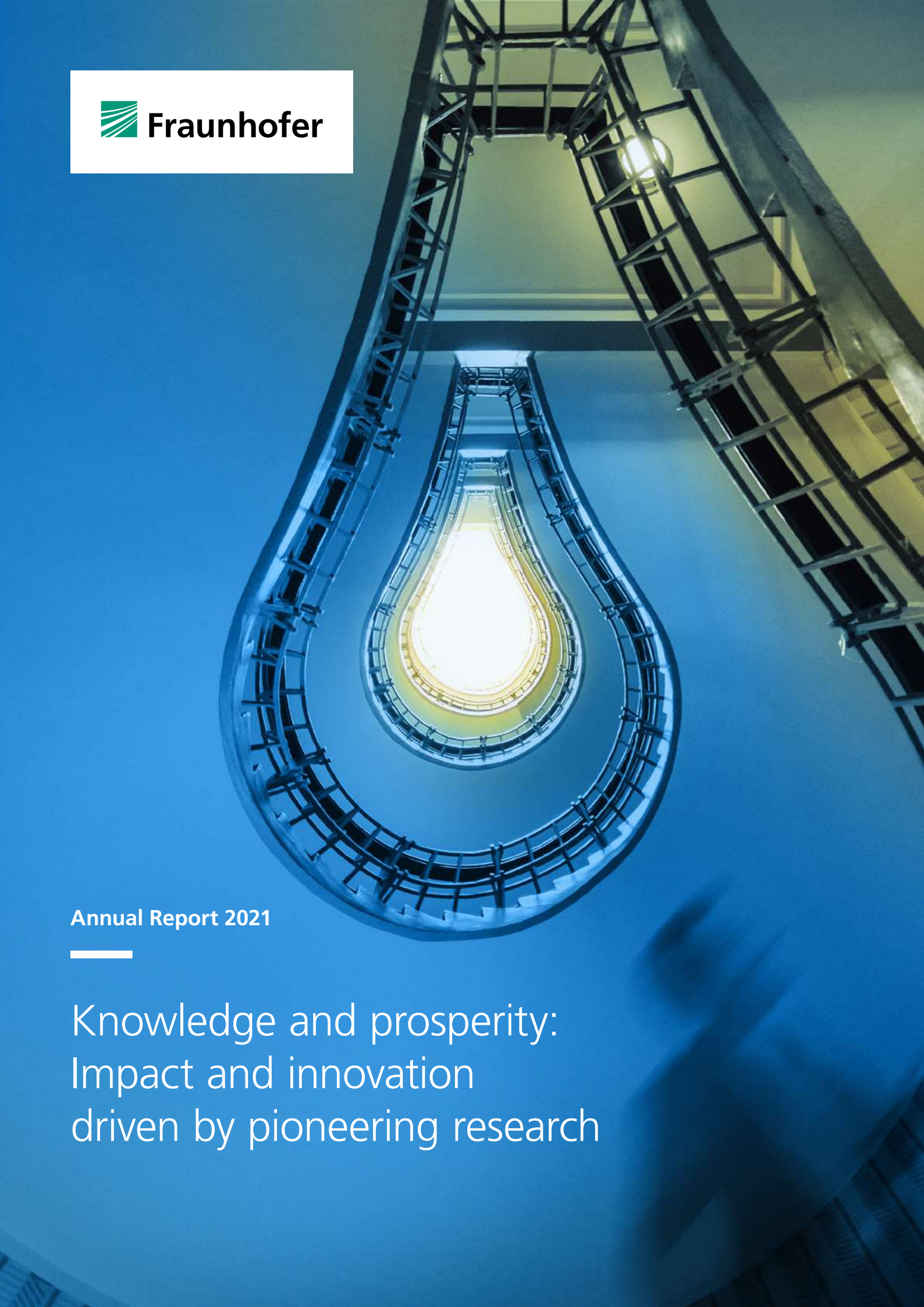
Fraunhofer



Annual Report 2021

Knowledge and prosperity: Impact and innovation driven by pioneering research

The Fraunhofer-Gesellschaft

Headquartered in Germany, the Fraunhofer-Gesellschaft is the world's leading applied research organization. With its focus on developing the key technologies of the future and on enabling their commercialization by business and industry, it plays a central role in the innovation process. Fraunhofer is a pioneer and catalyst for groundbreaking developments and a benchmark for scientific excellence. As a source of inspirational ideas and sustainable scientific and technological solutions, Fraunhofer is driving science and industry and helping to shape our society both now and in the future.

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

Founded in 1949, the Fraunhofer-Gesellschaft currently operates 76 institutes and research units throughout Germany. Over 30,000 employees from a predominantly scientific and engineering background work with an annual research budget of €2.9 billion. €2.5 billion of this comes from contract research, roughly two thirds of which comes from industry contracts and publicly funded research projects. The final third is provided by the federal and state governments in the form of base funding, so that the institutes can start developing solutions to the important challenges that will face industry and society in the near future.

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

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

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

Figures last updated: January 2022
www.fraunhofer.de

Annual Report 2021

Knowledge and prosperity: Impact and innovation driven by pioneering research

Foreword

Ladies and gentlemen,

The pandemic year of 2021 has made it abundantly clear — the only way to overcome a crisis is to ensure close collaboration between politics and science. Despite numerous challenges in what continues to be a difficult market environment, the Fraunhofer-Gesellschaft succeeded in achieving modest growth in 2021. We also owe our thanks here to the additional funding provided by the German federal government. Business volume rose by three percent to 2.9 billion euros, demonstrating the resilience of the Fraunhofer-Gesellschaft. Revenue from industry returned to pre-crisis levels. The cornerstone of this stability is the organization's staff. Now numbering more than 30,000 for the first time, Fraunhofer-Gesellschaft employees have shown high levels of motivation, impressive determination and flawless commitment in completing the organizational, administrative and research work required to create this stability, all while facing fresh challenges.

Of the many projects carried out by what is now 76 Fraunhofer institutes, I would like to highlight three in particular. During the second year of the pandemic, the Fraunhofer-Gesellschaft implemented more than 160 interdisciplinary projects aimed at combating the coronavirus — from data models that predict the spread of infection, to decontamination initiatives, to day-to-day protection measures and the discovery of new drugs and diagnostic procedures. By December, two-thirds of the initiatives contained in the anti-coronavirus program had been completed. This success is marked by 13 patent applications and 2 trademark applications. During the coronavirus crisis, we all heard the phrase "Science has delivered," an achievement that is also attributable to the hard work undertaken by Fraunhofer scientists. The 4D approach encompassing diagnostics, drugs, devices and data demonstrated how innovative health solutions can be developed when people work in a cross-disciplinary, highly collaborative way.

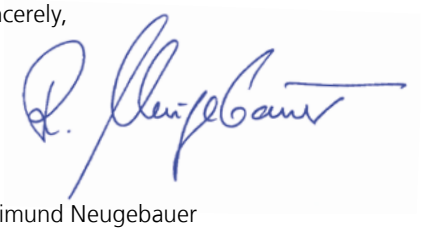
Prof. Dr.-Ing. Reimund Neugebauer, President of the Fraunhofer-Gesellschaft.

The energy transition is now recognized and accepted as a colossal global challenge even by, and especially within, German political circles. Germany is intent on becoming a global pioneer, as set out in the coalition agreement between the SPD, the Greens and the FDP. The structural transformation of coal-fired plants, which are to be removed from the grid by 2030, and the transformation into an effective energy system based on renewable energies will require a whole host of new individual solutions. Whether it's storage technologies, the all-important issue of green hydrogen, electromobility for transportation or heat pumps in the construction sector — Fraunhofer researchers have made decisive contributions across the board. A robust energy supply is vital to our country's sovereignty, our industry's stability and our citizens' quality of life.

Fraunhofer is supporting the structural transformation from coal to hydrogen with an integrated, holistic strategy. Research platforms such as Hydrogen Lab Görlitz, which focuses on fuel cell technology, and Hydrogen Lab Leuna, which focuses on electrolysis, are leading the charge here. It is clear that hydrogen can play a decisive role in ensuring the success of the structural transformation, industrial efficiency and sustainable lifestyles of our shared future.

We look forward to continuing our fruitful collaboration — a collaboration based on shared objectives and shared values.

Sincerely,



Reimund Neugebauer
President of the Fraunhofer-Gesellschaft

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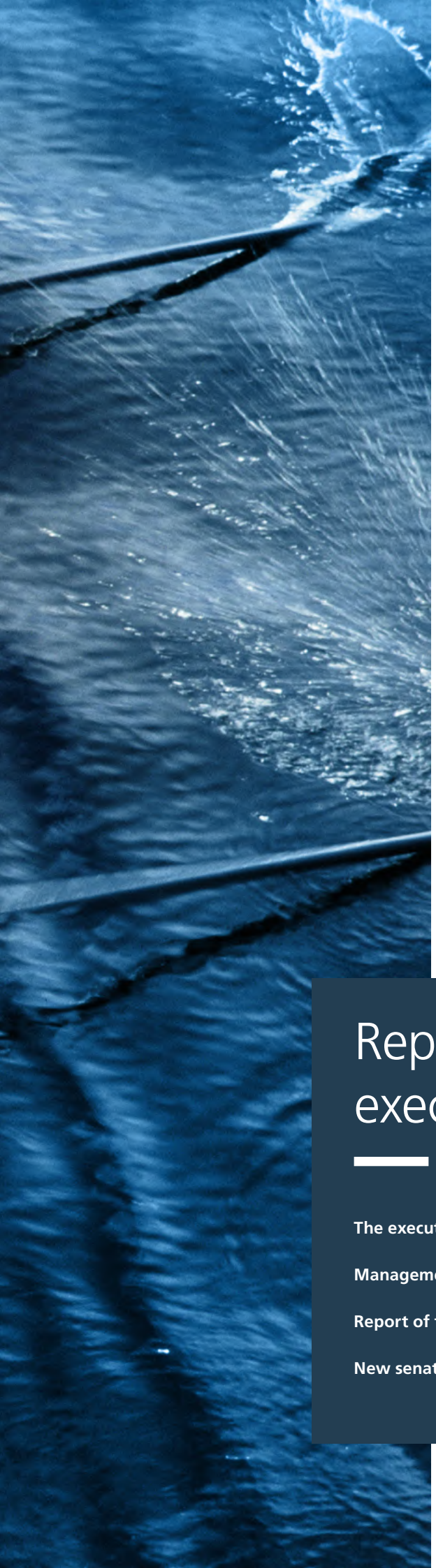
Photo: Rialto Images/Stocksy/F1 Online



Where does inspiration come from? How do ideas become innovations?

Gliding through water frees the mind. In a flow cytometer, cells flow past photodetectors. These devices can be used to conduct quality control for cell therapy agents — and in the future, AI will help with that, too. Read more to learn how we are making innovative treatments available to more people (p. 82).

Report of the executive board

The executive board

Reimund Neugebauer is a professor of machine tool design at the Chemnitz University of Technology. After leadership roles in the mechanical engineering industry, in 1991 he set up what is now the Fraunhofer Institute for Machine Tools and Forming Technology IWU. This grew to become an international center for manufacturing engineering during his 21 years of service as its director. He has served as president of the Fraunhofer-Gesellschaft since 2012.

Prof. Dr.-Ing. habil. Prof. E. h. Dr.-Ing. E. h. mult. Dr. h. c. mult.
Reimund Neugebauer
President

Photos: Fraunhofer/T. Dashuber

Andreas Meuer has occupied a variety of senior roles at Fraunhofer-Gesellschaft headquarters since 1992, most recently as director of Finance, Accounting and Business Planning. Having served as a member of the Fraunhofer executive board since 2018, he is retiring in spring 2022.

Dipl.-Kfm. Andreas Meuer
Executive Vice President for Finances and Digitalization (until December 31, 2021)
Executive Vice President for Finances and Controlling, acting Executive Vice President for Research Infrastructure and Digital Transformation (since January 1, 2022)

Alexander Kurz studied to become a lawyer before serving as an executive and a board member at major research organizations such as CERN in Geneva and the Karlsruhe Institute of Technology (KIT). He has been an executive vice president of the Fraunhofer-Gesellschaft since 2011.

Prof. Dr. rer. publ. ass. iur. Alexander Kurz
Executive Vice President for Human Resources, Legal Affairs and IP Management (until December 31, 2021)
Executive Vice President for Innovation, Transfer and IP Management, Executive Vice President for Human Resources, Corporate Culture and Legal Affairs (since January 1, 2022)

Management report 2021

Fraunhofer-Gesellschaft — key data for 2021 (in € million)

	2020	2021		Change
Total business volume	**2,832**	**2,915**	**+83**	**+3%**
Contract research	2,398	2,518	+120	+5%
Additional research funding	164	163	–1	–1%
Major infrastructure capital expenditure	270	234	–36	–13%
Business volume by budget	**2,832**	**2,915**	**+83**	**+3%**
Operating budget	2,357	2,445	+88	+4%
Capital expenditure[1]	475	470	–5	–1%
Project revenue	**1,716**	**1,858**	**+142**	**+8%**
Contract research	1,553	1,738	+185	+12%
of which industrial revenue	658	723	+65	+10%
of which public-sector revenue[2]	895	1,015	+120	+13%
Additional research funding	76	73	–3	–4%
Major infrastructure capital expenditure	87	47	–40	–46%
International project volume[3]	**276**	**287**	**+11**	**+4%**

1 Capital expenditure for contract research, additional research funding and major infrastructure projects.

2 Comprises German federal and state government, EU and other revenue.

3 Excludes license-fee revenue and project volume generated by legally independent international Fraunhofer affiliates through business with third parties (2021: €27 million).

Strategy and operating environment

Profile of the Fraunhofer-Gesellschaft

Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V. is a non-profit organization that was founded in 1949. It carries out applied research and development activities for the benefit of industry and society. The organization's **fields of research** focus on human needs: health, safety, communication, mobility, energy, and the environment.

Together, the 76 Fraunhofer institutes and research institutions in Germany employ over 30,000 people and generate an annual business volume of €2.9 billion. As the organization's primary area of activity, **contract research** accounts for €2.5 billion of this total. Around two thirds of this contract research revenue is derived from industry contracts and publicly funded research projects. The German federal and state governments contribute around another third as base funding, enabling institutes to develop solutions now to problems that will drastically impact industry and society in the near future.

At an organization-wide level, Fraunhofer identifies innovative fields of business and trending technologies with major market potential and significant relevance to society and advances them through in-house **research programs**.

Each individual Fraunhofer institute develops its own fields of business and core areas of expertise on the basis of its immediate market environment and its links with the wider scientific community. Although the institutes operate as separate profit centers, they are not autonomous legal entities.

To improve Fraunhofer's expertise profile and bolster its competitiveness, the Fraunhofer groups were restructured as of January 1, 2021. Since then, Fraunhofer institutes with related specialist focus areas have been organized into the following nine **Fraunhofer groups** in order to coordinate cross-institute R&D strategies in contract research:

- Energy Technologies and Climate Protection
- Health
- ICT Group
- Innovation Research
- Light & Surfaces
- Materials and Components
- Microelectronics
- Production
- Resource Technologies and Bioeconomy

In addition, institutes or departments of institutes with different areas of expertise work together in **Fraunhofer alliances** in order to develop and market solutions for specific business fields.

Creating opportunities through strategic initiatives

In 2021, as the pandemic continued into its second year, the following instruments, programs and processes bolstered Fraunhofer's competitiveness:

- Launch of a program for securing expertise during the pandemic
- Further development of the Fraunhofer Strategic Research Fields (FSF)
- Establishment of lead markets
- Consolidation of the Fraunhofer clusters of excellence
- Support from group road maps

Due to ongoing challenges in the economic situation, 2021 once again saw Fraunhofer institutes harnessing existing expertise in order to acquire substitute work in accordance with funding guidelines from the German Federal Ministry of Education and Research (BMBF) detailing the support available to non-university research organizations for applied research. The Fraunhofer executive board swiftly took action to define strategically relevant research topics and projects that are being implemented primarily using the funds specified in the abovementioned guidelines. The board focused on **internal pre-competitive research**, with a view to acquiring new industry projects in the short to medium term. The executive board defined four focus areas here:

- Transfer initiative: The objective of this funding program is to reinforce applied research in the high-performance centers at a structural level by establishing a system of self-supporting regional innovation hubs to enable optimal transfer of R&D results.
- "KMU akut" program: This scheme facilitates in-house research projects that foster research collaborations between institutes and small and medium-sized enterprises.
- Anti-Coronavirus Program: Having completed its initial phase in 2020, this program entered its second phase by assembling strategic projects that address medium- and longer-term issues in the fields of medication and vaccine development, diagnostics as well as industrial and social resilience.
- Fraunhofer Innopush Program: The objective of this program is to make an important contribution to the recovery of the industry sector and to generate significant innovation momentum.

The **Fraunhofer Strategic Research Fields (FSFs)** constitute a vital foundation for our efforts to continuously drive innovation at a market level. Collaborations across institutes and groups enable the acquisition of public funding for large, system-relevant projects, and the development of suitable business models and comprehensive system solutions for Fraunhofer customers. In 2021, the executive board resolved to implement the FSF Momentum program in order to promote the integration of the FSFs into the structure of the Fraunhofer-Gesellschaft, as well as their campaigning capabilities in a targeted way.

The concept of **lead markets** was concretely implemented in 2021 with the objective of more effectively addressing customer segments that have a major impact on Germany and Europe's innovative strength. The distinguishing feature of these lead markets is that they are fields where Fraunhofer promotes innovation with the aim of giving Germany a global competitive edge, securing technological sovereignty and creating value for society in the long term. To further strengthen Fraunhofer's positioning in these lead markets, the Fraunhofer alliances coordinate targeted cross-institute knowledge transfer activities. The following lead markets are addressed:

- Aerospace economy
- Chemical industry
- Construction industry
- Digital economy
- Energy sector
- Food industry
- Healthcare sector
- Mobility sector
- Plant, mechanical and vehicle engineering

In order to fulfill the ever more complex needs of industry and society, each **Fraunhofer alliance** acts as a "one-stop shop," offering selected customer segments a tailored transfer package from a single source. They also produce an annual transfer road map in order to drive the development of these sector-specific service offerings. The road map consists of services aligned with various transfer paths, such as R&D projects, further training programs, licensing of technological solutions and collaboration with Fraunhofer start-ups.

The six current **Fraunhofer clusters of excellence** underwent an interim evaluation in 2021 in terms of their technical quality and development of long-term collaboration structures. Based on the recommendations of external expert consultants, the Fraunhofer executive board approved continued funding for all clusters until the end of the initial five-year development phase.

In light of its goal of establishing a competitive post-pandemic position for Fraunhofer, the executive board launched **"Emerging stronger from the crisis,"** a strategic project with two lines of action: advising selected institutes as well as mobilizing all institutes to review their revenue structures for service and technology portfolios. The advisory services for selected institutes involved a strategic financial analysis focusing on revenue and cost structures. In the future, the method behind this anticipatory financial analysis will be made available to all institutes that are facing transformation processes or leadership changes. As part of the second line of action, all institutes were requested to produce a concrete forecast of their revenue structure until 2025, with the aim of mobilizing the entire Fraunhofer-Gesellschaft.

Public safety and security represents a particular challenge for urban areas, as they often face many combined security problems within limited spaces due to the possibility of multiple events taking place concurrently. Such complex, large-scale situations have created a need for novel tools that can create realistic maps of the interactions between technology, infrastructure and emergency personnel. The new Fraunhofer Center for the Security of Socio-Technical Systems SIRIOS in Berlin will address this need by researching new kinds of simulation technology and scenarios for the public safety and security field. Fraunhofer SIRIOS pools specific, relevant expertise from four Fraunhofer institutes.

Science policy framework

Throughout the 19th legislative period of the Bundestag, the Fraunhofer-Gesellschaft's president, Prof. Dr.-Ing. Reimund Neugebauer represented the organization in the high-profile scientific advisory boards, Innovation Dialogue and High-Tech Forum.

For more than ten years, **Innovation Dialogue** has served as a reliable, independent advisory board for the German federal government. In 2021, the Fraunhofer president participated in the preparation of dossiers on "The resilience of supply chains and value creation networks" and "From promoting technological cold frames to self-sustaining ecosystems." During the closing session of the 19th legislative period of the Bundestag, the round table provided advice on creating, bolstering and developing excellent ideas from research and development in the context of self-supporting, internationally competitive industry ecosystems.

During the 19th legislative period, the **High-Tech Forum** was the German federal government's central advisory board for implementing the High-Tech Strategy 2025 (HTS 2025). It consisted of 21 experts from science, industry and society. The role of chair was shared by Christian Luft, state secretary at the German Federal Ministry of Education and Research (BMBF), and Prof. Dr.-Ing. Reimund Neugebauer, president of the Fraunhofer-Gesellschaft.

Acting on behalf of the federal government, the forum analyzed important issues relating to Germany's future viability as a hub for research and innovation, and offered advice on the formulation of a strategic structure for and the further development of the concepts involved in the HTS 2025. In 2021, the High-Tech Forum produced a final report on its results, summarizing its previous advisory papers under five umbrella topics: "Mission-oriented innovation policy," "Participation as a strategic instrument of innovation policy," "Resilience and technological sovereignty," "Agile research and innovation funding" and "Initiative for freedom of technology transfer — promotion of knowledge-intensive start-ups." The report was published on April 21, 2021 as part of the High-Tech Forum's Final Conference — a large, interactive live show, with 2,000 viewers on the live stream, 1,000 live chat posts and 90 participants presenting on two virtual stages. The co-chair of the forum and Fraunhofer president, Prof. Dr.-Ing. Reimund Neugebauer represented the 21 members of the advisory board in presenting its final recommendations for a future innovation strategy to the German federal government, in a unique format: the recommendations were printed on synthetic DNA.

The forum explicitly urged support for and insistence on better participation and greater courage and practical action in terms of achieving sustainability goals. It also emphasized the importance of reinforcing a mission-oriented approach to innovation policy, in order to bring more cutting-edge research results into application on a large scale. Other recommendations included simplifying the process of founding a scientific start-up and establishing more experimental spaces and effective avenues for citizen participation.

In terms of research policy, 2021 was strongly impacted by the **German parliamentary elections** and the subsequent formation of the new government. During the electoral campaign, changes to general social conditions were the subject of intensive discussion. According to the coalition agreement reached between the Social Democratic Party (SPD), the Greens and the Free Democratic Party (FDP) at the end of November, the previous High-Tech Strategy will be replaced with a future research strategy covering the following six emerging scientific fields: (1) modern technologies for a competitive, climate-neutral industry; (2) effects of climate change and relevant adaptation strategies; (3) preventative, crisis-proof healthcare system; (4) technological sovereignty and the potential offered by digital transformation; (5) exploration of the oceans and outer space; (6) social resilience, cohesion, democracy and peace. The Fraunhofer-Gesellschaft's research portfolio addresses all six of these emerging fields.

The primary structural alteration faced by the Fraunhofer-Gesellschaft is the changes to the German Federal Ministry of Education and Research (BMBF) in terms of personnel and political party affiliation. When the government formation process was completed in December, leadership of the ministry switched from Anja Karliczek (CDU) to Bettina Stark-Watzinger (FDP), which resulted in multiple new appointments in the ministry's management team even before the end of the year.

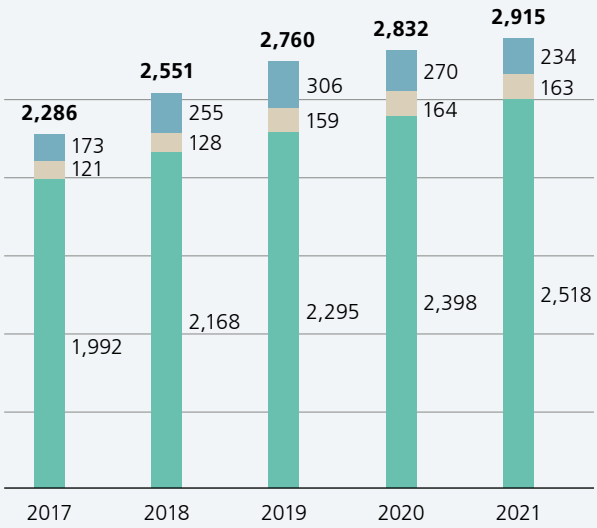
Business report

Total business volume

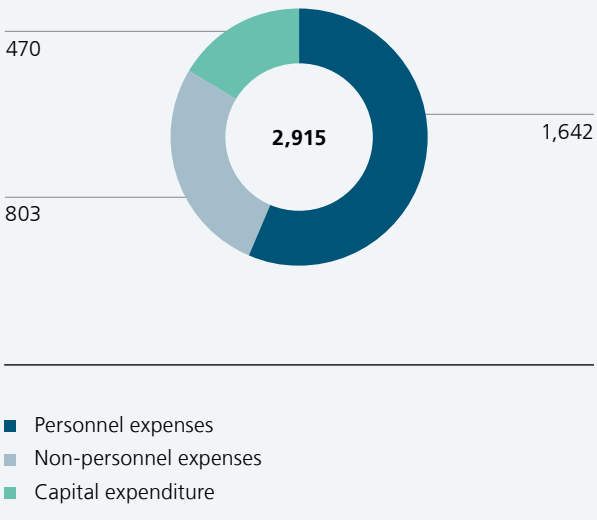
With tremendous effort from everybody involved and the support of funding agencies, the Fraunhofer-Gesellschaft once again succeeded in overcoming the effects of the pandemic in 2021. The results for 2021 show subdued growth of 3 percent, with a current total business volume of around €2.9 billion. Contract research accounted for 86 percent of this sum (around €2.5 billion) and represents the organization's core activity. Around one third of contract research funding is provided by base funding from the federal and state governments. Research of a long-term nature that falls outside the scope of this regular base funding is allocated to a new item, additional research funding, which amounted to €163 million in the reporting period. Major infrastructure capital expenditure amounted to €234 million. These three segments will be discussed in greater detail in the following sections.

Business volume is based on the performance statement, which meets the requirements of the funding agencies. In the operating budget, personnel and non-personnel expenses are recognized according to general accounting practice along with the change in the extraordinary item "License-fee revenue reserve for statutory purposes." As capital expenditure is recognized at the amount incurred at the time of purchase, depreciation, amortization and impairment losses are not included in the performance statement. In 2021, Fraunhofer's capital expenditure amounted to €470 million overall, a 16 percent share of the total business volume. Personnel expenses increased to €1,642 million, which can be attributed to a 1.4 percent increase to the pay scale that took effect on April 1, 2021 and to slight growth in the number of employees. At €803 million, non-personnel expenses slightly exceeded the previous year. The reserve fund balance remained unchanged in 2021; however, it was used in the course of the year to cover liquidity requirements.

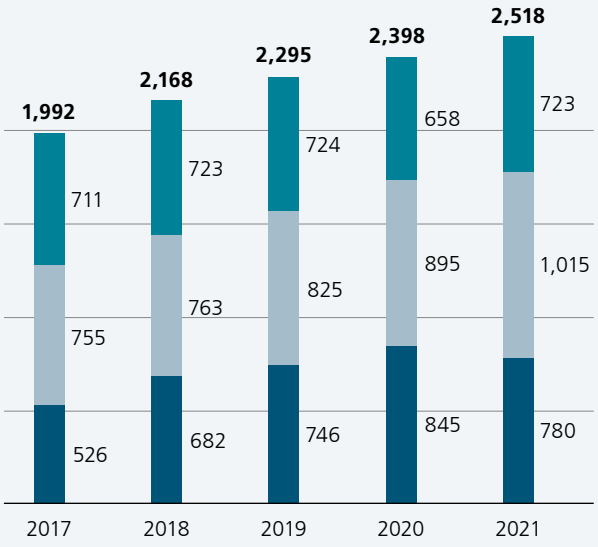
Fraunhofer total business volume in € million



2021: Total business volume by budget in € million

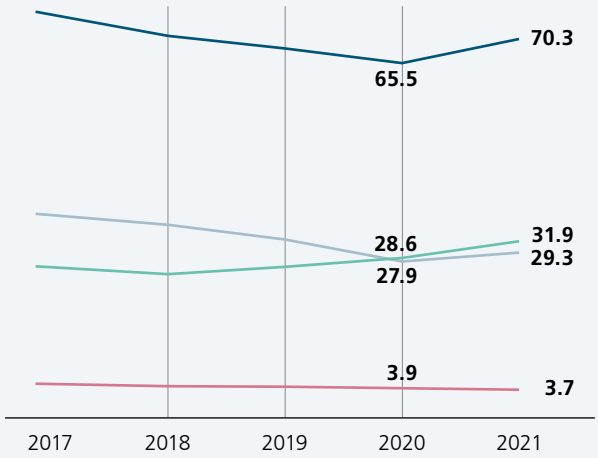


Revenue from contract research in € million



- Industrial revenue
- Revenue from publicly-funded projects
- Base funding

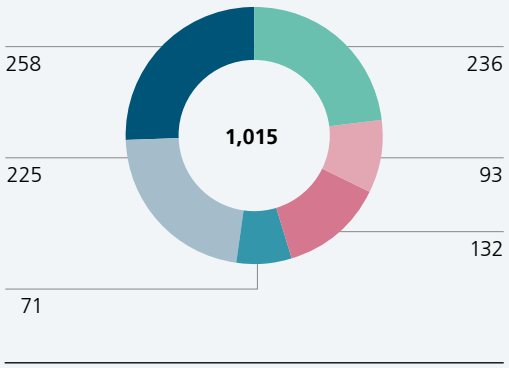
Funding share in %



- Total project revenue [1]
- Industry
- Federal and state governments
- EU

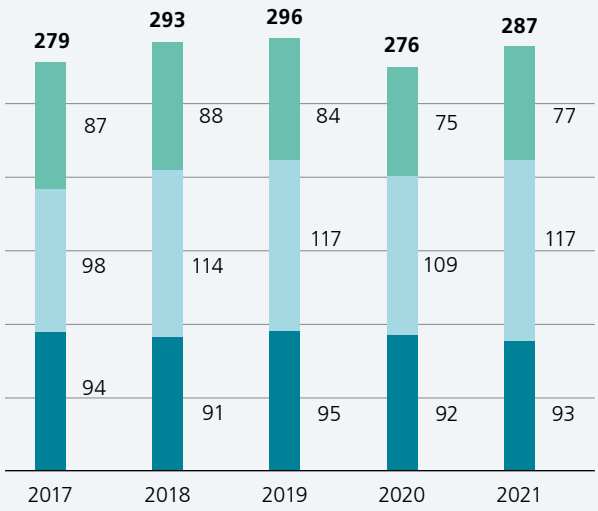
1 Funding share from other revenue in 2021: 5.4%.

2021: Revenue from publicly-funded projects in € million



- BMBF
- BMWK (previously: BMWi)
- Other federal ministries
- Federal states
- EU
- Other

International project volume in € million



- Customers and partners outside of Europe
- Customers and partners within Europe
- EU project funding

Contract research

Contract research is the mainstay of Fraunhofer's business activities and, in line with the **Fraunhofer funding model**, consists of three core areas, each contributing equal amounts to the organization's finances:

- Research directly contracted by industry
- Publicly funded research projects
- Pre-competitive research financed through base funding

In 2021, the base funding requirement amounted to €780 million. Base funding is provided by the German Federal Ministry of Education and Research (BMBF) and the state governments in a ratio of 90:10. An additional €93 million in federal government funding for applied research by non-university research institutions enabled Fraunhofer to adopt measures for retaining expertise, particularly internal pre-competitive research projects aimed at delivering a powerful kickstart to the industry sector as it makes its way out of the crisis. Initial signs of recovery could be seen in industrial revenue, which, at €723 million, returned to pre-crisis levels in absolute terms. Revenue from industry contracts rose to €609 million and license-fee revenue grew to €114 million.

Revenue from publicly-funded projects once again showed a significant increase, and continued to serve as an important source of support during the second year of the pandemic. Project funding from state governments jumped sharply by 20 percent to €236 million. Project funding from the federal government also grew by 14 percent to €554 million. At €93 million, EU revenue was on a par with the previous year. In the coming year, the new Horizon Europe framework program offers considerable potential for the Fraunhofer Strategic Research Fields in particular. Other revenue increased by 8 percent to €132 million, and includes funding granted by foundations, universities and other research-funding institutions.

In addition to acting as one of the Fraunhofer institutes' criteria for success, the high **share of funding** coming from external project revenue is a unique selling point for the Fraunhofer-Gesellschaft. The project funding share therefore serves both as a key performance indicator and as a barometer for establishing an optimal funding mix in contract research. It is calculated as the share of project revenue in the operating budget, including imputed depreciation of capital assets (excluding initial funding for newly established facilities and excluding changes in reserves). The one-time, permanent increase in base funding in 2017 meant that the external funding share declined in subsequent years as planned, coming into line with the Fraunhofer model once again in 2018 and 2019. Having reached its lowest figure in the previous year due to the pandemic, the project funding share showed the first signs of recovery in 2021, reaching a level of 70.3 percent. A sharp increase in revenue from federal and state governments resulted in their funding share rising to 31.9 percent. The share stemming from industrial revenue reached 29.3 percent.

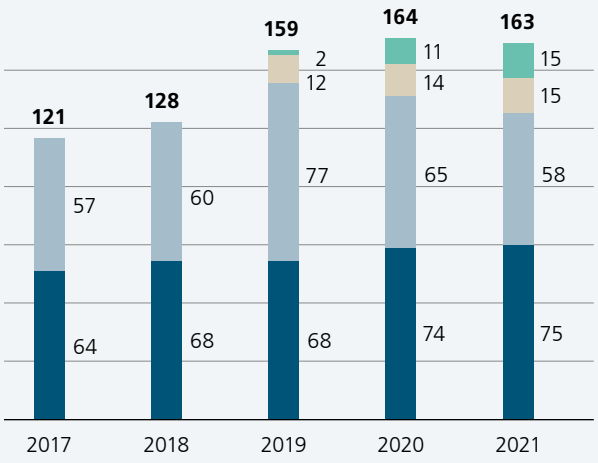
International project volume increased by 4 percent to reach €287 million (excluding license-fee revenue), thus returning to pre-pandemic levels in absolute terms. As such, its contribution to total project revenue from contract research amounted to 17 percent. Within international project volume, 32 percent came from EU-funded projects, 41 percent from customers and partners in Europe, and 27 percent from customers and partners outside Europe. The amount of project volume generated within Europe increased by 7 percent to €117 million, while project volume generated outside of Europe increased by 3 percent to €77 million. The largest international markets were the USA with a project volume of €35 million, Switzerland with €28 million and Austria with €16 million.

Additional research funding

Additional research funding covers long-term research activities that fall outside the scope of regular base funding. In addition to defense-related research, the National Research Center for Applied Cybersecurity **ATHENE** and the **Research Fab Battery Cells FFB** fall under additional research funding.

ATHENE is operated jointly by the Fraunhofer Institutes for Secure Information Technology SIT and Computer Graphics Research IGD in collaboration with Technical University of Darmstadt and Darmstadt University of Applied Sciences. Its research focuses on the protection of critical infrastructures such as power and transportation, and the safeguarding of IT systems. The center applies an interdisciplinary approach, combining IT and engineering with legal and economic issues, psychology and ethics. ATHENE, which is funded by the BMBF and the state of Hessen in a ratio of 70:30, recorded a slightly increased budget of €15 million in 2021.

Additional research funding in € million



- FFB project funding (BMBF)
- ATHENE base funding (BMBF and state of Hessen)
- BMVg project funding
- BMVg base funding

Construction on the **FFB** continued in 2021 with funding from the BMBF, as costs increased slightly to €15 million. The BMBF is providing a total of €500 million in funding for this large-scale initiative through project finance. The state of North Rhine-Westphalia is providing a further €200 million for the construction of a building to house the new facility in Münster.

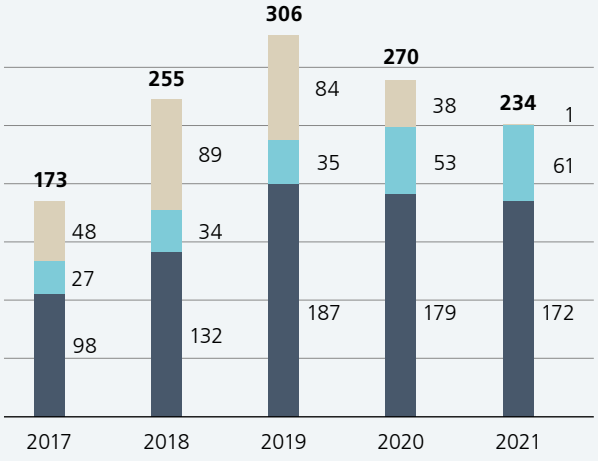
In the field of **defense research**, Fraunhofer has pooled the research and development (R&D) activities of seven institutes that receive base funding and ongoing project funding from the German Federal Ministry of Defence (BMVg). The objective of these R&D activities is to provide people, infrastructures and the environment with the best possible protection against potential security threats resulting from natural disasters or military, technological, terrorist or criminal activity. Although base funding from the BMVg rose by €1 million to €75 million, ongoing project funding from the BMVg fell by €7 million to €58 million. In 2021, funding for defense research thus fell by 4 percent overall to €133 million.

Major infrastructure capital expenditure

Major infrastructure capital expenditure comprises building projects and the purchase of scientific instruments and furniture to equip new facilities. Following significant increases in recent years, major infrastructure capital expenditure dropped to €234 million in 2021.

The main reason for this is the scheduled completion of the **Research Fab Microelectronics Germany (FMD)** and the reduction of the equipment expenditure to €1 million. The BMBF has provided funding for the construction of the FMD through project finance since 2017, thus bolstering a key German industry by means of microelectronics research and modernizing the sector's equipment infrastructure.

Major infrastructure capital expenditure in € million



- Research Fab Microelectronics Germany (FMD)
- Equipping of new facilities
- Building projects (major and minor)

Capital expenditure on the **construction and equipping of new facilities** remains at the same level as the previous year overall. While funding for building projects decreased by 7 million to €172 million, of which major building projects received €139 million and minor projects €33 million, capital expenditure on equipping new facilities rose by €8 million to €61 million. Special funding for major building projects and the equipping of new facilities is provided by the federal and state governments in a 50:50 ratio. The state governments often provide additional funding from the European Regional Development Fund (ERDF), which reduces the funding required from federal and state governments by an equivalent amount. Minor building projects are financed from joint base funding in a ratio of 90:10. The funding required from the federal and state governments totaled €187 million. ERDF funds from the state governments and other revenue accounted for €46 million of project revenue.

Financial and net asset position

As of Friday, December 31, 2021, the Fraunhofer-Gesellschaft had total assets of €4,186 million, up €243 million or 6 percent when compared to the previous year. Assets presented in the ordinary accounts comprised 99.6 percent of total assets, with non-profit organization capital accounting for the remaining 0.4 percent.

Noncurrent assets accounted for 63 percent of assets and were €173 million higher at €2,645 million. This increase was chiefly attributable to the fact that capital expenditure on property, plant and equipment exceeded depreciation of those assets. Property, plant and equipment assets grew by €172 million to €2,580 million.

Current assets accounted for 35 percent of assets and were €94 million higher at €1,478 million. While receivables from federal and state governments through project billing (including contracts) increased by €25 million to €252 million, receivables from affiliated companies decreased by €3 million to €8 million. Cash and cash equivalents (including bank account balances) increased by €132 million to €232 million. The value of the securities portfolio decreased by €1 million, dropping to €440 million. Of this fund, €416 million stemmed from license-fee revenue reserve and €25 million corresponded to the extraordinary item "For financing restructuring measures."

Equity — which comprises the non-profit organization capital that is not financed by government grants (€15 million) and the reserve for statutory purposes (€15,225) — increased by a marginal amount. Economic equity also includes four kinds of extraordinary items recognized in the balance sheet. The extraordinary item "Grants relating to noncurrent assets" was €173 million higher at €2,634 million. The extraordinary item "License-fee revenue reserve for statutory purposes" remained unchanged from the previous year at €416 million. The extraordinary item "Present value of installments from patent deal" amounted to €47 million. This item is matched by other receivables of an equivalent amount on the assets side of the balance sheet.

An extraordinary item of €25 million was entered for the necessary restructuring of cleanroom infrastructure. This item is matched by securities of an equivalent amount on the assets side of the balance sheet. Use of these funds is tied to a restructuring plan and contributes to the development of the main sites of Fraunhofer institutes and their secondary locations. The aim is to reduce fixed costs while also enhancing collaboration and the quality of services. A sum of €63,000 was allocated to the item, while reversals amounted to €452,000.

The extraordinary item "Grants used to finance current assets" is not included in financial equity and is used to account for income not yet received, less expenses not yet paid, by the reporting date. This essentially corresponds to advance project funding and amounted to €295 million at the reporting date.

