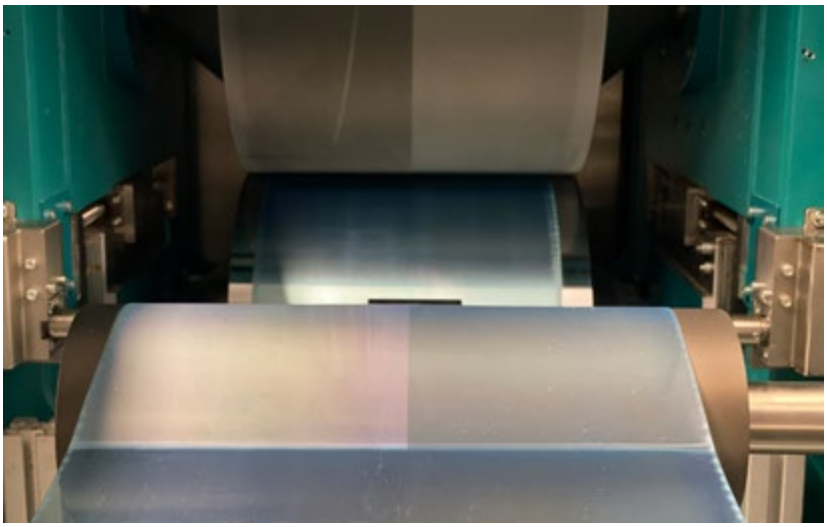
Self-adhesive films for environmentally friendly aircraft anti-icing

The formation of ice on surfaces is a major problem in many areas. This means that aircraft wings and moving parts of helicopters that have frozen over after being exposed to snow or rain combined with below-freezing temperatures need to be de-iced in a laborious process using de-icing agents. This is because ice on the wings impairs their aerodynamic properties, potentially by cutting off the laminar flow needed to provide lift. The weight of the ice also poses a risk to the operation of the aircraft. However, the standard process for de-icing passenger and transport aircraft and helicopters in the winter months not only involves significant quantities of environmentally harmful chemicals, but also adds to the carbon footprint of air travel.



PU film as a strip product in a roll-to-roll process for structuring.

During flight, an active de-icing process takes place: either the wings are heated with resistance heaters that are laminated into them, or hot exhaust air from the engines is diverted to the front of the wings (bleed air technique). The effect is both costly and harmful for the climate: It can increase fuel consumption by as much as 30 percent.

The ideal solution for the problem of ice formation is a water-repellent material that only allows ice to form very slowly, or that reduces adhesion between the ice and the surface.

New passive anti-icing system

A passive anti-icing system is being developed in the Functional Surfaces and Materials innovation field as part of the InTEnt-H project funded by the German Federal Ministry for Economic Affairs and Climate Action (BMWi). A unique and resource-saving anti-icing coating on self-adhesive, transparent and erosion-stable PU film is generating considerable cost savings and significant increases in the efficiency of active de-icing systems.

As well as this, we are now also able to produce layers that are both water-repellent and ice-repellent. These layers are produced using two separate roll-to-roll processes that use low-pressure plasma (pressure $p < 1$ mbar) in combination with a microstructure on which water remains fluid for long periods even at temperatures below 0°C. In ideal conditions, no ice will form on this microstructure at all. This is because the structured layers provide very few nuclei on the surface for the freezing water to crystallize around, so it remains in a supercooled state. Even when the water does freeze, less ice adheres to surfaces coated with this type of anti-icing system than to uncoated surfaces. We achieved a 6 kelvin reduction in the freezing point and a 90 percent reduction in ice adhesion on the developed film compared to a reference surface.

Outlook

In order to address environmental concerns even further, we are currently conducting in-depth research into silicone-like coatings with consistent water- and ice-repellent properties. We also intend to gradually expand the material portfolio of deployable films. The increased potential for variation in the two separate roll-to-roll processes for structuring and coating allows us to produce larger quantities of strip products on an individual basis compared to a batch process. Thanks to the process optimization, it is now possible to adapt the anti-icing system in a rapid and targeted way to specific requirement profiles.

▸ *www.igb.fraunhofer.de/en/intent-h*

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Bioorganic chemistry – The best of bio- and chemocatalysis

Quickly applying the moisturizer in the morning, putting on the freshly washed jumper and taking a tablet against the stubborn cold – off to work. Just these five minutes before leaving the house illustrate how much products of the chemical industry determine the everyday life of our modern society.

In times of raw material change, the Straubing innovation field of Bioinspired Chemistry, which also includes the subject area of bioorganic chemistry, has set itself the goal of developing the products of tomorrow.

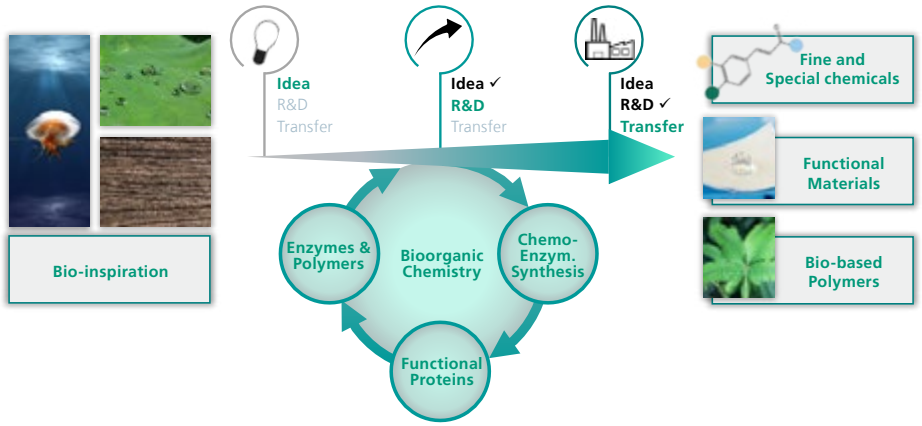
Nature as a role model
The idea behind both approaches – bioinspired as well as bioorganic chemistry – is the controlled use of molecular functionalities found exclusively in nature for the development of new synthesis routes to innovative green fine and speciality chemicals, functional materials and biobased polymers (Fig.).

Enzymes – Natural catalysts for fine and speciality chemicals
In addition to classical chemo-enzymatic synthesis, we are also engaged in the discovery of new enzyme activities. In this way, known enzymes can be replaced by enzymes with improved properties and thus synthesis can be optimized, but also completely new enzyme activities can be identified and thus novel synthesis routes and products can be derived. For example, we were able to establish a screening procedure for methyltransferases, a class of enzymes that can play an important role in the field of drug synthesis. The procedure enabled us to uncover previously unknown enzyme activities for various substrates.

Functional materials with natural properties
In the field of functional materials, both biomass (residues) and specifically produced proteins can be considered as starting materials. Our goal here is to preserve the functional properties (information) present in the natural starting material and transfer them to the end product.

This enables us to develop completely novel materials or to modify surfaces in a targeted way. For example, we were able to successfully use hydrophobic proteins for water-repellent textiles.

Back to nature – Closed-loop approach
In addition to these ongoing activities, we will also be working on the circular economy in the area of (biobased) polymers in the future. One approach is enzyme screening for the degradation of (biobased) polymers. In the long term, we hope to make monomers or oligomers available in high purity for repeated polymerization.



Bioinspiration as a source for new synthesis routes and materials in the field of bioorganic chemistry.

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

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A new electro-biocatalytic CO_2 reduction process for synthesizing fine chemicals

Many industries are setting their sights on CO_2 as an important feedstock for synthesis in the context of developing climate friendly and resource-efficient innovations, and the chemical industry is not the exception. In general, CO_2 will play an important role in the future alongside renewable raw materials, as the greenhouse gas can be converted into other substances using renewable electricity.

To help achieve the transition towards carbon neutrality, a multidisciplinary research team from the Bioinspired Chemistry innovation field at Fraunhofer IGB is developing a new, modular electro-biocatalytic process in the project eBioCO_2n, funded under the collaboration program with the Max Planck Society. Using electricity and under very mild reaction conditions, the process fixates CO_2 into a substrate, so that it can then be used to manufacture valuable fine chemicals by means of carefully coordinated enzymatic cascades.

Applying the fastest CO_2 fixating enzymes

Special redox enzymes called enoyl-CoA-carboxylases/reductases (ECRs), studied at the research group from Prof. Tobias Erb at the Max Planck Institute for Terrestrial Microbiology in Marburg, are being used for the biocatalytic CO_2 fixation. These enzymes are among the most efficient biocatalysts when it comes to CO_2 fixation. For the CO_2 reduction to take place, the ECRs require the continuous supply of NADPH as cofactor. This small, organic molecule acts as a hydride donor, and is required at a ratio of one cofactor molecule per CO_2 molecule being fixated.

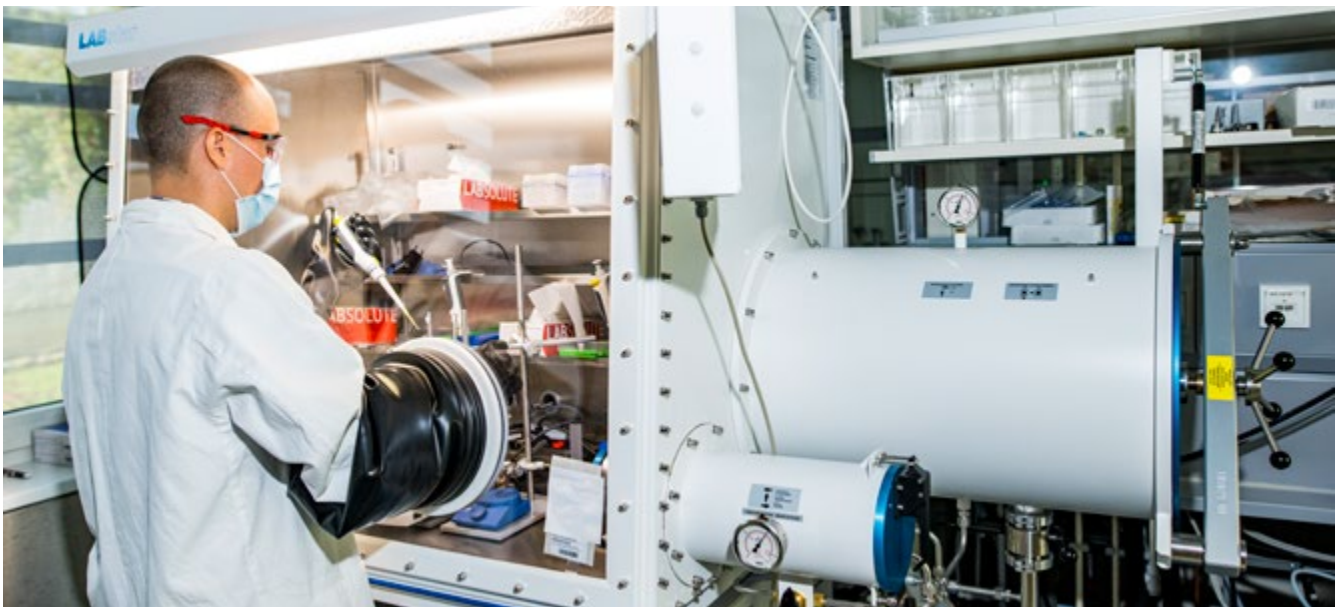
Regenerating the cofactor using electro-biocatalysis

Considering its high price, direct supply of NADPH would be very expensive making large scale application of ECRs not economically viable. As a result, the project team aimed towards a process that uses cheap green electricity to regenerate the cofactor molecules, so that its required amount could be considerably decreased while still continuously supplying the ECRs for the fixation of CO_2.

The electro-biocatalytic NADPH regeneration is achieved embedding ferredoxin $NADP^+$ oxidoreductase (FNR) in a custom-made redox-active hydrogel and drop casting it on an electrode. The FNR can continuously regenerate NADPH using electrons which are supplied through the electrode and transferred through the redox-active hydrogel. The basic principles allowing the three-dimensional flow of electrons were developed by a team from the Technical University of Munich (TUM), led by Prof. Nicolas Plumeré.

left:
In the "glovebox," the researchers investigate the functionality of enzymes electrochemically in the absence of air. The enzyme kinetics calculated on the basis of the measured current flow provide information on the most suitable enzymes for the eBioCO_2n process.

right:
The enzymes required for CO_2 fixation are biotechnologically produced and purified by FPLC for use in the redox-active hydrogel.



Demonstrating CO_2 incorporation into crotonyl-CoA

After achieving the electro-biocatalytic regeneration of NADPH, the CO_2 fixating platform was then built up by co-immobilizing one ECR homologue, crotonyl CoA carboxylase/reductase (Ccr). The platform enabled the regio- and stereoselective incorporation of CO_2 into crotonyl-CoA to produce ethylmalonyl-CoA, a prospective intermediate for the chemical industry, and the most complex product ever achieved in the electro-biocatalytic conversion of CO_2. The results of the studies were published in 2021 in "Angewandte Chemie," a scientific journal for applied chemistry, and selected as a "hot paper."

Modular platform technology

As the electro-biocatalytic reaction system can be extended on a modular basis, it can function as a platform technology. Depending on the target molecule (synthesis product), suitable enzymes can be selected from bioinformatic databases, manufactured using biotechnology, and embedded in the hydrogels. Consequently, the *e*BioCO_2n module can enable the manufacture of various biobased fine chemicals that can be diversified as needed using specific enzymatic cascades. This holds great application potential by companies in the pharmaceutical, agrochemical and food industries.

Outlook

Following this interdisciplinary approach combining CO_2 reduction, electro-biocatalytic technology, material chemistry and synthetic biology, the scientists were able to demonstrate the feasibility of the process at a milliliter scale. In the next steps, the team aims to complete the scaling and modular expansion of the process. Chemical synthesis based on biocatalytic CO_2 fixation is paving the way for a new form of circular economy by offering alternatives to fossil-based raw materials in chemical synthesis processes.

The enzyme for cofactor regeneration is dropped on the electrode together with the enzymes for CO_2 fixation. Both embedded on the redox hydrogel.

www.igb.fraunhofer.de/en/ebioco2n

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Polymers from biobased furanoates as substitutes for PET

PET is a fossil-based plastic used in large quantities for the production of packaging materials, for example beverage bottles, as well as for the production of fibers. The project "PFIFF – Polymers from biobased furanoates" aimed at tapping agricultural and forestry waste for the development of biobased polyesters to replace polyethylene terephthalate (PET).

development of new conversion processes and an increase in production with the ambitious goal of replacing one of the dominant plastics (PET) on the world market.

In the project, the Straubing BioCat branch of Fraunhofer IGB worked on two topics that are crucial for the future industrial production of PEF: the synthesis of FDCA from 5-HMF and the development of a process to purify FDCA to a quality sufficient for the production of high-quality polymers.

Polyethylene furanoate (PEF): Biobased sustainable packaging solutions.

Excellent properties of the polyester PEF
The polycondensate 2,5-furandicarboxylic acid (PEF) is easier to handle due to its lower melting point compared to PET and it is preferred for specific applications due to its higher glass transition temperature. PEF also has superior barrier properties to gases, making it predestined for use in the beverage industry. Its higher mechanical stability compared to PET means that smaller wall thicknesses and therefore less material can be used in the manufacture of packaging. The possibility of using agricultural waste as a raw material for the production of these biopolymers will considerably reduce production costs and thus lead to a cheaper packaging material compared to PET.

New raw material platforms for PEF
The focus of the PFIFF project was to develop new feedstock platforms for 5-hydroxymethylfurfural (5-HMF), which can be synthesized from sugars (fructose) and is considered to be a future new biobased platform chemical, and for furandicarboxylic acid (FDCA) obtained from 5-HMF, which represents the monomer unit for the production of PEF. Further tasks in the PFIFF project were the improvement of the polymer properties of PEF, as well as the

One of the major topics of BioCat's work is electrochemical synthesis. With this know-how, the Straubing scientists have succeeded in developing a promising process for the oxidation of 5-HMF to FDCA. Work on the purification of FDCA has also been very successful. With the commercially available FDCA purified at BioCat branch, the project partners were able to produce promising polymers for the planned applications.

Currently, the researchers are working on a second-generation purification process in the follow-up project PFIFFIG, which is to be transferred to the pilot plants at Fraunhofer CBP in the course of the project in order to enable the supply of larger quantities of purified FDCA to the project partners.

▸ *www.igb.fraunhofer.de/en/pfiff*

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Unraveling flexible fractionation of lignocellulose

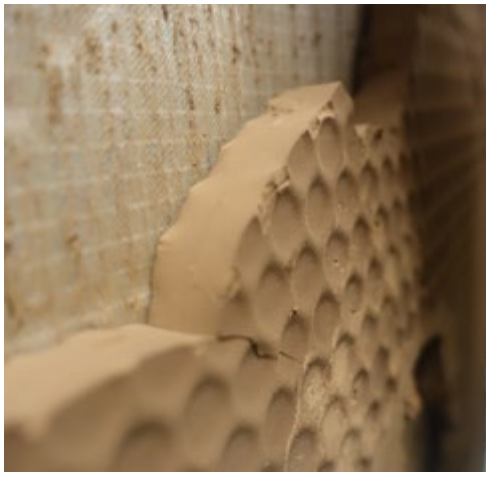
Lignocellulose represents a large proportion of the renewable raw materials on earth. The full utilization of lignocellulose as a raw material in the bioeconomy requires efficient and flexible processes of fractionation into the components cellulose, hemicellulose and lignin. In the BBI-EU project UNRAVEL, the novel FABIOLA™ organosolv digestion of lignocellulose was piloted for the first time. Acetone is used as the solvent. Compared to ethanol, it can be used at milder temperatures and the energy required for solvent recovery is reduced.

Successful scale-up of the flexible process

The concept was scaled up using the unique integrated pilot plant at Fraunhofer CBP. By integrating a pre-extraction step, it was possible to use complex feedstocks and residual materials such as birch wood with bark and branches or wheat straw. A mix of these raw materials was successfully processed as well. This demonstrated the flexibility of the process, which is a major advantage for industrial implementation.

Reprocessing and utilization of all three fractions

For the precipitation of lignin from the fractionation liquid, a process for continuous precipitation by evaporation of the solvent, patented jointly with the Max Planck Institute for Dynamics of Complex Technical Systems, was successfully transferred to the acetone process. After enzymatic hydrolysis of the cellulose, fermentation of the resulting glucose to acetone was successfully demonstrated on a 100-liter scale. The hemicellulose was fermented to xylic acid. The lignin was tested by the project partners CNRS and Soprema for applications in polyurethane foams and bitumen.



Outlook

The demonstration of the FABIOLA™ process at the CBP pilot plant provided promising results. If the techno-economic evaluation and life cycle assessment of the concept in the project are successful, the stage is set for industrial implementation.

above left:
Birch as raw material for use in the pilot plant.

above right:
Recovered lignin on the filter press.

below:
Hemicellulose filtrate after lignin precipitation.

▸ *www.cbp.fraunhofer.de/en/unravel*

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"Transnational Access" support SMEs in industrial biotechnology

IBISBA 1.0 is a project funded under the EU's H2020 Framework Programme with the aim of networking research institutions from across Europe to provide innovation services in the field of industrial biotechnology and accelerate the translation of life science research into industrial applications.