Provisions increased by €10 million to €209 million, €54 million of which was accounted for by provisions with maturities of more than one year. In the case of pension and compensated leave provisions, a corresponding amount of receivables from federal and sta te governments totaling €90 million was entered on the assets side of the balance sheet.

Liabilities rose by €96 million to €540 million. In addition to an increase of €109 million in unappropriated grants from federal and state governments from base funding and project billing, trade payables and other liabilities fell by €13 million.

As a beneficiary of public funds, the Fraunhofer-Gesellschaft is subject to budgetary constraints that prohibit it from making use of the capital markets or of lines of credit with banks. Nevertheless, the organization's **liquidity** is guaranteed at all times, as it can regularly call on cash payments from its funding agencies under base funding arrangements and can use its reserves as needed. Even in times of crisis, the Fraunhofer funding model is supported by a solid foundation.

Shareholdings and spin-offs

At the reporting date, the Fraunhofer-Gesellschaft held shares in a total of **84 companies** operating in a diverse range of sectors. Technology transfer to industry formed the focus of activities at 60 of the companies in the shareholding portfolio, while a further 18 shareholdings were of a strategic nature. The shareholdings also include six affiliated companies. In 2021, the Fraunhofer-Gesellschaft invested a total of €2.5 million in the acquisition of equity interests in shareholdings. The Fraunhofer-Gesellschaft added three companies to its investment portfolio and divested its shares in five others. The total carrying amount of shareholdings (including shares in affiliated companies) increased to €10.4 million (2020: €9.1 million). Income from the divestiture of shareholdings came to €2.2 million.

Spin-offs are an integral part of Fraunhofer's strategy for exploiting its industrial property rights. The Fraunhofer Venture department generally supports spin-off founders as they prepare to launch their new business. In individual cases, Fraunhofer takes a minority share in the spin-off under company law as part of its technology transfer activities. In 2021, Fraunhofer Venture supported 52 new spin-off projects; in total, 30 new businesses were spun off from the

Fraunhofer-Gesellschaft. Fraunhofer has set itself the goal of increasing not only the number of spin-offs but also their proportional contribution to overall industrial revenue. Our innovation hub AHEAD offers a comprehensive package of targeted measures and programs to help achieve this objective.

International activities

The internationalization strategy of the Fraunhofer-Gesellschaft is based on the principle of creating scientific value for Fraunhofer and generating positive effects both for Germany and Europe and for the partner country in question. Working in collaboration with the world leaders in every field enables Fraunhofer to develop future-proof solutions for global challenges. Fraunhofer has developed various formats for generating excellent scientific content and collaborating with attractive international partners.

The eight **legally independent international Fraunhofer affiliates** represent the most institutionalized form of such partnerships:

- Fraunhofer USA, Inc.
- Fraunhofer Austria Research GmbH
- Fraunhofer Italia Research Konsortial-GmbH
- Fraunhofer UK Research Ltd
- Fundación Fraunhofer Chile Research
- Associação Fraunhofer Portugal Research
- Fraunhofer-Chalmers Research Centre for Industrial Mathematics FCC (in Sweden)
- Fraunhofer Singapore Research Ltd.

These international affiliates are constituted under the laws of their country of domicile and function as the legal entities supporting Fraunhofer research centers outside of Germany, which number 13 at the reporting date. The latter are long-term, institutionalized partnerships between Fraunhofer and local universities, enabling Fraunhofer to conduct research activities abroad on a lasting basis. As their work is not profit-oriented, the international affiliates generally qualify for base funding from their country of domicile, and they are financed in a manner similar to the Fraunhofer funding model. As the Fraunhofer internationalization strategy is updated, the strategic focus for its legally independent international affiliates will be reconfigured. In the future, greater emphasis will be placed on promoting two-way scientific collaboration between the international affiliates' research centers and the Fraunhofer institutes based in Germany. In addition to project volume generated by the Fraunhofer-Gesellschaft with customers outside of Germany, the international Fraunhofer affiliates generated third-party project volume amounting to €27 million in 2021. Of this amount, Fraunhofer USA accounted for €7 million, followed by Fraunhofer Austria with €6 million, and Fraunhofer-Chalmers Research Centre for Industrial Mathematics FCC in Sweden and Fraunhofer UK, each with €4 million. The international Fraunhofer research centers engage in a broad spectrum of research activities, encompassing quantum technology as well as IT, artificial intelligence, industrial mathematics, production and logistics, biotechnology and solar energy technology.

The **Fraunhofer Innovation Platforms** (FIPs) — formerly known as Fraunhofer Project Centers (FPCs) — are vehicles that enable Fraunhofer institutes to collaborate with research organizations outside of Germany on a specific topic for a limited period of time. In each case, the partner organization sets up the FIP under its own local legal jurisdiction and collaborates closely with a Fraunhofer institute in Germany on the chosen topic. The aim of this form of collaboration is to carry out joint research and joint customer projects, and to take part in publicly funded projects.

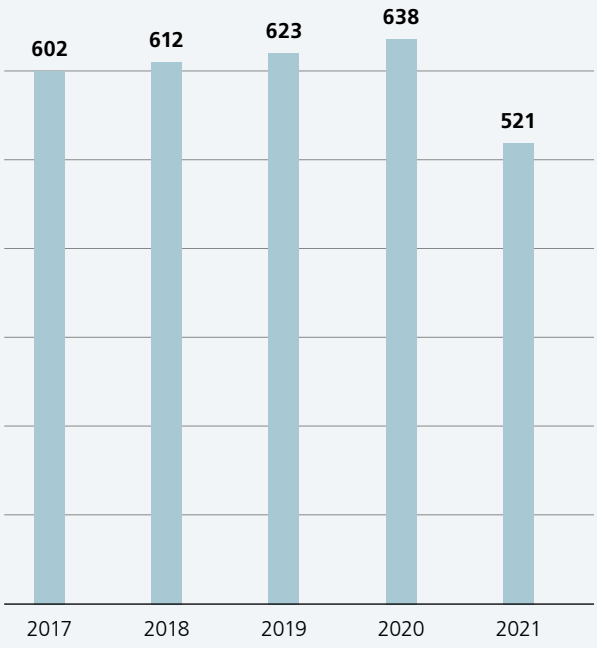
Two new Fraunhofer Innovation Platforms were launched in 2021. The **Fraunhofer Innovation Platform for Applied Artificial Intelligence for Materials & Manufacturing** (FIP-AI@VSB-TUO) was established in the Czech Republic as a collaboration between VSB — Technical University of Ostrava (VSB-TUO), the Fraunhofer Institute for Machine Tools and Forming Technology IWU and the Fraunhofer Institute for Chemical Technology ICT. The objectives of this collaborative initiative are to develop innovative heat recovery solutions for the industry sector based on modular energy storage and heat exchange systems, to combine these solutions with digital production technology and to integrate them into process chains.

Meanwhile, the **Fraunhofer Innovation Platform for Smart Shipping** (FIP-S2@Novia) was set up in Finland. In this platform, the Fraunhofer Center for Maritime Logistics and Services CML is joining forces with the Novia University of Applied Sciences in Turku to research maritime simulations and digital twins, i.e. virtual copies of ships, ship components and harbors.

The Fraunhofer internal program **ICON (International Cooperation and Networking)** enables strategic project-based partnerships with outstanding international universities and non-university research institutions. The program gave rise to three new collaborations in the course of 2021.

In the ICON project **Metasurfaces for Energy Efficient Devices** (MEEt), the Fraunhofer Institute for Solar Energy Systems ISE and AMOLF, a research institution operated by the Dutch Research Council, have teamed up to research metamaterials for optical applications, including high-efficiency solar cells, LEDs and optical sensors.

Patent applications claiming rights of priority



In **Layers of Protection Architecture for Autonomous Systems** (LOPASS), the Fraunhofer Institute for Experimental Software Engineering IESE and the Fraunhofer Institute for Cognitive Systems IKS have partnered with the University of York in the UK to develop techniques for fast, failure-free autonomous driving.

The Kyoto University and the Fraunhofer Institute for Microelectronic Circuits and Systems IMS are working together on the ICON project **Next Level Photonics** to research novel methods of generating and detecting light and to integrate those methods into powerful, but compact 3D imaging sensor systems.

The **Fraunhofer International Mobility Program (FIM)** was created to encourage international mobility and networking among Fraunhofer employees, and to support knowledge transfer. The program allows Fraunhofer employees from all fields of activity and at any career stage to stay abroad for periods of several months. However, the FIM was severely limited by the pandemic in 2021, and many stays abroad had to be postponed. However, the stays that had already commenced were successfully completed despite the restrictions caused by the pandemic.

International Fraunhofer representative offices in China, Brazil, India, Japan and Korea function as hubs for networking and marketing. They provide local support for all Fraunhofer institutes in initiating and setting up cooperations with research partners from their respective countries. With their knowledge of local research landscapes, representative offices can generate fresh impetus for the Fraunhofer research portfolio. In addition, senior advisors with similar responsibilities are active in seven countries across the world.

Exploitation of intellectual property rights

The Fraunhofer-Gesellschaft remains the **leader** among German research institutions in terms of its annual number of invention disclosures, new patent applications, and total volume of industrial intellectual property rights. The position achieved by the Fraunhofer-Gesellschaft is outstanding even when compared with that of industrial companies. Over the last decade, Fraunhofer has always ranked among the German Patent and Trade Mark Office's 10 to 20 most prolific patent applicants. Fraunhofer is also among the European Patent Office's most active patent applicants.

In 2021, Fraunhofer-Gesellschaft employees submitted 604 invention disclosure reports. They filed 521 patent applications claiming rights of priority with the relevant patent offices, which corresponds to a rate of around two patents per working day. The Fraunhofer portfolio of active patent families, each of which comprises all intellectual property rights in different countries, remained close to the previous year's figure at 7,620. To guarantee ongoing exploitation of intellectual property rights, Fraunhofer is continuing its efforts to group patents owned by different institutes into portfolios that are then offered to selected companies. This approach creates new opportunities to generate income from licensing agreements and R&D projects.

As a rule, Fraunhofer generates revenue from the **commercial exploitation of intellectual property (IP)** rights, not only by concluding licensing agreements, but also by including intellectual property within patent pools. The most successful of these pools consist of patents for audio and video encoding. In conjunction with other parties from different countries that hold patents that are relevant to standards, Fraunhofer uses various patent pools to issue licenses on a worldwide basis, enabling the exploitation of patents in well over 100 countries. The income from these pools is reinvested in pre-competitive research, thus helping strengthen Germany's position as a research hub for the long term. In 2021, Fraunhofer concluded 395 new IP exploitation agreements, bringing the total number of active agreements at the end of the year to 3,090. After a decline in the previous year, license-fee revenue has once again increased, reaching €114 million in 2021.

Corporate responsibility issues

Responsibilities of the Fraunhofer-Gesellschaft

Fraunhofer sees corporate responsibility (CR) as an **all-encompassing term** that covers economic, environmental and social concerns and is led by the principle of responsibility in its dealings with customers and partners, employees, subcontractors and suppliers. Commitment to this principle is also expressed in the way the Fraunhofer-Gesellschaft focuses its research on generating benefits for society and strengthening the industry sector in Germany and Europe.

In 2021, Fraunhofer also demonstrated its sense of responsibility as regards its own employees in the context of the ongoing pandemic. In addition to engaging in numerous research projects, for example, in order to develop medications to counter COVID-19, the Fraunhofer-Gesellschaft also contributed to the battle against the virus and the protection of its own employees by launching a **Fraunhofer-wide vaccination campaign**. Furthermore, on the initiative and with support of the Fraunhofer executive board, all employees were able to participate in an antibody study by the Fraunhofer Institute for Translational Medicine and Pharmacology ITMP, allowing them to be tested for SARS-CoV-2 antibodies on a voluntary basis. This opportunity was met with enormous interest across Fraunhofer as a whole, and employees took advantage of it in great numbers. The extensive protection and hygiene measures adopted in the previous year were continued, or where necessary, further expanded.

The solidarity within our organization and Fraunhofer's dedication to its own employees came to the fore in another painful event, **the extreme flooding of July 2021**. The floods, which caused serious damage all over Germany and in the Ahr valley in particular, also impacted many of our colleagues. The Fraunhofer-Gesellschaft quickly set up an account for donations from within its workforce, in order to cut through bureaucratic red tape and provide rapid assistance for employees that were badly affected. These funds — amounting to €165,000 in total — were distributed by a specially established donations committee at the end of November. These funds supported the victims of the floods in covering damages that did not come under insurance. Both those affected and the executive board expressed their gratitude for Fraunhofer employees' exceptional solidarity and willingness to help.

Sustainability research

As a worldwide leader in applied research, Fraunhofer primarily contributes to **maintaining our society's future viability by means of sustainable solutions**. The diverse examples of Fraunhofer research outlined in this year's annual report once again show that the Fraunhofer institutes are developing solutions in a wide variety of research fields to address highly complex challenges. These examples range from developments in the field of intelligent medicine (e.g., using minirobots to treat ailments without harming the body) to sustainable solutions in the field of bioeconomy (e.g., searching for an environmentally compatible substitute for palm oil or producing synthetic fuels from biogenic waste) and artificial intelligence applications aimed at securing our energy supply.

Protecting the climate is one of the most important tasks that our society faces across the world, particularly when it comes to switching our energy systems to renewable energy and defossilizing our industry sector. Fraunhofer researchers are making vital contributions to this process, for example, by participating in various hydrogen technology initiatives, or in a pilot project aimed at improving flexibility in our energy systems, so that industrial processes have access to a functional electricity supply that primarily stems from renewable sources. Fraunhofer scientists were also involved in the ARIADNE project, which produced a report outlining various scenarios that demonstrate how Germany's transformation to become climate neutral by 2045 could be achieved.

The **Fraunhofer Group for Energy Technologies and Climate Protection** was founded in 2021, so that Fraunhofer research could make an even greater contribution in this area. In addition to working on a wide range of different research projects, this group represents the combined voices of Fraunhofer energy research institutes in political bodies and research groups at both a national and EU level. Through science-based advisory services, the group supports policy-makers and industry in transforming the energy system and achieving climate neutrality.

Also founded in 2021, the **Fraunhofer Group for Resource Technologies and Bioeconomy** aims to make a decisive contribution to the achievement of sustainability goals at a national, European and international level. By taking ideas from the fields of resource efficiency, bioeconomy, circular economy and the sovereignty of value creation cycles from a concept to a reality, the group intends to ensure responsible management and use of natural resources. This includes the supply of raw materials and energy, climate and environmental protection, and ensuring food and healthcare security.

The **Fraunhofer-Zukunftsstiftung (Fraunhofer Future Foundation)** runs a funding program aligned with the UN's Sustainable Development Goals (SDGs). With an annual funding volume of €5 million, it provides targeted support for projects by Fraunhofer researchers that help to make the world more environmentally friendly, socially equitable and financially viable. EDDA — Efficient Humanitarian Assistance through Intelligent Image Analysis and FAVRE — Concrete Recycling for Climate and Resource Conservation represent two excellent examples of such projects from 2021. The foundation is increasingly focusing on collaborations with civil society as a means of transferring project results, and is promoting collaboration between that world and the world of science and industry. Plans are in place to bolster dialog with citizens through participative events and schemes in the future.

Socially responsible research

Since the BMBF-funded joint research project LeNa — Sustainability Management in Non-University Research Organizations ended in 2016, Fraunhofer has intensified its efforts to implement sustainability principles. The tools developed in this context greatly support the implementation of sustainability management measures, with a particular focus on infrastructure processes at the organizations in question. In addition to these tools, in 2021, the research organizations involved in the LeNa initiative began holding regular dialogues to discuss their experiences of the implementation process. The dialogues allowed those involved to learn from each other and to simplify implementation by exchanging examples of best practice.

The **joint research project LeNa Shape**, which was launched in 2021, now also aims at integrating the principle of socially responsible research into daily research work. Researchers from universities and non-university research organizations are collaborating in this area under two application-focused modules. The first module, LeNa Move, is focused on studying obstacles to implementation and then developing motivational tools, so that the LeNa reflection model can be implemented by researchers and scientific managers during their daily scientific work. The second module, LeNa Value, is developing criteria for assessing scientific excellence in terms of sustainability, as well as metrics and indicators for analyzing the effects of sustainable research. A common feature across the two modules is the development of previously non-existent methods and tools that can be used to address and implement questions of trans- and interdisciplinarity in sustainable research. The objectives here are to provide a scientific basis for the conditions required to integrate sustainability principles into researchers' daily work and align research processes with sustainability criteria, and to integrate sustainability principles into the academic landscape and our science and innovation ecosystems.

Efforts are being made to increase participation by citizens and offer them a wide variety of opportunities to get involved, for example, through the active inclusion of citizens in research and development processes — often known as citizen science. The goal here is not just to increase acceptance of innovations in civil society, but rather to restructure the entire process of innovation to focus more on application. Because ultimately, citizens are the ones that will use products and technologies in their daily lives. Including potential fields of application right from the research and development stage can give rise to vital inspiration for innovations, as well as enabling the consideration of differing viewpoints. This approach can serve as an excellent complement for Fraunhofer's research focus on fulfilling industry needs, while also helping to improve scientific communication and strengthen social acceptance of science. Fraunhofer researchers are currently developing the necessary methods and expertise.

Employees

At year-end 2021, Fraunhofer had 30,028 employees, 21,640 of whom were research, technical or administrative staff (RTA staff), 7,877 students, and 511 trainees. These employee figures substantiate the goal agreed between Fraunhofer and funding agencies at the beginning of the crisis in relation to retaining its staff levels and expertise. They also demonstrate that Fraunhofer can remain fully operational even under changed circumstances.

After omicron became the dominant SARS-CoV-2 variant in Germany, incidence rates grew rapidly and new record figures were recorded. The number of infections among the Fraunhofer-Gesellschaft's employees also increased massively. By the end of January 2022 inclusive, approximately 1,300 cases had been recorded since the beginning of the pandemic. Of those, just under 700 occurred in the period from November 2021 to January 2022 inclusive. These infections were almost exclusively traced back to the affected persons' immediate social environment — people from the same household played a particularly significant role here. Having conducted an initial **vaccination campaign** in collaboration with the company doctor service BAD to ensure basic immunity among employees in summer 2021, the Fraunhofer-Gesellschaft is now also providing booster vaccines. The first booster appointments took place back in December 2021, with the majority of boosters being dispensed in January and February 2022. By taking this measure to protect its own employees, the Fraunhofer-Gesellschaft has shown how it values their welfare and highlighted the excellent working conditions at the organization.

"Our success relies on the knowledge and enthusiasm of our employees for applied research. Fraunhofer offers its staff excellent work conditions paired with a high degree of autonomy."
From the Guiding Principles of the Fraunhofer-Gesellschaft

Through its strategic action areas, the HR Management division is bolstering this knowledge and enthusiasm, and establishing and further developing the ideal working conditions to allow them to flourish. Due to global megatrends such as digital transformation, Fraunhofer institutes must secure and increase their performance and innovation levels. In this context, how the institutes structure their working arrangements is crucial in determining their ability to adapt to changing circumstances. This also makes a decisive contribution to the organization's innovative capacity, attractiveness as an employer and resilience, even during the pandemic. Around 40 institutes have launched implementation projects in the **New Work** domain, using the ideas, tools and guidance resources offered by Fraunhofer headquarters:

- Developed during the pilot phase, New Work Radar is a tool the institutes can use for situation assessment and analysis. It allows them to take stock of the current status of their New Work initiatives and the maturity level they aim to reach in areas such as management and self-organization, increased flexibility, and innovation culture. The analysis can be conducted as a self-assessment or as a workshop led by an expert, with the goal of identifying initial action areas for New Work implementation.
- A New Work community was set up as an additional support structure, and has since been joined by 84 New Work project managers. It serves as a platform where the participating institutes can exchange ideas and offer each other advice. There are now around 15,000 employees directly or indirectly involved in New Work activities.
- So far, a total of more than 20 local works council agreements or regulations (at institutes without a works council) for flexplace and flextime working arrangements have been developed across Fraunhofer. Almost all of the institutes proceeded by conducting employee surveys and testing out the new working arrangements in pilot departments. Around 20 team charter processes have also been initiated or already completed at various institutes. The team charter has been generally deemed an extremely helpful tool for the process of establishing how managers and employees want to work together in the future.

- New Work can help make collaboration with customers more innovative and more agile, for example, through an agile project management team structure. Reacting quickly to changed needs and market conditions is an important factor in customer relations. This is why 16 institutes are engaging in three module series to tackle the topics of agile project management, collaborative leadership and new forms of collaboration.

"Our employees shape the future — in ambitious positions at Fraunhofer or in other areas of science and business. Fraunhofer therefore places great importance on their professional and personal development."
From the Guiding Principles of the Fraunhofer-Gesellschaft

"Knowledge transfer via individuals" is an important task for the Fraunhofer-Gesellschaft, and it has set out to implement it through the **Careers with Fraunhofer** campaign, a holistic HR development strategy. The goal of the campaign is to support employees in their individual career planning right from the beginning. The key tool for this planning is the employee performance review, which is treated as a development discussion at Fraunhofer. To provide guidance for development planning, Fraunhofer has defined fields and subjects for qualifications, as well as development and career paths following both internal and industrial, scientific or independent courses, and designed corresponding initiatives.

In addition, tailored career programs assist employees in networking across institute boundaries, e.g., the Vintage Class and Advanced Management Class for top-level and upper management staff, TALENTA for female scientists and scientific managers, and the Step Forward program for young professionals.

To evaluate these measures in the context of the overall HR development strategy, exit surveys are systematically conducted with departing employees, in order to collect data on various issues, such as to what extent they felt they were supported in their development planning.

These working conditions are one of the reasons that Fraunhofer is ranked on the **Top Employers** list every year. In January 2022, the Fraunhofer-Gesellschaft took sixth place in stern magazine's top 50 employers list.

Employees
(number at year-end)

Diversity

The aim of diversity management is to create a working environment in which every employee can participate on equal terms — irrespective of their ethnic origin, gender, religion, ideology, physical or other disability, age or sexual identity.

As of fall 2021, the **Diversity funding program** has been running for ten years. The continuing development of the program can be seen in the expansion of its funding objectives to cover inclusion (2016) and intercultural collaboration (2019). Since the program was launched, it has provided funding for 196 applications, amounting to a total volume of €1.8 million; the year 2021 saw 26 of these applications receive funding amounting to €182,000. The institute-specific initiatives funded in 2021 include strategies for raising diversity awareness, particularly as regards unconscious bias, innovative accessibility measures for people with disabilities, and virtual work-life balance services tailored to the current challenges posed by the pandemic.

At the end of 2021, the share of employees with severe disabilities was 2.6 percent (2020: 2.8 percent). The

inclusion of people with disabilities is one the focus points in the Diversity funding program. In 2021, the program concentrated on physical accessibility. For example, central funding was provided for a development project involving the creation and evaluation of a elevator prototype that can be used to make any elevator accessible for people with partial or total visual impairment, by means of an external device that can easily be added to existing elevators. Other focus points for the program involved information and communication measures on issues related to inclusion, disseminated via channels such as the Fraunhofer-wide intranet.

In 2021, the Fraunhofer-wide framework agreement with **pme Familienservice** covering services in emergency childcare, home care and elder care, and life coaching was extended for a further two years. The pme Akademie is also still included. Summer 2021 saw an unplanned expansion of the framework agreement to cover a support package for the victims of the flooding catastrophe, including measures such as a dedicated emergency hotline, income and budget consultation, emergency psychosocial care and a concierge service (e.g., for home help, tradesman services, pet sitting and running errands).

A simplified certification procedure for the **Fraunhofer family logo** was offered in 2021. Institutes that had already been awarded the logo were allowed to retain it until recertification could be conducted in 2022, while additional institutes were given the opportunity of obtaining the certification for the first time — leading the number of institutes awarded the family logo for excellence in work-life balance to rise to 19. A further 29 institutes demonstrated a very good level of work-life balance.

In the **Fraunhofer-specific cascade model**, Fraunhofer set transparent goals for increasing the proportion of female scientists at the various organizational levels by 2025. At level 3 (scientific employees without management responsibilities), the target for the year was achieved with the proportion of women reaching 24.3 percent. The target was also reached at the management level with a 16.8 percent proportion of female scientists. In contrast, despite a slight increase of 3 percentage points, the target of a 13 percent proportion of female employees at the top management level was not achieved.

The sourcing team established in 2020 is working toward the goal of recruiting more women for institute management positions. Since its founding, the sourcing team has identified more than 1,000 relevant female candidates both nationally and internationally and has already contacted more than 600 of them. The sourcing team has specifically reached out to more than 220 female candidates for 16 appointment processes. Thirty of these candidates subsequently submitted an application. Sixteen women were invited to interviews for nine appointment processes that were already at an advanced stage; six of them have already been appointed to positions with Fraunhofer. Each of the remaining three procedures already has a female candidate on their shortlist.

Fraunhofer is also striving to increase the **proportion of women on the advisory boards** at the institutes by 4 percentage points each year. The measures adopted by the Research Coordination department and the efforts being made on the institute side are having an impact: the target for 2021 was achieved, with the proportion of women in the institutes' advisory boards reaching 26.5 percent (2020: 22.3 percent).

Unconscious bias is a key focus in diversity management, as it is a crucial consideration in creating a culture of equality and diversity. The Fraunhofer-Gesellschaft has developed a comprehensive strategy for employees and managers in order to raise awareness of the impact of unconscious bias, to train them in how to approach it, and to reduce its negative effects on HR decisions and the sense of workplace unity. In addition to implementing various initiatives such as a module for use in presentations and training modules for management seminars, 2021 saw the development of an e-learning course in collaboration with an external service provider. The course will be published in spring 2022 and will help employees and managers take a wider range of perspectives into account when making decisions.

Promoting equality in research and innovation is an important concern for the EU Commission, one that is eagerly welcomed and supported by the Fraunhofer-Gesellschaft. As such, from 2022 onward, having a **Gender Equality Plan (GEP)** will be a mandatory requirement for admittance into the Horizon Europe program. In addition to containing a voluntary commitment on the issue by the executive board, the GEP describes the current gender distribution situation and gives an overview of targets, measures and programs for promoting equal career opportunities at Fraunhofer. Fraunhofer's GEP was formulated on the basis of the annual monitoring report for the Joint Initiative for Research and Innovation and is updated every year. In accordance with the stipulations of the EU Commission, Fraunhofer has published its voluntary commitment to promoting equal career opportunities on its website and the Gender Equality Plan on the intranet, where it can be accessed by all employees.

Initiative: climate-neutral scientific operations

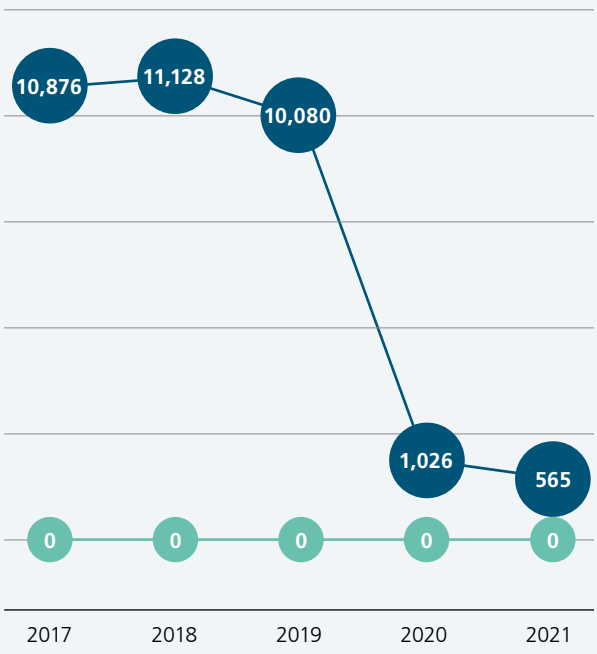
In addition to developing sustainable research solutions and contributing to the overall transformation of society to improve climate protection, the Fraunhofer-Gesellschaft is also taking on the responsibility of restructuring its internal processes and infrastructure to make them more climate

friendly. In this context, Fraunhofer has set itself the ambitious target of reducing its greenhouse gas emissions to achieve **climate-neutral scientific operations** by as early as 2030. Any remaining residual emissions that still require offsetting after the target year must be entirely eliminated by 2045 at the latest. In 2021, using the carbon footprint calculated in 2020 as a basis, Fraunhofer developed a practical road map containing fixed initiatives for reducing its CO_2 emissions. For Fraunhofer, one of the first major steps to achieving climate neutrality is procuring renewable energy for all its properties. An internal funding program for photovoltaic systems has been specially developed for this purpose and is expected to promote a massive expansion in Fraunhofer's capacity to generate its own electricity. In addition, a decision has been made to procure clean electricity for the entire Fraunhofer organization when the next framework agreement takes effect in 2023. In the medium term, this measure will be supplemented by individual solutions and direct energy supply agreements.

In 2021, the coronavirus once again imposed strict limitations on **business trips**. A large proportion of business trips, especially flights, were replaced by virtual means of communication. As such, the CO_2 emissions resulting from such trips remained at a low level in 2021; at 565 metric tons of CO_2, this figure was yet again almost half that of the previous year. In 2021, for the first time, the emissions from flights in 2020 were offset through compensation projects conducted with atmosfair. In concrete terms, this amounted to providing equal shares of support for a pioneering solar plant project in Senegal and a small biogas plant in Nepal. These projects facilitate secure, affordable, clean energy supplies in poor, decentralized regions, primarily for private households. Plans are in place to offset the flight emissions for 2021 as well. Thanks to the framework agreement between the federal government and German Rail (Deutsche Bahn), all rail travel continues to be carbon-neutral, and there have been no changes in this regard.

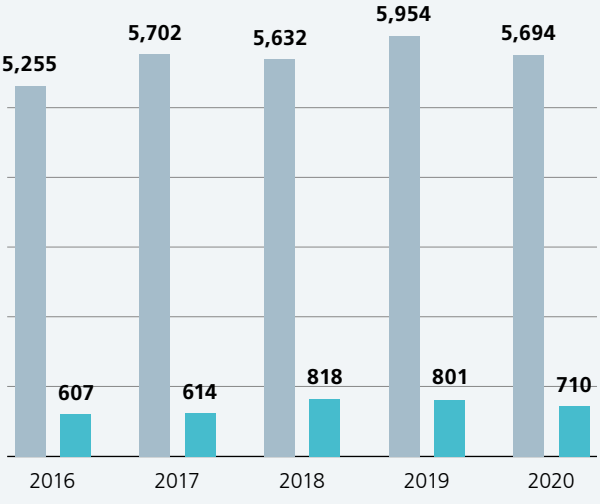
Officers have been appointed at the Fraunhofer institutes for operational **waste management** and the associated documentation. Up-to-date total waste figures are available for 2020 only. According to these figures, in 2020, the Fraunhofer institutes generated 5,694 metric tons of non-hazardous waste and 710 metric tons of hazardous waste. This amounts to a reduction of 4 percent in non-hazardous waste and 11 percent in hazardous waste compared to 2020. The reduction in non-hazardous waste is a result of the efforts made at the individual institutes. The fluctuations in hazardous waste can largely be explained by the fact that some projects generate more waste than others, and the amount of waste cannot always be assessed directly.

CO_2 emissions from business travel by Fraunhofer employees, in metric tons



- Air travel
- Rail travel: Carbon-neutral due to inclusion in the framework agreement between the federal government and German Rail (Deutsche Bahn), according to the information given by Deutsche Bahn

Volume of waste produced by Fraunhofer institutes, in metric tons



- Non-hazardous waste
- Hazardous waste

Risks and outlook

Risk management and risks

The Fraunhofer-Gesellschaft's risk situation has improved slightly in comparison to the previous year, although it continues to be affected by the impact of the COVID-19 pandemic. Overall, however, there is still no lasting threat to the Fraunhofer-Gesellschaft.

Thanks to the exceptional efforts made by all our employees and the support of the German federal and state governments, Fraunhofer was once again able to overcome the immense challenges of the pandemic, which were by no means diminished in its second year. However, due to uncertainty as to how the pandemic will continue to unfold, future economic developments and the extent of the impact on the Fraunhofer-Gesellschaft remain unclear. Consequently, the Fraunhofer executive board has devised possible scenarios and corresponding measures to enable a swift response to future developments. For instance, in 2021, the funding agency once again authorized an increased allowance to enable Fraunhofer to retain the staff expertise and capacity that play such an important role in tackling the crisis in Germany and Europe. The coronavirus crisis management team continues to closely monitor and analyze the evolving circumstances so it can adapt measures to the situation as it changes.

Fraunhofer takes **risk** to mean all internal and external events and developments that might jeopardize the organization's success. These include both risks where the monetary value can be directly ascertained and qualitative risks.

Fraunhofer's **risk management system** is designed to identify existing and potential risks at an early stage and to manage them by means of appropriate measures in such way that they either do not materialize at all or do not have consequences that could endanger Fraunhofer's business success or jeopardize its ability to fulfill its mission in accordance with its statutes. To achieve this objective, the Fraunhofer-Gesellschaft has set up a risk management system that takes into account its requirements and structure, undergoes continuous improvement, and has been accepted by Fraunhofer-Gesellschaft auditors as being adequate and suitable for this purpose.

In the cyclic risk management process, risk experts in the central departments carry out systematic, standardized risk assessments on a yearly basis. The individual risks identified in this process and the associated countermeasures are then summarized under the appropriate risk categories and prioritized in an annual risk report that is presented to the executive board, enabling individual risks of a similar nature to be evaluated collectively.

Additionally, the central departments inform the executive board of relevant risk-related developments — both routinely and on an ad hoc basis — via the established reporting channels.

The Fraunhofer-specific risk classification model provides a framework for the annual risk assessment, which in turn serves as a basis for the risk report presented to the executive board. The first layer of the model consists of four main areas of risk: business model, financing, resources and business operations. In the second layer of the model, individual Fraunhofer-specific risks (currently 19) are assigned to these four main areas.

Business model risk encompasses types of risk that represent a threat to the continuation and further development of the Fraunhofer business model. Such risks may arise from significant external circumstances or from the internal approach to applying the business model.

It is to be expected that the COVID-19 pandemic will continue to impact certain areas of the **research portfolio**. In anticipation of this, Fraunhofer is intensifying its ongoing activities in relation to strategic portfolio management.

Indirect financial risks may arise for the Fraunhofer-Gesellschaft from liabilities and operational risks incurred by its **independent international affiliates**. The long-running lawsuit between Fraunhofer USA, Inc. and a US company was resolved by means of an out-of-court settlement in 2021. Discontinuation of funding from the country of domicile has resulted in the closure of one center each in both Chile and Singapore. As such, the strategic focus and continuation of the organizations is also under review, and suitable measures have been taken.

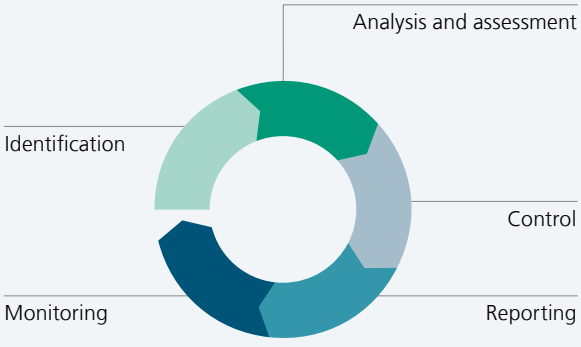
In the context of **financing risks**, the focus is on containing risks that might compromise Fraunhofer's access to research funding or its solvency.

Base funding by the federal and state governments is **one of three main sources of finance for the Fraunhofer-Gesellschaft**. It is used principally as a means of initiating quality-assured research activities in new fields and topics. For Fraunhofer as an applied research organization, revenue from industry is another of the three main sources of finance where it continues to experience difficulties in achieving its ambitious revenue goals due to the ongoing pandemic. In 2021, the BMBF granted Fraunhofer an additional allowance to enable the organization retain the staff expertise and capacity that play an important role in tackling the crisis in Germany and Europe.

In order to maintain the share of base funding in the funding mix in the long term, Fraunhofer proactively manages its growth and lobbies state and federal governments for base funding at a level in keeping with its mission and in proportion to its performance, along with business management conditions appropriate to the research sector. The current business management statutes enable Fraunhofer to operate in a flexible, efficient and autonomous way. If this were to be curtailed, it would limit the organization's **liquidity**, restrict its ability to make provision for risks and hamper its ability to adapt.

Projects for **building and equipping new facilities** that are co-financed by the federal and state governments and the EU (ERDF) are subject to restrictions concerning how long the funds are made available. If projects encounter lengthy delays, that may result in the late payment, or even forfeiture, of the funds provided. Fraunhofer has a construction control unit in place to closely monitor the progress of projects for building and equipping new facilities and to continuously explore possible means of expediting such projects. Furthermore, Fraunhofer strives to ensure uniform and flexible funding conditions for building projects.

Cyclic risk management process



Fraunhofer risk classification model

Main risk areas	Specific risk types
Business model	State aid law
	Non-profit status, taxation
	IP exploitation, spin-offs
	Corporate strategy, portfolio management
	International activities
Finances	Base funding
	Public-sector revenue
	Industrial revenue
	Operating expenses/Capital expenditure/Construction
	Liquidity, advance funding, other financial risks
Resources	Employees
	IP, know-how
	Infrastructure
	Financial assets, reserves
	Reputation, brand
Business operations	Service performance, contractual risks
	Legal risks
	Information security
	Governance, internal control systems

Resources risk encompasses those types of risk that may affect the availability of tangible and intangible resources needed to successfully carry out research activities.

Over the course of 2021, a wide range of protective measures including the tried and trusted Fraunhofer crisis management system proved their effectiveness, not only during the pandemic but also most recently in the flooding catastrophe. These measures allowed Fraunhofer to establish a crisis management team and support affected employees within a very short space of time. The Fraunhofer-Gesellschaft continuously works to improve its protection, prevention and crisis management processes, to further increase its resilience as regards possible threats and risks.

Business operations risk comprises those types of risk that may arise from research and administration processes, or from conducting specific research projects.

Secure information handling is of fundamental importance to the continued existence of a knowledge-based research organization. However, even research organizations cannot escape the (current) sharp increase in threats in the domain of **IT security**. However, Fraunhofer is continuously developing targeted measures to limit these risks, as well as documenting them in a binding handbook on information security. Currently, the risk of two-way cyber-attacks and espionage activities has shown a further sharp increase due to the war in Ukraine.

Outlook

After two challenging years of dealing with the impact of the coronavirus crisis, Fraunhofer is facing 2022 with confidence. In terms of total business volume, Fraunhofer expects to cross the €3 billion threshold for the first time. The number of orders for industry projects has increased in comparison to the previous year. However, achieving these ambitious revenue targets remains fraught with a certain level of risk, firstly because we have yet to entirely overcome the pandemic and secondly because the war in Ukraine is causing geopolitical upheaval that may have as yet unforeseen economic consequences.

The new **Fraunhofer Structural Transformation strategy group** is helping the Fraunhofer-Gesellschaft to establish a strategic position in this area. The group has adopted a holistic approach spanning different sectors and regions, and is working with points of contact in the participating states of Brandenburg, Lower Saxony, North Rhine-Westphalia, Saxony and Saxony-Anhalt to develop demand-based strategies and networks. In addition, the strategy group is driving a systematic, scientific, comparative study based on accompanying cross-institute research into value creation and acceptance processes in the regions, so as to be able to provide structural transformation stakeholders with recommendations for action as regards future innovation policy decisions and to unlock potential across the regions.

Identifying relevant topics and trends at an early stage and establishing a strategic position in these areas are essential to Fraunhofer's applied research. The use of new technologies and methods for data-driven planning support is of particular strategic importance here. The switch from our existing ERP system, SIGMA, to a pioneering **SAP S/4HANA system** has introduced a paradigm shift. Based on a standardized process environment, Fraunhofer's business processes and core procedures were digitalized with a consistent format across all organizational and functional units. In addition to standardizing processes, this also brought data collection and retention practices into alignment throughout the entire organization. With its legally dependent institutes spread across 80 locations, Fraunhofer represents a particularly significant interoperable, consistently standardized data and process landscape; with these new tools, the door has been opened for a new form of strategy development. The Fraunhofer-wide go-live for the SAP S/4HANA system occurred at all locations as planned in January 2022.

In 2022, a tool set is being rolled out for various user groups along with the organization-wide **Business Intelligence** suite; this tool set represents a simpler means of analyzing a range of internal data sets from various sources and differing usage contexts. In addition to the internal data generated by Fraunhofer, a data science platform is being used to create and develop a graph database using SAP HANA as a basis. This platform will give data scientists access to numerous data sets, while also serving as an external data pool for the business intelligence system.

The potential synergies generated by the 76 Fraunhofer institutes' broad range of interdisciplinary know-how, covering more than 1,000 core areas of expertise, represent a unique selling point unlike any other in the world. Harnessing this potential through more intense internal collaboration was the objective of the **Fraunhofer 2022 Agenda**, which was successfully completed through the development and establishment of new tools and processes. Consequently, from 2022 onward, joint group road maps will be produced, institute consortia will address the needs of lead markets and coordinated research will be conducted in strategic future research fields through clusters of excellence.