IBISBA 1.0 – Accelerator for innovation in industrial biotechnology and synthetic biology

Through IBISBA, it was possible for researchers, SMEs and large companies to gain subsidized access to the specialized research structures and facilities of the IBISBA network. A total of five calls for so-called Transnational Access Projects (TNA) were published regularly, to which researchers from the public and private sectors could apply.

Fraunhofer IGB is involved in a total of four TNA projects with its working groups Bioprocess Engineering and Bioprocess Scale-up.

Scale-up of microbial protein production for Calidris Bio

Last year, the first TNA project was successfully completed in cooperation with the Belgian start-up company Calidris Bio, which is active in the feed and food industry. Here, a fermentation process for the production of microbial proteins was optimized and scaled up to the 1 m³ scale. This allowed the provision of relevant data and sample quantities at Fraunhofer CBP for process evaluation and product testing.

Calidris Bio uses microorganisms that can convert available substrates into biomass with high protein content. The resulting microbial protein is rich in essential amino acids, vitamins, prebiotics and special fatty acids with customized composition and is suitable for application as feed for livestock, aquaculture and pets. Together with Fraunhofer IGB, Calidris Bio succeeded in taking a first step towards commercializing their process.

▸ *www.cbp.fraunhofer.de/en/ibisba*

At Fraunhofer CBP, the fermentation process was scaled up for the Belgian SME Calidris Bio to produce relevant sample quantities of the desired protein.

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A multifunctional coating system based on cationic surfactants made from vegetable oil

Bitumen-based coating systems have many different uses, such as sealing pipes and tanks, for example. However, as petrochemical materials, they perform poorly in environmental balance and they also contain non-biodegradable surfactants. The research project "BeStKat – Multifunctional coating system based on cationic surfactants consisting of vegetable oil" saw the development of the first partially biogenic coating systems that could be used for the same purposes as bitumen. Rather than fossil fuels, these new systems rely on vegetable oils and functionalized lignin. The researchers are hoping that their solution will not only be more environmentally sustainable, but will also offer a coating system that has a wider range of properties and will be easier to work with.

Coated metal samples (0 – 20 percent lignin content).

New biogenic cationic surfactants

It is in this context that Fraunhofer CBP has created a new synthesis of biogenic cationic surfactants, in which a cationic group is introduced into largely non-polar epoxidized oleic acid methyl ester by means of a reaction with betaine. The researchers used contact angle measurements to confirm the surfactant properties of the new molecule.

To make the coating system even more biogenic, they also added lignin to the mix. The lignin was chemically functionalized with carboxyl groups to enable more effective binding in the mixture. The concentration of the carboxyl groups was demonstrably increased from 1 to 2 mmol/g lignin through oxidation.

Acid- and alkali-resistant coatings with improved properties

Having worked with and tested a wide variety of coating systems in demonstrators (Fig.), Fraunhofer IMWS has been able to produce ligin-based coatings that are more stable when exposed to acids and alkalis than the reference coating. When weathered, the reference coating showed dripping at surface temperatures of up to around 40°C, whereas the coatings with lignin remained stable. This indicates that the lignin has been bound within the bitumen emulsion, which prevents dripping. Furthermore, adding lignin increased the hydrophilic properties of the coating emulsion, making the coating easier to work with and improving surface wetting.

Outlook

Overall, the new coating system showed better physical and chemical properties than the conventional system. After conducting life cycle assessment, the team will assess and test out the possibility of scaling the process with its project partner. The coating system could then be used for applications such as coating heat storage tanks and pipes or for abrasion-resistant coatings on conveyor belts. Other possible fields of application include the energy sector, machine and tool building, and transport technology.

▸ *www.cbp.fraunhofer.de/en/bestkat*

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Innovation alliance functionally optimized biosurfactants phase 2

The Biosurfactants Innovation Alliance is the first strategic alliance of renowned companies and research institutions in Germany aiming at finding sustainable and scalable alternatives to chemically synthesized surfactants, which have so far been produced from fossil raw materials. Therefore, we are examining and developing the technical production of biosurfactants in the alliance using biotechnological methods based on domestic renewable raw materials and residues. Together with our project partners, we systematically investigate their potential applications – for example, as components of detergents and cleaning agents, in cosmetics, bioremediation, crop protection and food.

Samples of different cellobiose- and mannosylerythritol lipid variants ready for shipment.

Comprehensive characterization of biosurfactants
During the first funding phase (2018 – 2020), the provision of regionally available sugar-, fat- and oil-containing raw materials was considered. A wide variety of microorganisms for the production of different biosurfactant classes were investigated, and promising candidates for subsequent process development on a laboratory scale were selected and investigated in terms of application technology.

Focus on process technology and scale-up
In the second phase of the project (2021 – 2024), greater emphasis will be placed on the implementation of scale-up. Here, the fermentation and purification processes are to be further developed in terms of robust, controllable processes and simplified purification methods to enable gradual scaling up to the next orders of magnitude.

Looking at the purification route, complex purification methods often represent the largest cost driver. Here, existing and innovative technologies need to be investigated, linked and optimized so that the number of steps for biosurfactant purification is minimized. The project partners are devoting themselves to this holistic process-related risk and cost minimization approach in the second phase of the project.

By providing larger sample quantities, the second phase will further provide detailed answers to open questions about the performance profiles of individual application areas. This is only possible with larger sample quantities from the 100-gram scale upwards, which goes hand in hand with an upscaling of the fermentation and downstream process.

Verification of safety-relevant properties
In addition, studies are needed to verify the safety profile for the environment and humans. In the second project phase, hazard analyses will therefore be carried out and safety data sheets prepared in order to identify necessary investigations for individual biosurfactants in the specific areas of application. This is particularly necessary because the criteria (regulations, guidelines) may differ fundamentally depending on the area of application, whether for use in cosmetics, food or cleaning agents, for instance.

▸ *www.igb.fraunhofer.de/biosurfactants-alliance-phase2*

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Piloting biotechnological production processes for industry

Industrial biotechnology is a key technology for the development of a sustainable chemical industry and especially for the bioeconomy. While academic research laboratories are widespread, pilot plants are still rarely found. Yet they are urgently needed, especially for smaller companies, to prepare innovations for the commercialization of new products. In addition to the technical advancement of biotechnological processes, the provision of larger quantities of material for application research as well as process data for economic and other studies on the feasibility of a manufacturing process are of particular importance.

Fraunhofer CBP – Partner for the optimization and scaling of biotechnological processes

For this reason, we are very proud that the Bioprocess Scale-up group at Fraunhofer CBP in Leuna was able to support 13 industry partners in the implementation of their projects in 2021, in addition to participating in publicly funded and internal projects. The commissioned work related to the scaling or optimization of fermentation processes, but also to studies on the scaling of downstream processes. In this context, a total of 37 fermentations were carried out on behalf of customers, seven of them on a 1000-liter scale and five on a 10,000-liter scale.

Broad product portfolio, international demand

The projects were carried out on behalf of various industries, e.g. in the fields of materials and plastics, food and dietary supplements, dyes, basic and bulk chemicals, and animal feed.

It is particularly pleasing that, with a 46 percent share of start-ups, we were able to support especially young and highly innovative companies with our services, not only nationally (33 percent) but also internationally (67 percent). In general, our customer base in 2021 included companies from nine countries on the three continents of Europe, Asia (incl. Middle East) and North America.

Some of our projects will continue in 2022, and we look forward to continuing to work closely with talented and enthusiastic entrepreneurs and scientists, as well as to new challenges in the context of new projects on the horizon.

Pilot plant for industrial biotechnology at Fraunhofer CBP in Leuna.

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

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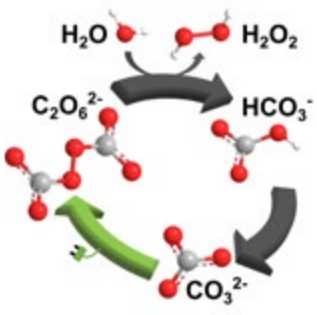
Successful conclusion of the CO_2EXIDE project: CO_2-based electrosynthesis of ethylene oxide

The international project CO_2EXIDE, coordinated by Fraunhofer IGB, has been successfully concluded in 2021. The project was funded by the European public-private partnership SPIRE (Sustainable Process Industry through Resource and Energy Efficiency) under the European Framework Programme for Research and Innovation Horizon 2020. The main goal of the project was the development of a reaction cascade to produce green ethylene oxide only from CO_2, water and renewable electricity as primary input. The consortium involved ten partners from six different countries. Besides Fraunhofer IGB, the project partners included prominent industrial players (Siemens Energy and Schaeffler AG), small companies (Axiom AG and EPC) and renowned universities from Krakow, Riga, Southampton and Budapest.



Suggested mechanism for anodic H_2O_2 production in aqueous electrolytes containing carbonate ions. (Source: Ref. [1]).

Novel process chain for producing green ethylene oxide

The CO_2EXIDE process starts with capturing CO_2 in a biogas plant in Bruck an der Leitha, Austria. After a membrane-based purification step, CO_2 is converted to ethylene (C_2H_4) via electrocatalytic reduction. In a tailor-made electrochemical cell, this reduction process, occurring at the cathode, was coupled to the simultaneous oxidation of water to hydrogen peroxide (H_2O_2) at the cell's anode. A specially designed ethylene enrichment facilitated the purification of ethylene from the gas mixture output of the electrochemical cell. The two products of the electrochemical process step, i.e. ethylene and hydrogen peroxide, were fed into a subsequent chemical reactor and converted to ethylene oxide under mild conditions.