As such, Fraunhofer is facing into the future from a robust, competitive position, thanks to the following instruments and structures:

- Efficient internal decision-making and business processes based on SAP tools
- Effective tools for combining elements within the Fraunhofer expertise portfolio, unhindered by obstacles
- A consistent mission focused on contributing to the sustainable development of society
- A resilient governance structure comprising institutes with autonomy in their specialist focus areas and independent connections to industry and the scientific community

The executive board would like to thank the members, patrons, friends and, most of all, the employees of the Fraunhofer-Gesellschaft for their support, dedication and hard work in 2021.

Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V.

The executive board
Prof. Dr.-Ing. Reimund Neugebauer
Prof. Dr. rer. publ. ass. iur. Alexander Kurz
Dipl.-Kfm. Andreas Meuer

Report of the senate on the financial year 2021

Prof. Dr.-Ing. Heinz Jörg Fuhrmann, Chair of the senate of the Fraunhofer-Gesellschaft.

In 2021, the Fraunhofer-Gesellschaft achieved slight growth, despite ongoing difficulties in the market environment. The enormous challenges of the second year of the pandemic were overcome thanks to the support of the German federal government, the German Federal Ministry of Education and Research (BMBF), and the German federal states, and the hard work and dedication of Fraunhofer's now over 30,000 employees. Initial signs of recovery could be seen in industrial revenue, for example, which reached pre-crisis levels in absolute terms.

Photo: Salzgitter AG/F. Bierstedt

In 2021, the Fraunhofer-Gesellschaft showed a stable financial performance, with its total business volume growing by 3 percent to approximately €2.9 billion. The organization also retained its staff capacity in its core business area of contract research, and even expanded capacity slightly in response to demand, particularly in the fields of medicine and energy, which constitute important focus points for both society and policymakers at present. In addition to revenue from publicly-funded projects, additional funding from the German federal government represented an important source of support. In 2021, this funding was used to launch initiatives such as the Fraunhofer Innopush Program, which facilitated the expansion of cross-institute expertise in emerging research fields across a total of 30 projects with 65 participating institutes. The focus of the program was to drive targeted growth in innovation for industry in key areas such as demand-driven innovations, networking and cross-fertilization, competitiveness through digitalization, and system integration and pilot testing. The Anti-Coronavirus Program supported national institutions like the Robert Koch Institute, state authorities, hospitals and initiatives such as the hackathon organized by the German federal government to develop technological solutions to combat the pandemic.

Thanks to a comprehensive crisis management system and the preventative measures adopted by employees, neither the institutes nor Fraunhofer-Gesellschaft headquarters started any infection chains. In addition to initiating these health protection measures, Fraunhofer expanded its positioning in future-oriented research fields such as energy and mobility research, quantum technologies and translational medicine. This included the three new groups established in 2021, namely the Fraunhofer Groups for Health, Resource Technologies and Bioeconomy, and Energy Technologies and Climate Protection. The latter showed the greatest revenue growth among all nine groups, and is making a vital contribution to the planned transformation of our civil society.

The Fraunhofer-Gesellschaft returned a solid balance sheet for 2021 and the auditing firm commissioned to review its financial statements once again delivered an unqualified opinion in its audit report.

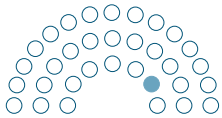
In 2021, the senate fulfilled the duties entrusted to it under the statute of the Fraunhofer-Gesellschaft. It convened twice in the course of the 2021 financial year: on May 4 and on October 21. Both sessions took place in a hybrid format due to the SARS-CoV-2 pandemic.

The main decisions taken in accordance with the statute concerned the structure of the Fraunhofer-Gesellschaft and matters relating to its executive board:

- Acting on the recommendation by the senate committee for the election and re-election of executive vice presidents, the senate initiated a restructuring of the Fraunhofer-Gesellschaft executive board that took effect from January 2022. This new, future-focused management structure comprises five executive units, rather than the previous four: "Corporate Strategy, Research and Communications" under the leadership of Prof. Dr.-Ing. Reimund Neugebauer, "Innovation, Transfer and IP Management" under the leadership of Prof. Dr. Alexander Kurz, "Research Infrastructure and Digital Transformation," "Human Resources, Corporate Culture and Legal Affairs" and "Finances and Controlling." New executive vice presidents will be appointed for the latter three units in 2022.
- In order to guarantee stability in the organization's leadership, the senate committee for the election and re-election of executive vice presidents recommended to the senate that Prof. Dr.-Ing. Reimund Neugebauer's presidency should be prolonged. In light of this recommendation and other factors, the senate re-elected Prof. Dr.-Ing. Reimund Neugebauer as president of the Fraunhofer-Gesellschaft for a further two years, until September 30, 2024.
- The senate resolved that the Research Fab Battery Cells FFB, formerly part of the Fraunhofer Institute for Production Technology IPT, should become an independent Fraunhofer institution in Münster as of January 1, 2022.

The Senate would like to take this opportunity to thank the executive board and all employees of the Fraunhofer-Gesellschaft for their great dedication and hard work under the challenging conditions of the ongoing global pandemic during the 2021 financial year.

Prof. Dr.-Ing.
Heinz Jörg Fuhrmann
Chair of the senate of the Fraunhofer-Gesellschaft



NEW SENATE MEMBERS

Dr.-Ing. habil. Katrin Sternberg
Executive board member for Research & Development, Quality Management, Regulatory Affairs & Medical Scientific Affairs | B. Braun/Aesculap AG

Katrin Sternberg has been a member of the executive board at Aesculap AG since 2018, with responsibility for the Research & Development unit. In 2019, she also took on responsibility for Quality Management, Regulatory Affairs & Medical Scientific Affairs. Aesculap is a manufacturer of medical engineering products and a division of the Melsungen-based B. Braun Group.

Before moving to Aesculap in 2014, where she has subsequently held a variety of management positions, Sternberg was deputy director of the Institute for Biomedical Engineering at Rostock University. In her last role at the university, the chemist was a consortium speaker within a national and international network focused on innovation in implant technology and funded by the German Federal Ministry of Education and Research (BMBF).

She started with Aesculap as Vice President for Research & Development. Purpose communication is a hot topic these days, but the researcher has already been practicing it in her own career for many years. While her doctoral thesis on reaction mechanisms of molecule structures may have been firmly anchored in basic research, Sternberg's career path always charted an ever more direct course toward the application of medical knowledge acquisition. For example, when qualifying for post-doctoral lecturing, she wrote a dissertation in the field of engineering, focusing on the potential of polymer coatings in depot drug formulations.

In her current position, Sternberg intends to expand Aesculap's strong positioning in the field of surgical instruments, implants and sterilization technologies. "Sensors are becoming an ever more important factor in treating illnesses," she says. Other research fields the board member sees as having a promising future include robotics, artificial intelligence — which could be used to improve diagnostics, for example — and in the long term, 3D printing tissue structures using bio-ink.

These are topics that Fraunhofer is researching intensively, for example, in the Strategic Research Fields for Digital Healthcare and Artificial Intelligence. Fraunhofer uses these platforms to pool its institutes' transdisciplinary expertise and find solutions that meet demand. This will be of especial interest to the field of healthcare research in terms of being able to provide cost-aware precision medicine for the benefit of patients in the future.

"The coronavirus pandemic increased appreciation for healthcare and trust in technology. In the future, humans will work ever more closely with intelligent components. The challenge is ensuring these systems are absolutely safe."

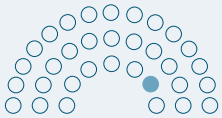
Dr.-Ing. habil. Katrin Sternberg

Photo: © B. Braun Melsungen AG

"My passion is rethinking energy for people and for our planet. That's why I became an engineer. I want to help make the future of energy more sustainable and more inclusive."

Anja-Isabel Dotzenrath

Photo: bp



NEW SENATE MEMBERS

Anja-Isabel Dotzenrath
Executive Vice President of Gas and Low Carbon Energy and executive board member | bp p.l.c.

Since March 2022, Anja-Isabel Dotzenrath has been driving bp's transformation from an international oil corporation to an integrated energy company. As Executive Vice President of Gas and Low Carbon Energy and a member of bp's global executive board, she is responsible for their gas activities worldwide, as well as expanding their business activities in the areas of renewable energy, hydrogen and biofuels.

"The world cannot just rely on companies that are already green if we are to achieve climate neutrality. Rapid transformation will require companies like bp, that may not be low emitters now, but are making a firm, genuine effort to become green (greening companies). By integrating gas, renewable energy, hydrogen and biofuels on a large scale, we intend to establish a world-leading company for low-emission energy," says the bp board member.

bp has set itself the target of becoming climate neutral by 2050 or earlier. It plans to invest US $3 to $4 billion in low-emission energy annually until 2025, at which point the figure will jump to around US $5 billion per year until 2030.

Fraunhofer is pooling its activities relating to climate neutrality in the Strategic Research Field for Resource Efficiency and Climate Technologies. The Fraunhofer Energy Alliance alone is bringing together 20 institutes with a total of over 2,000 employees to conduct research on the energy transition. The Fraunhofer Clusters of Excellence Circular Plastics Economy CCPE and Integrated Energy Systems CINES are helping bp achieve its goal of reducing CO_2 emissions.

Anja-Isabel Dotzenrath is a qualified electrical and industrial engineer (RWTH Aachen University). She has more than a quarter of a century of experience in the energy and industry sectors and in business consultancy. Until mid-2021, she was the CEO of RWE Renewables. Under her leadership, RWE Renewables became one of the world's largest renewable energy companies and the second largest provider of offshore wind energy. RWE Renewables was established in 2019 based on a merger between the renewable energy companies E.ON and Innogy. Prior to the merger, Dotzenrath had served as CEO and before that, as COO of renewable energy activities at E.ON.

She is also a member of the board of directors at Elkem ASA in Norway, one of the world's leading suppliers for advanced material solutions, Honorary Consul of Norway in Germany and a member of the advisory board for the think tank Agora Energiewende (Agora energy transition).

Dotzenrath was listed as one of the top 100 most successful female managers in the German industry sector by the publication manager magazin.

Photo: Allexxandar/shutterstock

Sometimes ideas come to us in the shower. And the way a microsystem switching element for a novel electron multi-beam mask writer works is not dissimilar to a showerhead. It allows minuscule structures to be produced via EUV lithography for next-generation 7 nanometer and 5 nanometer semiconductor chips (p. 96).

Review of Fraunhofer research

Transformation, values, impact: Turning ideas into innovations together

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Prof. Dr.-Ing. Albert Heuberger, Fraunhofer Institute for Integrated Circuits IIS
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Open access and communication
Roman Möhlmann, Fraunhofer headquarters
Eric Retzlaff, Fraunhofer Information Center for Planning and Building IRB

Europe's position in the world is determined by climate change, demographics, digitalization and technological transformation and to an increasing extent by geopolitical and security factors. These issues are influenced by underlying social negotiation processes regarding the energy of the future, the healthcare of the present and in the demographic context, regarding technological sovereignty and structural change as a process of transformation facing society as a whole. 2021 has brought the urgent challenges of our time into focus with a searing intensity.

Publicly funded research and development activities can provide a wide range of solutions, but they also require the trust of society and its political representatives. "Science has delivered!" became a common phrase during the coronavirus crisis. However, the long road taken in the fight against the pandemic is an example of how social negotiation processes must precede the successful transfer of scientific findings into application. For science this means, facilitating participation and involvement, intensifying communication activities and developing new formats for active dialogue with society.

Emerging from the crisis with better healthcare and a stronger SME sector

Infectious disease specialists and virologists had long warned of the danger of global pandemics. In 2019, the danger became an international reality for the first time — and in 2022 we are still battling the coronavirus pandemic, including all its medical, economic and, not least, social consequences. One example of how we can overcome new health challenges is a transdisciplinary approach that Fraunhofer has adopted to develop innovative health solutions. Known as the 4D model, this approach combines new diagnostic methods (Diagnostics) and research into pharmaceuticals (Drugs), including vaccines, with medical technology solutions (Devices) and data intelligence (Data).

To enable safe, rapid development of effective vaccines and therapeutic agents that can prevent severe progression of the disease, researchers worldwide, including at Fraunhofer, have been testing whether existing, approved drugs can be used to treat COVID-19 in a process known as drug repurposing. Multiple Fraunhofer projects have identified active agents that are now used in clinical trials. Scientists have also established an infrastructure for testing and evaluating vaccines and drugs, developed novel treatment strategies and built platform technologies aimed at preventing the virus from entering cells, combating it directly, and also regulating excessive immune responses.

In the field of diagnostics, new test systems have been developed and tested on initial patient samples. Known as the LAMP method, this system comes very close to the sensitivity of PCR tests, but delivers results much more quickly. Numerous projects have produced techniques and devices that can increase personal protection against infection and improve our understanding of how SARS-CoV-2 spreads. In one such project, scientists developed an indoor air filtration system based on electrochemical total oxidation that completely destroys organic substances such as viruses. Methods for assessing infection risk in indoor environments, including the implementation of innovative indoor air purification technologies, are now available as prototypes, as are solutions for decontaminating surfaces via irradiation, coating or mobile disinfection robots.

Fraunhofer has also achieved national visibility in the field of data analysis. Mathematical modelers at Fraunhofer are helping the German National Academy of Science Leopoldina compile scientific expert reports for federal policymakers, in which they forecast the course of the pandemic as regards the spread of infection. Institute consortia have also used data-driven methods to assess risks for severe disease progression, even on an individual basis, and for secondary diseases following a SARS-CoV-2 infection.

In line with its mission to strengthen the innovative capacity of SMEs even in times of crisis, the Fraunhofer-Gesellschaft launched the Anti-Coronavirus Program right at the beginning of the pandemic. Most of the over 160 projects in this interdisciplinary initiative were carried out in consortia, with topics ranging from finding new drugs, developing diagnostic methods and investigating the long-term effects of COVID-19, data models analyzing the spread of infection, right up to decontamination measures and the recovery of a New Normal in industry and society. By December 2021, two-thirds of the projects had been completed. Preliminary evaluations show that a high proportion of these projects achieved their targets, and concluded numerous successful collaborations with companies, hospitals, authorities, associations and NGOs. To date, thirteen patent and two trademark applications have been filed, and eight developments are participating in standardization procedures.

Transition of energy and raw materials for a climate-friendly and competitive industry

The political boundary conditions in Germany have focused more and more on climate protection. As stipulated in the coalition agreement between the SPD, the Greens and the FDP, coal-fired power plants should ideally be taken off the grid by 2030. Germany aims to be a global pioneer in this

area. Policymakers are oscillating between the two goals of keeping German industry competitive by creating supportive framework conditions on the one hand, and accelerating the transformation toward an energy supply that is less dependent on CO_2 on the other — primarily by using wind and solar power, but also hydrogen, biomass and geothermal energy. Retaining Germany's economic power in the production and plant engineering sectors, basic industries, the high-tech sector and many others is a non-negligible motivating factor here.

The only reason that the mammoth global task of completing the energy transition is conceivable at all is thanks to the substantial technological developments of recent decades. Today, renewable energy often has lower production costs than the fossil alternatives. Highly industrialized manufacturing processes are opening up the prospect of a rapid global ramp-up of these technologies. Constructing a secure energy system also appears feasible — thanks to major advances in the development of storage technologies, green material energy carriers, hydrogen-based chemical raw materials and systemic solutions for energy systems integration, through electromobility in transportation and heat pumps in the building sector, for example. Fraunhofer researchers have contributed significantly to all of these developments.

However, an energy system based on "renewables" requires a wide range of technical equipment, from the generation stage right up to use. Large quantities of valuable and also rare raw materials are required for transportation, distribution and storage. That is why the energy transition must go hand in hand with a resource transition, in which the use of raw materials is fundamentally understood as a cycle. Only when technological processes and ecological principles merge can the availability of rare raw materials be guaranteed in the long term. In this way, interference with the ecosphere can be minimized and nature can be given the opportunity to regenerate. In concrete terms, this means that the concept of a life cycle should be applied not only at the product level but also at the material level. For example, in the case of battery systems for electromobility, it is important to apply the life cycle assessment not only for manufacturing and efficiency improvements, but also to integrate the concepts of reusing and recycling into the systems from the very start. In order to meet the increasing demand for raw materials, it is essential to integrate renewable raw materials into technical applications to a much greater extent than previously, without lowering standards of quality or performance.

Constructing a secure energy system appears feasible — thanks to major advances in the development of storage technologies, green material energy carriers, hydrogen-based chemical raw materials and systemic solutions for energy systems integration, through electromobility in transportation and heat pumps in the building sector, for example.

For the energy and raw materials transition to succeed, sustainability must not be just a marginal consideration but rather a central purpose of action with which all aspects of value creation are consistently aligned. It is therefore necessary to move from creating value sustainably to creating value from sustainability; this offers attractive development opportunities for society and industry alike. The energy transition will only be seen as a success if, for example, it succeeds in attracting the associated production facilities to Europe, thus creating added value and prosperity locally.

As an energy carrier, hydrogen can form the hub that unites the previously separate energy sectors of electricity, mobility and industry. Future applications of green hydrogen include basic industries such as steel and chemicals; it could also function as a storage medium in the electricity industry and as a fuel for aircraft, ships and trucks in the mobility sector.

Structural transformation: From lignite to hydrogen

Germany, in particular, is committed to implementing climate protection and structural transformation targets without jeopardizing growth and prosperity in the affected regions. Fraunhofer is supporting this with a holistic approach. The strategy, which spans a range of regions, industries and technologies, is focused on developing key technologies for the future, applying them in innovative ways and acquiring a fundamental understanding of the transformation process through accompanying socio-economic research.

In the coal-mining regions of Lausitz, Central Germany, the Rheinland and Helmstedt, for example, Fraunhofer is making an important contribution to developing traditional energy technologies into new key technologies such as hydrogen. As an energy carrier, hydrogen can form the hub that unites the previously separate energy sectors of electricity, mobility and industry. Future applications of green hydrogen include basic industries such as steel and chemicals; it could also function as a storage medium in the electricity industry and as a fuel for aircraft, ships and trucks in the mobility sector. Thanks to its expertise in plant engineering and technologies in the mobility and energy sectors, Germany has great potential for the hydrogen economy — especially in regions undergoing structural transformation. For a hydrogen industry, these regions need to be put in contact with experts with the right know-how, as well as enabler technologies. There is a particular need for electrolyzers, compressors, infrastructure and sensors here. This will enable the technologies to scale rapidly and serve a growing market. The Fraunhofer-Gesellschaft's analyses of the various aspects of the hydrogen economy are providing a guide for this. New research platforms with industry partners in the structural transformation regions are serving as

flagships, such as the Hydrogen Lab Görlitz with its fuel cell research and the Hydrogen Lab Leuna with its electrolysis research on pilot plants in the megawatt range.

Hydrogen is an example of how structural transformation can be achieved successfully, namely by establishing key technologies strategically and systematically and by creating sustainable jobs in industry. Important milestones in this context include grouping together and taking a holistic view of the measures involved, as well as developing infrastructure and demonstration plants so as to establish a position of technological leadership.

Gaining ground in digitalization

Alongside sustainability issues, digitalization is determining the political agenda. During the pandemic, the need for the public sector in particular to make up for lost time has become evident. The task here is to catch up with the private sector in terms of actual technical equipment, with the implementation of the German Online Access Act (Onlinezugangsgesetz, OZG) setting the framework for this. At the same time, policymakers aim to reduce the dependence of public authorities on non-European technology suppliers in the interest of technological sovereignty, and to make Germany less dependent on external IT consultants by building up internal expertise within the administration.

Various initiatives are driving innovation in this field, such as the 5G/6G campus networks, where using local frequencies has made Germany a trailblazer. With its tools, Fraunhofer supplies testbeds worldwide, i.e., experimentation platforms for network operators and companies. Collaboration among public institutions is being promoted by the development of an open-source platform in the Phoenix project. Digitalization can also make the transportation system more sustainable, safer and more reliable. This is why Fraunhofer is researching safe mobility for cyclists, among other things. In another core area of expertise, namely data management, Fraunhofer supplies essential technical components for the central European Data Portal, for example. In addition to data curation, important building blocks of digitalization comprise artificial intelligence (AI), semantic knowledge technologies and, in the future, quantum computing. These technologies can support resilient supply chain management, process automation or, in media monitoring, the detection of misinformation, for example.

Maintaining technological sovereignty

The question of what future digital solutions for the public sector and industry will lead to also depends on the values and goals agreed on by manufacturers, users and policymakers. Europe will only be able to maintain its role as a leading hub for industry in the long term if it establishes itself as a resource-efficient production location with reliable, trusted hardware and software. At the same time, Europe needs digital sovereignty — i.e., the ability to develop technologies that are critical to its competitiveness and its governments' ability to act, by itself or to obtain them without one-sided dependence on other economic areas.

Microelectronics represent a key factor in digitalization. Germany and Europe's strengths here lie in design and packaging as well as in power electronics. Fraunhofer and the Research Fab Microelectronics Germany (FMD) are generating important impetus along the entire value chain here. The European Chips Act adopted in 2022 is intended to reduce dependencies in chip production — especially for highly integrated microchips — and to support the establishment and expansion of companies in Europe. Another core aspect of digital sovereignty is communication infrastructures with open interfaces. A current example of this is the Open RAN initiative, which is intended to ensure the interoperability of the radio access network components in future mobile communications standards. As international standards are of great importance for the technological openness of markets and the commercialization of research results, Fraunhofer makes significant contributions to many relevant standards.

In order to maintain and expand the competitiveness of German and European industry sectors — combined with the transformation toward a sustainable economy — it is essential to provide growth industries in particular with reliable, resource-efficient architectures, design methods and manufacturing processes.

Open access: Learning from the pandemic

The fact that the scientific community's global digital network ensures a comprehensive and rapid exchange of research results was and is particularly evident in the ongoing pandemic. Fraunhofer also published and disseminated its research output more openly than ever before, making its findings available to research teams worldwide. The World Health Organization's call in spring 2020 for publications on COVID-19 to be published under open access made an enormous contribution to improving our understanding of the SARS-CoV-2 virus and to the development of drugs, in the form of vaccines, for example.

Every second publication in Germany is now open access, and this rate is expected to reach 75 percent by as early as 2025. This creates potential in terms of access, visibility, transparency and, above all, the reusability of research and innovation processes, which can help accelerate scientific progress. Open access is an essential element in all "citizen science" research projects, i.e., projects where members of the public are involved. Start-ups and medium-sized companies without their own research and development facilities can also freely integrate the results into their innovation processes. Questions regarding intellectual property rights are clarified in advance here. The Fraunhofer-Gesellschaft has been following this credo for years, based on the principle of patenting first, then (openly) publishing its results. Only by openly sharing and collectively using research results will it be possible to meet global challenges such as climate change effectively, today and in the future.

Helping (the public) shape research and innovation — gaining trust

The major, interrelated challenges of our time show that technological solutions and corresponding access to know-how are not enough. In order for innovations to be successful and make the switch to application, social negotiation processes, transparency, dialogue and participation are necessary in order to gain the trust of users, and ultimately of society.

One approach that is regarded as promising by more than just Fraunhofer is to involve the public in research and development processes. This is discussed using terms such as co-creation, user insights and citizen science, but is only practiced to a limited extent. It is essential that the research and innovation process undergoes a profound and comprehensive expansion to enable citizen participation. However, these participation initiatives must not be aimed unilaterally at gaining acceptance, but rather must earn trust. In this collaborative process, citizens are users. They experience products and technologies in everyday life, and can express their needs, provide information about the consequences of adapting and doing without these products and technologies, and thus trigger developments in certain directions. The diversity of stakeholders involved means that a holistic spectrum of sustainability aspects (planetary needs) is included. At the same time, it is necessary to create transparency in scientific working methods and the fundamental challenges of the scientific process such as intersubjectivity, dialectics and the provisional nature of knowledge and to communicate this to civil society (empowerment). An intensified exchange between citizens and science can help to promote solution-oriented dialogue.

The involvement of members of civil society in the processes of research, development and innovation complements Fraunhofer's established focus on industry needs and lays the groundwork for a modern understanding of the meaning of applied research. At many Fraunhofer institutes, the approaches, expertise and methods required for participatory research and innovation processes are already being developed and practiced in projects in various research fields (see also p. 114).

The right "compass": communicating scientific research

Since the outbreak of the pandemic, Fraunhofer has participated in a number of surveys to ascertain the German public's understanding of and trust in research. The Science Barometer 2021 showed that, at 60 percent, trust in science and research remains at a consistently high level and has even increased since pre-pandemic times. More than two-thirds of respondents (69 percent) believe that political decisions should be based on scientific evidence. 75 percent think that scientists should speak out publicly when political decisions do not take

scientific findings into account. The representative survey was conducted by the non-profit organization "Wissenschaft im Dialog" (science in dialogue) in September 2021.

In a first for the German research sector, 2021 saw the initiation of a project, the Fraunhofer Communication Compass, that described the business models of communications units in a practice-oriented manner. The project also generated insights for the further development of communications at Fraunhofer and identified best practices in order to provide new impetus for the institutes to exchange experiences. The Communication Compass was a joint project between the University of Leipzig, the consultancy firm Lautenbach Sass and the Communications division at Fraunhofer headquarters. The project has also enabled the Fraunhofer-Gesellschaft to refine its reputation for innovation, within both the scientific community and the communications industry.

Outlook

In its guiding principles, the Fraunhofer-Gesellschaft has committed itself to actively and sustainably shaping the future so as to create an environmentally friendly, economically successful and socially equitable world. The Fraunhofer-Gesellschaft always aims to make an impact on three key areas: social progress, ethical value creation, and the preservation of an environment and natural world worth living in for future generations.

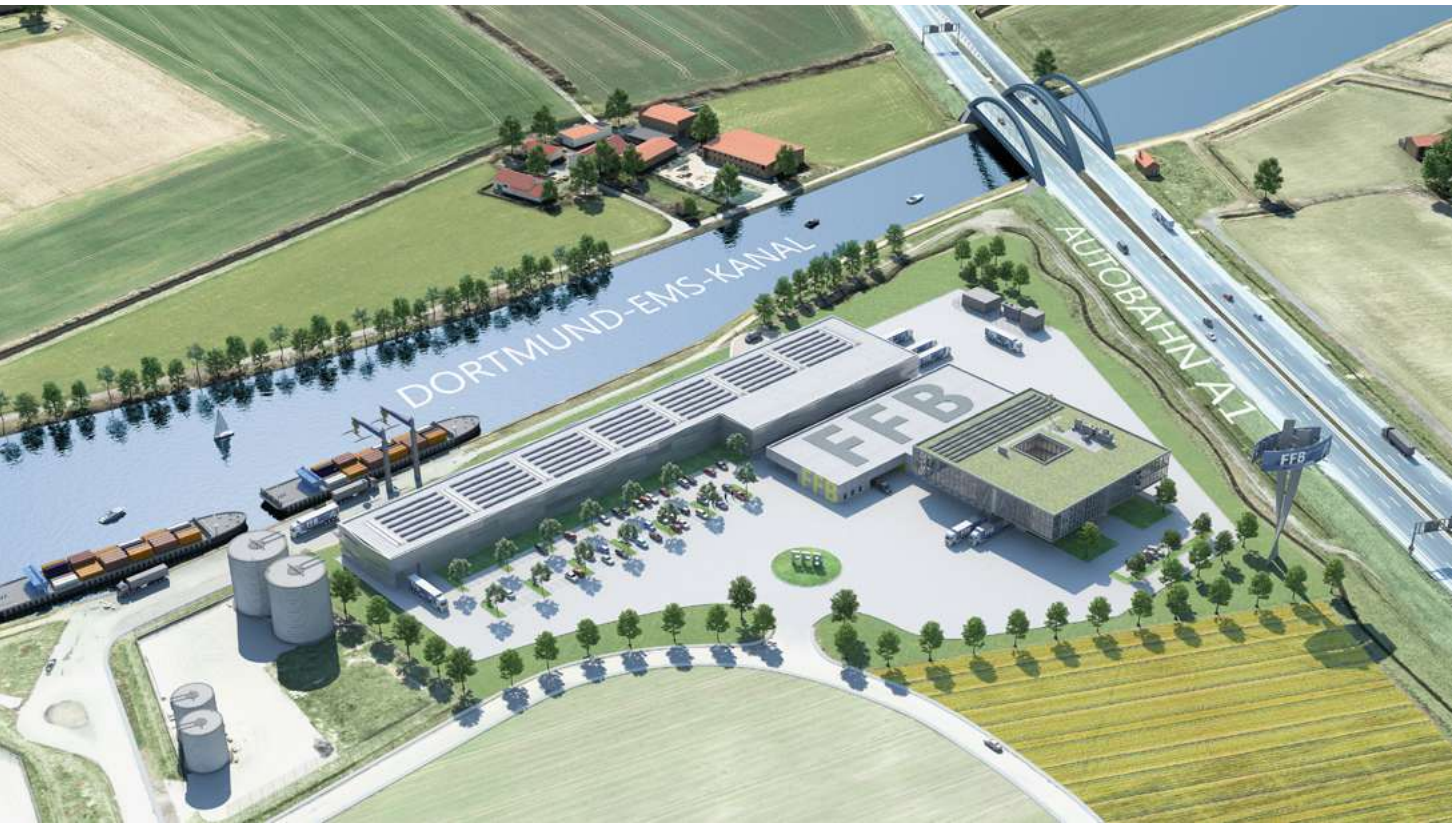
This is one of the reasons why Fraunhofer is playing a pioneering role in the German scientific community when it comes to its own climate neutrality. The goals are ambitious: Fraunhofer aims to be climate-neutral by 2030 — through the low-emission management of its buildings, sustainable and climate-friendly procurement and carbon-neutral transportation for its employees.

In order for innovations to be successful and make the switch to application, social negotiation processes, transparency, dialogue and participation are necessary in order to gain the trust of users, and ultimately of society.

New initiatives and infrastructures

- New research units
- Lead markets
- High-performance centers
- Initiatives
- Lighthouse projects

New research units as of 2022



The new Fraunhofer research unit in Münster will use new battery cell formats to supply large quantities of storage systems for the energy and mobility transition.
Graphic: ARTVISU Artur Krause

Fraunhofer Research Institution for Battery Cell Production FFB

Since January 2022, Fraunhofer Fab Battery Cells FFB has been an independent research unit under the umbrella of the Fraunhofer-Gesellschaft. Fraunhofer FFB was originally established in Münster as an institute branch of the Fraunhofer Institute for Production Technology IPT as part of the FoFeBat — Research Production Battery Cells Germany project funded by the German Federal Ministry of Education and Research (BMBF). The FoFeBat project is included in the BMBF's Research Fab Battery umbrella project, which brings together various battery technology competence centers and clusters.

The aim of FoFeBat, and thus the Fraunhofer Research Institution for Battery Cell Production FFB, is to accelerate the innovation and commercialization process of production technologies for existing and future battery cell formats. The objective is to produce

battery technologies more efficiently, more cheaply and to the highest quality, and thus avoid international dependencies on other markets for energy storage technologies in the long term. The initiative focuses primarily on gaining experience in operating a large-scale research factory in order to acquire expertise in this area and close any gaps in knowledge.

After two years of development, Fraunhofer FFB met all the requirements for an independent Fraunhofer research unit — a step toward possibly transitioning to a Fraunhofer institute in the future. The Fraunhofer Research Institution for Battery Cell Production FFB acts as a link between science and industry, providing the primary research and manufacturing infrastructure required to enable industry to produce batteries in a cost-effective and environmentally friendly way. It therefore plays an important role in supporting the future viability and sovereignty of Germany as a high-tech location.

Fraunhofer Center for the Security of Socio-Technical Systems SIRIOS

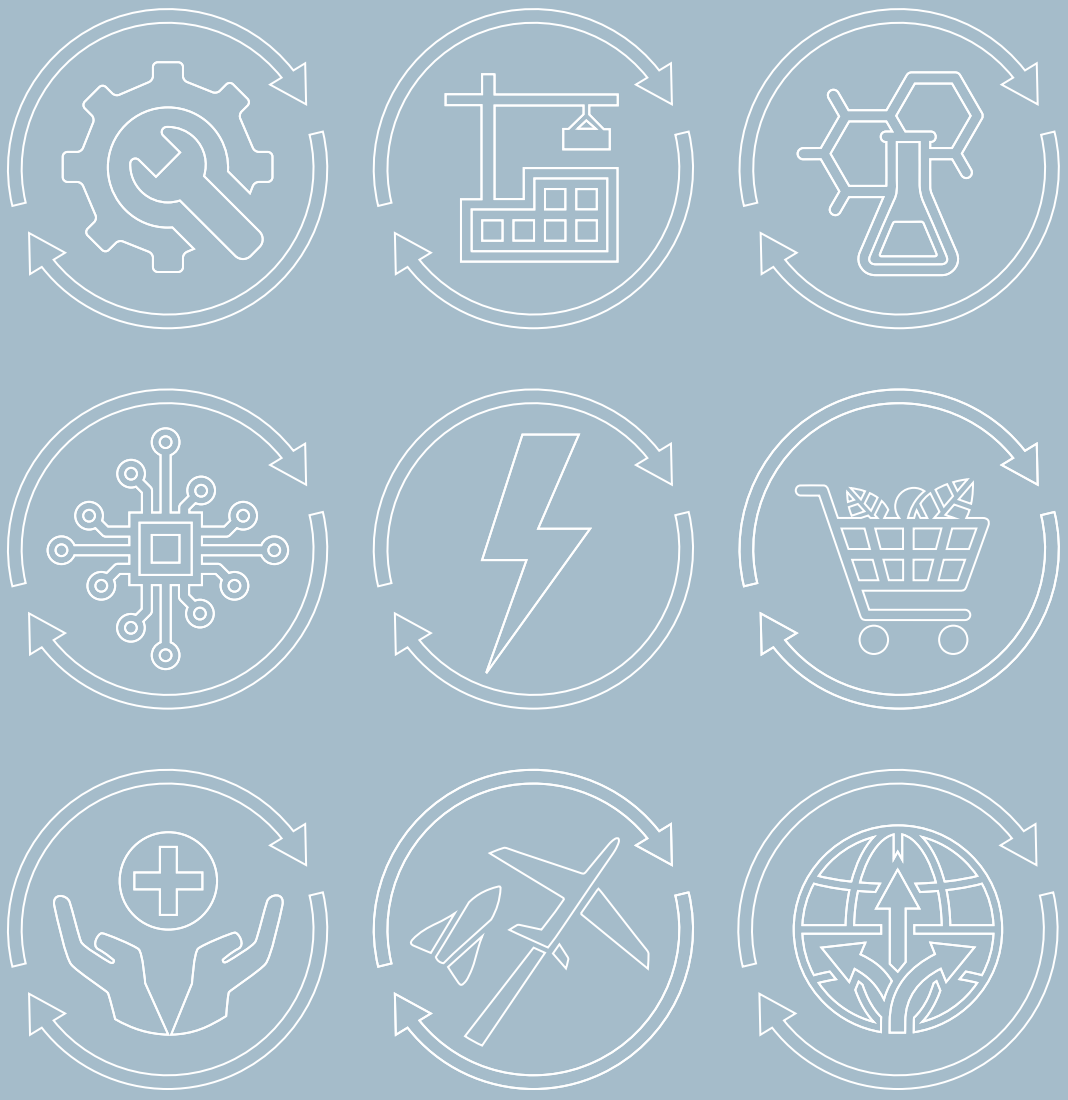
The newly established Fraunhofer Center for the Security of Socio-Technical Systems SIRIOS in Berlin is setting up a research, testing and training environment for security authorities, emergency service workers and critical infrastructure operators. In this environment, users will be able to simulate complex security scenarios, experience them virtually and test them out under real-life conditions. Plans to facilitate direct public participation are also underway.

Fraunhofer SIRIOS was established to build up a research, testing and training environment for security authorities, emergency service workers and critical infrastructure operators over the coming years. The initial focus will be on two threat scenarios: the impact of an extreme weather event on a big city and a disaster caused by human activity at a major event. In the medium term, further challenges such as industrial accidents or terrorist attacks will be researched, as well as the many interdependencies between people, technology and infrastructures in modern, highly networked societies that make ensuring public safety and security a difficult and complicated task. Disruptions within these kinds of socio-technical systems can have serious far-reaching effects, such as on the supply of electricity, internet, telecommunications, water and logistics. Researchers at Fraunhofer SIRIOS are using new comprehensive simulation systems to explore these interdependencies to be as well prepared as possible in the event of an emergency and to strengthen Germany's resilience in the long term.

The four Fraunhofer Institutes for High-Speed Dynamics, Ernst-Mach-Institut, EMI, for Open Communication Systems FOKUS, for Optronics, System Technologies and Image Exploitation IOSB and for Transportation and Infrastructure Systems IVI are combining their expertise in interdisciplinary R&D projects. The central office for Fraunhofer SIRIOS is located at Fraunhofer FOKUS in Berlin.

Extreme weather events are increasingly posing a threat to infrastructure. Fraunhofer SIRIOS is researching these kinds of complex security scenarios.

Photo: iStock



Lead markets — Strategic customer segments

Fraunhofer is known for acting as an applied research partner in industry. In line with our research fields, Fraunhofer has defined strategic customer segments, also known as "lead markets." Through innovation, these lead markets help give Germany a global competitive edge, in addition to safeguarding the technological sovereignty of Germany and Europe and creating sustainable value for society. To further strengthen Fraunhofer's demand- and market-oriented focus in these lead markets, the Fraunhofer alliances are initiating targeted cross-institute knowledge transfer activities. These activities are based on the ever more complex needs of industry and society. This way, in the future, Fraunhofer will be able to make an even more significant contribution to increasing the innovative strength of large enterprises and SMEs in these important customer segments. Here, the Fraunhofer alliances act as a one-stop shop, allowing industrial customers to access Fraunhofer's range of sector-specific services from a single source.

Plant, mechanical and vehicle engineering

Germany is the third largest machine manufacturer worldwide. Plant, mechanical and vehicle engineering is considered Germany's leading sector for exports and innovation. Covering the full scope of Germany's industrial capabilities, the mechanical engineering industry is dominated by medium-sized companies and represents a key driver of innovation in fields such as Industry 4.0, energy efficiency and automation. Average unit costs are sinking continuously thanks to process innovations. This development is due to the increased adaptation of new industrial process technologies, among other things.

Working closely with companies, as well as Germany's Mechanical Engineering Industry Association (VDMA), Fraunhofer is at the forefront of efforts to drive the digital transformation of industry and bring promising new technologies into play — from robots that anyone can program to navigation solutions for entire fleets of automated guided vehicles. Fraunhofer's expertise encompasses process technology, mechatronics, precision technology, laser systems, measurement technology and much more. By harnessing this wealth of knowledge, Fraunhofer researchers help companies enhance their production, accelerate the commercial availability of products and services — without cutting corners — and design sustainable engineering practices.

Fraunhofer Automobile Production Alliance

Since 2010, the Fraunhofer Automobile Production Alliance, which consists of 20 institutes, has been working in partnership with car manufacturers and their component and machinery suppliers and service providers to support research and development aimed at optimizing production processes. The Automobile Alliance was restructured and expanded in 2021 to include the latest research fields in plant and mechanical engineering, and is now ready to respond to complex inquiries about the future of automotive manufacturing.

Construction industry

The construction industry is coming up against huge challenges and necessary transformations — from digitalization to achieving climate targets right up to the circular economy. Important social and economic objectives relating to climate neutrality, the impacts of climate change and conserving resources mean that many established construction products and processes need to be adapted and made more sustainable. Through the construction industry lead market, Fraunhofer is using practical solutions to meet this huge need for development. To this end, it is not only combining the specifications of classic construction research, but also other important research fields such as digitalization, mobility, energy, mechanical engineering and health.

Fraunhofer Building Innovation Alliance

As the go-to contact for all the sector's issues and needs, the Fraunhofer Building Innovation Alliance works to find solutions for this lead market and quickly assembles interdisciplinary teams for this purpose.

Though the construction industry is not traditionally perceived as a very high-tech sector, both construction companies and their suppliers are actually producing significant innovations. However, it is primarily civil engineers and architects that know

where the potential for innovation lies. Up until now, this state of affairs has made it difficult to develop innovations in a targeted way. With its many years of experience in the construction sector, the Fraunhofer Building Innovation Alliance sees itself as the place where innovation potential meets innovative strength.

Chemical industry

The chemical industry is central to Germany's position as an industrial power. Whether in agriculture, industry or private households, chemicals are needed everywhere. Countless sectors of the economy rely directly or indirectly on developments and products from the chemical industry, which supplies basic materials for many other economic markets. This lead market is therefore of strategic importance to the technological sovereignty of Germany and Europe. It sees itself as a catalyst and driver of innovation for important future-oriented topics in the sector, such as climate protection, sustainable production and resource efficiency.