Crucial step: Electrochemical oxidation of water to H_2O_2

Besides the significant role as coordinator, Fraunhofer IGB was responsible for the process development of the electrochemical oxidation of water to hydrogen peroxide (H_2O_2) and its application in the subsequent catalytic epoxidation of ethylene to ethylene oxide. Such interdisciplinary process development and integration represents one of the core competencies of the innovation field "Sustainable Catalytic Processes" of Fraunhofer IGB.

H_2O_2 is a green oxidant widely used in the chemical industry. Because its degradation releases only oxygen and water, it is considered an environmentally friendly chemical. In this context, the electrochemical H_2O_2 production, based on water, air and (renewable) electric energy as input, is a potential alternative for on-site applications. The electrochemical oxidation of water to H_2O_2 was a particularly challenging task in the CO_2EXIDE project. Nevertheless, Fraunhofer IGB's researchers were able to produce significant concentrations of H_2O_2 in an electrochemical flow reactor using simple and low-cost carbon-based catalysts. By varying the pH of carbonate solutions and accurately calculating the ionic activity of the carbonate species (HCO_3- and CO_3^{2-}), a direct correlation of activity of carbonate ion (CO_3^{2-}) and H_2O_2 generation could be unveiled. Based on this observed correlation, a cyclic reaction mechanism involving CO_3^{2-} ion oxidation to peroxodicarbonate ($C_2O_6^{2-}$) species was suggested for the anodic H_2O_2 generation in aqueous media (Fig.).

Prospects and applications

The electrochemical H_2O_2 production from air, water and renewable electricity is a promising "green" alternative for several applications requiring decentralized on-demand production H_2O_2. Such applications include water sanitation, bleaching, and customized in-situ H_2O_2 production for enzymatic and chemical processes.

▸ *www.igb.fraunhofer.de/en/co2exide*

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Making money using carbon dioxide?

As a result of the inclusion of CO_2 emissions from the combustion of fossil fuels in the traffic and heating sector in national emission trading, taken effect at January 1, 2021, climate change is now also financially noticeable. Regarding this, open questions remain within the industry: Can the costs for companies triggered by CO_2 emission pricing be reduced? Is it possible to decrease CO_2 discharge by innovative and biointelligent processes or process chains and alongside making money?

CO_2 – An almost unlimited "ressource"?
The climate gas CO_2 is a globally almost unlimited resource in the atmosphere, which can also be extracted from flue gas streams of industrial combustion processes. From the viewpoint of a producing company, a more reliable source of raw material, when atmospheric CO_2 is considered, can hardly exist.

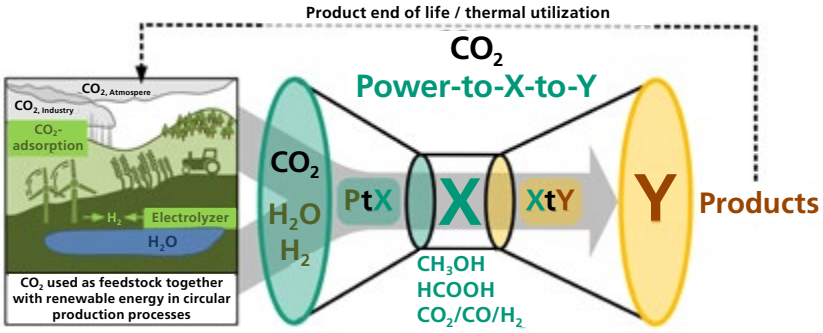
To date, the technology of adsorbing atmospheric CO_2 from air exists in form of air washers, which for example the Suisse company Climeworks developed recently. Due to the low CO_2 concentration (0.04 percent) in the air, the procedure is still energy and cost intensive.

In comparison to the atmosphere, for example, flue gas streams of cement- and steel facilities contain increased CO_2 concentrations. Therefore, these point sources provide the opportunity to utilize CO_2 as an intermediate in integrated value chains instead of emitting it as a waste product: The challenging waste product of the initial process turns into a useful feedstock for the second process and contributes to added value.

Commercial use of CO_2 – The way to go
Here, two economic levers useful for CO_2 discharging companies can be identified:

- On the one hand, cash can be saved by actively reducing CO_2 emissions.
- On the other hand, CO_2 can be used for the production of chemical added-value products and platform chemicals for commercial utilization.

A pioneer company developing such technology concepts is the New Zealand company Lanzatech, which produces bioethanol from steel industries' synthesis gas streams via gas fermentation. In addition, process cascades, which use CO_2 and renewably produced hydrogen gas from water electrolysis for production of intermediates such as methanol or formic acid depict an enormously important approach. These processes are often referred to as power-to-X technologies [1].



Extension of the power-to-X approach towards a power-to-X-to-Y concept pursued by Fraunhofer IGB.

Fraunhofer IGB is extending the power-to-X approach towards the power-to-X-to-Y concept, in which the CO_2 derived intermediates are further processed in coupled chemical and biotechnological procedures to more complex and higher-value products (Fig.). Using these techniques, various synthesis routes are accessible for a broad range of chemical products with increased added-value, relying on CO_2 as the primary feedstock. In this way, the urgently wanted path to an era of independence from fossil resources is paved.

▸ *www.igb.fraunhofer.de/making-money-with-co2*

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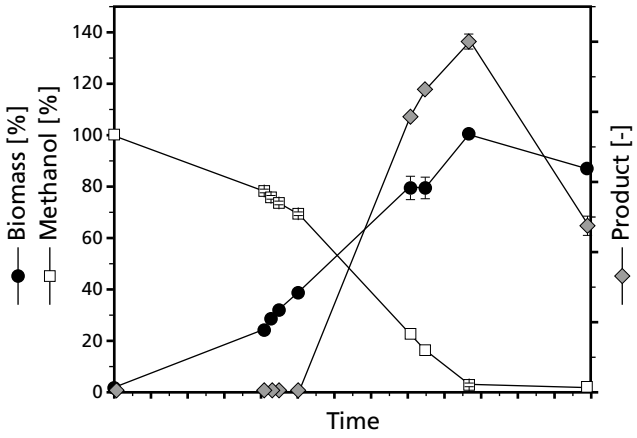
Biotechnological production of organic acids from methanol – An update

"Green" methanol can be produced easily from CO_2 and renewable energy. In particular, the use of CO_2 as a central raw material in chemical production has enormous sustainable potential. Especially the current political framework seeks such climate-positive approaches. Against this background, the joint research project EVOBIO, funded by the BMBF and Fraunhofer, was continued in the follow-up project EVOBIO-Demo by a Fraunhofer consortium consisting of the Fraunhofer institutes IGB, UMSICHT and IMW. Here, the focus is on the further development of a biotechnological production route for an organic acid from methanol.



Time course of the fermentation process for the production of an organic acid from methanol using genetically modified cells of M. extorquens AM1.

Methylotrophic fermentation as a starting point

In this context, methylotrophic microbes are promising host organisms which can convert methanol to value-added products in fermentation processes. A first-generation production strain for the synthesis of an organic acid, which had already been developed in the initial EVOBIO project, was initially characterized in terms of its production performance in the follow-up project and specifically improved by metabolic engineering and bioprocess development. This newly developed process for the production of the target organic acid from CO_2 is a promising future approach to support the reduction of industrial CO_2 emissions.

A promising process approach

After the identification of a tailor-made production strain, the production performance was evaluated in fermentation experiments. It was demonstrated that the first generation of the production strain was capable of producing significant amounts of the target product (Fig.). In the following project progress, rational strain development strategies based on in-silico modelling of the metabolism were identified to further increase the production performance and the product yield. In parallel, batch- and fed-batch fermentation experiments were conducted to identify further optimization strategies for the established process. In particular, it was targeted to produce exemplarily the organic acid from the so-called TCR® methanol provided by Fraunhofer UMSICHT to demonstrate the process cascade. The evaluation of the technology transfer potential to industry was carried out by Fraunhofer IMW. Finally, the results were included in an invention disclosure, which describes the developed biocatalyst.

Technology transfer to industry as a goal

These basic operations in EVOBIO-Demo demonstrated that it is possible to couple power-to-X processes with biotechnological production methods. In addition, such process cascades represent a promising approach for the valorization of CO_2 as a sustainable raw material. In a next step, the fermentation process will be further developed towards industrial application. Here, the search for interested project partners from industry has recently started.

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Recovering platform chemicals from condensate streams from the torrefaction of biomass using superheated steam

The drying and torrefaction process with superheated steam (SHS) is an excellent way of producing highly efficient biomass with good storage stability from lignocellulosic residues. This end product has a wide variety of applications: high-quality fuel, adsorbents, soil conditioners and even input material for pyrolysis or gasification processes.

Objective: Value creation from the valorization of condensable volatile substances
A by-product of SHS torrefaction is a condensate made up of water and potentially valuable substances, such as organic acids, methanol or furfural. In the VALORKON project funded by the BMBF, Fraunhofer IGB worked to develop separation processes that could be used to recover such platform chemicals at high purity levels from the condensate produced by the torrefaction of beech wood chips.

Separation of condensate streams
Fraunhofer IGB set up a batch rectification unit to separate the condensate streams into individual fractions. In combination with other separation processes such as extraction and electrodialysis, the researchers were able to recover furfural from the condensate at a very high purity level (95 percent). The purification of other valuable substance fractions, for example organic acids, is part of the ongoing work.

Environmental and economic assessment
In parallel to the technical work carried out at Fraunhofer IGB, Reutlingen University conducted an environmental and economic assessment of the entire process – from drying and torrefaction through to resource recovery using the condensate. The result is encouraging so far: The current process has a positive CO_2 balance and promising economic potential.