Fraunhofer Chemistry Alliance

Founded in 2021, the Fraunhofer Chemistry Alliance currently consists of 15 Fraunhofer institutes that support their partners at every point along the process chain, from raw materials to products. In so doing, the Fraunhofer alliance guides the chemical industry on its ambitious journey toward defossilization and the establishment of circular production processes. To this end, the institutes combine their specific expertise on chemical and biotechnological processes, including their knowledge of systemic solutions for successfully completing the energy and raw material transition.

Digital economy

Digitalization is paving the way toward advancement in industry and society. It promotes innovation, revolutionizes business processes and models and changes our daily working lives and social structures. Fraunhofer institutes are helping to shape this change by acting as pioneers and sources of inspiration. They develop digital technologies and solutions, support the digital transformation through technology assessment and advise companies and policymakers. With their expertise, they help develop digital services that complement physical products, providing solutions such as additional sensor technology, new data models, intelligent analysis processes and secure infrastructures.

Artificial intelligence, machine learning, big data analytics and smart sensors are key technologies that drive the digital transformation in companies and society. Industry and society benefit from better workflows, savings in time and costs, smart solutions in industrial production, transportation and healthcare, and better access to information.

Fraunhofer Big Data and Artificial Intelligence Alliance BIG DATA AI

The Fraunhofer Alliance BIG DATA AI combines cross-sector expertise and many years of experience from over 30 Fraunhofer institutes in the areas of big data and artificial intelligence (AI). Its range of services is oriented toward industry, government and society. The alliance supports companies on their journey to becoming data-driven enterprises by implementing big data and AI strategies. Here, transparent, trusted and reliable AI applications and systems are developed that comply with European data protection standards.

An extensive training program helps to address the growing demand for experts in artificial intelligence and data science.

Energy sector

The energy transition is in full swing. The restructuring of our energy system is already visible in many aspects of our society and industry. More and more homes are being built and renovated based on sustainability principles, smart sector coupling is revolutionizing energy generation, and there are ever more electric vehicles on the streets. The proportion of renewables in power generation — particularly solar and wind — is approaching 50 percent. But there is still a long way to go, especially when it comes to energy efficiency, storage and the use of renewable energy carriers.

Germany needs innovative ideas and developments to make a successful transition to renewables. Fraunhofer researchers are working on a number of solutions, including energy-efficient technologies, resilient power grids and smart sector coupling. Their goal is to achieve the ideal combination of electricity and heat generation on the one hand and optimum storage, distribution and usage on the other.

Fraunhofer Energy Alliance

In this alliance, more than 2,000 employees from 20 Fraunhofer institutes combine their specialist knowledge to form one of the largest energy research institutions in Europe, with the aim of developing investment-safe, future-oriented and competitive products for their customers and society. Research fields include digitalization of the energy sector, renewable energies, energy system analyses and storage technologies, and

energy efficiency technologies and components for buildings, neighborhoods and cities.

The wide-ranging spectrum is focused on small and medium-sized enterprises as well as industry and the energy sector, so that they can create strong positions for themselves with innovative products and conquer new markets. The alliance also advises political and public stakeholders and institutions. The Fraunhofer Energy Alliance's activities are always focused on and measured against the goal of creating a sustainable, secure, economical and socially just energy supply.

Food industry

Germany's lucrative food industry needs to make the transformation to sustainability. The lead market offers innovative solutions to both optimize production and improve quality and thus remain internationally competitive. In terms of environmentally friendly agriculture or the need for regional products, there are still many challenges to overcome. Climate change, resource shortages and fragile supply chains all add to the vulnerability of the global food system, as do rising food costs, speculation in the food market and the shortage and degradation of freshwater resources.

The Fraunhofer institutes are therefore combining their research activities and developing innovative solutions with their partners along the entire value chain of the food industry.

Fraunhofer Agriculture and Food Industry Alliance

This alliance, founded in 2008 under the name Fraunhofer Food Chain Management Alliance, is now reflecting its expanded portfolio by changing its name: In addition to offering solutions to issues throughout the food chain, with a focus on food analytics/processing, microsystems technology and logistics, it also carries out R&D activities in upstream and downstream areas such as agriculture and trade networks.

The alliance is developing solutions to help the food industry tackle challenges such as global warming, sustainable food production, digitalization in agriculture and new marketing models.

Healthcare sector

The healthcare sector contributed 12.1 percent to Germany's gross domestic product in 2020. Comprehensive healthcare coverage is a stand-out feature of the German healthcare market, which also excels in developing innovative, high-tech medical devices and pharmaceutical products, as well as new diagnostic and treatment methods.

Together with the data processing and electronics industry, the healthcare sector invests more in research and development than any other industry branch. This is particularly true for biotechnology, medical technology and telemedicine — fields that play a major role in Fraunhofer institutes' research portfolios. The institutes focus on all four key areas of health research — drugs, diagnostics, devices and data.

As an interdisciplinary organization, Fraunhofer acts as the meeting ground for medicine, natural sciences, computer science and engineering. This creates ideal conditions for rapidly implementing the latest innovations.

Aerospace economy

As a technology-intensive industrial sector, aerospace has a significant impact on economic and socio-political life. Aviation facilitates global mobility — a prerequisite for cultural and economic networking. Space travel promotes this global mobility by providing satellite navigation and communication. Orbit-based earth observation instruments can be used to find solutions to important problems such as the protection of the climate and environment.

With their broad portfolios of expertise, Fraunhofer institutes support the strategies of the European aerospace industry and help to secure and expand its competitive position. Their offerings include expertise in optics, sensor technology, communication, automation as well as digitalization and artificial intelligence. The sustainability of materials, components and processes also plays an important role.

Through this, Fraunhofer makes important contributions to national and European research funding programs (e.g., LuFo, INNOspace Masters, Clean Sky 2, Clean Aviation, ESA space programs and Horizon Europe) and collaborates closely with associations such as the Federation of German Industries (BDI), the German Aerospace Industries Association (BDLI) and the European Aeronautics Science Network (EASN).

Fraunhofer Aviation and Space Alliance

The Fraunhofer Aviation and Space Alliance represents the further development of the Fraunhofer Space Alliance, in which 17 Fraunhofer institutes have been collaborating to research applied space technologies since 2014. Expanding the alliance to include aviation institutes is a logical step toward even greater visibility in the aerospace industry and creates an opportunity to forge synergies, address R&D needs together

and strategically help shape the development of the industry. The member institutes are active in diverse and socially relevant areas, ranging from climate-neutral, sustainable flying to innovative Earth observation instrumentation.

Participation of Fraunhofer institutes in space missions — from the 1970s to the near future:
www.space.fraunhofer.de/en/missions.html

Mobility sector

The mobility sector has long been a core element of German and European industry and many other sectors are either directly or indirectly dependent on it. Innovations in this area of technology give a direct boost to Germany's role as an economic powerhouse. This means that quickly transferring research results is an important foundational element for innovative strength and economic success.

Emerging research fields in this sector include electrified powertrains, automated driving functions and vehicles that connect to infrastructure, the internet and other road users. The lead market also addresses environmental challenges such as decreasing fuel and CO_2 consumption, electromobility and reducing the use of materials while taking economic factors into account.

Fraunhofer Transport Alliance

Since 2003, Fraunhofer research units have been combining their expertise in areas relevant to transportation. They are developing conceptional solutions and transferring them to application for customers from the public sector and industry. International research programs connect the member institutions with industry and research companies in the transportation sector worldwide.

Find out more about the Fraunhofer alliances

https://s.fhg.de/automobile
https://s.fhg.de/building-industry
https://s.fhg.de/chemistry
https://s.fhg.de/bigdata-ai
https://s.fhg.de/energy-alliance
https://s.fhg.de/food-chain
https://s.fhg.de/health-research
https://s.fhg.de/aviation-and-space
https://s.fhg.de/transport

High-performance centers — Strengthened by knowledge transfer

Transferring knowledge reinforces the high-performance centers at a structural level. Transitional financing was secured for 2021 in the form of funding from the German Federal Ministry of Education and Research. The purpose of this funding was to maintain expertise and capacities in research throughout the coronavirus crisis.

From 2022, interdisciplinary knowledge transfer road maps and binding transfer targets will be used to further improve the high-performance centers' effectiveness as innovation ecosystems. The centers compete in an "omnibus model" that promotes agility. High-performance centers are eliminated at the end of each competition round, and an equal number of new centers are added in the following round. This creates a dynamic system that rewards facilities that act as models of good transfer practices and makes the direct regional impact of research visible. In 2021, five new innovation ecosystems were added to the 16 existing high-performance centers:

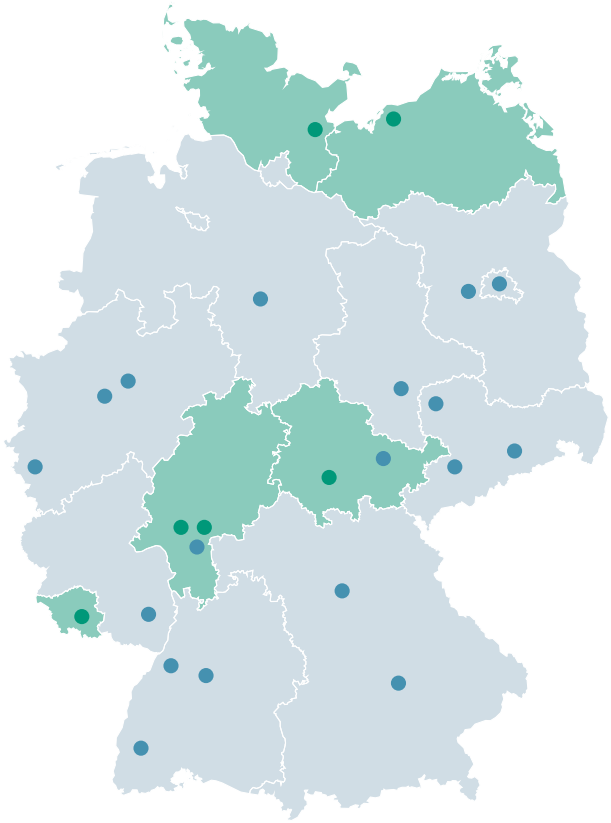
GreenMat4H2 — Green Materials for Hydrogen, Hanau/Darmstadt
The Technical University of Darmstadt is working with two Fraunhofer institutes to develop green material solutions for the hydrogen economy and ensure the reliability of hydrogen-powered systems. They are studying materials that can be used in hydrogen technologies for production, storage, transportation and application as well as the associated process technologies, with a focus on recyclability.

Innovative Therapeutics, Frankfurt am Main
The consortium, consisting of Goethe University Frankfurt am Main and two Fraunhofer institutes, aims to develop new drugs and treatment strategies for disorders that were previously difficult to treat, such as chronic inflammatory diseases of the gastrointestinal tract, musculoskeletal system or the skin — under the specific proviso that they must be made available for application in as short a time as possible.

Intelligent Signal Analysis and Assistance Systems InSignA, Ilmenau
Together with the Ilmenau University of Technology, five Fraunhofer institutes are collaborating with other non-university research institutions and partners from industry to develop prototype solutions and financially self-supporting business and commercialization models for the fields of production, energy supply and robotics.

Sensor Intelligence, Saarland
Two Fraunhofer institutes and Saarland University are developing innovative cognitive sensor systems and creating added value based on data recorded by sensors. These sensors generate information that serves as a guide for taking action, which is in turn used for knowledge-based decision-making. The aim is to create applications in the materials, production and healthcare sectors.

Sustainable Subsea Solutions, Rostock/Lübeck
Five Fraunhofer institutes are working with the University of Rostock and the Leibniz Institute for Baltic Sea Research Warnemünde (IOW) on solutions for sustainable underwater technologies. The initiative combines the available expertise at the sites in Rostock and Lübeck and is expanding these specifically as a technology broker in order to facilitate a comprehensive technology transfer into practice.



Initiatives for digitalization, data sovereignty and quantum technologies

The Data Spaces Business Alliance will set the stage for the European data economy.

Graphic: iStock

Data Spaces Business Alliance (DSBA)

Since fall of 2021, numerous European and international initiatives and associations have been combining their expertise and resources under the umbrella of the newly founded Data Spaces Business Alliance (DBSA). Gaia-X European Association for Data and Cloud AISBL, the International Data Spaces Association (IDSA), the Big Data Value Association (BDVA) and the FIWARE Foundation are working together to drive acceptance of data spaces across Europe and internationally.

The first initiative of its kind, the DSBA brings together the industry representatives needed to create a data-driven future for organizations and private individuals. Data spaces are a key technology for data sovereignty, enabling data to be shared in an interoperable and reliable way between markets and within society. Thanks to the complementary profiles of its member institutions, the DSBA can address multiple societal and economic areas, promoting the subject of the data economy across a wide range of fields — from technological advancement and standardization to integration across various industries.

Now that DSBA has demonstrated that data spaces can be "built" and shared, the next step is to realize the economic potential of secure data sharing on a large scale.

Gaia-X funding competition

In the Gaia-X funding competition run by the German Federal Ministry for Economic Affairs and Climate Action (BMWK), 16 consortia that are influential at a German and European level were chosen as winners in mid-2021 after a two-step selection process. The consortia will use their funding to build ecosystems based on the Gaia-X principles; 11 of these were approved in 2021. The competition focused on applications using the Gaia-X data space model, and sought pre-competitive projects that can be used to develop specific use cases. These cases will be used to demonstrate the technological feasibility, economic viability and usability of Gaia-X, as well as its societal acceptance.

Fraunhofer is involved in six projects as a partner, and is the leader of the consortium OpenGPT-X — Building a Gaia-X Node for Large AI Language Models and Innovative Language Application Services. Based on innovative language technologies that incorporate artificial intelligence (AI), Gaia-X will lay the foundations for delivering scalable computing resources as well as networked and cross-application data spaces for large AI language models.

Catena-X
Automotive Network

The Catena-X association was founded at the beginning of 2021, and is the largest project for developing future production processes in the automotive industry. This pan-European partner network provides software services on the basis of the International Data Spaces and Gaia-X. This will enable secure, trusted data exchange between all stakeholders in the automotive industry — from the initial delivery stage right through to the vehicle manufacturers (original equipment manufacturers — OEM). The association's members aim to achieve greater efficiency, transparency and sustainability throughout the entire value chain.

The Fraunhofer-Gesellschaft was among the founding members of Catena-X, along with some of the most important players of the automotive industry, including BMW AG, Mercedes-Benz AG, Robert Bosch GmbH, Schaeffler AG, ZF Friedrichshafen AG and Volkswagen AG, as well as industry companies and research organizations like ARENA2036, BASF SE, Deutsche Telekom AG, the German Aerospace Center (DLR), German Edge Cloud GmbH & Co., Henkel AG & Co. KGaA, ISTOS GmbH, SAP SE, Siemens AG and SupplyOn AG. Oliver Ganser (BMW) is chairman of the board of directors of Catena-X. Prof. Dr. Boris Otto was elected vice chairman. Prof. Otto is chairman of the Fraunhofer ICT Group, director of the Fraunhofer Institute for Software and Systems Engineering ISST and a board member of Gaia-X, the European Association for Data and Cloud AISBL and the International Data Spaces Association (IDSA).

Around a thousand users are expected to join Catena-X by the end of 2022.

Velektronik — a networking platform for trusted electronics

The Velektronik project and its associated platform were launched in 2021 as part of the Trustworthy Electronics flagship initiative within the German Federal Ministry of Education and Research's digital strategy. The project focuses on the safety of microelectronics and their value chains — fundamental components of any digital system.
The Fraunhofer Institute for Applied and Integrated Security AISEC is working on the Velektronik project along with the Research Fab Microelectronics Germany (FMD), its central office and the electronics network edacentrum. The project is focused on the security of electronic components, from design and production through to testing. The experts are also improving the security of value chains, particularly in the production of microchips in the electronics industry. The chips are usually produced by large manufacturers in the USA and Asia. Many different companies then take these chips and integrate them into modules, or process them further to form electronic components. However, this means that the resulting components are not always secure and reliable; the device may quickly break, for example, or be vulnerable to hacking attacks by external parties.

The microelectronics experts are therefore researching trustworthy design methods, analysis methods and approaches for particularly trustworthy manufacturing processes for small batch production, among other things. The envisaged Velektronik platform will focus on technological oversight, contributing to the necessary standardization, building connections between research and industry, and accumulating expertise in order to provide concrete solutions to meet the increased demand for more trusted electronics. An industry advisory board will ensure the platform remains focused on the practical sphere, so as to guarantee that its work is relevant to and accepted by industry.

6G initiative — research hubs launched

In 2021, the German Federal Ministry of Education and Research (BMBF) launched the 6G Research Hubs; Platform for Future Communication Technologies and 6G grant initiative as one of the BMBF 6G initiatives that are included in the German federal government's economic stimulus package.

Measuring a wafer using microelectric circuits for reliability.
Photo: Fraunhofer IAF

"With our platform around the IBM quantum computer and our Competence Network Quantum Computing, we are offering all companies and research institutions the opportunity to play an active part in advancing this future technology, gather the expertise they need to thrive in the quantum age and apply the newly acquired skills to good advantage."

Prof. Dr.-Ing. Reimund Neugebauer
President of the Fraunhofer-Gesellschaft

Since August 2021, four selected consortia have been working to advance research into 6G, the next generation of mobile communications. The consortia are coordinated by the German Research Center for Artificial Intelligence (Open6GHub), the Fraunhofer Institute for Telecommunications, Heinrich-Hertz-Institut, HHI (6G-RIC), RWTH Aachen University (6GEM) and the Technical Universities of Dresden and Munich (6G-life).

Altogether, nine Fraunhofer institutes are involved in the four selected research hubs. Headed up by Fraunhofer HHI, 6G-RIC aims to develop mobile communication systems that use open interfaces that transcend all technology boundaries. The primary focus is on building a powerful infrastructure for testing new technology components under realistic and open conditions. This will allow the components to be put into application more quickly, and support the establishment of a new ecosystem in the medium term.

The 6G hubs will form crucial building blocks for the future 6G standard. Important design criteria here are safety, cost-effectiveness and, above all, energy efficiency. Concepts will also be developed for computing resources distributed in the network, which will enable data to be processed more quickly through short paths to users.

As a second phase of the grant initiative, in fall of 2021, there were calls for tender for 6G industry projects to explore holistic systems and sub-technologies for sixth-generation mobile communications as part of the "Souverän. Digital. Vernetzt." (sovereign, digital, connected) research program for communication systems.

Competence Network Quantum Computing — IBM Quantum System One

Since January 2021, Fraunhofer has had exclusive access to the quantum computer operated by IBM in Ehningen, which has 27 superconducting qubits and a quantum volume of 64. The IBM Q System One provides a secure and protected testing area — data security and data locality, which were key concerns for Fraunhofer, have been contractually, organizationally and technically ensured. User and project data remains in Germany at all times. Moreover, the contractual regulations for operating the quantum computer are subject to German law, and European and German data protection regulations are observed.

To advance applied research in quantum computing, the Fraunhofer-Gesellschaft has founded a national network of regional competence centers, consisting of Fraunhofer institutes in seven German states. The network cooperates closely with partners and customers from research and industry and offers a broad range of application fields. The IBM Q System One enables research in a wide range of areas, from essential algorithms, software development and the design of basic logical operations to controlling the quantum processor during the actual computing process. Current projects illustrate both the wide range of possible applications for the system and the close collaboration that Fraunhofer engages in with industry, universities and other non-university research institutions. In the SEQUOIA research project funded by the state of Baden-Württemberg, for example, Fraunhofer is working on software engineering for industrial, hybrid quantum applications and algorithms along with various universities based in Baden-Württemberg and companies in sectors such as mechanical engineering, logistics and IT. As part of the EnerQuant joint project, the project partners, led by the Fraunhofer Institute for Industrial Mathematics ITWM, are working in an interdisciplinary consortium on using quantum computing to solve optimization problems in the energy industry.

The goal of the Competence Network Quantum Computing is to create an ecosystem in Germany made up of SMEs, start-ups, large industries and research organizations. To ensure technological sovereignty in Germany, the members of the network are building up expertise in software and algorithms as well as in standardization and patenting.

Initiatives for reducing CO_2 using hydrogen and electrification

Hydrogen Republic of Germany

The German Federal Ministry of Education and Research (BMBF) put out a call for applications for its Hydrogen Republic of Germany competition. This ideas competition represents the largest research initiative to date on the subject of the energy transition. Three key projects were selected to make key contributions to implementing the National Hydrogen Strategy (NWS) over the next four years and to support Germany's entry into the hydrogen economy.

With a total of €740 million in prospective funding available, in spring of 2021, over 240 partners from science and industry launched their projects to tackle the challenges facing a future hydrogen economy. Research is being conducted into the serial production of large-scale water electrolyzers (H_2Giga), the offshore production of hydrogen and its secondary products (H_2Mare) and technologies for transporting hydrogen (TransHyDE).

H_2Giga

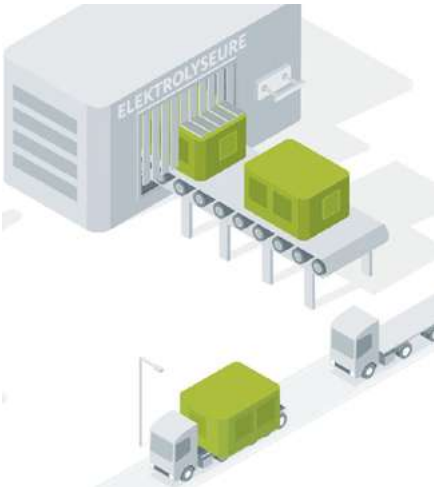
Currently with 120 partners and funding of €450 million, this BMBF key project aims to industrialize the mass production of electrolyzers. Electrolyzers use electricity to split water into hydrogen and oxygen — in other words, they transform electrical energy into chemical energy, thus creating a bridge from renewable energy sources. The current manual manufacturing process creates a bottleneck in the journey toward a hydrogen economy.

That is why the most important task for the Fraunhofer consortium involved in this initiative is setting up the Reference Factory for High-Rate Electrolyzer Production (FRHY). Here, the best and most economical processes are reproduced using digital twins and converted into a technology construction kit. Industrial companies should ultimately be able to use the kit before planning production processes to determine the exact production costs that they will incur for particular types of electrolyzers. The goal is to reduce the production costs of electrolyzers for green hydrogen by more than one fifth.

Multiple institutes in the Fraunhofer Group for Production are researching the manufacture of bipolar plates using the roll-to-roll process, production technologies for the porous transport layer that comes between the plates, as well as membrane technologies and high-throughput processes for testing new materials. Researchers at the Fraunhofer Hydrogen Labs Görlitz and Leuna are testing individual cells and reporting on issues with materials and production.

In the Ready for Gigwatt consortium, which is part of H_2Giga, Fraunhofer institutes are investigating how to upscale alkaline electrolysis processes, with the aim of reaching a production capacity of 500 megawatts by 2025. As the costs of optimized alkaline electrolysis will be comparably low, this will significantly reduce the barriers blocking transformation.

Within subprojects, multiple Fraunhofer institutes are supporting H_2Giga industry partners such as Schaeffler and MAN in setting up efficient production systems for large-scale, industrial stack production. As an R&D partner, the Fraunhofer Group for Production plays a major role in this key project.



H_2Giga: Mass-produced electrolyzers are needed to make green hydrogen competitive.

Graphic: Project Management Jülich on behalf of the BMBF

TransHyDE: The hydrogen economy needs suitable transport infrastructure.

H_2Mare

In the future, hydrogen could be produced directly on innovative offshore wind turbines in a highly energy-efficient process. After all, this process is based on electricity produced from renewable energy, which can currently be supplied by offshore wind turbines with an average rated output of 5 megawatts (MW). On land, wind turbines only achieve an output of around 3.5 MW. The costs for connecting the infrastructure in offshore plants would also be lower. Hydrogen or its derivatives would be transported via ships or pipelines — meaning there would be no need for expensive power line connections to the shore.

Siemens Energy and the Fraunhofer Institute for Wind Energy Systems IWES are coordinating the 32 partners working toward these objectives. The H_2Wind and OffgridWind consortia are working on methods to operate the electrolysis unit directly in the turbine. Fraunhofer institutes are involved here at both the technical level — for example, in integrating the electrolysis system and storing the hydrogen — as well as at the system level and in assessing the economic viability. To this end, they are applying their expertise in offshore hydrogen production.

The H_2Wind consortium is focusing on using PEM electrolysis. For this purpose, Fraunhofer institutes are developing membrane materials and prototypes for electrolysis stacks and testing the electrolysis cells.

In PtX-Wind, in addition to the generation of green hydrogen with novel electrolysis systems, other synthesis routes for the generation of downstream products from hydrogen, such as e-fuels, are being considered and investigated for their offshore suitability. TransferWind is examining certification and environmental issues and engaging in dialogue with the public. The technical and experimental sides of the work are being aligned by means of simulation studies and technical and economic assessments.

The project is being funded to the amount of €100 million.

H_2Mare: Offshore wind farms are the most cost-effective way to produce green hydrogen. PtX technologies are also needed.

TransHyDE

Several 100 million tons of hydrogen are needed per year for the transition to the hydrogen economy. Germany can only produce part of that. That is why the key project TransHyDE is primarily focusing on how to transport hydrogen: What solutions are best suited for short-, medium- and long-distance transport? Where can existing gas grids be repurposed? What entirely new transport technologies will be needed?

Within the TransHyDE project, in collaboration with a network of more than 100 close and associated partners, Fraunhofer is playing a significant role in four research projects: system analysis, creating safe infrastructure by means of material testing and sensor technology, and various storage options for hydrogen — such as liquid organic hydrogen carriers (LOHC) or storage in the form of ammonia. In addition, a trial implementation is being carried out on the island of Helgoland using a technology platform. There, pilot projects and specific applications are set to demonstrate the large-scale implementation of offshore hydrogen production, conversion and utilization and develop a concrete maritime and land-based logistics chain.

The key project is being funded to the amount of €140 million.

Graphics: Project Management Jülich on behalf of the BMBF

National Action Plan for Fuel Cell Production

By using hydrogen as an energy carrier, Germany could reduce its CO_2 emissions by 55 percent by 2030. New, cost-efficient manufacturing technologies to mass-produce fuel cells are required for entry into the hydrogen economy. The manufacturing costs must not be higher than they are for fossil-fuel engine systems. Beyond the climate policy aspects, this would open up the opportunity for Germany to establish sustainable value creation in the region through this key technology.

Fraunhofer aims to enable the cost-optimized, demand-driven, scalable mass production of fuel cells, to dramatically improve their technological and economic potential, and ensure that their structured roll-out in industry and society is significantly accelerated and expanded. The action plan focuses on fuel cell applications in heavy-goods vehicles and offers particular support for mechanical and plant engineering.

The Fraunhofer Institute for Machine Tools and Forming Technology IWU has coordinated the creation of the following technology networks:

- Roll-to-roll processing technology for coating the membrane electrode assembly, the core element of PEM fuel cells
- Equipment for continuous high-rate forming processes to manufacture the bipolar plates
- Automated bipolar plate production with continuous process control and quality control
- Plant design for stack assembly from single cells, including disassembly and recycling processes
- Virtual reference factory for fuel cell production, including AI functionalities and standardized digital twins.

The National Action Plan for Fuel Cell Production is intended to accelerate the economic breakthrough for fuel cells within Germany and internationally, and to massively reduce the costs of hydrogen production and hydrogen applications.

The German Federal Ministry for Economic Affairs and Climate Action (BMWK) is funding the initiative to the amount of €80 million.

Support council for the National Hydrogen Strategy

In 2020, the German federal government set out its National Hydrogen Strategy. The Fraunhofer-Gesellschaft had already contributed its expertise in its hydrogen road map during the preparation phase for the strategy. The German federal government has appointed a National Hydrogen Council to implement the National Hydrogen Strategy. As an independent, impartial committee, 25 experts from industry, science and civil society advise the government on further developing and implementing their strategy.

The National Hydrogen Council members from Fraunhofer are Dr.-Ing. Sylvia Schattauer, acting director of the Fraunhofer Institute for Wind Energy Systems IWES, and Prof. Dr. Karsten Pinkwart, deputy head of department at the Fraunhofer Institute for Chemical Technology ICT. Prof. Pinkwart is also the professor for electrochemical energy storage devices and converters and vice dean of the faculty for Electrical Engineering and Information Technology at the Karlsruhe University of Applied Sciences.

Dr. Schattauer takes responsibility for the subject of hydrogen process technology on behalf of the Fraunhofer executive board. She previously served as deputy head of Materials on the executive board at Fraunhofer headquarters and deputy head of the Fraunhofer Institute for Microstructure of Materials and Systems IWMS.

Initiatives for structural transformation

Fraunhofer Center for Digital Energy

The Fraunhofer Center for Digital Energy is supporting structural transformation in the Rhenish mining area. In 2021, the center significantly expanded a large laboratory in collaboration with RWTH Aachen University. Using a digital control room with control systems and state-of-the-art communications technology such as 5G, researchers create models of current and future network operators' energy infrastructure.

Along with their industry partners, the researchers are working to create and implement energy infrastructures that are technically reliable, secure against hacking attacks and economically attractive. In 2021, a blockchain-based digital platform for regional trade in future energy supply systems was launched as part of the German Federal Ministry for Economic Affairs and Climate Action's "pebbles" research project. This platform is the first of its kind in Germany. The local communities created on the platform have not only positioned end users at the center of the energy transition, but also reduced the need for network expansion. Participating partners included Siemens AG, Allgäu-Netz GmbH, Allgäuer Überlandwerke and Kempten University of Applied Sciences.

The EU's OneNet lighthouse project addresses solutions for creating a coordinated and stable energy supply across Europe. Due to the increasing decentralization of the power supply system, solutions are needed for transmission system operators, distribution system operators and consumers. OneNet has an overall budget of €28 million and involves over 70 partners, including several major network operators, major IT players, leading research institutions and two European associations for network operators.

The Fraunhofer Institutes for Applied Information Technology FIT and for Communication, Information Processing and Ergonomics FKIE are participating in setting up the Fraunhofer Center for Digital Energy, along with the chairs of the Power Engineering and Computer Science departments at RWTH Aachen University.

District heating from thermal water — from Weisweiler to Aachen

Deep geothermal systems could one day replace the Weisweiler coal-fired power plant by enabling sustainable energy generation in the Rhenish mining area, thus supporting structural transformation. This has been stipulated in a collaboration agreement between the Fraunhofer Institute for Energy Infrastructures and Geothermal Energy IEG and RWE.

Using a test power plant, the partners are planning to bring underground heat generation to operational maturity. A geophysical observatory is being used to explore beneath the Earth's surface in Weisweiler and assess its potential. Above ground, Fraunhofer is opening a research site for georesources and setting up a pilot plant for geothermal conversion technologies. This center will investigate all aspects of geothermal plant technology, from high-temperature borehole pumps to marketable processes for power, heat and cold generation through to operating strategies. Processes for materials storage and heat storage are also in development. In 2022, exploration drilling to a depth of up to 1,500 meters will begin as part of an EU project. Later, researchers plan to conduct a three-dimensional, scientific survey beneath the Earth's surface and, based on this, to drill to depths of up to 4,000 meters. If successful, warm thermal water can then be extracted. The advantages of geothermal energy are its sustainability, the fact that it is generally available from local sources, its base load capacity and that it requires little space.

There is already an infrastructure for heat supply in place — the Aachen-Weisweiler

district heating network, which supplies district heating from the Weisweiler coal power plant to areas including the Aachen region.

Fraunhofer Hydrogen Labs — structural transformation through climate neutrality

From 2023, new technologies for producing, storing and using hydrogen will be developed and tested on an industrial scale at the Fraunhofer Hydrogen Lab on the Siemens Energy Innovation Campus in Görlitz (HLG). This position of technological leadership is intended to promote the establishment and further development of companies in the future market of hydrogen, and to support the structural transformation from a coal region to a hydrogen region.

Together with the Fraunhofer Hydrogen Labs in Leuna and Bremerhaven, the HLG help to achieve climate neutrality and secure technological leadership in hydrogen technologies. With a connected load of around 12 megawatts, the HLG will provide an internationally unique research infrastructure for hydrogen technologies in central Germany.

The initial focus is on the generation and storage of hydrogen in mobile and stationary fuel cells, particularly for mobility and to supply neighborhoods and industrial sites. Research is required for this in the areas of evaluating stacks and systems, microstructure analytics and diagnostics, digitalization, production processes, power electronics and certification. For example, the ontoHy research project is creating a data and knowledge space for SMEs that is connected to the "DurcH_2atmen" (breathe with H_2) regional hydrogen network. The companies involved include Siemens Energy and Stadtwerke Görlitz.

The HLG will combine research expertise from the Fraunhofer Institutes for Machine Tools and Forming Technology IWU and for Wind Energy Systems IWES, and is jointly funded by the German federal government and the state government of Saxony.

Cluster Decarbonisation in Industries in Lusatia

The newly founded Cluster Decarbonisation in Industries (CDI) helps energy-intensive industrial companies to stay innovative and competitive as they go through energy transition. The founding members are the Brandenburg University of Technology (BTU) Cottbus-Senftenberg, the Institute of Low-Carbon Industrial Processes of the German Aerospace Center (DLR), the Fraunhofer Research Institution for Energy Infrastructures and Geothermal Systems IEG and the Competence Centre on Climate Change Mitigation in Energy-Intensive Industries (KEI), which also acts as coordinator. This interdisciplinary network combines its expertise and provides ideas for successfully transforming to a carbon-neutral industry. From their common location in Cottbus, the four members aim to play an active role in shaping structural transformation in Lusatia.

Structural transformation through the hydrogen economy will create innovations and new jobs. A hydrogen test laboratory, Fraunhofer HLG, is being built on the Siemens Energy Innovation Campus.
Photo: Pawel Sosnowski

Initiatives for improving preventive healthcare

Cluster for personalized medicine in future clusters competition

As regional innovation networks, the Clusters4Future represent a central element of the German federal government's High-Tech Strategy 2025. The winners of the German Federal Ministry of Education and Research's 2019 competition for future clusters were announced in spring of 2021. Since then, seven of these regional innovation networks have been launched in various fields of research and innovation. These networks involve collaboration between universities, research institutions, companies and stakeholders in society and other areas in different regions. They are expected to make a significant contribution to the transfer of knowledge and technology in the near future.

Of the seven Clusters4Future, two in which Fraunhofer is participating are focusing on innovative approaches for improving drug delivery in personalized medicine. The clusters' areas of research are personalized cell and gene therapy methods (SaxoCell) and new approaches to drug development (PROXIDRUGS).

"Living drugs" that activate the body's self-healing powers are produced in the clean room. Photo: Fraunhofer IZI

SaxoCell — affordable personalized medicine

This consortium in the Dresden/Leipzig area is researching innovative cell and gene therapies and new production methods for innovative treatments, such as "living drugs" that are intended to activate and support the body's self-healing powers. In the treatment of blood and lymph node cancers, for example, the body's own immune cells (CAR T cells) can be genetically altered to specifically target and destroy the tumor cells. After they have been clinically tested, the aim is to produce these kinds of cells with specifically defined functions and a high safety profile so that they can be applied on an industrial scale and at a socially acceptable cost. This will establish a realistic and sustainable economic model with high potential for creating added value in the region.

The consortium's partners are TU Dresden, the University of Leipzig, the Klinikum Chemnitz hospital and the Fraunhofer Institute for Cell Therapy and Immunology IZI, as well as partners from academia and industry.

PROXIDRUGS — outsmarting cellular "garbage disposal"

As part of the PROXIDRUGS future cluster, led by the Goethe University Frankfurt am Main, the Fraunhofer Institute for Translational Medicine and Pharmacology ITMP is researching the development of innovative treatments for a broad spectrum of human diseases. Its focus is on the substance class of proximity-inducing drugs. These drugs take effect by bringing illness-related proteins into spatial proximity with enzymes and specifically marking them for the body's degradation process. As this method is highly specific, it allows doctors to administer the drugs in low doses with few side effects, resulting in major advantages.

Most drugs available today can only render 20 percent of all disease-related proteins harmless due to the single bonding between their molecules. It is expected that drugs activated by spatial proximity will focus on the protein masses and other structures that have not been targeted before. The new substance class of proximity-inducing drugs has great potential for transfer to clinical application and will enable the development of new tailored treatment options for illnesses that occur frequently in the population, such as for oncological, inflammatory, infectious, cardiovascular and neurodegenerative diseases.

The partners of PROXIDRUGS are the Goethe University Frankfurt am Main, the Technical University of Darmstadt, the Fraunhofer

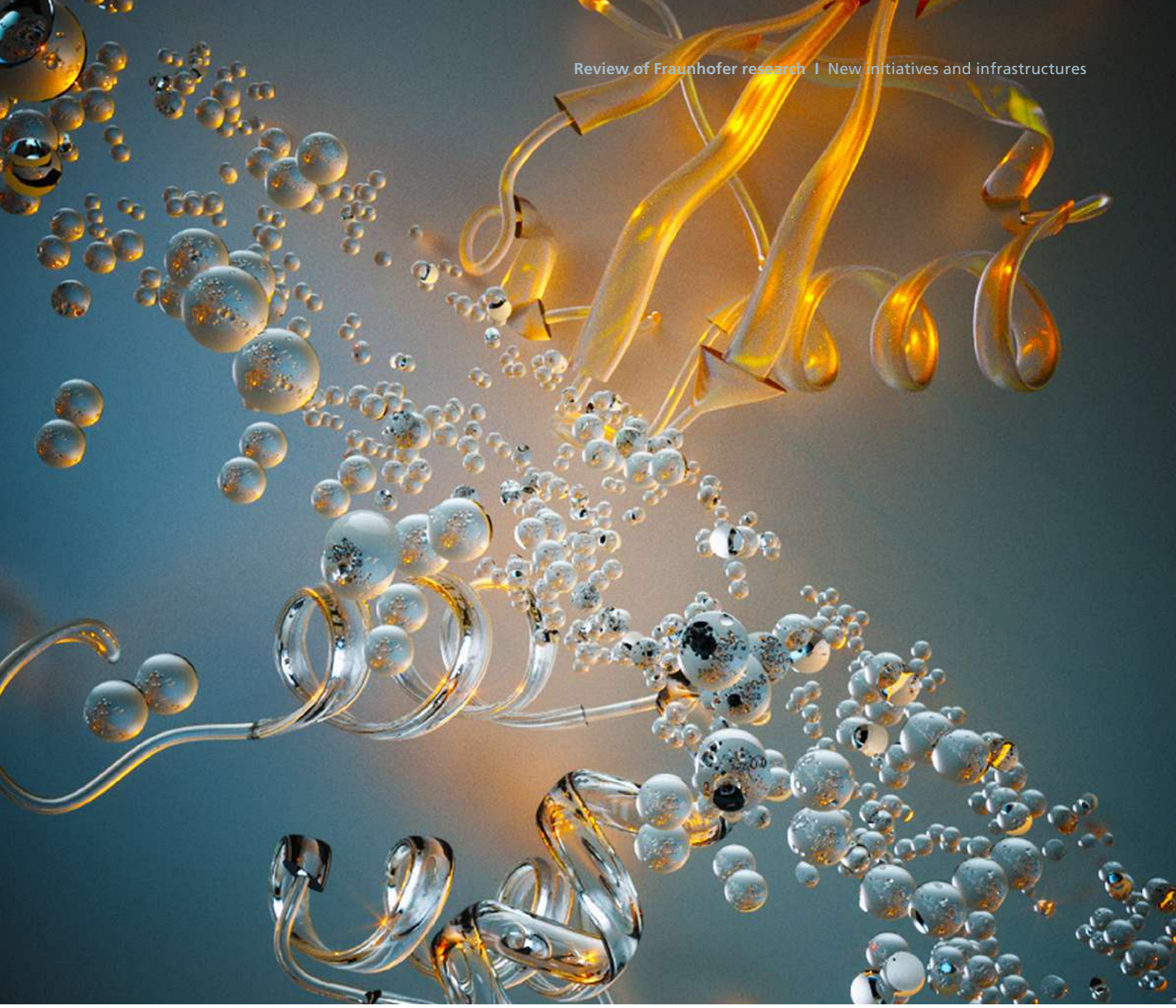


Image: Goethe University Frankfurt am Main/Ella Maru Studio

Molecular research creates new treatment options for many diseases — particularly those that have previously been untreatable.

Institute for Translational Medicine and Pharmacology ITMP, the Max Planck Institute of Biophysics and pharmaceutical and biotechnology companies in the Rhine-Main region.