Outlook: Entire biorefinery process
The next steps towards pre-industrial development are the recovery of other products from the condensate, the transfer to a continuous, scalable complete process and its application using other biomass residues.

In addition, there are plans for a joint publication with Reutlingen University on the environmental and economic potential of the entire biorefinery concept.

left:
Condensate from the torrefaction of beech wood chips.

right:
Fractions recovered from the condensate.

▸ *www.igb.fraunhofer.de/en/valorkon*

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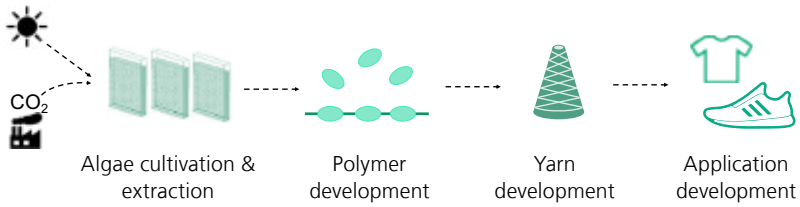
AlgaeTex – Spinning biobased polymer yarn from microalgae

With fossil-based resources becoming more scarce, the textile industry has an ever growing need to identify and develop alternative raw materials for manufacturing textiles fibers. In the AlgaeTex project, researchers are striving to manufacture a variety of polymers using algae-based fatty acids as the main constituent. Their goal here is to develop polyesters and polyamides suitable for melt spinning processes, so they can be widely used in the textile industry (Fig.).



Flow chart showing a new textile value creation chain based on raw materials produced from algae.

Optimized algae cultivation

Previous projects focused on developing the multi-stage processes needed for accumulating a fatty acid content of just over 50 percent in algal cells; now, in AlgaeTex, Fraunhofer IGB is optimizing those processes [1]. Meanwhile, a pilot plant at Fraunhofer CBP has already conducted open-air production trials using both sunlight and artificial light. When compared to the space required for agricultural production, algae cultivation with artificial lighting is 500 times more effective in its use of space.

Energy efficiency gets a boost with a new, compact, modular photobioreactor

This improved use of space comes at a price: electricity consumption is high, with one kilogram of algal biomass requiring 70 – 100 kWh of energy. The IGB team needs to make the accumulation of high levels of fatty acids in the biomass as efficient as possible and to optimize the conversion of light energy within the algal biomass. To achieve this, they will carry out extensive testing with the institute's newly constructed compact, modular stack photobioreactor. The bioreactor is equipped with unique features such as extensive LED lighting and connections between the individual chambers, which makes it possible to harness their entire combined capacity.

Reprocessing and polymer synthesis

At Fraunhofer CBP, the fatty acids are extracted and reprocessed to form biodiesel (fatty acid methyl ester, FAME), which is then passed on to the Macromolecular Chemistry II department at the University of Bayreuth for further processing. Using a green chemistry approach, the scientists at the university synthesize basic bifunctional monomers (such as diols and dicarboxylic acids) that can be polymerized to form polyamides and polyesters suitable for melt spinning. The process continues at the Institute of Textile Technology in RWTH Aachen University, where the polymers are extruded and tested for their suitability for melt spinning. Then, in conjunction with Adidas AG, the RWTH team assesses whether the materials can be processed to form a woven textile.

Outlook

As the project continues, the team hopes to process the algal yarn further to create high-quality textile demonstrators. In particular, they intend to investigate whether their multifilament yarns are suitable for application in textiles for the sport industry at Adidas AG. The innovation space BioTexFuture was established with the objective of driving the textile sector's transformation from petroleum dependency to a biobased industry. As it helps the German textile industry take this major step toward sustainability, the AlgaeTex project is also supporting the sector's future viability.

▸ *www.igb.fraunhofer.de/en/algaetex*

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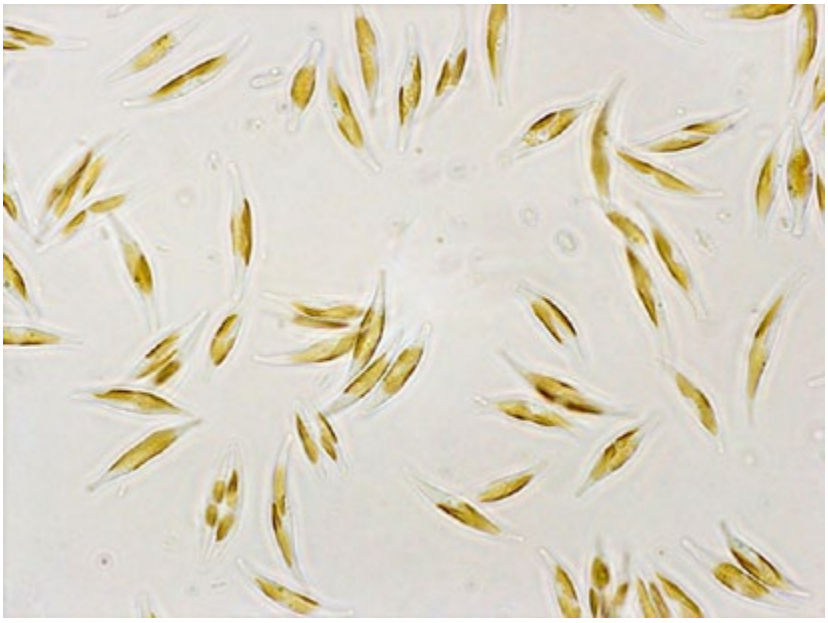
Chrysolaminarin, soluble β-glucan from microalgae

Diatoms which belong to the microalgae, produce chrysolaminarin, a soluble β-1,3-1,6-glucan as an energy and carbon storage. Due to its immunomodulatory properties, the polysaccharide is suitable for application in human or animal nutrition. Plants also react to contact by activating their defense mechanisms. Therefore, the β-glucan has a possible application as a plant strengthening agent in agriculture as well.

Chrysolaminarin for plant strengthening
In the application area of agricultural production, field trials were carried out by our project partners in 2021, after chrysolaminarin had previously been successfully tested as a plant strengthening agent in the greenhouse. The aim of the trials was to reduce the amount of copper needed as a fungicide in viticulture by using the β-glucan. However, further field trials in different vegetation periods are needed to obtain reliable results.

Chrysolaminarin for animal nutrition
In animal nutrition, experiments with our soluble β-glucan have been successfully conducted by project partners. Feeding trials on fish showed that β-glucan extracts, specifically from the diatom *Phaeodactylum tricornutum*, have a positive effect on the intestinal health of juvenile fish in aquaculture due to their anti-inflammatory and antioxidant effects [1]. In experiments on zebrafish, a cholesterol-lowering effect of β-glucans from microalgae was observed, similar to the effect of β-glucans from yeast already on the market [2]. The results show that β-glucans from algae could possibly also be used as cholesterol-lowering agents in human nutrition. However, this requires further studies.

Optimization of the production process
In addition to supporting our project partners in application trials, our work at Fraunhofer IGB focused on improving the production process of β-glucan with microalgae (upstream processing). Thus, scenarios were developed on how the β-glucan process can be implemented on an industrial scale. Moreover, the extraction of β-glucan from the produced biomass (downstream processing) was also further investigated and optimized. For this purpose, β-glucan extraction was integrated into an already existing biorefinery concept described by Derwenskus et al. [3].



Diatom Phaeodactylum tricornutum

Outlook
We were able to acquire further projects to continue our work on this interesting topic. In addition to further experiments on possible applications, the focus is on the implementation of the β-glucan production process, its scale-up and automation. Special attention will be given to sensor technology and bio-intelligent process control in order to further optimize the yield and energy efficiency of the production process.

▸ *www.igb.fraunhofer.de/en/mirefung*

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Environment

Sustainable resource management for industry, municipal government and agriculture

The Environment business area develops systemic solutions that provide integrated environmental protection for industry and for city and regional authorities, both in Germany and abroad. Our activities in this field comprise the development of new ideas and processes as well as individual solutions and products. Our aim is to achieve the greatest possible efficiency in the use of resources by taking into account the idea of the circular economy and the question of sustainability.

Fraunhofer IGB is active in the development of

- innovations and solutions in water management and water treatment,
- processes for generating biogas from organic waste and residues,
- solutions that recover and reclaim nutrients from wastewater, organic waste and residues,
- processes for drying/torrefaction of organic waste fractions to produce soil conditioners,
- separation processes on the molecular and atomic level for the recovery of precious metals, and rare earth compounds as well as
- humidifier membranes for water management in fuel cells.

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).

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 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 fertilizers to biostimulants for agriculture. 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, analytics, automation and data analysis.

Biogas

Biogas is a key enabler in the energy transition, because it can be produced independently of the sun and wind and can be stored for a long period of time. Our method of high-load digestion for the efficient production of biogas from sewage sludge has already been implemented at a number of municipal wastewater treatment plants. We also develop specific solutions for the conversion of biowaste to energy. These range from fermentation tests to the design of plants on a technical scale and the optimization of agricultural biogas plants in terms of productivity and efficiency.

Secondary resources, raw materials and water reuse

With its 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 from industrial and agricultural sources.

▸ *www.igb.fraunhofer.de/environment*

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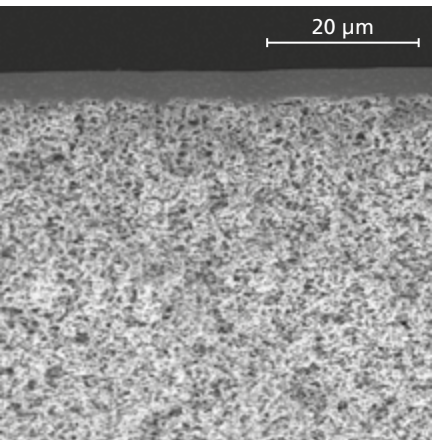


above:
Test rig for parallel characterization of three humidifier membranes.

below:
SEM image of an IGB flat membrane for humidification.