The digital transformation of medicine

The Fraunhofer Institute for Digital Medicine MEVIS has a new building where it can focus even more strongly on one of the greatest challenges in medicine — its digital transformation. As image and laboratory data increases and the numbers of treatment options rise, hospitals and doctors' practices are seeing their daily routines become more and more complex. To successfully manage this complexity in the future, Fraunhofer MEVIS is developing new computer processes, such as artificial intelligence (AI) and clinical decision-making support. It is intended that these will collate relevant information, make diagnoses and treatments more efficient and reduce side effects in the process. The goal is to create precision medicine that offers solutions tailored to individual patients.

The methods currently in development include a new AI-supported process that can be used to more quickly and accurately complete follow-up checks on tumor treatments such as chemotherapy. In addition, a method has been developed to compensate for respiratory motion when using focused ultrasound in minimally invasive liver cancer treatment. This is the only way to ensure the focused ultrasound pulses actually hit the tumor and not the surrounding healthy tissue.

Lighthouse projects

Lighthouse projects at the starting line

NeurOSmart — high-performance computing for sensor systems
The NeurOSmart consortium aims to integrate efficient, neuromorphic HPC accelerators into sensor nodes using hardware-software co-design. An existing Fraunhofer technology, the open LiDAR system, was adapted for human-robot collaboration to serve as a demonstrator platform.

The project will address the need for sensor solutions that are fit for Industry 4.0, particularly in the European factory and logistics automation sector. These branches are increasingly turning to mobile robots and driverless vehicles. According to predictions, in less than ten years, the peripheral sensor equipment for these devices will need as much computing power as our current supercomputers. The biggest challenges that scientists must overcome in order to use high-performance computers in mobile systems are architecture scalability, sufficient transmission bandwidth between the sensors and data processors, and minimization of the energy requirements.

Researchers in the NeurOSmart project are creating neuromorphic HPC accelerators to make sensor solutions fit for Industry 4.0. Image: Fraunhofer ISIT/Concrete Brandbuilding

Researchers in the NeurOSmart project aim to develop a new standard for intelligent sensor systems. Thanks to their tailored, hybrid-computing architecture, a large portion of the raw data that the sensors generate can be processed directly in the sensors themselves. An analog neuromorphic HPC chip with an AI-driven pre-processing pipeline interprets the data by means of object identification and classification. The advantages to this system are that it eliminates the need for costly communications and edge-computing infrastructure and that it is less vulnerable to attacks. This combined approach, along with the co-design process, is expected to result in a minimum twofold increase in the energy efficiency rate of the data processing.

Lead management: Fraunhofer Institute for Silicon Technology ISIT

RNAuto — automated production of mRNA therapeutics
In the future, innovative pharmaceuticals such as new vaccines and mRNA-based gene and cell therapy methods will be available to large numbers of patients as part of an affordable healthcare system. This will create a need for automated production technologies that can safely and reliably produce drugs in accordance with the high standards required for pharmaceuticals (GMP certification). In order to develop an AI-driven, automated production process with digital monitoring capacities that is fit for the world of Industry 4.0, the consortium is creating a pool of interdisciplinary expertise covering the fields of medicine, biology and engineering.

The project partners will concentrate on two drug candidates to demonstrate the process automation. The first is an mRNA vaccine for preventing West Nile fever, which is becoming endemic in Europe, while the second is an mRNA-induced gene therapy for treating cancer, based on natural killer (NK) cells from healthy donors.

The consortium is working on an automated screening system for rapid process development of mRNA nanotransporters, with a digital mapping function for process and quality control. They are also developing an expansion module with integrated quality control for manufacturing allogenic gene and cell therapies. The key biological challenges here are that the stability of mRNA molecules is fundamentally limited and that correctly encapsulating the mRNA in lipid nanotransporters is a difficult process. Producing mRNA-based pharmaceuticals in an industrially

scalable way will be a key priority in the researchers' work.

Lead management: Fraunhofer Institute for Cell Therapy and Immunology IZI

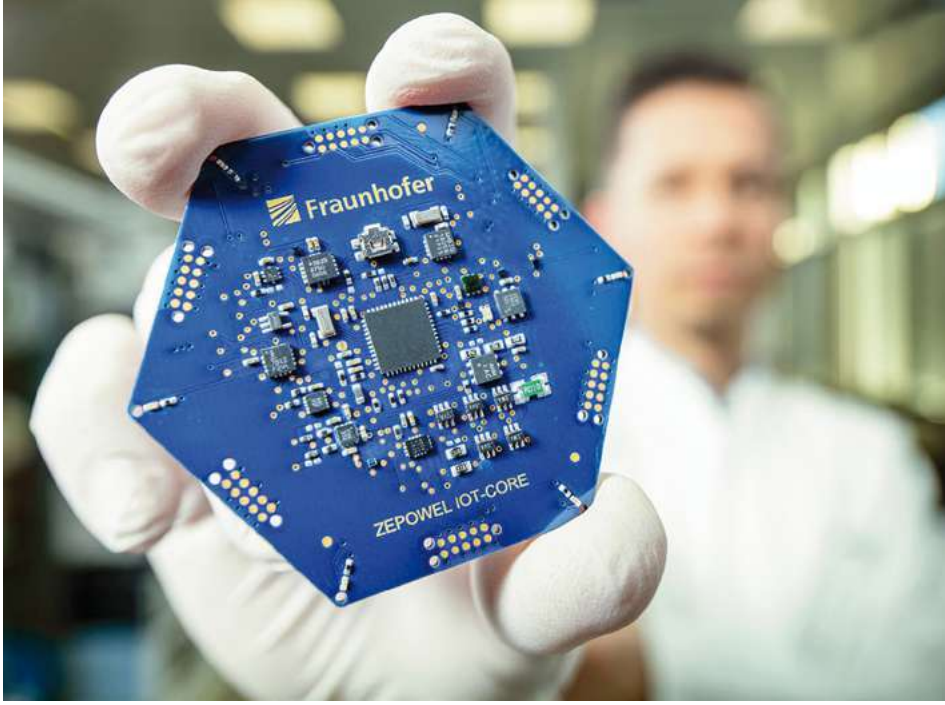
SUBI²MA — sustainable, biobased and biohybrid materials

The participants in the SUBI²MA project are developing novel materials to support the global objective of a biotransformation in plastics technology. Keeping global warming within the 1.5 degrees Celsius threshold and the associated goal of achieving net zero emissions by 2050 will require rapid defossilization of all economic sectors. It is not enough for the materials industry to merely replace established, fossil-based materials with biobased (and, in the medium term, generally more expensive) materials. To bolster demand, novel, biobased materials must exhibit additional, advantageous properties and functionalities.

This is why the consortium is researching a variety of functionalities, including degradability, complex sensory factors, selective separation processes and increased compatibility with commonly used polymers. The consortium hopes to use digitalization processes to create new, biobased/biohybrid materials for PET, cellulose and (bio)polyamides at speed, and so to accelerate future material substitutions. To begin with, the researchers will concentrate on Caramid-R® and Caramid-S®; developed by Fraunhofer, these biopolyamides are manufactured from terpene 3-carene, a waste material from pulp production. The consortium is also working on a circularity concept in order to assess the materials and their properties.

According to the commercialization objectives, the aim is for the SUBI²MA materials to provide solutions to the challenges faced by the plastics and chemical industry, aftermarkets such as construction and textile chemistry, the automotive industry, and the health sector in the context of national and international sustainability strategies.

Lead management: Fraunhofer Institute for Applied Polymer Research IAP



The self-sufficient sensor node developed as part of the ZEPOWEL project falls into deep-sleep mode when it is not needed.
Photo: Fraunhofer IZM/Volker Mai

Completed lighthouse projects

ZEPOWEL — energy-saving sensor nodes

Due to the Internet of Things (IoT), the number of devices connected to each other wirelessly is growing — and so is power consumption. Innovative sensor systems are providing a solution — they are energy-efficient and/or function completely autonomously. This could save up to 20 percent of the carbon dioxide emissions generated by sensor and IoT systems in Germany.

The Fraunhofer consortium's research included integrated sensors and signal processing, generating power from the environment, improved storage technologies and efficient wireless communications in networked IoT systems. The systems' modular technology can be tailored to various IoT applications. In the future, sensor nodes will be able to autonomously supply themselves with energy.

The self-sufficient Smart City Node, for example, records environmental data in real time. When idling, the sensor node consumes only a few nanowatts. It only powers up when it is activated wirelessly — so that it can measure nitrogen oxide or particulate matter and transmit the measurements using wireless technology, for instance. The Smart City Node is set to be installed in cars and buses over the coming months. Harnessing an energy converter, the sensor node obtains its power from the vibrations it experiences during journeys. Another prototype, Smart Fabrication, records the operating status of machines, motors and pumps in connected

New sensor systems that are resistant to moisture, vibration and pressure and can withstand temperatures ranging from minus 40 degrees Celsius to 300 degrees Celsius.
Photo: Fraunhofer IMS

production lines. The IoT node helps reduce energy requirements by switching off systems during idle time, especially machines with rotary motors. The sensor node enables the machine to power up and down as needed and operate precisely at the required speed. This is made possible through measurement technology and innovative power electronics.

These types of sensors can be used in a range of applications, from agriculture and the manufacturing industry to holistic systems used to establish an effective and sustainable Internet of Things.

Lead management: Fraunhofer Institute for Reliability and Microintegration IZM

eHarsh — sensors under extreme conditions

As part of the eHarsh lighthouse project, a Fraunhofer consortium has developed sensor systems for use in extremely harsh environments. Among other things, the innovative, robust sensor systems ensure the more efficient and reliable operation of sensor-based engines, turbines, (offshore) wind farms and geothermal plants. By enabling continuous monitoring of complex wear parts such as aircraft engines, the sensor systems can also be used for proactive maintenance and can therefore have a role to play in delivering more sustainable air travel. They also allow new energy sources such as hydrogen to be used and produced more easily.

The developed prototypes are resistant to moisture, vibration, pressure and aggressive media, and remain fully functional in temperatures between minus 40 degrees Celsius and 300 degrees Celsius. Unlike existing conventional systems, signals can not only be measured under these extreme conditions in situ, they can also be connected via a network and (pre-)processed. The temperature range of the sensors — in aircraft engines or gas turbines, for example — exceeds 300 degrees Celsius, which is twice what today's conventional sensors can typically withstand.

The consortium brought together its expertise in materials, integrated circuit packaging, integrated circuits with resistance to high temperatures, sensors, materials diagnostics and test procedures as well as reliability testing and modeling. The test rigs they built can simulate use of the sensor system on an aircraft engine based on NATO guidelines, for example, or the resilience of electronics and sensors in conditions of up to 2,000 bar and 200 degrees Celsius. They have also developed a MEMS-based ultrasonic sensor (CMUT) for use in geothermal drilling. The sensor will be capable of reliably detecting the presence of rock wall through drilling sludge, to an accuracy of just a few centimeters. The consortium intends to explore additional application fields connected to Industry 4.0, i.e., industrial techniques such as forming and chemical processes.

Lead management: Fraunhofer Institute for Microelectronic Circuits and Systems IMS

ML4P — machine learning for production

The goal of the ML4P project was to use machine learning (ML) to increase the performance and (resource) efficiency of complex production facilities. The consortium developed the first tool-based process model that is designed to make using artificial intelligence (AI) methods in industrial contexts both easy to plan and iterate, and user friendly.

One particular challenge here is that, though the level of expert knowledge is high, there are frequently only limited amounts of data available. The interdisciplinary consortium overcame this challenge by developing new data analytics tools. The ML4P components are organized in a modular processing pipeline, which enables the real-time transfer of data and information from various IT and process control systems in a format suitable for machine learning. Hybrid AI methods make it possible to combine expert, domain-specific knowledge with data-driven machine learning, so that reliable, verifiable results can be produced even with small data volumes.

The advantage of the machine learning methods is that they can build up a pool of data that can be used to identify correlations and model processes. The self-learning mechanisms make the systems flexible and easy to change quickly. The modular ML4P overall architecture allows the creation of instances for the ML4P components both on site at the customer premises or distributed in the cloud.

In close coordination with the digital economy lead market, the consortium developed consultancy resources and other services for the design, implementation, commissioning and long-term operation of customer-oriented ML4P solutions. Before the project was even completed, the scientists demonstrated the feasibility of deploying the solutions in various industry application fields by means of continuous trials in the areas of packaged goods, batch production and process engineering. A trial operation of the modular software suite has already been running at the membrane filter manufacturer SUEZ Water Technologies & Solutions since late 2021.

Lead management: Fraunhofer Institute for Optronics, System Technologies and Image Exploitation IOSB

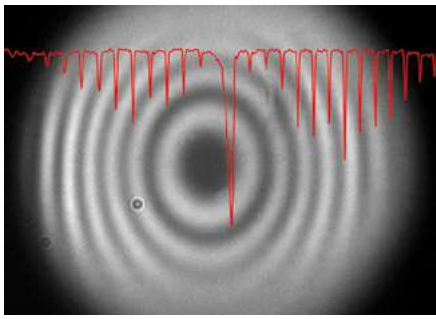
QUILT — pushing the boundaries of optics

Different wavelengths of light can provide information about our environment. Short-wave ultraviolet radiation, for example, can make the smallest structures in cells visible, infrared radiation provides information about harmful gases in the air or the composition of plastics, and long-wave terahertz radiation in particular makes it possible to precisely determine the thickness of paint layers. While light sources and cameras for visible things are highly advanced, inexpensive and widely available, other areas require a great deal of effort to generate and detect light. The goal of the Fraunhofer lighthouse project QUILT — Quantum Methods for Advanced Imaging Solutions was to develop quantum optical solutions for these hardly accessible wavelength ranges.

The consortium successfully integrated quantum entanglement into different measuring methods. By using different wavelengths in entangled photons, the information collected by one photon can be transferred to a second and made visible to the camera.

For the first time, the project partners created a method for detecting terahertz radiation in this way, and developed a quantum optical equivalent to the classic Fourier transform spectrometer for infrared spectroscopy. The consortium successfully recorded a video by using undetected light for imaging for the first time. They also developed a method for image reconstruction in asynchronous ghost imaging, and created prototypes for quantum-based imaging, spectroscopy and optical tomography. Together with partners from industry, the consortium evaluated the potential for application for the quantum-based methods, and the added value they can create, especially for industrial sectors such as environmental technologies and medical engineering. The QUILT lighthouse project paved the way for many quantum technology projects, including QuNET.

Lead management: Fraunhofer Institute for Applied Optics and Precision Engineering IOF



Entangled photons and interference effects allow infrared spectra of molecules (in this case, methane) to be made visible to cameras.
Image: Fraunhofer IPM

Projects and results 2021

Hydrogen Technologies

Global hydrogen potential atlas

In the HyPat project, which is running until 2024, nine world-famous institutions led by the Fraunhofer Institute for Systems and Innovation Research ISI are developing a global atlas for hydrogen potential. The atlas, which consists of a comprehensive overview of the countries that will produce and import hydrogen, taking into account their unique technical, social and economic features, is intended to ensure that Germany can continue to meet its energy requirements in the future by importing green hydrogen and hydrogen synthesis products. The aim is to develop a global supply and demand forecast for 2050. This crucial step lays the foundations for assessing the supply costs that future imports of hydrogen and synthesis products will incur for Germany and Europe.

To create the atlas, Fraunhofer ISI is conducting global analyses of renewable energy potential, taking into account issues such as social acceptance and stakeholder interests. The analyses will also outline demand scenarios for hydrogen and synthesis products. In addition, Fraunhofer ISI is analyzing funding instruments to support the market start-up and developing solutions for the certification of green hydrogen and green synthesis products.

The Fraunhofer Research Institution for Energy Infrastructures and Geothermal Systems IEG is conducting a technical and economic evaluation of the production and in particular the transportation of green hydrogen. To this end, it is analyzing the potential needs the countries themselves may have. Fraunhofer IEG also provides support through its expertise on existing gas infrastructures, the construction of hydrogen infrastructure, transportation options, and the production and use of hydrogen and synthesis products.

The Fraunhofer Institute for Solar Energy Systems ISE is also involved in HyPat, and is contributing its extensive process engineering expertise. One main focus area for Fraunhofer ISE is the analysis of future production processes and costs for hydrogen and synthesis products in the selected countries.

The HyPat project is funded by the German Federal Ministry of Education and Research (BMBF) as part of the Hydrogen Republic of Germany ideas competition.

Existing natural gas pipes are set to transport hydrogen-rich gases.

Photo: iStock

Green methanol from Leuna

TotalEnergies, Europe's largest producer of methanol, is joining forces with the electrolyzer manufacturer SunFire and Fraunhofer to test the production of methanol from hydrogen generated in a low-carbon process and separated carbon dioxide — an important step toward reducing harmful greenhouse gas emissions, especially in the field of basic chemistry.

The consortium project e-CO_2Met aims to test the interaction between three innovative processes. The consortium is using CO_2 from the TotalEnergies refinery, generating green hydrogen with the 1 megawatt high-temperature electrolyzer from SunFire, which boasts an efficiency of more than 80 percent, and conducting the subsequent methanol synthesis on the Fraunhofer Hy2Chem scaling platform.

As part of the project, TotalEnergies is exploring CO_2 capture and storage as a financially viable means of reusing CO_2, by converting the greenhouse gas into methanol using renewable electrical energy. The methanol produced in this way can already be considered an e-fuel and a replacement for crude oil and natural gas in the chemical industry. In addition, the synthetically generated methanol will be used as a starting material for further refining, for example, to produce sustainable aircraft fuels.

The production of synthetic methanol is being tested on a large scale for the first time at the Fraunhofer Hydrogen Lab in the Leuna chemical park with the Hy2Chem scaling platform. The test stand is fully integrated into the local chemical industry's infrastructure network and enables power-to-X (PtX) processes, for example, by feeding hydrogen into the pipeline system of Linde, another collaboration partner. The Fraunhofer Center for Chemical-Biotechnological Processes CBP and the Fraunhofer Institute for Wind Energy Systems IWES are involved in the Hydrogen Lab and the Hy2Chem platform.

In particular, the use of hydrogen as a chemical raw material offers potential for the existing chemical site in Leuna, in terms of shaping structural transformation and establishing a hydrogen economy in Germany and Europe.

Synthetic fuels for transportation

In the future, operating means of transportation such as ships or aircraft will also have to be climate neutral. However, switching them to electric propulsion will not be easy. Synthetic fuels (synfuels) help to reduce CO_2 emissions because the CO_2 emitted during locomotion was previously taken from other, unavoidable sources. This means that significantly fewer greenhouse gases are released overall.

Under the leadership of the DECHEMA industry network, some 37 partners are working toward sustainable future mobility by developing an overall strategy for introducing sustainable synfuels. The partners are developing sustainable synthesis processes, including upscaling, and investigating the motor properties and emissions of these future fuels so that conventional diesel and gasoline engines can be retrofitted quickly. The Fraunhofer Institute for Solar Energy Systems ISE is researching scaling for the production of oxymethylene ethers (OME3–5) up to the benchmark of 1 million tons per year. One crucial aspect here is integrating the individual OME synthesis steps into a highly efficient overall process, starting with green hydrogen/methanol and going all the way through to the production of a standard-compliant fuel. The partners have created an assessment procedure to evaluate the processes in terms of energy efficiency, financial viability and carbon footprint in order to identify the most promising one. The Fraunhofer Institute for Chemical Technology ICT is involved in suitability tests to determine the compatibility of synthetic fuels and mixtures with various fuel-carrying components. The test methods developed should provide meaningful insights regarding the chemical durability of materials when in contact with the new types of fuels.

Reducing the CO_2 emitted due to transportation will become possible if the synthetic fuel can be produced based on green hydrogen and the addition of CO_2. Oxymethylene ethers have good combustion properties and can also significantly reduce local emissions such as nitrogen oxides and soot. They are non-toxic, have a high cetane number, which is important for the efficient operation of diesel engines, and are highly compatible with the existing infrastructure.

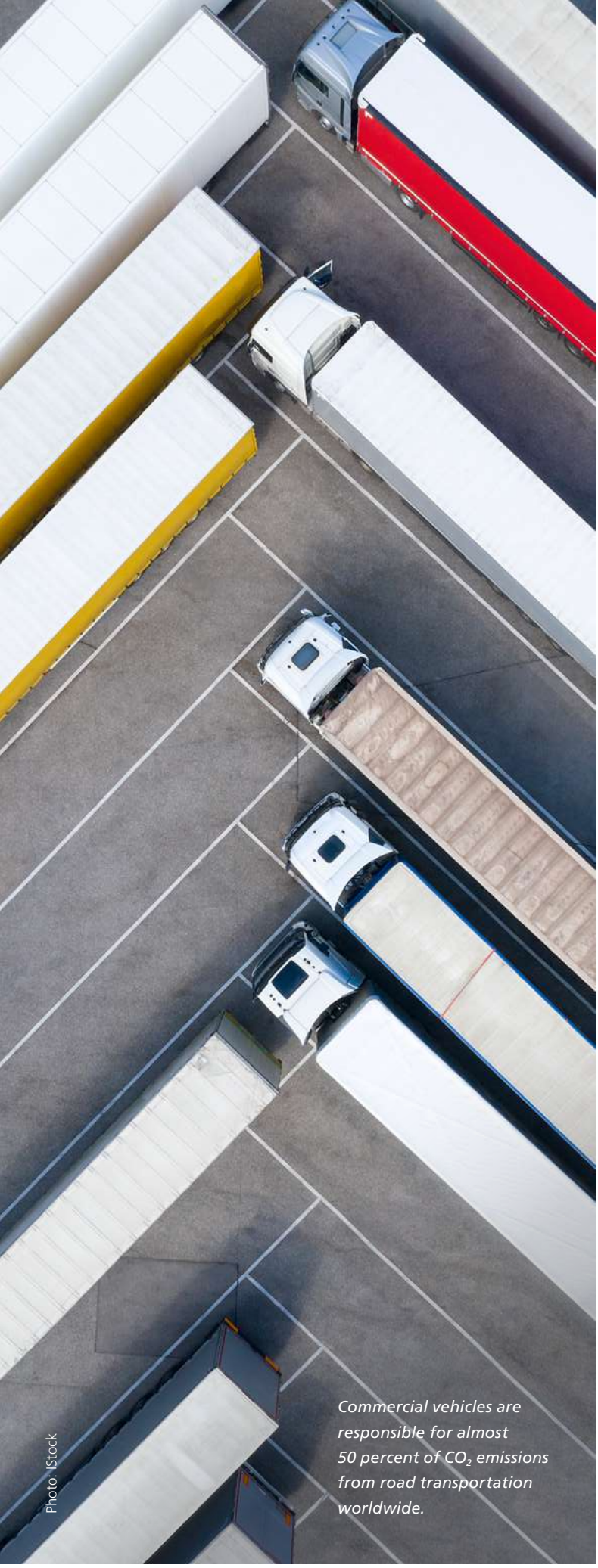


Photo: iStock

Commercial vehicles are responsible for almost 50 percent of CO_2 emissions from road transportation worldwide.

Trucks may soon go diesel-free

Commercial vehicles are responsible for almost 50 percent of CO_2 emissions from road transportation worldwide. Accounting for 74 percent of all transportation, trucks form the backbone of freight transport in Germany and Europe. In order to achieve the climate targets, road transportation must be completely defossilized by 2045 according to the German Climate Protection Act (Klimaschutzgesetz, KSG).

While electric vehicles are already used on a daily basis in passenger transportation, there is still a great need for development when it comes to the commercial vehicle sector. Technological innovations from the passenger car sector can only be transferred to the commercial vehicle sector to a limited extent. Apart from the differing use purposes, the situation for commercial vehicles is also very different when it comes to factors such as their significantly longer service life, minimal life cycle costs or the secondary market in countries with emerging and developing economies. That is why a Fraunhofer consortium has been developing highly efficient drivetrain systems specifically for commercial vehicles since 2020.

In order to account for the different use purposes, the systems have a modular design, and each module has an additional buffer battery. The consortium is studying energy supply via fuel cells as an option for industrialized countries and exploring the possibility of an electric generator power pack for countries with emerging economies. By modeling low-temperature fuel cell (PMFCs) systems, including the stack and components, the consortium has clearly demonstrated the potential for optimization. In order to optimize the electric traction drive, printed sheets with a high silicon content were developed and their magnetic characteristics determined in order to further improve efficiency. Synthetic energy sources were also studied with a view to the later use of commercial vehicles in countries with developing and emerging economies, which often rely on unstable power supplies.

The research was funded by the Fraunhofer Innopush Program. As such, maintaining and expanding expertise in market-relevant technologies such as fuel cells or digitalization was a particular focus.

Resource Efficiency and Climate Technologies

The path to climate neutrality by 2045

In 2021, the ARIADNE project published its first comprehensive scenario report on the path to climate neutrality by 2045. In the report, scientists compared models of various transformation pathways. The study, which involved more than 50 researchers from various institutes, showed that the volume of electricity generated from wind and solar energy would have to be about three times greater by 2030 than in 2020. The vital step of phasing out coal-based power generation could then take place as early as 2030, thus preventing the emission of significant quantities of CO_2. In addition, considerable efforts are needed in the industry, building and transport sectors.

The researchers analyzed six different scenarios for achieving the climate targets, focusing on four key areas of technology: direct electrification, hydrogen, synthetic e-fuels such as methane, and an energy mix. Their conclusion is that there is an urgent need to make investments and replace old plants before they reach the end of their useful life. Compared with the transformation path envisaged in the 2021 German Climate Protection Act (Klimaschutzgesetz, KSG), a more aggressive defossilization of the energy industry by 2030 would be more cost-effective. Direct electrification of energy consumption is key to achieving climate targets.

In the ARIADNE target scenarios, the share of electricity in the final energy mix increases from 18 percent in 2019 to 40 to 69 percent by 2045. In addition to direct electrification, indirect electrification using hydrogen and synthetic fuels contributes between 8 and 37 percent to the final energy mix. Existing industrial energy sources have to be replaced by sustainable alternatives such as electricity from renewable energy sources or hydrogen. For the heating transition, by 2030, the annual renovation rate must reach 1.5 to 2 percent, 5 million heat pumps must be installed and around 1.6 million buildings must be newly connected to district heating networks. In the transportation sector, direct electrification has the greatest potential for reducing greenhouse gases for the time being.

ARIADNE is one of the four projects funded under the Kopernikus initiative by the German Federal Ministry of Education and Research (BMBF), with the Fraunhofer Cluster of Excellence Integrated Energy Systems CINES being one of the members of the project consortium.

In order to achieve climate neutrality, the proportion of electricity generated from wind and solar energy has to be increased.

Photo: iStock

Green electricity: pilot project with Mercedes-Benz AG

In another BMBF Kopernikus project, around 100 partners from science, industry and society explored ways of meeting industrial electricity demand primarily from renewable sources. Companies can design their processes and organizational structure in such a way that energy consumption can be flexibly adapted to the volatile energy supply.

As a member of the consortium, the Fraunhofer Institute for Manufacturing Engineering and Automation IPA identified more than 40 conceivable measures for improving energy flexibility, with Mercedes-Benz and several supplier companies representing the entire automotive industry. Driverless transport systems, for example, are suitable for energy storage — provided that production is not operating at full capacity and electricity costs are low. The ventilation of a factory building can also be adapted to an intelligent power supply within a defined area.

The researchers at Fraunhofer IPA and their partners Software AG and TRIMET Aluminium SE have developed an initial prototype for a cloud-based energy synchronization platform. First, the team mapped energy flexibility in a data model, then used this as a basis to work out appropriate optimization measures. These measures were then implemented on IT services in the energy synchronization platform, enabling standardized, automated marketing of energy flexibility measures — from the production machinery right to the energy market.

Experts from Fraunhofer IPA and the University of Stuttgart analyzed potential for making electricity demand more flexible in industry. In the German industry sectors they studied, they identified potential for flexibility amounting to a load increase of 1.5 gigawatts and a load decrease of 3.3 gigawatts for a period of 15 minutes. That is roughly equivalent to the output of 430 to 940 onshore wind turbines. Extrapolating these figures for a whole year produced a potential energy flexibility of 2.5 to 4.4 terawatt hours.

Locations for producing carbon-neutral fuels

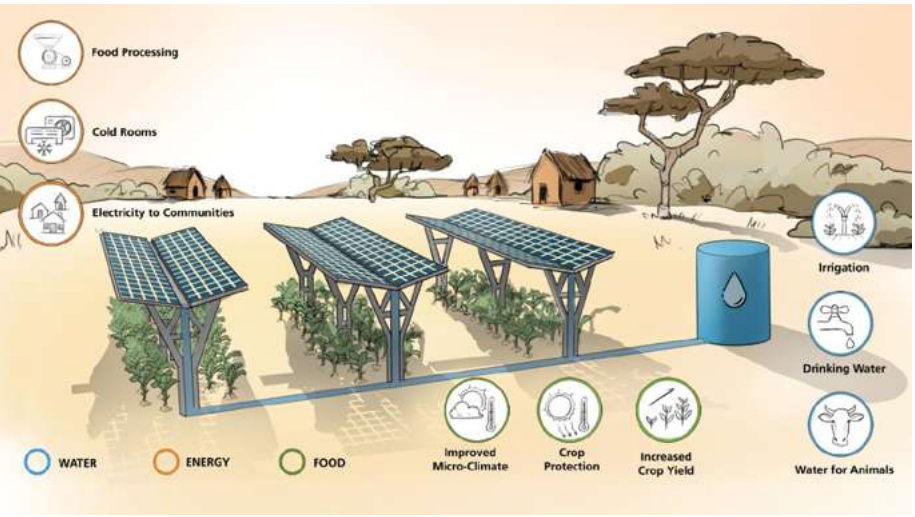
For applications such as aviation, shipping and basic industries, synthetic fuels produced with green hydrogen (known as power-to-liquids) can offer a solution when it comes to reducing CO_2 emissions. The Fraunhofer Institute for Energy Economics and Energy System Technology IEE developed the first global atlas on these power-to-X (PtX) processes to determine which sites would be suitable for the production of power-to-liquids, taking into account the technical and economic potential of energy carriers derived from green electricity. The IEE analyzed multiple factors here, such as land availability and weather conditions, local water availability, nature conservation, investment security and transport costs. In calculating the economic potential of individual locations, the researchers took into account not only electricity production costs and the efficiency of the energy conversion processes, but also the costs of peripheral devices, storage and transport.

The atlas shows that the lowest production costs are found in locations with good conditions for wind energy, preferably in combination with photovoltaics. The cost of transportation to Germany can be a decisive factor, especially in the case of hydrogen. Producing synthetic fuels for the European market directly where green hydrogen is produced might prove to be more efficient than simply transporting hydrogen.

The researchers narrowed down the projected total potential for storable electricity produced outside Europe further by including factors such as investment security and existing infrastructure. When scaled down to focus solely on Germany, the study concluded that the remaining fuel requirements could be adequately met by suitable production facilities located outside Europe.

However, energy efficiency and the direct use of renewable electricity must always take priority for the energy transition, warn the researchers. The PtX Atlas was created as part of the DeV-KopSys, a project funded by the

Gas-powered magnesium pressure casting process: a starting point for bivalent energy supply.
Photo: C&C Bark



Left: Illustration of an agrivoltaic plant including rainwater collection in Mali.
Graphic: Fraunhofer ISE

Right: Synthetic fuels and combustibles that are produced with green hydrogen reduce CO_2 emissions. Suitable locations for their production are shown in the global PtX atlas on https://s.fhg.de/power-to x-atlas.
Source: Fraunhofer IEE

German Federal Ministry for the Environment (BMUV). The project team is studying sustainable development paths for transportation across the energy sector.

Agrivoltaics: improving use of sun, rain and land in West Africa

For some time now, the Fraunhofer Institute for Solar Energy Systems ISE has been developing dual land use models for combining agricultural land use with photovoltaics — also known as agrivoltaics. Since 2020, an international consortium from Germany, Mali and Gambia has been investigating the possibility of going one step further and achieving three-purpose land use in West Africa, i.e., using the land to cultivate food, produce solar power and collect and store rainwater via the solar energy system.

The partners are constructing a demonstrator with a built-in water management functionality in Mali. Setting up the solar modules in a V-shape allows them to collect rainwater and direct it into a water tank via hollow posts in the substructure. This is intended to compensate for fluctuations in rainfall and thus improve agricultural cultivation capacities. It protects local groundwater reserves, while also creating the possibility of increasing yields through a stable water supply.

In Gambia, the four planned demonstrators will be adapted to the specific region so that they can be better combined with irrigated rice cultivation or systems for rainwater use, for example. The electricity generated should enable the use of water pumps, grain mills, cooling chambers and harvesting equipment, as required.

The international consortium combines R&D activities in agricultural science, socio-economics and solar energy, and aims to provide energy for value-adding services in local communities by building agrivoltaic plants. The consortium's economic research activities are aimed at developing financing models with a focus on the common good for the local population. The revenue generated from the systems will be used to repay investors and to maintain the equipment.

Bioeconomy

Plastics with biological functions

From pipes that no longer clog because they are made of self-cleaning plastics to self-degrading materials and surfaces that prevent mold growth: Integrating active enzymes into plastics can open up a whole world of possibilities.

However, a challenge is presented by the fact that while plastics are usually processed at temperatures above 100 degrees Celsius, common enzymes are denatured at these temperatures and become inactive. A research team from the Fraunhofer Institute for Applied Polymer Research IAP and the Brandenburg University of Technology (BTU) Cottbus-Senftenberg has successfully achieved functional integration of the enzymes — and in fact technical production beyond laboratory scale is already underway. The first functionalized plastic granules, films and injection-molded objects with active enzymes have been produced, using porous inorganic carriers that store the enzymes. Although this does limit the mobility of the enzymes, they remain active. However, there is no general stabilization process that applies to every enzyme, so a suitable carrier and technology must be found for each individual enzyme.

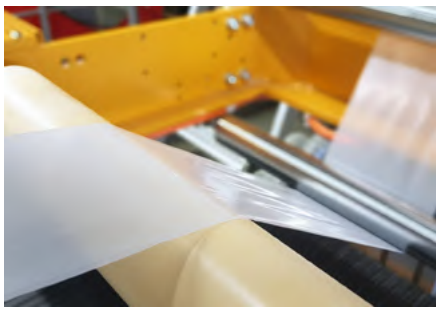
The stabilized enzymes can not only be applied to the surface of the plastic, but can also be incorporated into it directly in order to maintain the functionality of the material in the event of wear and tear. Researchers have developed a process that is suitable for bioplastics as well as for classic petroleum-based plastics such as polyethylene. Their studies also showed that stabilized enzymes were able to cope with even higher thermal loads after incorporation into the plastic than they were before processing. This represents a significant advantage when it comes to the use of the enzymes, as well as for all process steps.

Until now, researchers at Fraunhofer IAP have mainly been working on protein-cleaving proteases. Plastics that are functionalized using these enzymes can have a self-cleaning effect. Meanwhile, the partners at BTU are focusing more on enzymes that help degrade plastics and toxic substances.

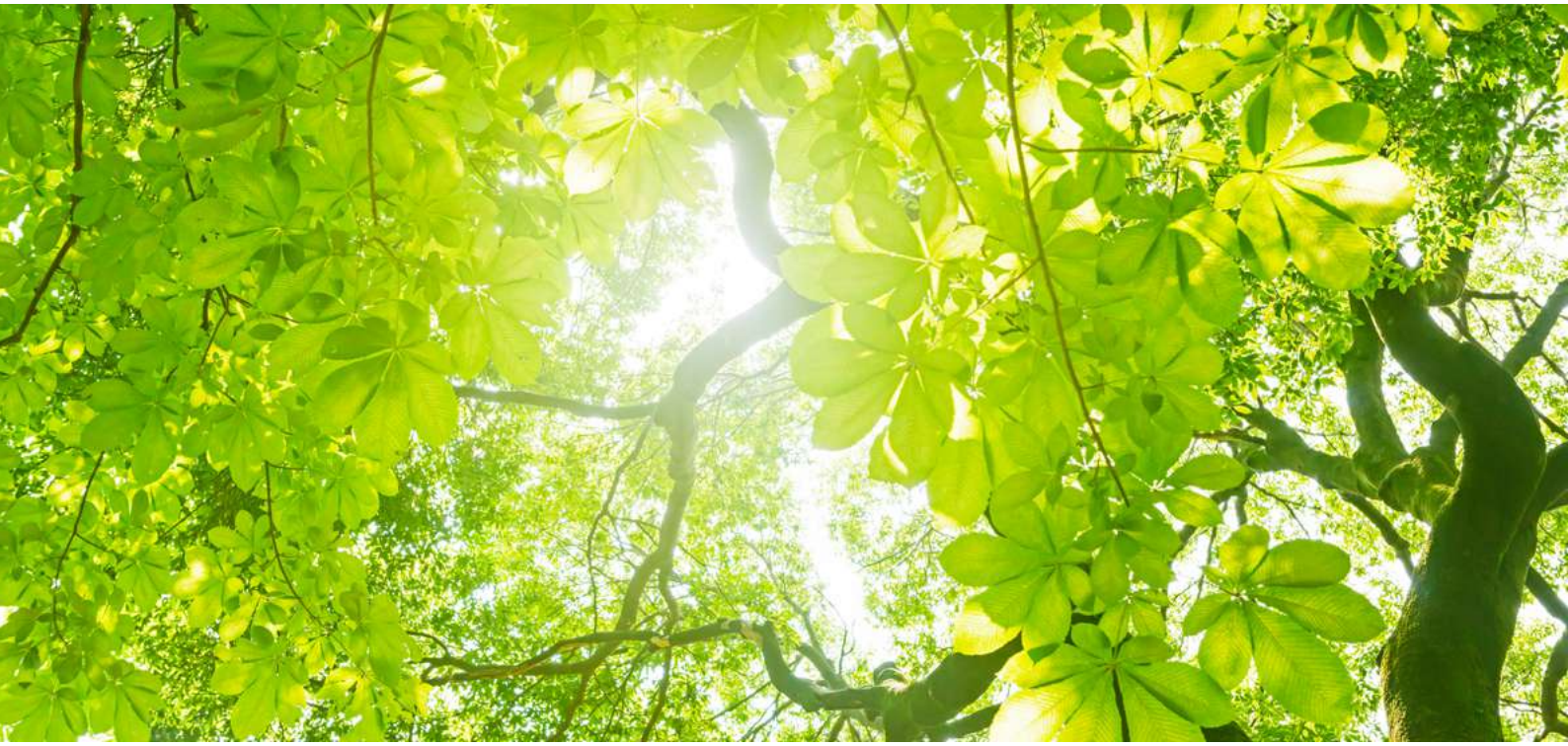
The project Biofunctionalization/Biologization of Polymer Materials — BioPol is funded by the state of Brandenburg and will continue until 2023.

Climate-neutral bio-oil from wastewater treatment plants

In Germany, 98 percent of the energy required to drive vehicles and 22 percent of the energy used for heating is still based on liquid energy sources, which originate mainly from fossil fuels. Some 16 percent of the petroleum quantity is consumed in the chemical industry. Two important milestones on the way to reducing greenhouse gas emissions are climate-neutral synthetic biofuels and chemical raw materials, for example, from biogenic waste materials.



A biofunctionalized film is produced using processing technology.
Photo: Fraunhofer IAP



The e$BioCO_2n$ project develops technologies modeled on photosynthesis.

Fraunhofer research groups have made significant progress in unlocking the potential of these raw material sources. A thermochemical conversion process, known as Thermo-Catalytic Reforming (TCR® technology), can be used to produce an oil similar to a fossil crude oil from many waste materials. It has a high heating value and very low acidity, and is also thermally stable. In refineries, it can be processed together with petroleum or converted into products such as gasoline, diesel or aviation fuel at other locations.

In a project on using biogenic residues, bio-oil was produced from sewage sludge and agricultural residues, meaning residual materials that had previously been declared as waste became useful, carbon-neutral products. In addition to the oil, the researchers have produced a stable bio-coal and synthesis gas, which can be catalytically converted to methanol at Fraunhofer plants in Sulzbach-Rosenberg and Straubing.

With the TCR® technology, biomass is broken down into solid and volatile components in a continuously operating screw reactor in the absence of oxygen. The resulting vapors are further refined to improve the yield and quality of the gas. During the subsequent condensation step, oil and process water are separated and the remaining gas is purified. This project on using biogenic residues is part of the largest Fraunhofer consortium project for bioeconomy: Evolutionary Bioeconomic Processes EVOBIO — Integrative Use of Material Flows to Produce Optimized Materials for Innovative Products in Bioeconomic Process Cycles. The funding was provided as part of the Fraunhofer Innovation Program.

Low CO_2 production of fine chemicals with enzymes

The raw materials shift means that the chemical industry will have to stop using fossil-based raw materials to a great extent. In the future, CO_2 will play an important role as a building block for the production of chemicals. An interdisciplinary research team in Straubing and Marburg is developing technologies modeled on photosynthesis in a project titled e$BioCO_2n$.