Humidifier membranes for water management in fuel cells

One approach to sustainable energy management is the use of hydrogen as an energy carrier. This can be generated by electrolysis, using fluctuating renewable energy, and can then be used for mobile and stationary applications in which electric power is generated with fuel cells. The management of the resulting water plays an important role for the performance and lifetime of the fuel cell. Membrane humidifiers can be used as an external component to protect the ionomer membrane in the fuel cell from drying out at any time. However, commercial membrane humidifiers do not adequately meet the very demanding requirements for automotive applications in terms of water transfer, long-term stability, harmful gas tolerance and cost.

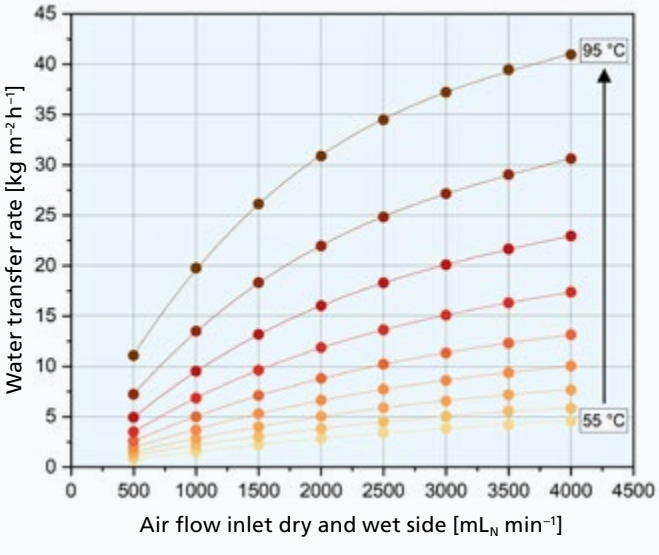
Test rigs for automated testing of humidifying membranes

In the AMBITION project, the Membranes innovation field at the IGB has built up an extensive infrastructure (Fig. above left) and the corresponding know-how to comprehensively characterize humidifier membranes. In the meantime, a total of four test rigs for hollow fiber and flat membranes are available to determine the water transfer of humidifier membranes in relevant parameter spaces automatically (24/7) (Fig. below). Furthermore, gas leakage tests and long-term stability investigations are performed. With the help of these data, membranes can be rationally evaluated and also different geometries can be compared with each other. This know-how is offered as a service to customers.

Development of humidifier membranes

However, the existing infrastructure for testing and our membrane expertise is also used to develop humidifier membranes in a targeted manner in the HIKS project. Based on the preliminary work on coated hollow fiber membranes [1], it is now possible to coat flat membranes roll-to-roll with suitable fluorine-free polymers on a Coatema Smartcoater (Fig. below left). One material approach here is the use of hydrophilic, uncharged polymers crosslinked via suitable reactions [2]. The membranes developed in this way thus represent a good alternative to commercially available membranes with their humidifier performance.

▸ *www.igb.fraunhofer.de/humidifier-membranes*



Typical measurement curve for water transfer with a variation of overflow and temperature in a counterflow module.

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Coating of additive manufactured bionic filters for air and water purification

Both clean air and clean water are of fundamental importance for the health and quality of life of humans and animals. Unfortunately, air and water are often polluted with various substances, some of which pose a risk to our health and/or the environment and must be removed. When these pollutants are particles, filters are generally used for their removal. However, filters cause flow resistance and thus necessitate greater pump power for material flows – in this case air or water.

In the joint project "Bionic Filters (BiFi)," which is funded by the Carl Zeiss Foundation (Carl-Zeiss-Stiftung), scientists from the Heilbronn University of Applied Sciences (HHN) and Fraunhofer IGB are working together to develop filters that are characterized by high filtration efficiency and minimum flow resistance. To that end, the researchers are using flow simulations, additive manufacturing and coating technologies to create new filters. Fraunhofer IGB has been entrusted with the development of the coatings. The purpose of these is to ensure that aerosols, pollen and particulate matter cannot permanently attach to the air filters and can instead be removed mechanically or using a brief counterflow. Other anti-adhesive coatings will be designed as part of the project, which will be of interest for not only air purification but also the removal of microplastics from water.

Oil- and water-repellent coatings

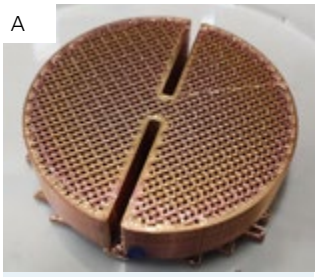
The project partners at the Heilbronn University of Applied Sciences computed the initial range of filter structures and produced these using additive manufacturing. These printed filters were then coated at Fraunhofer IGB to optimize the surface properties. The figure shows an example of an air filter equipped with a very thin metallic coating (antistatic, approx. 30 nm). An additional coating of just a few nanometers in thickness was then applied using plasma polymerization. This coating has oil- and water-repellent properties and protects against corrosion at the same time.

Outlook

Optimized filters offer enormous potential for many different separation tasks: Beyond the aforementioned task of removing particles from gas and water flows, the separation of different liquid phases, e.g. like in diesel fuel filters, is also an aim of the project. This filter optimization will ideally improve filtration efficiency and, at the same time, save energy as the pressure drop across the filter should be significantly lower than before. The project's filter development, which will initially focus on the above-mentioned main applications, will act as the starting point for individual further developments.

▸ *www.igb.fraunhofer.de/bionic-filters*

A



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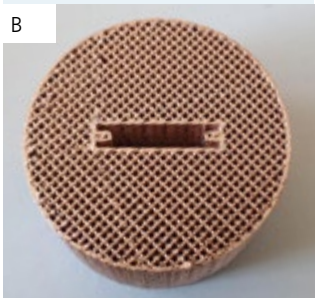
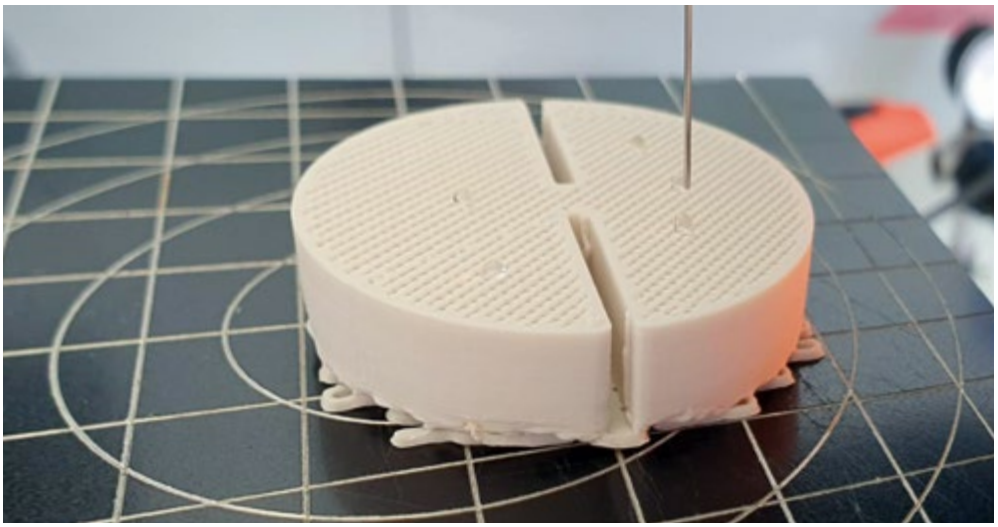


above:
Additively manufactured, coated filter specimens with recesses (A+B) for coating analysis.

below:
Filter test specimen with antistatic finish and water-repellent topcoat.



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Methanogenic stage of anaerobic biogas installation with fixed-bed circulation reactor.

Demand-driven biogas production as a contribution to the energy transition

Power generation from biogas must become more flexible in order to be able to compensate for fluctuations in power generation from the sun and wind. To achieve this, the anaerobic digestion process must be operated in such a way that the microorganisms involved in methane production can react quickly to changes in operating conditions. As part of the NextGenBiogas project funded by the German Federal Ministry of Food and Agriculture (BMEL), Fraunhofer IGB is working with Hamm-Lippstadt University of Applied Sciences to develop a process that makes this possible.

Applied concept

The anaerobic digestion process is a so-called two-stage anaerobic system: in a first, hydrolytic stage, acid formation takes place, and in a subsequent, methanogenic stage, biogas is formed. For running the two-stage system efficiently, the following criteria should be considered: the construction of reactors involved in both stages, the operating conditions, the composition of the inoculum, and the composition of the feeding substrate. In order to be able to quickly increase methane production in the second stage if required, easily convertible organic acids and alcohols are produced as storage medium in the first hydrolytic stage. The identification of microorganisms with good adaptation properties to changes in system operation for fast and efficient methane production is an important topic within the NextGenBiogas project. The hydrolytic stage and the methanogenic stage have been tested separately under laboratory conditions.

Efficient acid production in the hydrolytic phase

In the hydrolytic stage, the optimal conditions for fast and efficient acid production have been identified corresponding to the highest potential methane production, which can be obtained when applying this hydrolysate in the methanogenic reactor. The optimal conditions were found under t = 51°C, pH = 5.5, the addition of organic dry residues in the amount of 30 g. The highest acid formation was achieved at the ratio of shredded corn silage to cattle slurry of 50:50 in the substrate input.