In this process, biocatalytic reactions are powered by electricity in order to use CO_2 for the production of valuable chemicals such as amino acids via cascade reactions. To simulate natural photosynthesis, enzymes

Photo: iStock

are embedded in customized redox-active hydrogels on electrodes. This means that large amounts of enzymes can be used. It also ensures an excellent electron flow and protects the enzymes, which in turn guarantees a high product yield.

Certain cofactors are needed if the sequential enzyme reactions are to take place. These are small, but expensive organic molecules that are essential for the functionality of the enzymes. Therefore, in the *e*BioCO_2n system, they are regenerated in an electrically powered reaction involving enzyme systems developed in-house.

The aim is to drive complex, carefully coordinated multi-enzyme cascades and thus develop a modular platform for the sustainable synthesis of the future. The consortium will initially develop a milliliter-scale demonstrator that will produce valuable intermediate products from CO_2. Their approach combines technologies from the fields of bioelectrocatalysis and synthetic biology, and is intended to pave the way for the circular CO_2 economy — for example, for companies in the pharmaceutical and agrochemistry industries or for the production of taste and odor molecules.

The *e*BioCO_2n project is funded through the collaboration program between Fraunhofer and Max Planck. Partners from the innovation field of bio-inspired chemistry at the Straubing institute branch of the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB, the Department of Biochemistry and Synthetic Metabolism of the Max Planck Institute for Terrestrial Microbiology in Marburg, and researchers from the Technical University of Munich (TUM) are all involved in the project.

An environmentally friendly palm oil substitute

Over the last 20 years, global demand for plant oils has doubled and will continue to grow. In 2020, around 200 million tons of plant oil were produced. Soy and palm oil have been the main sources so far, accounting for more than 62 percent of that figure — and resulting in massive damage to the environment, including rain forest clearing.

The macauba palm, which is native to South America, could provide the substitute for palm oil that the industry is so urgently seeking. The Brazilian palm requires significantly less water than classic oil palm trees and can also be grown in (semi-)dry regions, thus eliminating the need to clear tropical rain forest areas. Due to the high biomass production, macauba can bind up to 25 tons of CO_2 per hectare per year. This species of palm can survive in low-quality soil, but at the same time makes a considerable contribution to improving water retention in the soil.

In Brazil alone, 200 million hectares of grassland and semi-arid regions could be planted without negative interference with ecosystems, in order to cultivate macauba palms in combination with the other crops (e.g., coffee) or with livestock.

Increasing cultivation and use of the macauba fruit for oil production would generate enormous amounts of press residue and shred pellets. The Fraunhofer Institute for Process Engineering and Packaging IVV is working with Brazilian partners in the Fraunhofer Innovation Platform for New Food Systems on site in Campinas to make use of this side stream. For example, the proteins from macauba kernels are ideal for the production of purely plant-based foods, while the fruit pulp contains valuable fiber that could also be used in food production. However, it is also possible that macauba fractions could be used in technical applications such as flexible packaging solutions.

The Fraunhofer IVV Food Process Development department is involved in Acrowards, a funding project from the German Federal Ministry of Education and Research (BMBF). Fifteen partners from Germany and Brazil are cooperating in the project. In addition, the potential applications of macauba pulp fiber are being investigated in the Cornet AiF project AcroFiber, which is funded by the German Federal Ministry for Economic Affairs and Climate Action (BMWK).

Electricity is used to bind CO_2 to an initial substrate, as part of efforts to eliminate fossil-based raw materials.
Photo: Fraunhofer IGB/Marc Müller

Digital Healthcare

The micro-robot is 3 millimeters long and 1.2 millimeters in diameter — that is smaller than a grain of rice.
Photo: Anna Bakenecker

Magnetic mini-robots for gentler treatment

Research teams from the Fraunhofer Research Institution for Individualized and Cell-based Medical Engineering IMTE and the University of Lübeck are developing tiny robots that swim through the bloodstream. These can be guided to where they need to be in the body by means of a magnetic steering system. Once they reach their destination, the mini-submarines dispense targeted drugs, for example, for chemotherapy, or carry out gentle interventions in areas that are difficult to access.

Together with radiology experts from various departments of the University Hospital Schleswig-Holstein, the scientists successfully steered one of these micro-robots through a model of an average human cerebral artery to an aneurysm, using magnetic fields. The original study was published in the Scientific Reports journal in July 2021.

The micro-robot coated with magnetic nanoparticles was manufactured using 3D printing methods at the Institute of Medical Engineering at the University of Lübeck. Rotating magnetic fields cause the robot to twist, thus moving it forward.

To be able to observe the microrobot, the research teams at Fraunhofer IMTE and the University of Lübeck use tomographic and real-time magnetic particle imaging based on the magnetic nanoparticle coating. These magnetic fields are harmless to the body as no radiation is necessary. As a theranostic method, magnetic fields are opening up a wide range of new applications.

Artificial intelligence lends a helping hand for automation in medicine

Customized medical treatments such as modified stem cell transplants or cell and gene therapy, known as advanced therapy medicinal products (ATMPs), open up new treatment opportunities for complex diseases. For example, genetically modified T cells or lymphocytes (CAR-T or CAR-NK cells) have already been used successfully to treat certain types of cancer. However, the predominantly manual production processes and accompanying quality control of these treatments involve high levels of cost and effort. This has so far severely limited the likelihood of innovative treatments being widely available in future.

Researchers have now succeeded in advancing the automation of the quality control step. AI-driven flow cytometry can already detect the different types of lymphocytes (B cells, CD4- and CD8-positive T cells, killer cells) in patients' blood with a reliability of 98.6 percent. The next step is to drive quality control of the ATMPs Palintra® and Palixizumab® using AI. These cell products are used to prevent rejection reactions in stem cell transplants.

The AIControl project is supported by the Fraunhofer KMU akut funding program, which promotes research activities for SMEs. It is part of a consortium within the Fraunhofer Innopush Program that focuses on cost-effective,

*Researchers in **Hospital 4.0** are studying how to optimize logistics in hospitals.*

Photo: iStock

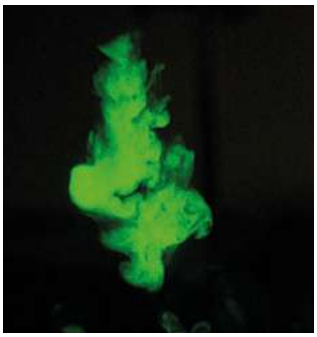
intelligent pharmaceutical production. This means modifying production processes to make them flexible and automated with increased throughput, and ensuring low costs while maintaining high quality standards. Various Fraunhofer institutes are pooling their biological and medical know-how as well as their expertise in automation technologies in order to make the production of cell and gene therapies and vaccines faster, safer and more cost-effective.

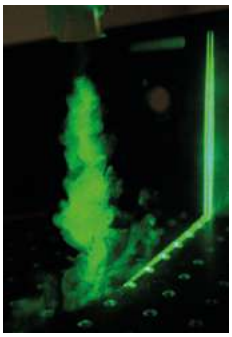
Completing the Hospital 4.0 project

In the Hospital 4.0 funding project, which aims to develop lean, digitally supported logistics processes for hospitals, researchers examined how logistics in hospitals can be optimized by means of technology-based processes. The main focus was on logistics for medical devices, consumables and beds. In addition, a further training program for hospital staff has been established throughout Germany in order to communicate the strategies and methods resulting from the study with a wider audience.

In the study's reference processes, namely warehouse logistics and bed management, researchers helped improve the transparency, safety and efficiency of logistics processes. Streamlining and automation of targeted processes gives hospital staff more time to spend on patient care. For example, RFID technology can make relevant information available in real time, thus generating transparency and rapidly creating links between all the people and resources involved — and making day-to-day work much simpler. The results made it clear that the integration of digital technologies, combined with accompanying staff training, substantially increases the quality and efficiency of patient care and significantly alleviates the pressure on nursing staff. Space, material and personnel requirements can be reduced.

Based on a comprehensive analysis of the processes and potential involved, the project participants developed a vision of how hospital logistics will look in 2030. Reference models for optimizing hospital logistics, including a training strategy and tools for digitalization, were summarized in a book about lean, digitally supported logistics processes in hospitals.





For administration by inhalation, the drug is finely nebulized (made visible here with green light), so it can get to where it is needed, directly in the respiratory tract and lungs.
Photo: Fraunhofer ITEM/Ulrich Froriep

Researchers in multiple projects are studying effectiveness of the pancreatic drug nafamostat against the coronavirus.

In addition to the Business & Information Systems Engineering institute branch of the Fraunhofer Institute for Applied Information Technology FIT, participants in the BMBF-funded project included Augsburg University Hospital, Bayreuth hospital, Technische Hochschule Ingolstadt technical university and the software company POLAVIS, which specializes in IT solutions for hospitals.

Wanted: drugs to treat COVID-19

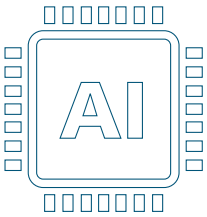
One method for speeding up the development of medical resources in the fight against the pandemic is drug repurposing — the use of therapeutic agents already approved for other purposes. Several Fraunhofer research consortia are using the Drug Repurposing Hub to search for promising drugs from around 5,600 substances at Discovery Research ScreeningPort, the Hamburg site of the Fraunhofer Institute for Translational Medicine and Pharmacology ITMP. A highly effective therapeutic agent for use in the early stages of COVID-19 would still be very important despite the availability of vaccines. Although breakthroughs have been made with vaccines, there is also a risk that other SARS-CoV-2 variants may develop, which may prove to be more resistant to the available vaccines.

The protease inhibitor nafamostat has shown a high degree of effectiveness in protecting against cell damage caused by the SARS-CoV-2 virus. The mechanism influenced by nafamostat plays an important role in the entry of SARS-CoV-2 into the host cell and therefore especially in the early course of COVID-19. To date, the synthetic drug, which has been approved in Japan since 1986, has been used primarily to treat inflammation of the pancreas and acute thrombus formation. In the case of SARS-CoV-2 infection, the synthetic drug inhibits the human protease TMPRSS-2, which the virus needs to enter the host cell.

A consortium is now researching ways of packaging nafamostat in microparticles or liposomes in order to modify the therapeutic agent for inhalation or targeted respiratory control after an injection, as the closer the drug gets to the infected parts of the body, the higher the efficacy and the lower the quantity that needs to be administered. This also reduces the risk of side effects. At the same time, Fraunhofer is developing a smart inhaler that uses respiratory motion to release the drug.

In the search for a medicine to treat COVID-19, research groups from seven different Fraunhofer institutes are collaborating with the scientific community in various projects — on both a global and national level. The projects include collaborating with Helmholtz institutes in RENACO, a funding project from the German Federal Ministry of Education and Research (BMBF), in the international Fraunhofer funding project iCAIR®, and in the Fraunhofer Anti-Coronavirus Program with the projects DRECOR and BEAT-COVID.

Artificial Intelligence



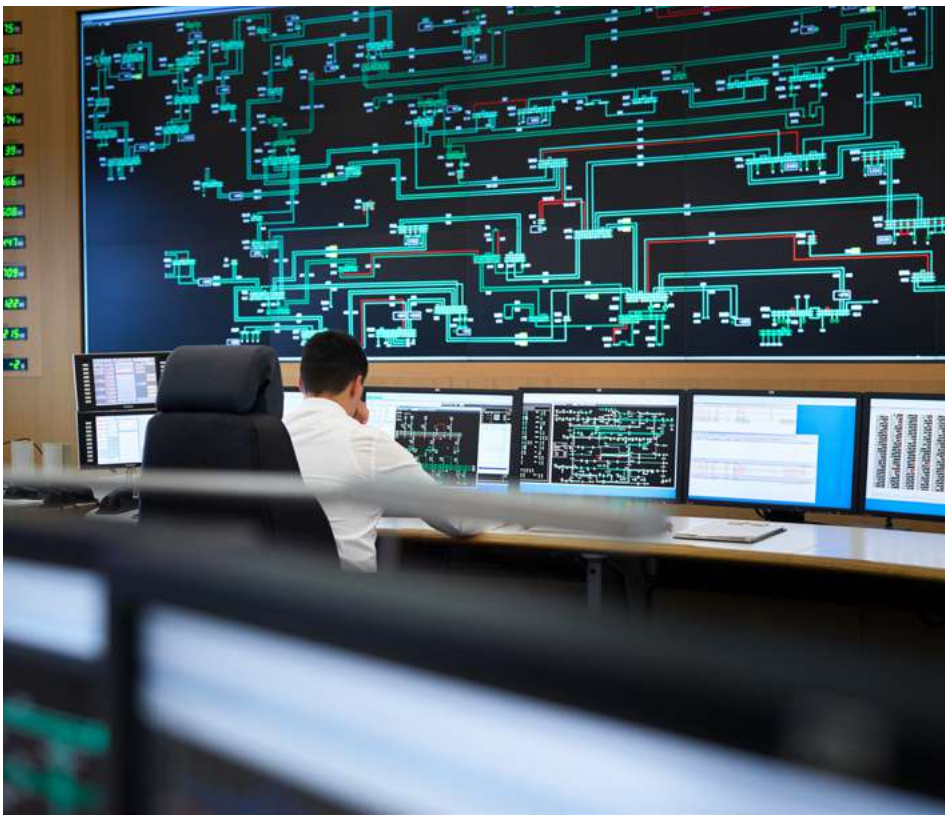
A secure energy supply with AI

The transmission system operator 50Hertz, together with institutes from the Research Fab Microelectronics Germany (FMD), is making our energy supply more secure and sustainable. They have implemented continuous condition monitoring by means of image capturing with drones, AI algorithms and neural networks, and they are also planning to use learning algorithms to automatically evaluate and classify images. This allows possible defects on overhead lines and power towers to be identified and located more precisely, and corrected more quickly. Until now, condition monitoring has been carried out via helicopter flights and foot patrols. 50Hertz and the Belgian network operator Elia, which are both operated under the umbrella of the Elia Group, supply energy to 30 million people over 19,000 kilometers of power lines, e.g., in Eastern Germany.

50Hertz has provided extensive image material from drone and helicopter flights to allow researchers to build up an AI database. In addition to the FMD central office, the Fraunhofer Institute for Reliability and Microintegration IZM and the Fraunhofer Institute for Telecommunications, Heinrich-Hertz-Institut, HHI are contributing their specialist expertise. A web-based tool for labeling and image management has already been developed, and an initial test for corrosion damage of towers and lines has been successfully carried out.

A feasibility study on predictive maintenance of the substation equipment will be carried out in a further project involving 50Hertz.

The goal is to proactively monitor this network infrastructure using machine-learning and AI methods to detect anomalies. Up to now, the team has carried out measurements with emergency batteries and circuit breakers, and conducted manipulations to imitate wear scenarios in several substations in the 50Hertz network area. The evaluations have resulted in a system model that includes implementation recommendations for the use of sensors and AI for maintenance. Four Fraunhofer institutes and the FMD central office are involved in the project.



Intelligent AI-driven monitoring of critical supply infrastructures at 50Hertz. Photo: 50Hertz/Jan Pauls

A traffic light system in Lemgo-Lüttfeld goes through a test phase.
Photo: Fraunhofer IOSB

Fraunhofer is making traffic lights intelligent

Artificial intelligence (AI) could improve traffic flow on roads by 10 to 20 percent. This would also reduce emissions of harmful substances — by up to 30 percent. These findings come from testing and simulation phases conducted in Lemgo with smart traffic lights in 2021.

The novel light signaling systems do not just collect information about current traffic volumes with radar technology, cameras or sensors like previous modern traffic lights; they also use reinforcement learning technology. Through many thousands of iterations, the algorithm learns which phase sequence of a traffic light leads to optimal traffic flow in a simulation of vehicles at a crossing. Unlike previous traffic light systems, AI can recognize regular patterns and draw conclusions for future traffic situations. This new technology could also be used to optimize deployment of emergency vehicles.

The test phases were carried out by Stührenberg, a manufacturer of traffic engineering systems, and a team from the Fraunhofer Institute for Optronics, System Technologies and Image Exploitation IOSB at its Industrial Automation branch in Lemgo. In fall 2021, researchers also commenced studies into the steering of pedestrian flows through traffic lights.

In addition to Lemgo, cities such as Cologne and Wuppertal are currently also switching to adaptive, environmentally-sensitive, real-time traffic management systems. However, the research project underway at the Lemgo institute branch of Fraunhofer IOSB has produced a transport technology innovation. The testing of a reinforcement learning agent for traffic light control under real conditions is something entirely new in the current research landscape.

Live operations commenced in the winter months of 2021/22. For this purpose, the traffic light test system was upgraded to include an additional control box that facilitates a wireless connection between the sensors and the edge computer that is also installed in the system. The optimization algorithms of the traffic light control run on this edge computer.

Photo: iStock

Attacking and defending AI algorithms

Under the motto "AI made in Germany," research groups at the Fraunhofer Institute for Applied and Integrated Security AISEC are working to ensure that artificial intelligence can be used safely in industry, as well as working to secure applications using AI. An important area of research relates to adversarial attacks, in which the researchers identify AI vulnerabilities and develop solutions to detect and defend against attacks at an early stage.

The research team have managed to circumvent a common object recognition system in such a way that it "recognizes" a Fraunhofer logo printed on common PC hardware as a car, for example. These creation attacks reveal the limits of AI and its operational capabilities — especially in critical infrastructures and traffic situations. The deception is based on prepared image or audio files that lead to misinterpretations by AI algorithms. Until now, such attacks have only occurred when the manipulated file is transferred directly to the computer. However, a new type of attack (physical adversarial attacks) now even allows attacks to be carried out in the real, physical world. To do this, the research team refined the attacks so that they now work remotely, i.e., via images from a camera. Using gradient-based methods, researchers were able to gain an understanding of how the input has to be adapted to deceive the underlying neural network. This allows them to create an image that fully meets the AI's expectations about the target object — even though no such object is physically there.

The research team is building on these results to develop appropriate detection systems that can combat this new type of attack. In various projects, they have already developed possible means of making the security of neural networks measurable — meaning that it can be certified in the future.

An intelligent hearable for the industrial workplace

Many industrial workplaces have an increased noise level, which can make communication on site difficult. A small hearable that fits into the ear can solve this problem. The Fraunhofer Institute for Digital Media Technology IDMT aims to combine some of its technological developments on an AI-driven platform. Integrated in a small button in the ear, a single device should be able to improve comprehensibility, and enable voice control and voice documentation as well as acoustic monitoring for quality control.

Microphones in and around the ear ensure optimum recording of audio and voice signals. Subsequent signal processing using machine learning techniques intelligently dampens background noise and highlights voices. This allows natural vocal exchanges not only with people, but also with machines. Because, when combined with the robust speech recognition solutions developed by the Oldenburg Branch for Hearing, Speech and Audio Technology HSA, things such as voice control can be implemented for systems at workplaces where there is a great deal of noise.

This also enables hands-free, verbal documentation of processes. In situations with high noise levels, microphones with voice recording functions positioned directly inside the ear canal have demonstrated particularly great potential because external noises are effectively shielded and speech is still easy to understand thanks to Fraunhofer's algorithms.

The various functions of the hearable can be combined in customized ways depending on the client's specific area of application. For example, acoustic monitoring of machines and processes can be integrated for quality assurance purposes. The functions do not require a cloud connection and can be integrated into existing systems, thus satisfying the high data protection and security requirements.

A small hearable for comprehensible communication, voice control and documentation, and acoustic quality monitoring.
Photo: Fraunhofer IDMT/ Anika Bödecker

Quantum Technologies

The first quantum-secured connection between federal authorities becomes a reality

In August, a milestone in quantum technology research was achieved: At a press conference, a live, quantum-secured video connection between the German Federal Ministry of Education and Research (BMBF) and the German Federal Office for Information Security (BSI) was conducted in public for the first time in Bonn.

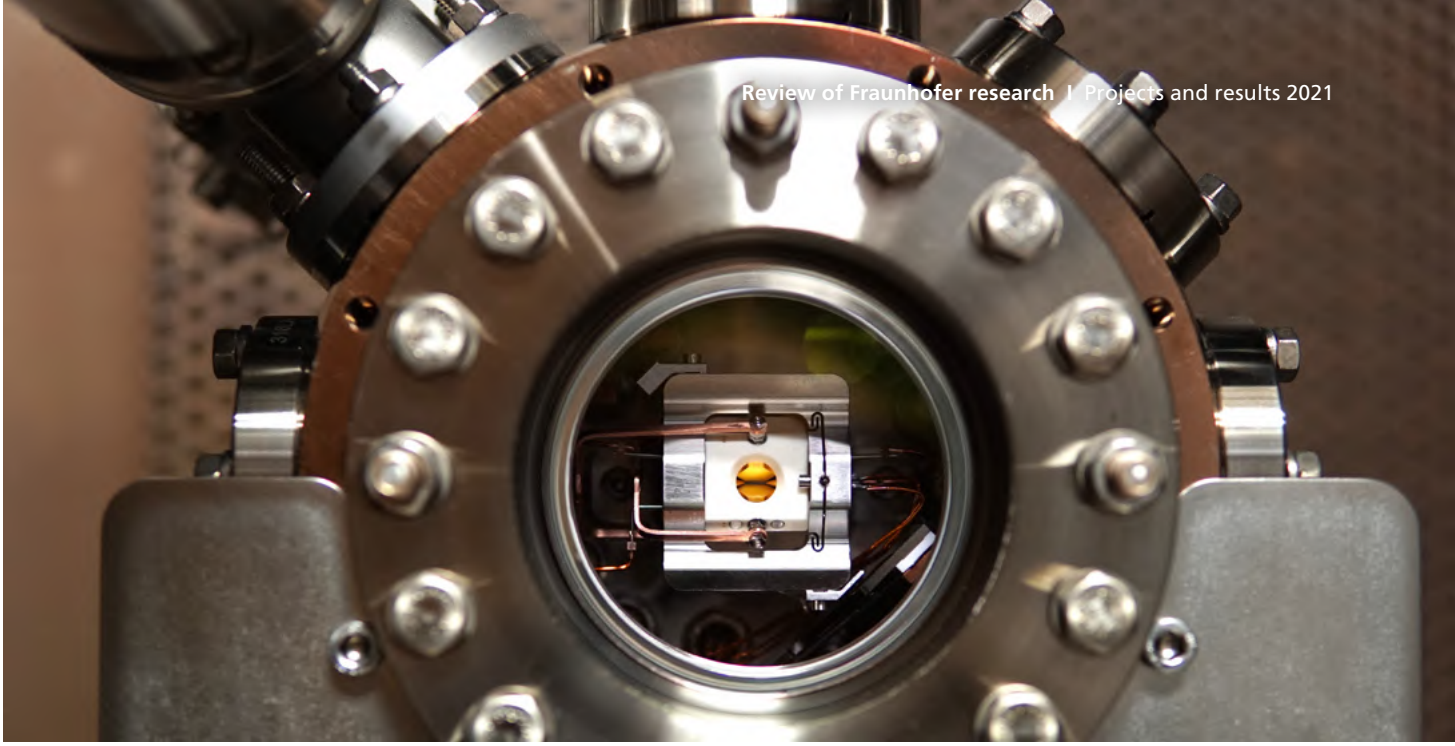
Secure, tap-proof data transmission is part of the BMBF-funded QuNET initiative. Fraunhofer, the Max Planck Society and the German Aerospace Center (DLR) are working together in QuNET to develop technologies for a pilot network for quantum communication in Germany. To achieve this, the project partners are studying the overall architecture for quantum-secure communication systems as well as the possibilities for exchanging quantum keys over long, medium and short distances using free-beam and fiber systems. To that end, the research teams are combining novel and established methods of conventional cryptography. In the process, the teams are careful to ensure that the methods can be integrated into existing communication network infrastructures. For transporting quantum states over long distances and across national borders, research is being conducted on optical free-beam systems using aircrafts and satellite-compatible technologies.

Former German Federal Minister of Research Anja Karliczek launches the first quantum-secured connection between two federal authorities in Germany.
Photo: BMBF/Hans-Joachim Rickel

Fraunhofer researchers are focusing on free-beam and fiber systems for quantum-based communication over medium and short distances. They are exploring possibilities in relation to coupling quantum technology with fiber optic infrastructures, as well as in relation to quantum light sources and to telescopes that can be used to create short-term, mobile connections.

Quantum communication is one of the key technologies for tap-proof networks and for dealing with threats in IT security. Online security and sovereignty are prerequisites for stable democracy.

The project partners include the Max Planck Institute for the Science of Light (MPL), the DLR Institute of Communications and Navigation (IKN), the Fraunhofer Institute for Applied Optics and Precision Engineering IOF and the Fraunhofer Institute for Telecommunications, Heinrich-Hertz-Institut, HHI.



The key element of the quantum computer from the EU project AQTION: the ion trap in the vacuum chamber.
Photo: University of Innsbruck

Optical addressing for trapped-ion quantum computers

Physicists at the University of Innsbruck have built a demonstrator for an industrial trapped-ion quantum computer. In the minimal space of two 19-inch server racks, they managed to individually control and entangle 24 calcium ions (Ca+) in a vacuum chamber. In order to manipulate the ions as qubits, the Fraunhofer Institute for Applied Optics and Precision Engineering IOF has developed laser optical addressing.

The research team uses laser light of different wavelengths to prepare the quantum states and perform the calculation operations on the quantum register. Among other things, single ions are illuminated with an addressing beam. This addressing takes place in the (sub-) micrometer range. The Fraunhofer researchers have developed an optomechanical unit in which piezoelectric actuators move micro-prisms. This means that a rigid array of incoming fibers produces a dynamically adjustable array of laser sources. The optical path had to be folded multiple times to enable compact optics that can be integrated into systems. For this purpose, a parabolic mirror with an optimal focal length was manufactured at Fraunhofer IOF. Furthermore, a patent has been applied for in relation to the functional principle of the entire beam guidance optics system. The calculation result from the quantum computer is read out by reference to the state of the ions arranged in the trap as a linear chain. The state of the ion at the time of measurement is determined by the fluorescent signal of the ion.

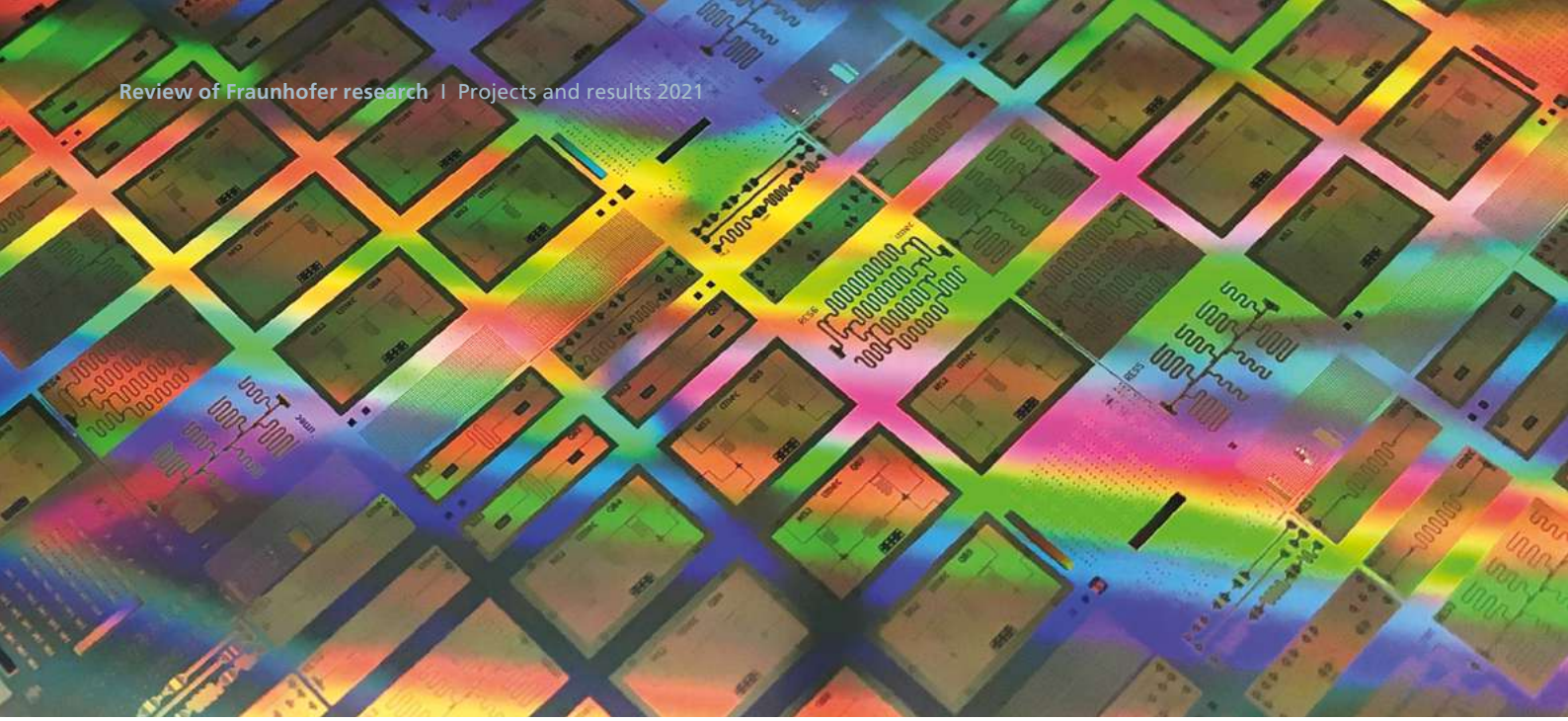
For the ion trap, the Fraunhofer IOF researchers collaborated with the laser specialists of TOPTICA Photonics and the quantum experts of the spin-off Alpine Quantum Technologies (AQT). In conjunction with this spin-off from the University of Innsbruck and the Austrian Academy of Sciences, Fraunhofer intends to build a commercial quantum computer for Europe.

The scalable quantum computer in Innsbruck was created during the Advanced Quantum Computing with Trapped Ions (AQTION) project, as part of the EU Quantum Flagship initiative.

Silicon qubits for the semiconductor industry

The development of highly scalable quantum processors in silicon is the goal of the EU project Quantum Large-Scale Integration with Silicon — QLSI. Silicon-based spin-qubits can be produced using established processes and the infrastructure from the semiconductor industry. These qubits are more compatible with existing technology, which may make it possible to scale and harness this approach more quickly. QLSI is part of the EU Quantum Flagship initiative. Among the participants in the project are the Fraunhofer Institute for Photonic Microsystems IPMS and the Fraunhofer Institute for Applied Solid State Physics IAF.

Since February 2021, a European consortium of industry, science and quantum



Test chip with superconducting qubits based on 300-mm wafer technology.
Photo: IMEC

start-ups has been working to develop semiconductor-based quantum processors for industrial use in Europe. For this purpose, they are using spin qubits as the basis for quantum information processing. Silicon qubits in particular can be controlled and read efficiently. Due to their compact array, their high quality and their compatibility with industrial manufacturing processes, they appear to be particularly suitable for rapid implementation with a view to establishing industrial quantum computing.

With its Center Nanoelectronic Technologies, Fraunhofer IPMS is contributing its expertise in the field of state-of-the-art, industry-compatible CMO semiconductor production at the 300-mm wafer standard. Nanostructuring, material development and electrical controls will be particularly relevant here.

In close collaboration with Infineon Dresden, RWTH Aachen University and Forschungszentrum Jülich, Fraunhofer plans to realize the first qubit demonstrators at wafer level. Fraunhofer IAF will focus on the characterization of qubits at low temperatures. The institute's extensive infrastructure for the characterization of cryogenic components will be used to analyze the aspects of variability between individual qubits and to understand them, with a view to future industrial production.

By 2025, the 19 partners, led by the French research institute CEA-Leti, hope to establish a competitive industry for quantum technologies in Europe.

Processor with superconducting qubits

The joint project German Quantum Computer Based on Superconducting Qubits — GeQCoS is focusing on the principle of superconducting qubits. The consortium centered around the Walther-Meißner Institute of the Bavarian Academy of Sciences and Humanities intends to demonstrate a quantum processor prototype with a particularly high degree of fidelity. The components have undergone fundamental improvements and are designed to better shield the qubits against external interference, thus guaranteeing the stability of the quantum properties over a long period of time. Achieving closer alignment between hardware and software is another focus area for the consortium. The participants are developing algorithms that are ideally adjusted to suit the type of qubits and operations, as well as the existing connections between the qubits.

Infineon will develop scalable manufacturing processes, while the Fraunhofer Institute for Applied Solid State Physics IAF will optimize chip housings to effectively control the highly sensitive quantum circuits, while simultaneously shielding them from the environment. Fraunhofer IAF is also contributing its expertise in construction and connection technology in order to be able to conduct operations with and scale the qubits at low temperatures. The Karlsruhe Institute of Technology (KIT), the Friedrich-Alexander-Universität Erlangen-Nürnberg and Forschungszentrum Jülich are also involved in the project, which is funded by the German Federal Ministry of Education and Research (BMBF).

Next Generation Computing

Energy-efficient AI chips for detecting atrial fibrillation

For artificial intelligence (AI) to be widely used in everyday life, its energy consumption has to be reduced. This is why the German Federal Ministry of Education and Research (BMBF) initiated the Energy-Efficient AI System pilot competition to promote innovation. The task was to develop an AI chip including software that accurately detects and classifies atrial fibrillation in real-time — all with the lowest possible energy consumption. Fraunhofer was involved in two research groups among the four winners.

In the FPGA (field programmable gate arrays) category, the team led by Dr. Jens Krüger from the Fraunhofer Institute for Industrial Mathematics ITWM and Prof. Dr.-Ing. Norbert Wehn from the TU Kaiserslautern technical university took first prize. FPGAs are flexibly configurable chips used to map neural networks. They can be used in a wide variety of circuits, and so they allow the best possible execution of an optimal algorithm. The FPGA can be reprogrammed as often as desired and provides support in searching for the optimal neural network. This was identified by means of automated neuronal learning. A holistic approach ensured that the hardware was also taken into account in addition to the neural network.

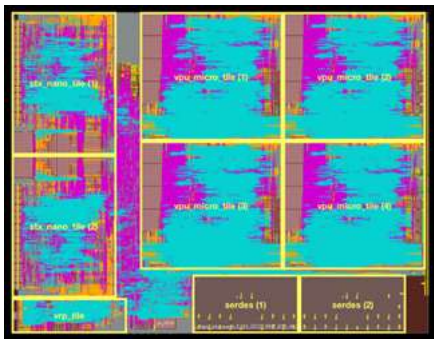
A research group led by Dr. Marco Breiling from the Fraunhofer Institute for Integrated Circuits IIS and Prof. Dr.-Ing. Dietmar Fey and Dr. Marc Reichenbach from the Friedrich-Alexander-Universität Erlangen-Nürnberg also took first place in the ASIC 130 category (application-specific integrated circuits with 130-nanometer technology). The group used deep learning to develop a neural network with very compact data types (ternary, i.e., only with weight values +1, 0, –1) and thus significantly greater efficiency. They achieved energy savings of up to 95 percent by reducing the processing time to a few milliseconds and by putting the AI part to sleep during most of the time needed for signal acquisition. A special data-flow-oriented chip architecture also contributes to energy efficiency, and the automation of the design process has allowed fast turn-around cycles.

The winning teams are currently continuing the development of their ideas together with industrial consortia, with support from the German Federal Ministry of Education and Research (BMBF).

First RISC-V chips for Europe's future high-performance computers

The traditional "Hello world" greeting has been sent, the European Processor Initiative (EPI) reported in September 2021. Known as EPACs and developed on the basis of the open instruction set architecture RISC-V, these accelerator chips have now commenced operations. The novel microprocessors and accelerators are core components of the first energy-efficient high-performance computer

Layout of the EPAC chip with accelerators in GlobalFoundries 22FDX technology.
Photo: Fraunhofer IIS



in Europe, which the EPI initiative aims to complete by 2024. The computer is primarily intended to strengthen the competitiveness of industry and science in Europe. To begin with, the research consortium is focusing on European high-performance data centers as well as the industry sector and car manufacturers. After all, autonomous driving and the related field of mobility, for example, require more and more computing power and greater safety — while simultaneously lowering their energy consumption.

One of the core components are hardware accelerators that are customized for specific applications. They deliver much greater computing efficiency than general-purpose processors or graphics processing units (GPUs). Their architecture, hardware design, compilers and software are based on European expertise that Fraunhofer contributes to significantly. The instruction set architecture for the RISC-V processor architectures these chips are based on is not patented and thus freely available.

In the summer of 2021, the first 140 of these novel EPAC accelerator chips were manufactured using 22 nanometer technology from GlobalFoundries in Dresden. The chip boasts multiple different accelerator units. Two of the four installed accelerator units are from the Fraunhofer Institute for Integrated Circuits IIS and the Fraunhofer Institute for Industrial Mathematics ITWM, as well as from ETH Zurich. Fraunhofer IIS was responsible for integrating the individual components into the chip. Following testing of the first EPAC chips, the next steps will see the introduction of a chiplet approach to achieve even greater computing power and lower energy consumption.

The EPI initiative, part of the EU's Horizon 2020 framework program, brings together 28 partners from 10 EU countries.

Production of qubits: stable and scalable

Qubits are the central hardware element of solid-state quantum computers. In order to be able to use them on an industrial scale, it must be possible to manufacture them in a stable and scalable way. To that end, the EU project Materials for Quantum Computing — MATQu was launched in mid-2021. The Fraunhofer Institutes for Photonic Microsystems IPMS and for Applied Solid State Physics IAF are contributing their expertise in 300-mm production and in low-temperature measurement technology.

For the production of stable Josephson contacts — the most common way of achieving superconducting qubits — it is already possible to use established production processes. However, the performance of the qubits produced in this way is highly dependent on the quality of the substrates and materials used and on the reproducibility of the manufacturing processes. Improved tuning of the qubits and reduced variability between them are also prerequisites for boosting the current scaling limits in the qubit number of current quantum computers.

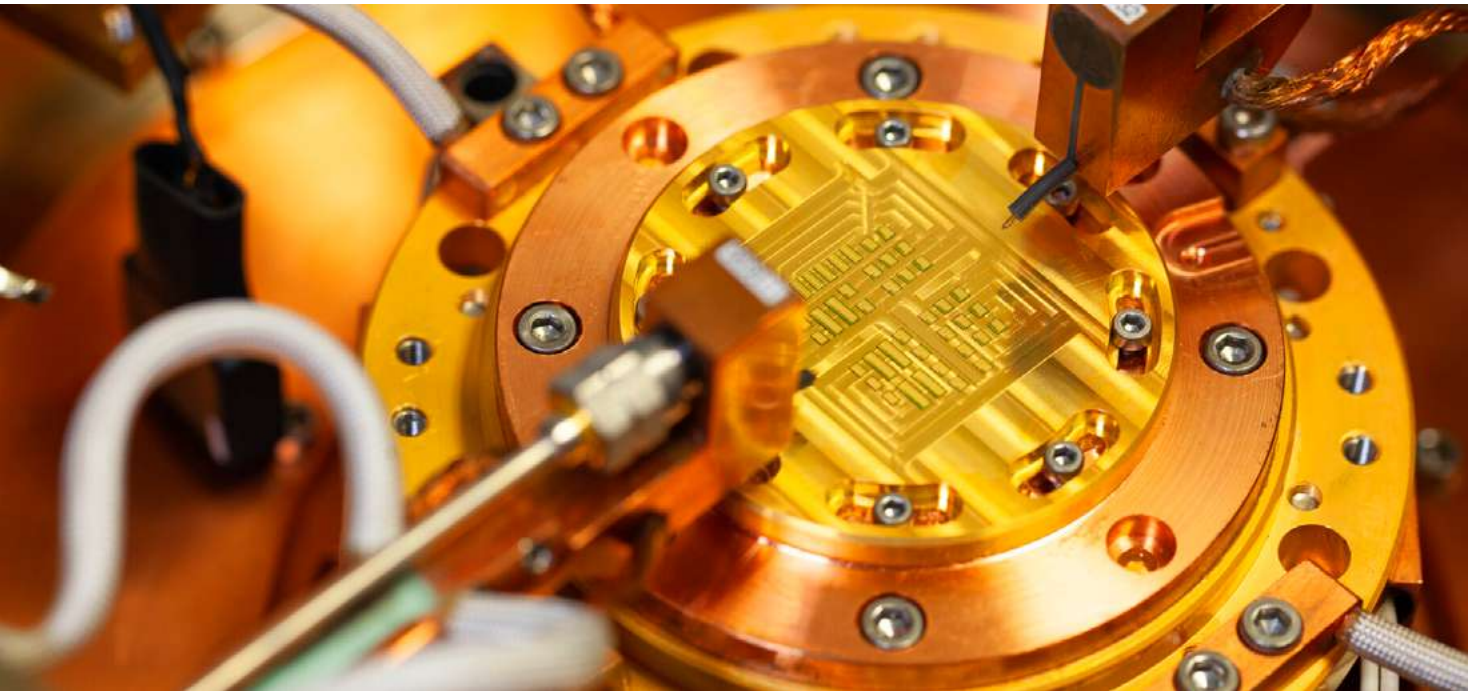
Graphic: iStock

Fraunhofer IPMS is contributing its expertise in 300-mm production, which already serves as the industry standard for CMOS computing platforms, as well as its extensive knowledge relating to the separation, structuring and integration of superconducting layers. Fraunhofer IAF is contributing its equipment and knowledge regarding low-temperature measurement technology, in particular to investigate the variability of superconducting layers.