Flexible and demand-oriented biogas production in the methanogenic phase

In the methanogenic stage, different scenarios of flexible feeding have been tested, aiming at the fastest microorganisms' recovery and the highest biogas production efficiency after selected starvation phases. The synthetic medium corresponding to the hydrolysate from the first stage is used as a feed substrate.

Process monitoring and regulation through microbial approach

Alongside monitoring and evaluating the experimental trials, metagenome and metatranscriptome analyses of the inoculum and the samples from the two-stage system are carried out [1–3]. Based on the acquired microbial data, we were able to both classify the species involved in each case and determine their relative abundance. This information enables us to map the microorganisms involved in the fermentation process. By conducting the metagenome and metatranscriptome analyses, the microorganisms' behavior in response to the experimental changes will be identified and assessed. This enables targeted inoculation of the process with these microorganisms, and in addition, the search for the optimal growth conditions could be streamlined.

Outlook

The ongoing lab-scale experiments are aimed at optimizing biogas production in the methanogenic phase, which is carried out in a fixed-bed circulation reactor. The obtained results are of the most interest for designing and operating a two-stage anaerobic system for biogas production in full-scale.

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

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Large-scale implementation of water reuse in a hydroponic system

Competing demands for water pose a significant conflict potential over regional water resources. These are not uncommon. Due to climate change, urbanization and pollution of water resources, these conflicts are expected to intensify in the coming decades. Even in Germany that is rich in water, conflicts of use are becoming more frequent. This is why new concepts and processes for water reuse are needed.

From 2016 to 2020 hydroponic plant production involving reclaimed water was piloted for the first time in Germany in the research project HypoWave, which was funded by the German Federal Ministry of Education and Research (BMBF). A case study conducted in this project identified a possibility as well as interested stakeholders for large-scale implementation of this approach in the region of Gifhorn (Lower Saxony). Since the beginning of 2021, we have been supporting this in a new alliance, the HypoWave+ project, which is coordinated by the TU Braunschweig and also funded by the BMBF.

Wastewater becomes an important resource when it is cleaned in an environmentally friendly manner and used for hydroponic plant production.

Research approach
The aim of the transdisciplinary research team is to establish a new form of regional vegetable production. Based on the results of the HypoWave research project, farmers in the Gifhorn region decided to establish a company that produces hydroponically grown vegetables. HypoWave+ accompanies this project scientifically and investigates open questions in the areas of water treatment, vegetable production, intelligent process control, quality management and institutional arrangements. The aim is to further develop the marketability of hydroponically produced vegetables by means of environmentally friendly water recycling with the aim of applying it at other locations as well.

Digitalization and risk management
Within the framework of HypoWave+, Fraunhofer IGB is working on the integration of the implemented plants and processes by digital tools. To this end, the team is coordinating the work on integrated data acquisition and control of the water treatment and the greenhouse production, as well as on setting up and operating the infrastructure required for data acquisition, data processing and plant communication.

Furthermore, the IGB coordinates the detection of (plant)-pathogenic microorganisms and viruses in the treated water. Finally, in close collaboration with the other partners the IGB brings in its technical expertise on questions of acceptance and quality of the new process chain in the associated risk management regime. The latter is also relevant in the context of EU Regulation 2020/741 on minimum requirements for water reuse, which was published on June 26, 2020 and which will come into force on June 26, 2023, across all member states of the European Union – and thus also in Germany.

▸ *www.igb.fraunhofer.de/en/hypowave-plus*

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above:
The studied cities of Kochi, Piura, and Saltillo.

right:
Polluted canal in Kochi.

Morgenstadt Global Smart Cities: Water worldwide

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

Adapted methodology for emerging countries

For this reason, as part of the International Climate Initiative (IKI) of the German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Production (BMUV), the methodology for urban analysis of the Morgenstadt City Lab has now been adapted to conditions in emerging countries and carried out as an example in the following three cities: Kochi (India), Saltillo (Mexico) and Piura (Peru). The aim of this Morgenstadt Global Smart Cities Initiative (MGI) was to use these analyses to identify potential opportunities for climate protection as well as adaptation to climate change in the three cities. Fraunhofer IGB is involved here in the areas of drinking water supply, wastewater treatment and flood protection.

City Lab analysis reveals climate potential

The City Lab methodology has been successfully adapted to the conditions in emerging economies in the context of this project and has proven to be particularly useful in the context of climate change adaptation and limiting greenhouse gas emissions. After conducting a sectoral analysis, including interviews with stakeholders from the water sector, a list of specific project proposals was generated for the analyzed cities that shall improve their resilience to climate change and help reduce greenhouse gas emissions (see table). Some of the exemplary solutions, such as the proposal for sustainable redevelopment of an urban neighborhood in Kochi, can serve as a blueprint for other cities with similar conditions. Pilot implementation of some of these measures is planned for 2022.

Outlook

The support for developing countries in climate protection and adaptation to climate change by industrialized countries recently discussed at the UN Climate Change Conference in Glasgow in November 2021 makes clear that in the future it will be important to identify the appropriate measures. The pledge was for 87.4 billion euros a year, which is urgently needed. At the same time, however, they must be used sensibly.

▸ *www.igb.fraunhofer.de/en/mgi*

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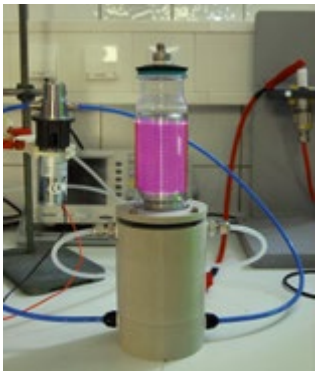
Comparison of cities and measures

	Water sector city profile	Proposed measures
Kochi, India	The city of Kochi has a population of about 600,000 inhabitants, the urban agglomeration of about 2.1 million habitants. Kochi is the economic, touristic and commercial center of the state of Kerala in southwestern India. Over the past decade, increased frequency of extreme rainfall events, sea-level rise and rising temperatures have led to growing concern as well as incidents with fatalities and high property damage. Geographic risk factors for climate change impacts: ■ Altitude 5 m above sea level ■ 48 km of coastline ■ Surrounded by network of rivers, ditches and canals Water supply ■ Main water source: Periyar River, 20 km northeast of the city ■ 85% of the population with access to central drinking water supply ■ Drinking water supply not regular, therefore additional supply with private water tankers or from bore-wells ■ 40–80% water losses due to old, leaking pipes Wastewater disposal ■ 71% of households use private septic tanks ■ Only 3–6% of households connected to sewer system ■ Most of the wastewater is discharged untreated into the environment	In Kochi, 15 project proposals were developed and submitted to the city in the form of a roadmap. One of these proposals is the exemplary integrative development of a Sustainable Neighborhood, which can serve as a blueprint for other areas in the city, as well as for other cities with similar conditions. ■ Installation of photovoltaic systems on roofs → Decentralized generation of regenerative energy ■ Construction of green infrastructure for rainwater storage → Reduction of the risk of flooding, cooling effect for entire urban area through water evaporation ■ Decentralized wastewater treatment and organic waste composting → Reduction of soil and water pollution and improvement of quality of life
Piura, Peru	The city of Piura has a population of about 500.000 inhabitants and is the capital of the province of the same name, located in northwestern Peru. ■ Location in desert region, along the Piura River ■ Low rainfall, low water level in the river ■ Poor water quality of the river due to discharge of sewage and waste ■ Heavy rainfall and flooding due to geographic location (El-Niño-Southern Oscillation, ENSO) ■ Critical average annual rainfall of only 223 mm ■ 95% of households connected to central drinking water supplies	■ Installation of nature-based solutions (NBS), e.g. floodable park on the banks of the Piura River or bamboo park ■ Implementation of decentralized wastewater treatment systems with reuse of treated water to irrigate green areas on site ■ Identification and repair of leaks through digitalization of the water supply system to mitigate water losses
Saltillo, Mexico	The Mexican city of Saltillo has a population of approximately one million inhabitants. The City's "Environmental Agenda" emphasizes the commitment to initiate a transition to sustainable urban development. ■ Water scarcity due to geographic location in Coahuila Desert ■ Critical average annual rainfall of 370 mm ■ Expectation that climate change will increase prolonged droughts and floods in intensity and frequency ■ Water has played a critical role in urban and economic development in recent decades ■ 99.6% of households connected to central drinking water supplies	In Saltillo, the responses from the interviewed stakeholders showed a clear common concern regarding water availability. To mitigate water scarcity, an increase of rainwater infiltration into the permeable soil is targeted. ■ Implementation of green infrastructure all over the city, e.g., rain gardens, green rooftops, vegetated median strips or pedestrian ways → Increasing the infiltration rate during rain events → Function as a sustainable water storage buffer ("sponge city effect")



above:
Batch reactor for UV-C/H_2O_2 treatment of water.

center:
Plasma reactor for pollutant removal from water.

below:
Determination of transferred ozone, foaming risk and treatment cost.

Removal of trace organics and hard COD

Pollutant of the month

"The new pollutant of the month" chemists in water analytics often joked when they had matched another one of the many recurring peaks in the analytical spectrum of wastewater samples to a specific substance. If it is an artificial, man-made substance that is or could be toxic such an identification can provoque a wave of media coverage and in case of real concern a wave of further measurements and political initiatives.

Regulated monitoring of micropollutants in water

On a European level the process is more systematic. REACH regulation [1], EU-monitoring lists [2], regular reporting as part of the water framework directive [3] and regular updates of the EU directives for drinking water [4] and urban wastewater [5] include risk evaluation and assess systems as a whole. The limit values of EU directives are then successively implemented into national legislation. The German Federal Center for Trace Substances at UBA, located in Leipzig, was founded in 2021. It connects interest groups with the goal to reduce critical substance emissions to water even faster.