The project is coordinated by the joint central office of the Fraunhofer Group for Microelectronics and the Research Fab Microelectronics Germany (FMD) as well as Fraunhofer IAF, in a consortium comprising 18 EU partners. It is funded through the EU's ECSEL Joint Undertaking (JU) program as part of Horizon 2020.

Automated driving: energy efficiency meets data security

Control units for autonomous driving currently require up to 500 watts of power. The brain of a car driver, however, consumes only 20 watts. In order to achieve similar efficiency in data processing, a Fraunhofer consortium is researching



and developing a computing platform with neuromorphic processors that are based around the way a human brain works. The current questions being addressed include: How can computing processes be handled with extreme energy efficiency in close sensor proximity in the future? How can machine learning be conducted on distributed federated systems?

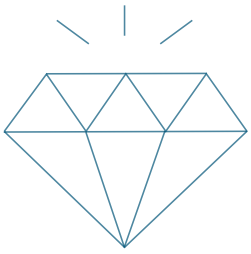
The neuromorphic accelerators that are being created in the SEC-Learn-Fly project section will have considerably lower power consumption than classic von Neumann architectures and will be optimized for AI algorithms. A spiking neural network will enable energy-efficient sensor signal processing on edge devices. The machine learning process will then be distributed across multiple edge devices without having to send vast amounts of training data to the central cloud. In this way, sensitive data can remain in the local systems, ensuring that the data is protected. Fraunhofer already has some patents for the necessary neuromorphic components (memristors).

The aim of the overall SEC-Learn project is to develop a new computing architecture for edge cloud computing across the entire value chain by 2024 — from neuromorphic components to accelerator hardware, and from distributed training algorithms to the cloud. The consortium focuses on voice recognition as well as autonomous driving as use cases. Eleven institutes from the Fraunhofer ICT Group and the Fraunhofer Group for Microelectronics as well as the Research Fab Microelectronics Germany (FMD) are involved in the SEC-Learn-Fly project section, which is funded under the German federal government's economic stimulus plan.

Left: Neuromorphic processors work in a way that is modeled on the human brain.

Right: The inner workings of a cryogenic on-wafer probe, which enables the characterization of wafers at extremely low temperatures.
Photo: Fraunhofer IAF

Awards 2021



Fraunhofer's employees are known for their excellent achievements in research, and help Fraunhofer to occupy a leading position in European research. Each year, a number of prestigious national and international awards are presented to Fraunhofer employees in recognition of their excellent achievements.

Fraunhofer research prizes

Joseph von Fraunhofer Prize
Since 1978, the Fraunhofer-Gesellschaft has awarded annual prizes to its employees for outstanding scientific achievements that solve practical problems.

Fraunhofer prize for Human- and Environment-Centered Technology
Every two years, the Human- and Environment-Centered Technology prize is awarded in recognition of achievements made in the fields of research and development — these achievements make a crucial contribution to improving people's quality of life and maintaining their ability to live productively on an everyday basis and into old age, as well as ensuring a healthier environment. This prize is presented by the Fraunhofer-Gesellschaft, the Fraunhofer Excellence Foundation and former executive board members and institute directors.

Hugo Geiger Prize
The Bavarian Ministry of Economic Affairs awards the Hugo Geiger Prize to three outstanding dissertations. These dissertations are assessed on the criteria of scientific quality, relevance to industry, originality and use of interdisciplinary methods. The award is named after the Bavarian secretary of state Hugo Geiger, who sponsored the inaugural assembly of the Fraunhofer-Gesellschaft on March 26, 1949.

Joseph von Fraunhofer Prize 2021

Microchips:
smaller, more powerful, unrivaled

Electronic microchips, such as those found in smartphones, are set to continue getting smaller, faster and more powerful. Until now, manufacturing technologies have only been able to build chip structures around ten nanometers in size.

Michael Kampmann and Martin Witt, along with their research team at the Fraunhofer Institute for Silicon Technology ISIT and Dr. Jacqueline Atanelov from IMS Nanofabrication GmbH, have developed a new microsystem switching element for an electron multi-beam mask writer. This makes it possible to create structures of less than ten nanometers in mass production based on EUV lithography, which will enable the production of semiconductor chips that are five or seven nanometers in size. Instead of applying the mask with a single beam during the lithography process, this new process uses over 262,000 beams. The electron beams flow as if through a membrane — though not in parallel like water jets from a shower head. Instead, they can be controlled individually via special control electrodes. Currently, this process is unrivaled, making it indispensable to those who want to write the smallest possible structures onto microchips. The devices are now making an annual revenue of US $400 million for the IMS.

Explaining its choice of winner for the Joseph von Fraunhofer Prize, the jury commented that "this technology enabled IMS Nanofabrication GmbH to achieve its market-leading position."

Dr. Jacqueline Atanelov, Michael Kampmann and Martin Witt (from left).

Photos: Fraunhofer/P. Banczerowski

Joseph von Fraunhofer Prize 2021

Internet of Things:
creating efficient and robust networks

Connecting objects in the Internet of Things (IoT) is becoming ever more important. The demand for connected IoT devices is already increasing rapidly and gaining momentum in the consumer sector as much as for Industry 4.0. Simple, battery-operated or energy-self-sufficient sensor nodes that transmit information over several kilometers are particularly important in this regard. The amount of data involved is usually small or very small, and only needs to be transferred occasionally. But until now, no suitable, reliable method of communication has been available for transferring many thousands of data packets at the same time.

A team of researchers led by Prof. (Univ. Navarra) Michael Schlicht, Josef Bernhard and Dr. Gerd Kilian from the Fraunhofer Institute for Integrated Circuits IIS has developed mioty®, a completely new, standardized solution. This system transfers data from between several thousand and a hundred thousand sensor nodes per square kilometer — in other words, up to 1.5 million data packets a day — to a single collection point in an urban area, industrial area or even an area without mobile communications coverage. It accomplishes this without any transmission loss. What's more, the wireless sensors and mioty® protocol are so energy-efficient that the batteries can last for up to 20 years.

Explaining its choice of winner for the Joseph von Fraunhofer Prize, the jury highlighted factors such as "reliability of data transmission, range, scalability and energy efficiency."

Dr. Gerd Kilian, Prof. (Univ. Navarra) Michael Schlicht and Josef Bernhard (from left).

Joseph von Fraunhofer Prize 2021

Redox flow batteries:
a step toward the mass market

Energy storage represents a key technology in the energy transition, with redox flow batteries showing particular promise. They are cyclically stable, non-flammable, recyclable, scalable and free of critical materials — however, they have always been too expensive for the mass market.

Now, at the Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT, Prof. Dr.-Ing. Christian Doetsch, Lukas Kopietz and Dr. Thorsten Seipp have completely redesigned the stack of the redox flow battery — in other words, its "heart" — to help solve this and other problems. This was made possible through an innovative process that can be used to manufacture the bipolar plates, the core components of the stack, on a mass production scale. In this powder-to-roll process, a very thin "infinite plate" is created from a powder mixture consisting of ground plastic and graphite, which allows for the production of flexible bipolar plates up to several square meters in size that can be welded using thermoplastic methods. The researchers found that the new stack requires less material, making it 80 percent lighter. Furthermore, it no longer requires any sealing surfaces, meaning that no assembly work is involved. All this results in a significantly more cost-effective stack when compared to conventional models. Volterion GmbH was founded as a spin-off to launch the new product on the market.

Explaining its choice of winner for the Joseph von Fraunhofer Prize, the jury highlighted factors including "the successful exit from Fraunhofer, which serves as a prototype for marketing new manufacturing technologies."

Lukas Kopietz, Prof. Dr.-Ing. Christian Doetsch and Dr. Thorsten Seipp (from left).

2021 Fraunhofer prize for Human- and Environment-Centered Technology

Vaccine production:
inactivating pathogens using low-energy electrons

Toxic chemicals such as formaldehyde are often used to inactivate viruses in killed vaccines. However, this comes with considerable disadvantages: The chemical destroys part of the external structure of the virus and harms the environment, even when disposed of correctly. It also requires the vaccine to be extensively purified before use. Furthermore, the inactivation process can take weeks or even months, depending on the virus.

Dr. Sebastian Ulbert and Dr. Jasmin Fertey from the Fraunhofer Institute for Cell Therapy and Immunology IZI, Frank-Holm Rögner from the Fraunhofer Institute for Organic Electronics, Electron Beam and Plasma Technology FEP and Martin Thoma from the Fraunhofer Institute for Manufacturing Engineering and Automation IPA have developed a process that inactivates pathogens within a matter of milliseconds by treating them with low-energy electrons. This development paves the way for faster, more environmentally friendly, efficient and affordable vaccine production processes.

Explaining its choice of winner for the Fraunhofer prize for Human- and Environment-Centered Technology, the jury highlighted factors such as "the simple and efficient method for largely retaining the structures that are important to the efficacy of the vaccine."

Dr. Jasmin Fertey, Frank-Holm Rögner, Martin Thoma and Dr. Sebastian Ulbert (from left).
Photos: Fraunhofer/P. Banczerowski

Hugo Geiger Prize 2021

Record-breaking efficiency:
coated multi-junction solar cells

The efficiency of silicon single-solar-cell technology, which has more or less reached its maximum maturity level, is limited to a maximum of 29 percent. As it stands, multi-junction solar cells with compound semiconductors made of materials from group III (earth metals/boron group) and group V (nitrogen family) chemical elements can achieve efficiency rates of up to 39.2 percent, making them perfect for use in smaller areas.

However, III-V semiconductors are still too expensive for flat solar modules — as a result, they are almost exclusively used in space technology. However, by applying several thin III-V semiconductor layers directly to a silicon cell, both technologies can be combined in a cost-effective way.

For his doctorate, Dr. Markus Feifel collaborated with the Fraunhofer Institute for Solar Energy Systems ISE to develop a complex, high-performance solar cell structure, which set several efficiency records. A particularly important aspect of his work was to achieve low crystal defect density at the boundary between the silicon and the III-V layer that is deposited on it, and thus to minimize output losses in the III-V sub-components above this. Dr. Feifel made a breakthrough here by using the ECCI method to detect and analyze defects and adjusting the III-V growth conditions as required — it was the first time the method had been applied with this material system.

Dr. Markus Feifel (left).
Right: Optimized multi-junction solar cells produce more power.
Photos: Fraunhofer/C. Duepper

Hugo Geiger Prize 2021

Recycling a higher proportion of plastics: a solid base for odor research

Recycling is essential. However, substances that trigger undesirable odors are a significant limit to the widespread use of recycled polyolefins. On top of that, odor contamination can indicate that other unwanted and harmful substances are present in the material.

As part of her doctorate, and in collaboration with the Fraunhofer Institute for Process Engineering and Packaging IVV, Dr. Miriam Strangl characterized the odor-active substances in plastic waste and recycled materials of various origins. She achieved this using a chemoanalytical approach. For the first time, most of the identified components could be detected in a plastic matrix. Her thesis broke new ground by clarifying the origin of these substances, as well as their possible formation mechanisms, and evaluating individual steps in the recycling process in terms of their potential for reducing odors. The results of her research lay the foundation for developing targeted strategies for deodorizing recycled materials with the aim of replacing new materials with competitive secondary raw materials in high-value applications at an ever-increasing rate.

Aside from generating industrial revenue, her doctoral thesis also formed the basis for the ongoing EU research project Circular Plastics Network for Training (C-PlaNeT) with the Friedrich-Alexander University of Erlangen-Nuremberg, which received funding of almost €4 million. Dr. Strangl played a significant role in designing the project.

Dr. Miriam Strangl (left). Photo: Studioline
Right: Odors are "captured" with liquid nitrogen.
Photo: Fraunhofer IVV

Hugo Geiger Prize 2021

Human-technology interaction: user state diagnostics focus on the human element

In her dissertation on adaptive human-machine interaction, completed in collaboration with the Fraunhofer Institute for Communication, Information Processing and Ergonomics FKIE, Dr. Jessica Schwarz made the conscious decision to focus on people.

The development of RASMUS, a diagnostic tool for user states, enables the mental states and influencing factors affecting workers to be recorded and evaluated even as they work on their tasks, so that technical systems can be dynamically adapted to suit human needs.

One particularly noteworthy feature of the tool is the multidimensional state assessment process: Drops in performance are recorded to ensure that the technical adaptation process does not counteract the user's productive self-regulation strategies. Recording different mental states also means the technology can offer tailored support. Humans do not have to adapt to machines, but rather machines must adapt to humans — this is an important ethical component of the dissertation.

The findings have already been implemented in a naval setting, where this method of adapting technology based on context and conditions successfully helped improve both occupational safety and work results. Other fields of application include energy control centers and air traffic control.

Dr. Jessica Schwarz (left).
Right: An experimental structure for human-machine interaction.
Photos: Fraunhofer FKIE

National and international research prizes 2021

Nominated for the 2021 German Future Prize

Sustainable tires made from natural, dandelion-based rubber

The team behind the project Sustainable Tires from Dandelions — Innovations from Biology, Technology and Agriculture was one of three nominated for the 2021 German Future Prize, the Federal President's Award for Technology and Innovation. The winner that year was the team from BioNTech, who had developed a vaccine against SARS-CoV-2.

Since 2011, a team comprising Dr. Carla Recker (Continental), Prof. Dr. Dirk Prüfer (University of Münster) and Dr. Christian Schulze Gronover (Fraunhofer Institute for Molecular Biology and Applied Ecology IME) has been attempting to extract natural rubber from locally grown dandelions — an alternative to importing rubber from far-flung, tropical regions. Continental has since begun producing Urban Taraxagum, the first mass-produced bicycle tire made from dandelion rubber. An ongoing follow-up project between Continental and Fraunhofer is focusing on the serial production of car tires.

The process of turning the Russian dandelion into a cultivable source of raw materials proved to be a major challenge for the researchers. Together with the plant breeding company ESKUSA and the Julius Kühn Institute, they succeeded in breeding high-yielding, hardy plants from wild Russian dandelions. A crucial part of the process was analyzing the DNA markers. These are naturally occurring sites in the genome that can help establish the presence of desired properties, such as high rubber content. Using these markers, researchers can examine plant seedlings to discover if they have the desired properties and, as a result, assess whether or not it is worth continuing to use the plants for breeding.

Dr. Christian Schulze Gronover, Dr. Carla Recker and Prof. Dr. Dirk Prüfer (from left). Photo: German Future Prize

CNA Intelligence for Transport and Logistics innovation award 2021

Higher capacity at goods transshipment points with active noise control

Maximiliane Lorenz and Achim Klukas from the Fraunhofer Institute for Material Flow and Logistics IML and Valentin Mees and Georg Stoll from the Fraunhofer Institute for Structural Durability and System Reliability LBF, together with TriCon Container-Terminal Nürnberg GmbH, have received a special prize for their outstanding entrepreneurial and scientific achievements as part of the CNA Intelligence for Transport and Logistics innovation award 2021. The award is presented by the Center for Transportation & Logistics Neuer Adler (CNA) to recognize companies for their outstanding projects, products or services that make a significant contribution to long-term economic growth, as well as to safeguarding jobs and maintaining the competitiveness of Bavarian industry.

The Fraunhofer research team developed a system for reducing noise when handling containers at terminals, whereby sound waves from the gantry cranes are neutralized using suitable sound waves from loudspeaker systems. Prototypes for the active noise control (ANC) system developed by Fraunhofer were adapted at TriCon for use at transshipment terminals, with the aim of reducing noise emissions while loading containers onto rails. Among other things, this allows transshipment facilities to increase their working capacity at night. This development is part of the I²PANEMA project, which digitalizes processes in ports, making them more efficient and sustainable. The ANC prototypes illustrated how innovations such as the Internet of Things can be transferred to processes at ports, both inland and at sea. The researchers believe the technology could also be adapted for use in other railway applications, for example in train formation or maintenance systems, as well as in industrial plants.

Maximiliane Lorenz, Valentin Mees, Achim Klukas and Georg Stoll (from left). Photo: Fraunhofer IML

Two Hugo Junkers Awards 2021 for Halle

Biomimetic rubber
A new type of wound dressing

The Fraunhofer Institute for Microstructure of Materials and Systems IMWS in Halle (Saale) received two awards in the category for most innovative projects in applied research at the Innovationspreis (innovation award) of the state of Saxony-Anhalt in 2021.

A team led by Prof. Dr. Mario Beiner took first place for developing a biomimetic synthetic rubber that reduces tire abrasion. Second place went to Dr. Christian Schmelzer, Tobias Hedtke and Dr. Marco Götze for their innovative method for making wound dressing materials from natural elastin. In the Biomimetic Synthetic Rubber — BISYKA research project, the team researched the reasons why natural rubber has unique mechanical properties, before successfully transferring these properties to synthetic rubber. Then, they used the newly developed biomimetic synthetic rubber to manufacture tires with reduced abrasion and a high potential for value creation.

Dr. Christian Schmelzer and his team from matriheal, which is scheduled to become a spin-off in 2022, are using their newly developed wound dressings to find innovative solutions for treating chronic and slow-healing wounds. The research team converted elastin into a water-soluble derivative. This was then further processed into nanofiber fleece and protein sponges — these resorbable wound dressing materials can be used to treat large-area wounds such as burns. The developed materials combine natural, biodegradable components to mimic the mechanical and biochemical properties of the skin.

Prof. Mario Beiner (left). Photo: Fraunhofer IMWS Right: Dr. Christian Schmelzer, Tobias Hedtke and Dr. Marco Götze (from left). Photo: Fraunhofer IMWS/M. Menzel

Amazon Research Award 2021

Optimized call graphs for Java Enterprise applications

Among the recipients of the 2021 Amazon Research Awards was Prof. Dr. Eric Bodden, director of the Fraunhofer Institute for Mechatronic Systems Design IEM and head of the Secure Software Engineering group at the Heinz Nixdorf Institute of Paderborn University.

Amazon is providing US $60,000 in funding to support Bodden's research project to improve automated code analysis. Static code analysis has been used more and more in recent years to identify security gaps in software programs. Much like flowcharts, call graphs show the calling relationships between individual functions of a program. All possible function calls should be represented, using static call graphs in particular. However, constructing a complete, precise call graph remains a major problem, especially when analyzing Java web applications. For example, modern web frameworks call certain parts of programs automatically, and this must be modeled accordingly using code analyses. With his HybridCG project, Bodden aims to optimize the quality of these call graphs for Java Enterprise applications. To do this, he wants to develop a tool chain that accumulates dynamic information from the runtime in a static call graph, and can later be integrated into existing code analyses. This approach will be tested using the open-source program analysis framework Soot (www.soot-oss.org), which is maintained at the Heinz Nixdorf Institute and is already being used by Amazon Web Services.

The Amazon Research Award has been supporting research projects by means of donations and scientific conferences since 2015.

Prof. Dr. Eric Bodden.
Photo: Fraunhofer IEM

German prize for software quality 2021

Software quality in research, teaching and for business

Prof. Dr.-Ing. Ina Schieferdecker received the 2021 Deutscher Preis für Software-Qualität (German prize for software quality). Ina Schieferdecker has worked at the Fraunhofer Institute for Open Communication Systems FOKUS since 1993. From 2015, she headed up the institute together with Prof. Dr. Manfred Hauswirth. In 2019, she moved to the German Federal Ministry of Education and Research, where she became head of Department 5, Research for Technological Sovereignty and Innovation. On top of that, she is the founding director of the Weizenbaum Institute for the Networked Society.

The jury stated that Schieferdecker has shown great commitment to promoting the subject of software quality in both research and teaching, as well as in transfer projects with companies and in public discourse. Since the 1990s, she has made significant contributions to performance and security testing, as well as to the further development of the Testing and Test Control Notation (TTCN-3) specification language. She also initiated the UML Testing Profile (UTP), a graphical modeling language for model-based test specifications based on UML.

Schieferdecker plays a key role in various curricula for vocational training and further training. In particular, she campaigned to introduce qualifications for test automation engineers and quality engineers — both required for the Internet of Things.

The prize, an initiative of the Working Group Software Quality and Training (ASQF), was awarded for the first time in 2021, in conjunction with a group of relevant specialists from the German Informatics Society and the German Testing Board (GTB).

Prof. Dr.-Ing. Ina Schieferdecker.
Photo: Fraunhofer FOKUS/M. Heyde

2021 Deutscher IT-Sicherheitspreis (German IT security award)

Cache test — a security check for internet infrastructures

Prof. Dr. Haya Shulman won first place in the 2021 Deutscher IT-Sicherheitspreis (German IT security award). The award is worth €100,000, the highest amount for any IT security prize in Germany. It was presented to Prof. Shulman for the development of Cache Test, a market-ready cybersecurity solution for protecting internet infrastructures. With Cache Test, manufacturers and operators can automatically test the security of their products and infrastructures against cache poisoning attacks. Cache poisoning is a common type of cyberattack that manipulates the Domain Name System (DNS). For many IP-based networks, the DNS is one of the most important services. Its purpose is to control traffic and convert the hostnames contained in URLs into IP numbers. Attacks can involve internet users being redirected to fake websites, where they are misled into disclosing sensitive data and passwords. They can also serve as the basis for more far-reaching attacks involving the interception of phone calls and forged web certificates.

Prof. Shulman is one of the world's leading scientists in the field of cybersecurity. She studied computer science in Israel and, after completing her doctorate in 2014, came to Germany through the Fraunhofer Attract program, where she joined the Fraunhofer Institute for Secure Information Technology SIT. Shulman is a board member for the National Research Center for Applied Cybersecurity ATHENE in Darmstadt. Since February 2022, she has been a professor in the Department of Computer Science at the Goethe University in Frankfurt am Main and holds a LOEWE top professorship.

This is the eighth time that the Horst-Görtz-Stiftung (Horst-Görtz foundation) has awarded the German IT security award.

Prof. Dr. Haya Shulman.
Photo: F. Diehl

Paul Martini Award 2021

Options for treating heart failure

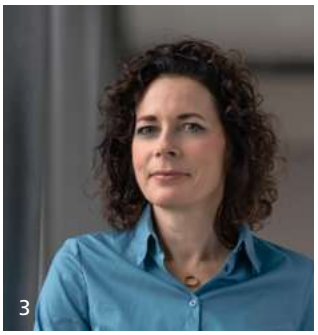
Prof. Dr. Dr. med. Thomas Thum, cardiologist at the Hannover Medical School (MHH) and institute director at the Fraunhofer Institute for Toxicology and Experimental Medicine ITEM in Hannover, received the Paul Martini Award worth €50,000. With this award, the Berlin-based Paul-Martini-Stiftung (Paul Martini foundation) recognizes outstanding achievements in clinical drug research. Thomas Thum received the award for his research on the design and initial testing of a new form of heart failure treatment. Chronic heart failure affects more than two million people in Germany alone. As it stands, only the symptoms can be treated — not the disease itself. Thomas Thum identified the effect of non-coding RNA molecules, known as miRNA, on cardiovascular diseases, developed new RNA-based treatments and assisted in transferring his findings to trials with patients.

Chronic heart failure causes the cardiac muscle cells to grow in an abnormal way, as the cardiac muscle tries to compensate for the insufficiency. In animals and humans, this growth is regulated by miRNA molecules. With the help of synthetically produced molecules that have a normalizing effect on cardiac muscle cells, Thomas Thum's team was able to test one of these new RNA active substances as part of an initial study. The active agent proved to be well tolerated and showed signs of therapeutic efficacy. This raises the possibility of not only treating the symptoms of heart failure, as has been the case to date, but also of curing the disease itself in the chronic stage. Plans are in place for another study with a larger number of patients.

Prof. Dr. Dr. med. Thomas Thum.
Photo: w/L. Parsyak

People in research 2021

The Fraunhofer-Gesellschaft's success is rooted in its employees' enthusiasm and expertise. Here, we present six individuals from the world of research — a small sample of the many employees who do excellent work at Fraunhofer.



1 Anita Schöbel
2 Thomas Thum
3 Ulrike Beyer
4 Steffen Meyer
5 Sabrina Schreiner
6 Rüdiger Quay

Photos: Fraunhofer/L. Parsyak

Prof. Dr. rer. nat. Anita Schöbel

Mathematician | Director of the Fraunhofer Institute for Industrial Mathematics ITWM in Kaiserslautern | Professor of Applied Mathematics at TU Kaiserslautern

Even as a child, Anita Schöbel was fascinated by numbers and formulae. During her university studies, she discovered a passion for applying mathematics practically — for instance, to optimize public transport and other complex systems. She graduated high school with top marks, and later completed a degree and a doctorate in mathematics, both with distinction. This is in spite of caring for her two children during her doctoral studies, who were one and three years old when she completed her doctorate in 1998.

That same year, Prof. Schöbel began working as a research fellow at the Fraunhofer Institute for Industrial Mathematics ITWM, where she was head of a working group on transportation. She spent her mornings in the office and her evenings at home on the computer — but the afternoons were for her children. After returning to TU Kaiserslautern as a research assistant, she was appointed to Göttingen in 2004. She taught at the Institute of Numerical and Applied Mathematics at the University of Göttingen holding a W3 professorship until the end of 2018. This period included spending an unforgettable research semester in New Zealand together with her family, which proved to be as personally rewarding as it was scientifically beneficial.

In 2019, Prof. Schöbel returned to Kaiserslautern to work as both Professor of Applied Mathematics at TU Kaiserslautern and as institute director of Fraunhofer ITWM. Here, she developed her vision of achieving a bright future through mathematics, since it is her ideal to enact real change through her research — and she's doing just that. Under her leadership, researchers at the ITWM are using mathematical models to gain a better understanding of how the coronavirus pandemic developed. Mathematical models are also useful for discovering new approaches for the energy and transportation transitions, as well as optimizing cancer treatment. Her specialist field of discrete optimization works to provide a greater level of efficiency in production processes, in designing new materials and in logistics. She also plays a key role in developing next-generation computing infrastructures, such as quantum computing. Her success in these areas primarily stems from what a customer once described as her ability to clearly explain mathematics to non-experts, as well as the fact that she always takes a practical approach.

It's therefore not surprising that she is one of the most in-demand researchers in Germany. She holds more than ten official positions, not only at Fraunhofer and her university, but across her federal state and nationwide. She is the spokesperson for the Fraunhofer research field Next Generation Computing, the "KI-Lotsin für Mobilität" (AI pilot for mobility) in Rheinland-Palatinate, a member of the scientific senate of the National Research Data Infrastructure (NFDI) and, since the beginning of 2022, has also been President Elect of the Association of European Operational Research Societies (EURO) — and these are just a few of her titles.

As institute director, she has much to appreciate: not just the numerous exciting projects at her institute, but also her employees' dedication and enthusiasm and the solidarity with directors of other institutes. Both in her research work and within the Fraunhofer-Gesellschaft, she advocates for less bureaucratic red tape and greater individual responsibility. Another issue of great importance to her is promoting understanding between cultures — something she hopes to do in the future through country-specific scientific and cultural services.

"Next Generation Computing is hybrid. Classic processors, neuromorphic computing and quantum computing are used where they fit best."

Prof. Dr. Dr. med. Thomas Thum

Physician | Director of the Fraunhofer Institute for Toxicology and Experimental Medicine ITEM in Hannover | Professor of cardiology at Hannover Medical School (MHH)

He is known as one of the world's leading experts in non-coding RNA. Not only that, he is a cardiologist, a successful entrepreneur, a W3 professor and director of a Fraunhofer institute. Put simply, Prof. Thomas Thum's heart belongs to applied medical research — literally: He specializes in cardiac medicine.

Growing up in a family of doctors, he was fascinated by medicine from an early age. As a child, he often accompanied his father on house calls. His father's compassion when dealing with patients made a big impression on him, and he decided that in the future, he wanted to help people, too. His special interest in cardiac muscle cells first emerged during his medical studies at Hannover Medical School (MHH). In 2001, he wrote his doctoral thesis at the institute that preceded Fraunhofer ITEM, which won him the Hugo Geiger Prize for the best scientific thesis. This was followed by positions in Würzburg and London, where he pursued a clinical career as an internist and cardiologist. He then returned to MHH in Hannover, where he remains a W3 professor to this day.

It was in 2004 that Thomas Thum first encountered non-coding RNA molecules, specifically miRNA. At the time, the possible uses of these molecules were still a mystery to doctors. Thomas Thum, then a young researcher, wanted to solve the puzzle. He began to investigate the molecules' specific effects on cardiovascular diseases in particular, which have long been the most common cause of death in the western world. In 2008, he first published his results in the renowned Nature journal, which received widespread attention. In order to quickly transfer this basic research into clinical practice, he founded the company Cardior Pharmaceuticals, through which he was able to raise venture capital for his clinical research. His efforts met with success: In 2019, he and his team began the world's first clinical trial with miRNA in heart patients — a big moment for the researcher. In 2021, he was awarded the Paul Martini Prize for designing and conducting the initial trials for this new method of treating heart failure.

Almost 20 years after his career began at Fraunhofer, Thomas Thum returned to Fraunhofer ITEM, where he holds the position of institute director in tandem with Prof. Norbert Krug. He is now responsible for 400 Fraunhofer employees, as well as 60 staff at MHH and about 25 employees at his company. As institute director, he is expanding the spectrum of research at Fraunhofer ITEM, which previously specialized in lung research but now also covers the cardiovascular system. Here, he emphasizes knowledge transfer and translation. He wants to strengthen the connection between research at universities and at Fraunhofer, as well as bolster the Hannover metropolitan region as a business location. He is also interested in promoting young talent in translational medicine. As a father, he is especially proud when his daughter and two sons visit him at the institute and express an interest in medical research.

"My aim is to develop a new generation of RNA-based medicine for treating cardiovascular diseases and bring it to market maturity."

Dr.-Ing. Ulrike Beyer

Mechanical engineer | Diploma in industrial engineering | Head of the TaskForce Hydrogen@IWU at the Fraunhofer Institute for Machine Tools and Forming Technology IWU in Chemnitz | Head of the initiatives "National Action Plan for Fuel Cell Production" and "Reference Factory for High-Rate Electrolyzer Production"

Hydrogen comes first. This is true for the periodic table, and also for Dr. Ulrike Beyer. As her LinkedIn profile attests, she's keen to step on the gas when it comes to using hydrogen for the energy transition and climate neutrality — but particularly for industry, which aims to bring value creation back into national areas of expertise through the production of hydrogen systems. Developing new technologies is essential to achieving these goals. As the doctor of mechanical and industrial engineering always says when promoting the opportunities that hydrogen affords both industry and society: "Hydrogen offers a unique chance to combine the goals of protecting the climate and securing Germany's position as a production location."

As head of the TaskForce Hydrogen@IWU at the Fraunhofer Institute for Machine Tools and Forming Technology IWU, Beyer is researching how hydrogen can replace coal and other fossil fuels as energy carriers. This requires new solutions for the industrial mass production of hydrogen systems. The most important of these is electrolyzers for hydrogen production, which led her to launch the Reference Factory for Electrolyzer Mass Production. This Fraunhofer consortium has five institutes under Beyer's leadership and supports H_2Giga, a lighthouse project by the federal government that particularly focuses on technological evolutions for reducing production costs. The aim is to make green hydrogen a cost-neutral alternative to fossil fuels.

The production technologist believes that we also need to step on the gas when it comes to fuel cells. However, if they are to be industrially produced in batches, then certain solutions must be developed. That is why Dr. Beyer designed and coordinated the "National Action Plan for Fuel Cell Production" at the Fraunhofer-Gesellschaft, which combines research expertise and infrastructure from 18 institutes. The aim is to scale up fuel cell production and make it more efficient. In particular, significant acceleration is needed in the structured roll-out of innovative developments, as well as their implementation in industry. After all, in the medium- to long-term, this market will be worth billions. Not only that, it holds the potential for new value creation and to create a huge number of jobs that will continue to be viable in the future — the hydrogen expert estimates 150,000 such jobs in Germany alone.

Hydrogen is also the number one element in Dr. Beyer's personal life. With her various expeditions to potential and established "hydrogen regions" in Europe (by bike, of course, to keep things climate-neutral), she is awakening her family's curiosity and enthusiasm for the element of the future, often known as H.

"Hydrogen has the potential to be the coal of the future. I'm not only promoting hydrogen research for reasons relating to climate change policy, but also as an important avenue of value creation with future viability. This will allow Germany to ensure a lasting position as a location for research and production."

Dipl.-Inf. Steffen Meyer

Information scientist | Group manager for Location Awareness & Process Analytics at the Fraunhofer Institute for Integrated Circuits IIS in Nuremberg

Geolocation is Steffen Meyer's area of expertise. The information scientist has been researching the field since writing his thesis at the Fraunhofer Institute for Integrated Circuits IIS in 2001. He is fascinated by localization technology: "Just moving myself or an object can trigger an action in a system," he explains. The new 5G and 6G networks, which Fraunhofer IIS is currently working to standardize, will break new ground for apps that have far more precise positioning systems than are possible today. There are many ways to optimize industrial processes — for example by looking at human-machine interactions. For end users, mobile assistance systems can be practical aid, such as in supporting elderly people to remain living in their own homes for longer.

Geolocation can be used in several applications, and this means that Meyer comes into contact with vastly different groups of customers. These include Deutsche Bahn, as the geolocation team at Fraunhofer IIS helped create a door-to-door solution for DB Navigator. The National Maritime Museum in Greenwich is also among the museums that have drawn on Meyer's expertise. There, his team helped enable visitors to overlay ships on historical nautical maps and "navigate" them along their old routes.

Then, in 2020, the pandemic began, and with it came the need for contact tracing apps. Fraunhofer collaborated closely on the technological aspects of the German contact tracing app, which was published by the Robert Koch Institute (RKI) and developed by SAP and Deutsche Telekom. In order to assess the risk of individual encounters, a form of geolocation was sought that could both assess the distance between two people and measure the duration of their encounter. This was achieved using the exposure notification interface, which records the time spent within specified distances. The team at Fraunhofer IIS contributed its expertise in signal exchange between devices, following the Bluetooth Low Energy (BLE) standard. "From March to the end of April 2020, including over Easter, the work was very intensive. And at the same time, our third child, Pauline, was born," recalls Meyer. During this development phase, their motto was, "Whatever it takes!"

On June 12, 2020, the Corona-Warn-App was launched in Germany, three months to the day after the WHO declared COVID-19 a pandemic. Two days prior, in a call between representatives of the chancellery, of the German Federal Ministry of Health and of industrial groups, it was decided that the app would be made publicly available. Not only was Steffen Meyer on the call, he actually gave a presentation on the app. He remains deeply impressed by how successfully the experts from various disciplines were able to work together in these exceptional circumstances, working without contractual restrictions and across institutional borders.

Today, the Corona-Warn-App is the most successful contact-tracing app worldwide, with 40 million downloads by the end of 2021. From the time of its launch to the end of 2021, over a million alerts had been sent out by people who had tested positive. Geolocation expert Meyer has a good overview of the situation. He knows the development consortia in Denmark, the United Kingdom, Switzerland, Italy and the USA, and even advises some of them.

"When guided by the motto 'whatever it takes,' industry and research can launch a product like the Corona-Warn-App on the market within seven weeks."

Dipl.-Des. Sabrina Schreiner

Industrial designer | Group leader for User-centered Technology at the Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT in Oberhausen

She brings design professionals together with groups of senior citizens. She shapes dialogue about new biogas plants and gives citizens the opportunity to discuss the topic of sustainable bioeconomy with researchers. Sabrina Schreiner, who has a degree in industrial design, works at the intersection between science and society with the aim of more closely involving the future users of applications in their development. As group leader for User-centered Technology at Fraunhofer UMSICHT in Oberhausen, she designs interactive formats and methods for involving the respective target groups in product development and research projects at an early stage. Their expertise is then taken into account as researchers search for solutions.

One example of Schreiner's work is the +SeniorDesignLab at Fraunhofer UMSICHT. Her team was responsible for coordinating the project, which saw senior citizens collaborate with researchers to develop products for the demographic transition and to help them continue living independently into old age. Schreiner sums up one of their findings: "The ideas from the teams made up of a mix of amateurs and designers were rated by our jury as more creative and user-centric." "We were also able to provide scientific proof of this effect." This discovery — that it pays off to bring in 'experts' from the real world — can now be put to use in other projects."

The results and experiences that came out of the +SeniorDesignLab have been summarized in a publication called "Developing a Two-Hour Design Thinking Workshop to Examine the Potentials of Age-Divers Co-creation: Why Product Design Teams Should Invite Users Aged 50+, when Designing for the Demographic Change."

Schreiner believes that science will need to pursue a participatory approach when developing sustainable and future-oriented technologies and products, including in the fields of mobility, bioeconomy and circular economy. At the Fraunhofer Cluster of Excellence Circular Plastics Economy CCPE, Schreiner is currently working on designing circular child seats, as well as new product-service systems. Her interdisciplinary working group reflects the diversity of their tasks: The represented fields include not only design, but biology, psychology and mechanical engineering. This way, the citizen participation projects benefit from a variety of research methods. "It's important to speak the language of another person's discipline," says Schreiner.

She was a student when she first came to Fraunhofer UMSICHT, where she worked on her thesis. Shortly afterward, she became a research fellow. In the beginning, she was still dealing with classic design tasks. Today, she coordinates exchange between different interest groups. "In purely practical terms, how can technology and innovation processes be aligned with social needs?" she asks. "That is design on a more abstract level."

A mother of two, she leads her research group part-time — a working model available at the Fraunhofer-Gesellschaft. This enables her to continue working with the participation team at Fraunhofer UMSICHT toward their common goal: "With our approach, we have the opportunity to build a sustainable future for the next generation."

"Everyone involved benefits when society is incorporated more into research and development projects. This provides fertile soil for creating a sustainable future."


partner

Prof. Dr. Rüdiger Quay

Diploma in physics | Diploma in economics | Acting managing director at the Fraunhofer Institute for Applied Solid State Physics IAF in Freiburg | Holds the Fritz Hüttinger Professorship for Energy-Efficient Radio-Frequency Electronics at the University of Freiburg

Scientifically speaking, says Rüdiger Quay, progress is not a linear phenomenon. During his time in research, he has worked on developments that some people thought had no apparent use. At the time, they'd say "but no one needs that!" — then some years later, they wonder why it's not yet industrially available. This is the case now with the changed technical requirements for semiconductors used in 5G and 6G. Exponentially higher data rates mean higher frequencies, which require more energy-efficient transmitters and receivers. At the moment, Prof. Quay is focusing on improving these. He envisions an internet that saves more resources than it uses. Ten years ago, the use of gallium nitride semiconductors in mobile communications transmissions was entirely optional. Now, the material is used in many 4G base stations. This, says Prof. Quay, is thanks in a large part to Fraunhofer IAF: They had the expertise to produce the semiconductor material through a technique known by experts as materials growth, as well as to ensure a level of technological reliability that allowed the base station to operate for more than 20 years. "This gives me a certain feeling of calm — including for our current pre-competitive research. On top of that is the hope that current circumstances might change. I think both are important prerequisites for researchers."

It was clear to him from an early stage that he wanted to come up with developments that will actually drive progress — in other words, that are applied in more than just a prototype. Perhaps this stems from his days as a student at the RWTH Aachen University in the 90s. At that time, he says, many students of natural sciences received a clear warning that you would never hear today: concentrate on application and learn a second skill. But because of this advice, Prof. Quay now not only holds a professorship in energy-efficient, high-frequency electronics, but is also a graduate economist. Personally, he has found it helpful to go beyond his role as a natural scientist in order to understand how other people understand correlations. "It taught me to change my perspective, which was extremely important." His sporting activities may have had an influence, too: To this day, Prof. Quay runs half marathons.

To ensure that progress from research is introduced to society at a quicker pace, the physicist and economist would like the industrial and political sphere to have the courage to wait a few years for promising, ongoing developments. Prof. Quay also hopes that new paths could be forged if people were better informed — this could be achieved, for example, if ethical and charitable interest groups met with representatives of science to agree on the possible approaches that could be adopted as regards consumption in the context of electronic devices. The electricity consumption of current telecommunications networks is expected to grow from 1 to 5 percent as early as 2025. In Prof. Quay's estimation, this represents a critical increase for Germany — one that cannot be slowed down by halting efforts to keep pace with digitalization. Efficient network components will certainly be required, and Prof. Quay will demonstrate how these can be created. In the end, only he will know how long he spent on the research.

"When you turn on your phone, you're in constant communication with a base station. That base station's amplifier uses energy-efficient technology that we helped develop."