Many German wastewater treatment plants are currently already planning or building an additional treatment step called the 4th stage to further reduce emissions – usually ozonation and filtration or active carbon adsorption. This is already obligatory in Switzerland and in wastewater treatment plants which indirectly feed into drinking water reservoirs.

However, the lists of substances to monitor are growing longer, as are the lists of individual substances of potential concern. Intensive research is currently being conducted into the avoidance, replacement and removal of per- and polyfluorinated substances (PFAS), which are man-made and have been proven to be detrimental to human health in some cases.

Fraunhofer IGB is part of this and offers independent scientific consulting

The IGB offers independent scientific consulting on pollutants and trace pollutants removal to public and industrial customers. Our technicians regularly test degradation of biologically inert organic pollutants called hard COD by ozone and UV-C/H_2O_2 because accumulation of hard COD prevents closed water cycles in many production lines. Our engineers and scientists compare these treatment options to our customer's respective alternatives, e.g. filtration and adsorption units.

Development and application of emerging technologies along with their critical assessment in view of environmental and economic benefits is our daily task in several research projects. These national and international cooperations of several partners are often partially supported by public funds.

Plasmaoxidation, electrooxidation, 172-nm UV-irradiation and catalytic degradation induced by UV-A or sunlight can remove water pollutants at concentrations of several hundred mg/l but also at trace levels of a few ng/l. This is however only useful in those cases in which pollution prevention and biological treatment are inefficient.

▸ *www.igb.fraunhofer.de/en/aop*

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The wastewater treatment plant as a biorefinery?

The path to the bioeconomy is a transformation process that changes established value chains and develops them into communicating value networks. In this course, Fraunhofer IGB is developing concepts for a complete transformation of wastewater treatment plants into wastewater biorefineries with the use of residual and waste materials.

Bioeconomy approach for local circular economy

This can be an important building block in terms of a local circular economy and a modern bioeconomy approach and is essential for closing material cycles. The focus here is on the recovery of nutrients and other valuable materials and the use of side streams such as CO_2 for the manufacture of downstream products. Products manufactured in this way are to be used iteratively in value-adding processes as starting materials in order to be able to realize a truly sustainable circular economy.

Solution approach: Process combination centered on recyclable materials

The project "Sewage sludge as a source of raw materials and climate protection at wastewater treatment plants" (RoKKa), which is funded by the state of Baden-Württemberg, pursues the vision of driving the development toward a wastewater treatment plant as a biorefinery by linking innovative processes in a value-centered, climate-friendly and participatory manner. By integrating the infrastructures at the wastewater treatment plants, which are already working efficiently for environmental protection, it will be possible to transfer the approach of a wastewater treatment plant as a biorefinery.

High-load digestion enables valuable material production from sewage sludge and CO_2 utilization

RoKKa uses a total of six pilot plants at the Erbach (Danube) wastewater treatment plant to demonstrate the production of valuable substances from the partial stream of sewage sludge treated in a high-load digestion system. Nitrogen and phosphorus recovery is coupled with the production of microalgae. Carbon capture and utilization (CCU) as a basic chemical will be piloted with the CO_2 in the biogas stream. As a result of RoKKa, environmental protection goals of wastewater treatment plants can be considered multidimensionally in the future (water protection, bioeconomy, climate protection).

High-load digestion at the Erbach wastewater treatment plant.

Outlook

The Ulm-Steinhäule wastewater treatment plant (440,000 population equivalents), which is only 20 kilometers away from Erbach, also plans to treat the sewage sludge in a high-load digestion system in the future. When the high-load digestion system is commissioned, a large proportion of the ammonium contained in the sludge will be dissolved back and fed back to the wastewater treatment plant via the sludge water. The AmmoRe nitrogen recovery process piloted in Erbach could be used here to reduce the nitrogen load on the one hand and to recover the nitrogen as a valuable substance on the other. In this respect, the participation of the Steinhäule sewage treatment plant in the RoKKa project is a good driver for implementing the piloted processes in a technical scale.

▸ *www.igb.fraunhofer.de/en/rokka*

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Water 4.0 – The digitization of the water industry

As in many other areas of life, digital applications become increasingly important within the water industry. Modern sensors, complex modeling, artificial intelligence or digital twins offer incredible application potential for resource management, the monitoring of water flows and qualities or even in the optimization of technical plants and processes for water treatment.

At Fraunhofer IGB, we are working in an increasing number of projects on the development and integration of digital applications in environmental engineering applications. One main focus is on establishing efficient data and communication infrastructures to enable effective communication of sensor-based system components and smart process control. Here, we bring in our longstanding experience and expertise in automation technology for environmental engineering plants.

above:
The degree of contamination of street drains can vary greatly.

below:
Air sensors in Erlangen and Ludwigsburg monitor air quality on roads – the data is used to help in modeling road drainage.

System architecture for AI-optimized process control
In the "Hypowave+" project funded by the German Federal Ministry of Education and Research (BMBF), we are working together with research and industry partners from agriculture and water management on safe water reuse in a hydroponic greenhouse. As IGB, we are coordinating the work on digitization with the objective of integrating the numerous process, plant and sensor data into an overall process control system.

With our work, we enable the effective communication of the environmental technology systems and develop an overarching control system for the entire treatment and reuse scheme. This communication then enables our partners to perform analyses using artificial neural networks (KNN), the results of which serve to automatically optimize the overall control system and thus all system components along the process chain. In this way, optimized solutions for the sometimes competing objectives – nutrient elimination in wastewater treatment and nutrient supply in plant cultivation – are identified. The derived measures, for example an extended aeration time, are communicated back to the corresponding components and trigger the respective process adaptation as needed.

In addition, we are investigating the potential of digitization for hygiene risk management in water reuse, for example with regard to pathogens and how the results of microbial investigations in the laboratory, e.g. for the detection of viruses and bacteria, can be linked to sensor-based monitoring in order to ensure adequate hygiene in an efficient manner.

Data-supported control of blue-green infrastructures
The communication and data-based optimization of water management components is also the subject of our activities in the BMBF project "Leipziger BlauGrün." At the campus of the Helmholtz Centre for Environmental Research in Leipzig, we are working on automated control of rainwater runoff from green roofs. The pilot green roof is installed on a carport at the campus and is used for rainwater collection and retention. The substrates within this green roof are monitored for moisture, conductivity and temperature by sensors. In addition, the fill level of the connected cistern is continuously measured. The higher-level data collection system also interfaces with a weather station. If a heavier rain event is predicted, the green roof and cistern can be drained in a controlled manner to create controlled runoff and make room for further rain retention. At the IGB, we are involved in developing the infrastructure for data collection and communication. A key challenge here is the harmonization of different communication formats and the integration of existing system components with newly implemented elements. Here, the expertise of the IGB in process automation and in handling measurement data can be transferred to the level of the urban neighborhood.

Modeling for use of alternative water resources
Besides green and blue infrastructure, grey infrastructure elements, such as roads account for the largest part of urban spaces. In the BMBF project "Straße der Zukunft" (Road of the Future), we are investigating sustainable concepts for more resource efficiency in the streetscape. To investigate whether and under what circumstances rainwater collection on

streets can be suitable for purposes such as irrigation, we are using air quality sensors and analyzing possible correlations with water quality parameters of street runoff. As part of the project, a rainwater cistern with a capacity of 50 cubic meters was also installed in Ludwigsburg's Dragonergässle in the immediate vicinity of several school buildings. The cistern is continuously monitored digitally for its filling level. Due to the high level of pollution in the street runoff, the collected rainwater is primarily used for sewer flushing. With the help of laboratory analyses of rainwater and street runoff quality as well as air quality sensors, scientific research is being conducted to determine the extent to which predictions can be made about the water quality of surface runoff. These could then serve to promote a broader use of collected rainwater, such as the irrigation of green spaces, and thus contribute to greater resource efficiency in streetscapes and neighborhoods.

Driving digitization together with partners

This small excerpt already shows the diverse development and application possibilities of digitization in water management. In addition, there are many opportunities for cooperation with companies and municipalities in Germany and abroad. For example, as part of the "Smart Water Monitoring Solapur" project funded by the Landesagentur Umwelttechnik BW, we are working with the measurement technology providers Jumo GmbH and Nivus GmbH, our partners in the German Water Partnership network, to implement a digital monitoring system at a drinking water plant in Solapur, India. Increased data availability will enable operators to identify faults more easily and optimize their operations.

Sustainability goals are crucial for tomorrow's cities, but additional dimensions such as resilience or adaptability to increasing extreme situations and changing framework conditions require new approaches, strategies and infrastructures. Together with partners from administration, industry and research in the Fraunhofer Morgenstadt network, we are driving digitalization for sustainable water management.

above:
The mayor of Solapur inaugurating the Jumo control cabinet.

below:
Technicians from Jumo and the drinking water plant in Solapur are installing the sensors.

▸ *www.igb.fraunhofer.de/water-digitization*

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*e*BioCO$_2$n

Researchers at Fraunhofer IGB, together with partners from TU München and the Max Planck Institute for Terrestrial Microbiology, have developed a new process for utilizing the greenhouse gas CO_2: In the *e*BioCO$_2$n project, CO_2 is electricity-based fixed to a substrate in an electrochemically driven enzyme reaction, and converted into biobased fine chemicals with further enzyme cascades. With the help of renewable energy, the novel modular electrobiocatalytic process thus enables the climate- and resource-efficient production of specialty chemicals for the pharmaceutical, agrochemical or food industries. With the new platform technology, the project takes an important step toward a circular carbon economy.

In the picture: Dr. Leonardo Castañeda-Losada from the innovation field Bioinspired Chemistry has applied a redox-active hydrogel containing bioengineered enzymes for CO_2 fixation to an electrode.