Semiconductor wafers with GaN transistors for 5G and 6G base stations.
Photo: Fraunhofer/L. Parsyak

Companies established with Fraunhofer

Fraunhofer institutes are prized by industry and government alike for their ability to draw existing companies into their orbit, as well as for providing the foundation on which new companies are formed. Every year, a multitude of Fraunhofer employees use the expertise they have acquired at Fraunhofer to start up their own businesses. The following pages present some recent examples.

Customcells Holding GmbH

CUSTOMCELLS®, a Fraunhofer spin-off, forms a joint venture with Porsche

It's technology transfer at its finest: In 2012, CUSTOMCELLS® became a spin-off of the Fraunhofer Institute for Silicon Technology ISIT in Itzehoe. From the beginning, their business model has been based on using lithium-ion batteries as a core technology for storage solutions. CUSTOMCELLS® has become a leading company for the development and mass production of application-specific battery cells.

These are used in areas such as the automotive industry. So it's no surprise that in 2019, CUSTOMCELLS® began collaborating with Porsche on an initiative by the Stuttgart-based management consultancy firm P3 Group. In 2021, the partners decided to invest tens of millions in the CUSTOMCELLS® technology for manufacturing high-performance batteries. Thus Cellforce Group GmbH was founded. With this joint venture, they aim to position themselves at the forefront of the global competition for the most powerful battery cell — and secure a sustainable future for the sports car.

The new high-performance cells, which have a more compact design, will allow for a significant increase in energy density compared to current batteries that are connected in series. On top of that, the application-specific cell development process enables particularly low internal resistance. This low internal resistance is required to improve recuperation, as well as to allow fast, more powerful charging. One of the development partners for this next generation of lithium-ion battery materials is BASF. This chemical company is working on developments for Cellforce such as high-energy cathode materials and binders on the anode side. In the future, these will be manufactured with one of the lowest carbon footprints in the industry. Numerous partners are contributing to the development of the new Cellforce high-performance battery cells.

Cellforce's pilot production facility near Reutlingen is expected to achieve a capacity of at least 100 megawatt hours per year. This corresponds to enough high-performance battery cells for 1,000 vehicles.

www.customcells.org

CUSTOMCELLS®
Ahead in cell innovation

Bluu GmbH

Cultivated fish, fresh from the bioreactor

Bluu GmbH ("Bluu Seafood") has a goal: Keep sea fish on our menus, without harming the environment. Bluu GmbH is the first company in Europe to specialize in producing so-called cell-based or cultivated seafood that is made from real fish cells and cultivated in a bioreactor. Unlike fish that are caught in the wild or farmed in aquacultures cultivated seafood does not come at the expense of animal welfare. Over 90 percent of our oceans are either overfished or fished to their maximum sustainable level. For hundreds of millions of people, this means their basic food supply is at risk.

Bluu GmbH was launched in May 2020 as a spin-off of the former Fraunhofer Research Institution for Marine Biotechnology and Cell Technology EMB. Just ten months later, it was able to secure €7.1 million in private investment. As a first step, Dr. Sebastian Rakers and Simon Fabich, the founders of Bluu, want to launch their products in restaurants in first markets by the end of 2023. Online retail and supermarkets will be targeted afterwards.

When producing cultivated seafood, there are multiple ways to grow cells: Bluu Seafood has successfully managed to grow cells in suspension. Another method they explore is to construct porous scaffold structures in such a way that the cells receive a sufficient supply of oxygen and nutrients. Once this is ensured, the cells growing on the scaffold structure can form and develop as they would in natural fish tissue. A key ingredient is the suitable growth medium the cells are grown in. Bluu Seafood has successfully been able to fully replace fetal bovine serum.

There are a number of advantages to producing seafood from cells: Slaughtering fish becomes unnecessary, as does aquaculture — a process similar to factory farming that causes pollution and eutrophication in water bodies. Other advantages of Bluu's cultivated fish products are its high nutritional value and its availability, which results in short supply chains. On top of that, the use of genetic engineering, antibiotics and environmental toxins such as heavy metals or micro plastics will also become a thing of the past.

www.bluu.bio

Sensry GmbH

Innovative semiconductor technologies for SMEs

A new start-up, established by Fraunhofer, GlobalFoundries and Next Big Thing, is working on electronic solutions based on cutting-edge sensor and communication systems research. Their objective is to give small and medium-sized enterprises (SMEs), in particular, the ability to participate in the growing field of the Internet of Things.

Sensry GmbH gives its customers access to highly integrated, trustworthy and cost-effective sensor systems. Sensry uses a modular design that offers maximum flexibility for prototypes and small-batch production. This means each customer receives a tailor-made sensor node with flexible customer-specific equipment for sensors and communication solutions. The platform combines state-of-the-art, energy-efficient assembly and packaging technologies (FD-SOI on 22FDX technology) with the latest semiconductor design methods and an advanced processor architecture (RISC-V). In addition to guaranteeing high levels of data security through its security components, the platform allows a wide variety of sensors to be integrated for fog, edge and cloud computing.

Sensry originated from the Universal Sensors Platform — USeP project at the end of 2018. The project was funded by the state of Saxony and the European Union as part of the European Regional Development Fund (ERDF). The aim of the project was to allow sensor and communication systems providers, particularly smaller companies, to access the next generation of electronics. As drivers of innovation, SMEs are largely responsible for achieving technology transfer on a wide scale.

The Engineering of Adaptive Systems EAS institute branch at the Fraunhofer Institute for Integrated Circuits IIS and the All Silicon System Integration ASSID center of the Fraunhofer Institute for Reliability and Microintegration IZM, along with the Fraunhofer Institutes for Photonic Microsystems IPMS and for Electronic Nano Systems ENAS, contributed to laying the technological foundation for Sensry.

https://sensry.net

E-VITA GmbH

Disinfecting seeds with electrons

Since 2021, the joint venture E-VITA GmbH has been dedicated to the chemical-free, sustainable treatment of seeds and animal feed with the aim of ridding them of pathogenic fungi, bacteria and viruses.

E-VITA harnesses the germicidal effects of accelerated electrons in its environmentally friendly, entirely physical process for disinfecting seeds. If the high-energy electrons encounter harmful organisms within their effective range, they kill them efficiently. The electrons only penetrate the husk to a depth at which it is demonstrably impossible for them to affect the embryo or endosperm inside the seed. The grain is not only disinfected, but also treated with biological stimulants to bring about a sustainable increase in yields and improve resilience. Initial developments for the safe, chemical-free treatment of seeds began back in the 1980s at the Manfred von Ardenne Research Institute. The Fraunhofer Institute for Organic Electronics, Electron Beam and Plasma Technology FEP brought the method to industrial maturity through a series of development projects across many years. Since 2014, the technology has been used extensively by the agricultural trading group Ceravis AG, which is mainly active in northern Germany. Since 2019, it has also been used by BayWa AG in Saxony. Its production volume now amounts to over 20,000 tons per year in Germany. Since 2021, Fraunhofer FEP and Ceravis AG have been collaborating through the joint venture E-VITA.

In order to ensure the process is also an attractive option for smaller quantities, it was necessary to develop more a compact systems technology. The key element of this is a ring-shaped electron beam developed by Fraunhofer FEP. E-VITA GmbH mainly (though not exclusively) offers systems that use this new, compact technology. These systems work efficiently even with low annual throughputs, making them a worthwhile investment for agricultural operations of various sizes.

www.e-vita.de

E-VITA

Batalyse GmbH

Battery analysis with Batalyse

Optimized materials and components determine the service life and performance of battery and fuel cell systems. The spin-off Batalyse GmbH offers extensive visualization options for evaluating customers' material development, cells and stacks and comparing them to their competition. Protecting sensitive data is always the top priority. That's why the data stays with the customer — Batalyse only provides the software solution for the evaluation.

Batalyse GmbH allows test analysis and production data to be automatically collected, documented, logically connected, categorized, standardized and evaluated. This is useful for material developers and battery cell manufacturers, as well as for development or quality management departments at companies in the electrochemical energy storage and fuel cells field.

The process is based on three software solutions: Data Analysis evaluates the battery and fuel cell test data. Collect collects, categorizes and standardizes test, analysis and production data, storing it on a central server with its own authorization system. Mind is a laboratory information and management system for linking the obtained data with information on the materials, tools, systems and processes used. This combination of modules results in an automated evaluation process, whereby data and information can be prepared to be used with artificial intelligence.

The founders' own experience provided them with the impetus to become an independent spin-off: As researchers at the Fraunhofer Institute for Chemical Technology ICT, Dr. Markus Hagen and Eran Nave found that an immense amount of time in battery research was spent on data evaluation and documentation. They spent three years preparing the spin-off, with a great deal of support from Fraunhofer Venture, and were finally ready to launch in May 2021.

https://batalyse.com

BATALYSE

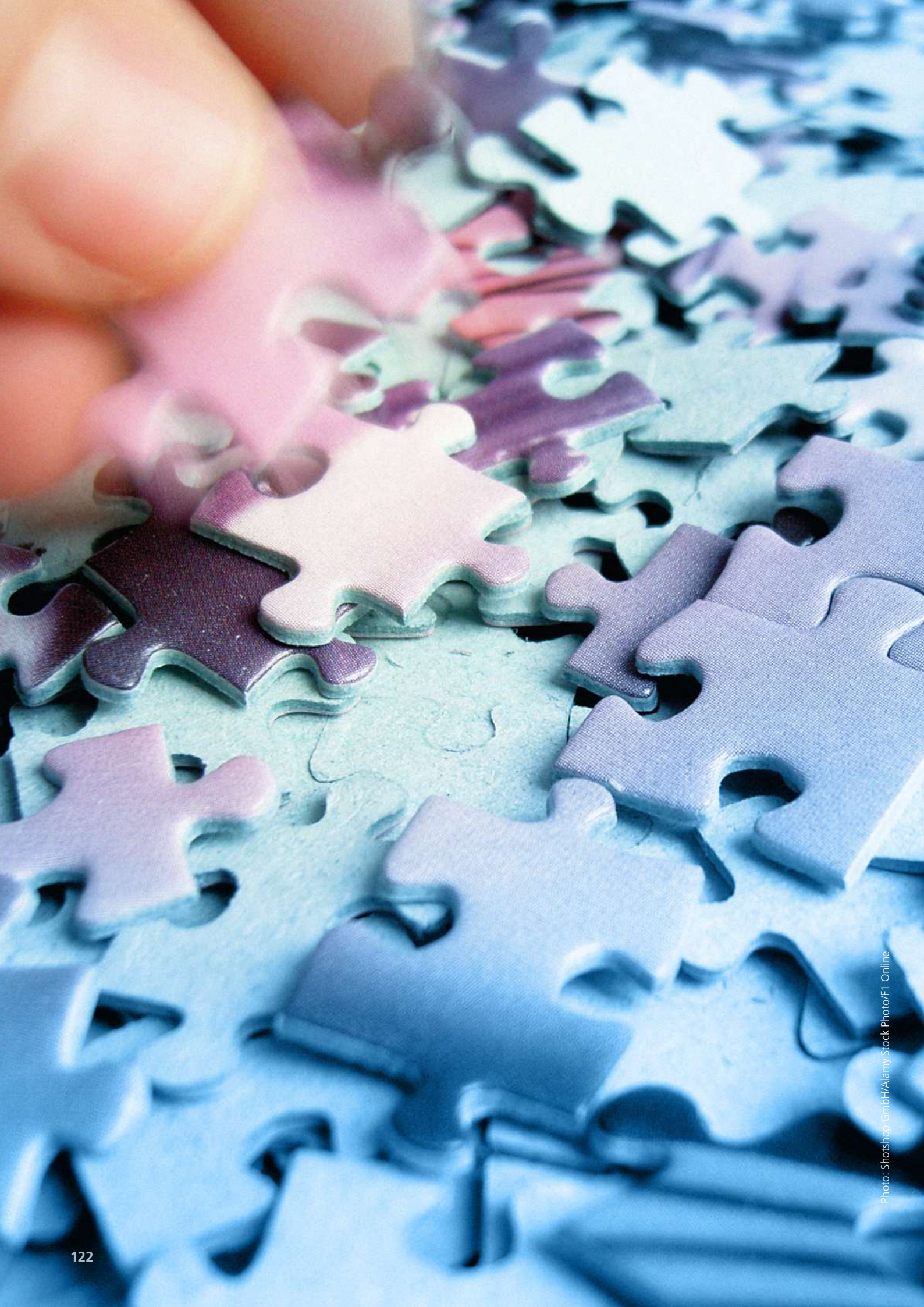


Photo: Shotshop GmbH/Alamy Stock Photo/F1 Online

Puzzles help to build concentration and endurance. Just as applications will have to fit the chips in tomorrow's high-performance computers, the pieces of the puzzle will eventually come together. The STX stencil/ tensor accelerator has been designed as a chip component that can be used to generate complex simulations in a way that is as quick and energy-efficient as possible (pp. 91/92).

Finance

Balance sheet at December 31, 2021

Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V., Munich

ASSETS		2021 in €	2021 in €	2021 in €	2020 in € (1000)
A. Noncurrent assets					
I. Intangible assets					
1. Concessions, intellectual property rights and similar rights and assets		12,780,079.94			11,370
2. Advance payments		33,252,200.15			34,999
			46,032,280.09		46,369
II. Property, plant and equipment					
1. Land, land rights and buildings, including buildings on third-party land		1,461,940,820.57			1,296,791
2. Technical plant and machinery		642,086,036.60			570,624
3. Other plant, operating and business equipment		49,377,596.83			47,846
4. Advance payments and assets under construction		427,074,683.40			493,152
			2,580,479,137.40		2,408,413
III. Financial assets					
1. Shares in affiliated companies		92,782.82			93
2. Shareholdings		10,326,794.50			9,010
3. Securities held as noncurrent assets		8,296,616.21			8,522
4. Other loans		265,000.00			128
			18,981,193.53		17,753
				2,645,492,611.02	2,472,535
B. Current assets					
I. Inventories					
1. Work in progress —		527,029,022.13			494,665
advance payments received		–425,125,091.54			–408,822
			101,903,930.59		85,843
II. Accounts receivable and other current assets					
1. Trade receivables		204,486,086.66			201,246
2. Receivables from the federal and state governments					
a) relating to base funding	39,051,590.36				104,249
b) relating to project billing, including contract research	251,996,231.84				226,996
c) relating to pension and compensated leave provisions	90,131,800.00				85,405
		381,179,622.20			416,650
3. Accounts receivable from affiliated companies		7,759,852.39			10,586
4. Other current assets		110,539,165.89			128,419
			703,964,727.14		756,901
III. Other securities			439,849,778.06		440,611
IV. Cash and cash equivalents			231,980,334.25		100,211
				1,477,698,770.04	1,383,566
C. Prepaid expenses and deferred charges				63,084,911.54	87,124
				4,186,276,292.60	**3,943,225**
Trust assets				8,574,603.12	23,018

Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V., Munich

EQUITY AND LIABILITIES	2021 in €	2021 in €	2021 in €	2020 in € (1000)
A. Equity				
I. Non-profit organization capital				
Carried forward	15,387,267.43			15,340
Annual result	65,795.74			47
		15,453,063.17		15,387
II. Reserves for statutory purposes				
Carried forward	18,825.00			16
Transfers	5,000.00			–
Allocations	1,400.00			3
		15,225.00		19
			15,468,288.17	15,406
B. Extraordinary items				
1. License-fee revenue reserve for statutory purposes		415,508,285.76		415,508
2. Grants relating to noncurrent assets		2,633,935,494.63		2,460,606
3. Grants used to finance current assets		295,492,150.84		324,711
4. Present value of installments from patent deal		47,410,084.22		53,577
5. For financing restructuring measures		24,611,000.00		25,000
			3,416,957,015.45	3,279,402
C. Provisions				
1. Provisions for pensions and similar obligations		9,031,800.00		8,805
2. Other provisions		200,064,869.54		190,202
			209,096,669.54	199,007
D. Current liabilities				
1. Trade payables		93,898,393.57		100,404
2. Unappropriated grants from the federal and state governments				
a) relating to base funding	270,723,478.51			204,528
b) relating to project billing	150,602,251.84			108,062
		421,325,730.35		312,590
3. Accounts payable to affiliated companies		–		186
4. Other current liabilities (of which relating to tax: €0 million; previous year: €9 million)		25,241,424.51		31,627
			540,465,548.43	444,807
E. Accrued expenses and deferred income			4,288,771.01	4,603
			4,186,276,292.60	**3,943,225**

Trust liabilities	8,574,603.12	23,018

Income statement for the financial year 2021

Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V., Munich

			2021 in €	2021 in €	2021 in €	2020 in € (1000)
1.	**Revenue from base funding**					
1.1	Federal government			860,393,848.93		1,013,632
1.2	State governments			167,310,401.47		162,298
					1,027,704,250.40	1,175,930
2.	**Revenue from own activities**					
2.1	Revenue from research and development activities					593,075
2.1.1	Federal government:	Project funding	608,119,080.10			17,979
		Contracts	15,472,180.07			215,691
2.1.2	State governments:	Project funding	263,533,465.67			2,267
		Contracts	3,271,042.31			662,416
2.1.3	Industry, business and trade associations		729,837,671.82			
2.1.4	Research funding organizations and other sources		147,063,586.92			132,128
				1,767,297,026.89		1,623,556
2.2	Other revenue			6,498,060.70		8,208
Total revenue					1,773,795,087.59	1,631,764
2.3	Increase in work in progress			32,364,185.05		38,799
2.4	Other internally constructed and capitalized assets			7,507,804.13		7,061
2.5	Other operating income			41,955,051.13		34,745
2.6	Income from shareholdings			2,108,372.31		2,107
2.7	Other interest and similar income			1,030,011.39		1,526
					84,965,424.01	84,238
Total of base funding and revenue from own activities					2,886,464,762.00	2,891,932
3.	**Change in extraordinary items**					
3.1	License-fee revenue reserve for statutory purposes					
3.1.1	Allocations			–14,753,755.84		–13,091
3.1.2	Reversals			14,753,755.84		13,091
3.2	Grants relating to noncurrent assets					
3.2.1	Allocations (capital expenditure)			–469,931,632.22		–475,310
3.2.2	Reversals (depreciation and amortization)			295,203,372.82		310,052
3.3	Grants released through financing of current assets			29,218,488.50		–59,497
3.4	For financing restructuring measures					
3.4.1	Allocations			–63,000.00		–25,000
3.4.2	Reversals			452,000.00		–
					–145,120,770.90	–249,755
4.	**Total of base funding and revenue from own activities available to cover expenditure**				**2,741,343,991.10**	**2,642,177**

Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V., Munich

		2021 in €	2021 in €	2021 in €	2020 in € (1000)
Carryover				2,741,343,991.10	2,642,177
5.	**Cost of materials**				
5.1	Expenditure on raw, auxiliary and operating materials	214,246,229.25			202,906
5.2	Expenditure on purchased research and development services	235,611,799.70			223,938
			449,858,028.95		426,844
6.	**Personnel expenses**				
6.1	Salaries	1,325,823,722.01			1,268,901
6.2	Social contributions and expenses for pension schemes and other benefits of which for pension schemes: €67,927,204.95 (Previous year: €63,802 thousand)	301,287,596.86			282,525
			1,627,111,318.87		1,551,426
7.	**Amortization of intangible assets and depreciation of noncurrent assets**		294,485,370.34		309,117
8.	**Other operating expenses**		368,323,928.07		347,470
9.	**Amortization of financial assets and securities classified as current assets**		863,908.33		6,831
10.	**Interest and similar expenses**		639,240.80		439
Total expenditure				2,741,281,795.36	2,642,127
11.	**Net income for the year**			62,195.74	50
12.	**Transfers from reserves**			5,000.00	–
13.	**Allocations to reserves**			–1,400.00	-3
14.	**Annual result**			65,795.74	47
15.	**Allocation to non-profit organization capital**			–65,795.74	–47
				–	**–**

Reconciliation between income statement, performance statement and revenue and expense statement

Income/receipts	Performance statement in €	Non-profit organization capital in €	Reconciling items in €	Income statement in €
Income/receipts				
from base funding	1,022,977,850.40		4,726,400.00	1,027,704,250.40
from research and development activities	1,802,355,381.64		−35,058,354.75	1,767,297,026.89
from other sources	1,353.89		6,496,706.81	6,498,060.70
Increase in work in progress			32,364,185.05	32,364,185.05
Other internally constructed and capitalized assets	7,507,804.13			7,507,804.13
Other income	48,500,280.38	395,691.56	−3,802,537.11	45,093,434.83
Total income/receipts	**2,881,342,670.44**			
Change in extraordinary items				
Grants relating to noncurrent assets				
Allocations to extraordinary items (capital expenditure)			−469,931,632.22	−469,931,632.22
Reversals of extraordinary items (depreciation and amortization)		19,847.81	295,183,525.01	295,203,372.82
Grants released through financing of current assets	29,218,488.50			29,218,488.50
For financing restructuring measures			389,000.00	389,000.00
Change in grants receivable relating to pension and compensated leave provisions	4,726,400.00		−4,726,400.00	
Total business volume	**2,915,287,558.94**			
		415,539.37	−174,359,107.21	2,741,343,991.10

Expenditure/disbursements	Performance statement in €	Non-profit organization capital in €	Reconciling items in €	Income statement in €
Expenditure/disbursements				
Cost of materials	405,765,201.38	21,574.95	44,071,252.62	449,858,028.95
Personnel expenses	1,641,898,187.94	5,640.00	–14,792,509.07	1,627,111,318.87
Amortization of intangible assets and depreciation of noncurrent assets		165,753.66	294,319,616.68	294,485,370.34
Other operating expenses	397,895,759.59	160,375.02	–28,229,057.41	369,827,077.20
Expenditure as per the income statement				**2,741,281,795.36**
Change in the extraordinary item				
For financing restructuring measures	–389,000.00		389,000.00	
Capital expenditure (current and major infrastructure capital expenditure)	470,117,410.03		–470,117,410.03	
Net income for the year		62,195.74		62,195.74
Total business volume	**2,915,287,558.94**			
		415,539.37	–174,359,107.21	2,741,343,991.10

Performance statement for individual Fraunhofer entities

Fraunhofer Institute/Research Institution for	Location	Expenditure		Income	
		Operating budget	Capital expenditure	Project revenue	Base funding [1]
Fraunhofer Group for Energy Technologies and Climate Protection (as of January 1, 2021)		**2021 in € (1000)**	**2021 in € (1000)**	**2021 in € (1000)**	**2021 in € (1000)**
Energy Economics and Energy System Technology IEE	Kassel	29,668.5	2,167.8	25,106.2	6,730.1
Energy Infrastructures and Geothermal Systems IEG	Bochum	10,297.3	1,394.7	8,347.1	3,344.9
Solar Energy Systems ISE	Freiburg	104,394.2	12,269.3	106,815.7	9,847.9
Wind Energy Systems IWES	Bremerhaven	37,631.7	15,274.0	50,356.1	2,549.6
Total for the Fraunhofer Group for Energy Technologies and Climate Protection		**181,991.7**	**31,105.9**	**190,625.1**	**22,472.5**
Fraunhofer Group for Health (as of January 1, 2021)					
Biomedical Engineering IBMT	Sulzbach	17,278.1	1,465.8	11,723.8	7,020.1
Cell Therapy and Immunology IZI	Leipzig, Potsdam-Golm, Halle	44,487.6	6,308.4	35,957.7	14,838.3
Individualized and Cell-Based Medical Engineering IMTE	Lübeck	4,937.9	326.6	3,844.9	1,419.6
Medical Image Computing MEVIS	Bremen	11,448.1	947.0	9,350.5	3,044.6
Toxicology and Experimental Medicine ITEM	Hannover, Braunschweig, Regensburg	38,142.8	3,016.2	28,435.8	12,723.2
Translational Medicine and Pharmacology ITMP	Frankfurt, Berlin, Penzberg, Göttingen	12,767.9	860.9	6,487.2	7,141.5
Total for the Fraunhofer Group for Health		**129,062.4**	**12,924.8**	**95,800.0**	**46,187.2**

1 Figures rounded on the basis of actual values.

Fraunhofer Institute/Research Institution for	Location	Expenditure		Income	
		Operating budget 2021 in € (1000)	Capital expenditure 2021 in € (1000)	Project revenue 2021 in € (1000)	Base funding[1] 2021 in € (1000)
Fraunhofer ICT Group					
Algorithms and Scientific Computing SCAI	Sankt Augustin	15,604.4	384.6	11,482.5	4,506.6
Applied and Integrated Security AISEC	Garching	12,989.6	1,152.7	11,237.1	2,905.1
Applied Information Technology FIT	Sankt Augustin, Augsburg	22,005.9	2,768.5	17,971.9	6,802.5
Cognitive Systems IKS	Munich	8219.6	357.1	7,826.3	750.4
Communication, Information Processing and Ergonomics FKIE	Wachtberg	11,392.8	154.0	7,984.7	3,562.1
Computer Graphics Research IGD	Darmstadt, Rostock	16,287.0	1,239.0	8,639.9	8,886.1
Digital Media Technology IDMT	Ilmenau, Oldenburg	11,950.2	432.6	8,086.7	4,296.1
Experimental Software Engineering IESE	Kaiserslautern	17,016.4	641.4	14,841.1	2,816.7
Industrial Mathematics ITWM	Kaiserslautern	33,958.2	2,118.5	26,696.8	9,380.0
Intelligent Analysis and Information Systems IAIS	Sankt Augustin	26,922.6	1,504.7	23,005.2	5,422.1
Open Communication Systems FOKUS	Berlin	33,239.1	1,231.2	26,315.8	8,154.5
Optronics, System Technologies and Image Exploitation IOSB	Karlsruhe, Ettlingen, Ilmenau, Lemgo	40,826.6	3,894.7	32,472.9	12,248.4
Secure Information Technology SIT	Darmstadt	8,574.7	224.7	7,470.6	1,328.7
Software and Systems Engineering ISST	Dortmund	8,157.7	262.4	8,631.7	–211.6
Transportation and Infrastructure Systems IVI	Dresden	14,952.2	2,766.1	13,764.4	3,953.9
Central office of the Fraunhofer ICT Group IUK-GS	Berlin	280.2	18.2	18.4	280.0
Total for the Fraunhofer ICT Group		**282,377.2**	**19,150.3**	**226,445.9**	**75,081.6**
Fraunhofer Group for Innovation Research					
Industrial Engineering IAO	Stuttgart	40,245.5	2,053.1	34,895.6	7,402.9
Information Center for Planning and Building IRB	Stuttgart	7,576.9	33.2	2,440.7	5,169.4
Systems and Innovation Research ISI	Karlsruhe	31,909.8	963.3	25,087.9	7,785.2
Technological Trend Analysis INT	Euskirchen	5,141.0	853.8	2,560.0	3,434.8
Fraunhofer Center for International Management and Knowledge Economy IMW	Leipzig	9,983.2	354.9	6,300.4	4,037.7
Total for the Fraunhofer Group for Innovation Research		**94,856.4**	**4,258.2**	**71,284.7**	**27,830.0**
Fraunhofer Group for Light & Surfaces					
Applied Optics and Precision Engineering IOF	Jena	40,435.5	19,416.9	45,862.4	13,990.0
Laser Technology ILT	Aachen	39,699.6	3,848.3	29,233.6	14,314.3
Material and Beam Technology IWS	Dresden	28,148.5	3,971.9	21,465.9	10,654.6
Organic Electronics, Electron Beam and Plasma Technology FEP	Dresden	27,572.2	1,297.8	21,224.5	7,645.5
Physical Measurement Techniques IPM	Freiburg	21,076.0	1,929.7	13,725.7	9,279.9
Total for the Fraunhofer Group for Light & Surfaces		**156,931.7**	**30,464.6**	**131,512.0**	**55,884.3**

1 Figures rounded on the basis of actual values.

Fraunhofer Institute/Research Institution for	Location	Expenditure		Income	
		Operating budget 2021 in € (1000)	Capital expenditure 2021 in € (1000)	Project revenue 2021 in € (1000)	Base funding [1] 2021 in € (1000)
Fraunhofer Group for Microelectronics					
Applied Solid State Physics IAF	Freiburg	17,287.2	4,574.3	17,493.1	4,368.4
Electronic Nano Systems ENAS	Chemnitz	17,132.5	7,733.4	17,305.9	7,560.0
High Frequency Physics and Radar Techniques FHR	Wachtberg	20,598.1	1,010.5	16,460.4	5,148.2
Integrated Circuits IIS	Erlangen, Dresden	197,762.6	7,461.4	151,538.3	53,685.7
Integrated Systems and Device Technology IISB	Erlangen	29,157.9	1,938.7	21,624.5	9,472.1
Microelectronic Circuits and Systems IMS	Duisburg	27,318.5	150.9	16,211.1	11,258.3
Microsystems and Solid State Technologies EMFT	Munich	16,188.8	540.8	11,056.1	5,673.5
Photonic Microsystems IPMS	Dresden	49,289.4	2,578.3	34,837.4	17,030.3
Reliability and Microintegration IZM	Berlin, Dresden	38,485.0	4,255.6	30,725.4	12,015.3
Silicon Technology ISIT	Itzehoe	24,373.1	1,801.1	17,996.9	8,177.3
Telecommunications, Heinrich-Hertz-Institut, HHI	Berlin, Goslar	62,412.9	8,874.1	51,181.4	20,105.6
Central office of the Research Fab Microelectronics Germany (FMD)	Berlin	904.1	48.7	269.7	683.1
Total for the Fraunhofer Group for Microelectronics		**500,910.1**	**40,967.9**	**386,700.3**	**155,177.7**
Fraunhofer Group for Production					
Additive Manufacturing Technologies IAPT	Hamburg	8,977.4	1,718.5	5,631.8	5,064.1
Casting, Composite and Processing Technology IGCV	Augsburg	17,715.8	1,847.3	15,780.4	3,782.7
Factory Operation and Automation IFF	Magdeburg	19,127.4	745.1	13,415.5	6,457.0
Large Structures in Production Engineering IGP	Rostock	11,207.4	422.0	8,818.8	2,810.6
Machine Tools and Forming Technology IWU	Chemnitz	48,973.6	5,264.3	37,249.2	16,988.7
Manufacturing Engineering and Automation IPA	Stuttgart	68,853.6	4,625.8	57,333.1	16,146.4
Material Flow and Logistics IML	Dortmund, Hamburg	39,878.6	4,065.3	34,391.9	9,552.0
Mechatronic Systems Design IEM	Paderborn	13,823.0	1,503.6	11,787.4	3,539.2
Production Systems and Design Technology IPK	Berlin	18,679.2	1,840.5	12,680.7	7,839.0
Production Technology IPT	Aachen	29,568.9	1,928.1	22,942.8	8,554.2
Surface Engineering and Thin Films IST	Braunschweig	15,792.9	1,712.1	9,250.3	8,254.7
Total for the Fraunhofer Group for Production		**292,597.9**	**25,672.7**	**229,282.0**	**88,988.6**

1 Figures rounded on the basis of actual values.

Fraunhofer Institute/Research Institution for	Location	Expenditure		Income	
		Operating budget 2021 in € (1000)	Capital expenditure 2021 in € (1000)	Project revenue 2021 in € (1000)	Base funding[1] 2021 in € (1000)
Fraunhofer Group for Resource Technologies and Bioeconomy (as of January 1, 2021)					
Environmental, Safety and Energy Technology UMSICHT	Oberhausen, Sulzbach-Rosenberg	53,931.0	3,905.9	44,698.2	13,138.8
Interfacial Engineering and Biotechnology IGB	Stuttgart, Leuna, Straubing	26,962.1	1,507.1	19,552.3	8,916.9
Molecular Biology and Applied Ecology IME	Aachen, Schmallenberg, Gießen	32,102.5	2,005.1	22,250.4	11,857.2
Process Engineering and Packaging IVV	Freising, Dresden	29,028.8	2,527.0	21,435.3	10,120.5
Total for the Fraunhofer Group for Resource Technologies and Bioeconomy		**142,024.5**	**9,945.1**	**107,936.1**	**44,033.4**
Fraunhofer Group for Materials and Components					
Applied Polymer Research IAP	Potsdam-Golm, Hamburg	24,798.8	3,563.3	15,374.1	12,988.1
Building Physics IBP	Stuttgart, Holzkirchen	29,582.6	1,128.7	20,566.2	10,145.0
Ceramic Technologies and Systems IKTS	Dresden, Hermsdorf	64,990.1	18,005.9	58,557.9	24,438.1
Chemical Technology ICT, Polymer Engineering research branch	Pfinztal	25,784.6	1,327.4	16,951.3	10,160.8
High-Speed Dynamics, Ernst-Mach-Institut, EMI	Freiburg	10,998.6	504.5	8,680.2	2,823.0
Manufacturing Technology and Advanced Materials IFAM	Bremen, Dresden, Stade	54,656.0	6,794.7	45,778.1	15,672.6
Materials Recycling and Resource Strategies IWKS	Alzenau, Hanau	7,981.2	78.2	3,447.3	4,612.1
Mechanics of Materials IWM	Freiburg	25,446.0	2,200.9	16,840.4	10,806.5
Microengineering and Microsystems IMM	Mainz	13,102.7	595.5	7,250.7	6,447.5
Microstructure of Materials and Systems IMWS	Halle	25,137.8	3,738.9	20,001.5	8,875.2
Nondestructive Testing IZFP	Saarbrücken	14,168.7	988.1	7,517.5	7,639.4
Silicate Research ISC	Würzburg, Bayreuth	26,793.8	1,208.0	16,949.9	11,051.8
Structural Durability and System Reliability LBF	Darmstadt	27,293.0	1,909.1	18,014.0	11,188.1
Wood Research, Wilhelm-Klauditz-Institut, WKI	Braunschweig	15,037.6	1,240.9	12,476.4	3,802.1
Central office of the Fraunhofer Group for Materials and Components V-MAT	Darmstadt	453.1	0.7	62.6	391.2
Total for the Fraunhofer Group for Materials and Components		**366,224.6**	**43,284.8**	**268,468.0**	**141,041.4**

1 Figures rounded on the basis of actual values.

Fraunhofer Institute/Research Institution for	Location	Expenditure		Income	
		Operating budget 2021 in € (1000)	Capital expenditure 2021 in € (1000)	Project revenue 2021 in € (1000)	Base funding[1] 2021 in € (1000)
Institutes outside of Fraunhofer groups					
Fraunhofer headquarters	Munich	42,267.6	5,896.5	7,447.6	40,716.5
Institute Center Birlinghoven	Sankt Augustin	427.6	27.1	31.5	423.2
Institute Center Stuttgart	Stuttgart	603.9	39.9	20.9	622.9
General overhead costs		94,235.4	1,047.9	22,321.3	72,961.9
Fraunhofer Competence Network Quantum Computing	Ehningen	9,092.9	0.0	236.3	8,856.6
Total for institutes outside of Fraunhofer groups		**146,627.4**	**7,011.4**	**30,057.6**	**123,581.2**
Additional research funding[2]					
Defense and Security					
Applied Solid State Physics IAF	Freiburg	14,608.3	1,687.8	5,967.3	10,328.8
Chemical Technology ICT, Chemical Energy Carriers research branch	Pfinztal	15,378.6	1,492.1	5,349.0	11,521.7
Communication, Information Processing and Ergonomics FKIE	Wachtberg	28,310.8	872.5	15,203.2	13,980.1
High Frequency Physics and Radar Techniques FHR	Wachtberg	18,063.4	1,321.9	5,811.6	13,573.7
High-Speed Dynamics, Ernst-Mach-Institut, EMI	Freiburg	16,645.3	1,514.4	6,575.2	11,584.4
Optronics, System Technologies and Image Exploitation IOSB, Ettlingen research branch	Ettlingen	22,256.5	2,916.1	16,494.7	8,678.0
Technological Trend Analysis INT	Euskirchen	6,649.8	562.3	2,187.4	5,024.8
ATHENE					
ATHENE Computer Graphics Research IGD	Darmstadt	2,135.1	38.4	0.0	2,173.5
ATHENE Secure Information Technology SIT	Darmstadt	13,020.1	34.2	0.0	13,054.3
FFB					
Research Fab Battery Cells FFB	Münster	14,498.4	710.9	15,209.3	0.0
Total for additional research funding		**151,566.3**	**11,150.7**	**72,797.7**	**89,919.3**
Major infrastructure capital expenditure			234,181.0	47,455.4	186,725.5
Performance statement		**2,445,170.1**	**470,117.4**	**1,858,364.8**	**1,056,922.7**
Total business volume			**2,915,287.6**		

1 Figures rounded on the basis of actual values.

2 Excluding contract research for defense-related institutes in addition to ATHENE and FFB.

Excerpts from the notes to the financial statements 2021

1. General disclosures

Headquartered in Munich, the Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V. is a non-profit organization registered with the district court of Munich under the reference code VR 4461.

The annual financial statements for the year ending December 31, 2021 were prepared voluntarily and in accordance with the requirements of the German Commercial Code (Handelsgesetzbuch, HGB) as applicable to large corporate entities. The income statement was prepared in accordance with the total cost method.

The basis of the Fraunhofer-Gesellschaft's accounting method is the performance statement, from which the annual financial statements are derived.

The performance statement is adapted to the requirements of the public funding authorities in terms of format and reconciliation. It provides a breakdown of operating expenses and capital expenditure at three different levels: individual institutes, headquarters and the organization as a whole. The components of the operating budget are presented as income or expenses in accordance with generally accepted accounting principles. Capital expenditure on property, plant and equipment and on financial assets, on the other hand, is recognized at cost on acquisition of the assets. Therefore the operating budget does not include any depreciation/amortization expenses on these items.

In order to account for grants received from grant authorities, the performance statement for the organization as a whole is reconciled to the revenue and expense statement format used in single-entry bookkeeping by eliminating the effect of cash-neutral income and expense items. The income statement includes these changes in payables and receivables compared with the previous year as well as depreciation/amortization charges. In the balance sheet, these reconciliation items are included under the extraordinary items "Grants used to finance current assets" and "Grants relating to noncurrent assets." The figures in the performance statement are explained in the management report, where they are broken down into the three areas of contract research, additional research funding and major infrastructure capital expenditure.

Annual financial statements of the Fraunhofer-Gesellschaft	Income statement	Reconciliation to the **revenue and expense statement format** used in single-entry bookkeeping
Balance sheet Management report Notes to the financial statements	Reconciliation between income statement and performance statement	
	Performance statement	
	Budgeted operating expenses and capital expenditure at Fraunhofer-Gesellschaft "Total business volume" level	
	Separate financial statements of the institutes/headquarters	
	Operating budget Costs (excluding depreciation and amortization) Income	**Capital expenditure** Expenses Income

2. Recognition and measurement methods

Intangible assets and property, plant and equipment are measured at amortized cost, i.e. the cost of acquisition or production less depreciation/amortization calculated on a straight-line basis.

Intangible assets are amortized over a useful life of three years.

Institute buildings on Fraunhofer and third-party land are depreciated as follows:

- Added before April 1985: 2 percent
- Added between April 1, 1985 and December 31, 2000: 4 percent
- Added after January 1, 2001: 3 percent

A useful life of five years is applied to movable items of property, plant and equipment. However, a useful life of four years is assumed for communication, video and audio systems, and three years for IT hardware. Motor vehicles are depreciated over a useful life of four years.

Financial assets are measured at cost or at fair value, whichever is lower.

Since the noncurrent assets presented in the ordinary accounts are financed by government grants, the extraordinary item "Grants relating to noncurrent assets" is reduced by an amount corresponding to the depreciation/amortization of these assets. Therefore, these adjustments have no impact on the income statement.

Work in progress is measured at the cost of production or fair value, whichever is lower. Production costs include applicable personnel expenses, cost of materials, general administrative expenses and depreciation/amortization charges. Advance payments received (including VAT) are openly deducted under inventories.

Trade receivables and other assets are recognized at their nominal value. Irrecoverable debts are remeasured at the reporting date. The overall non-payment risk is limited by creating a provision for doubtful debts corresponding to 2 percent of the total amount of accounts receivable.

Securities classified as current assets are recognized at cost.

Cash and cash equivalents are recognized at their nominal value.

Payments made before the reporting date for which the associated benefits will be received in a future period are recognized as prepaid expenses in the balance sheet.

The Fraunhofer-Gesellschaft makes use of the instrument provided for in its financial statutes of recognizing a balance sheet reserve, which mainly comprises revenues from the licensing of audio-encoding technologies. The purpose of this reserve is to enable the organization to finance its own pre-competitive research in the medium term.

Funding used to finance noncurrent assets is allocated to the extraordinary item "Grants relating to noncurrent assets." A separate extraordinary item is used to account for grants used to finance current assets.

Provisions for pensions and similar obligations, for which the Fraunhofer-Gesellschaft has a reinsurance policy in place, are measured on the basis of the capitalized amount calculated by the insurance company at the reporting date. The capitalized amounts are calculated in accordance with the information provided by the insurance company and on the basis of the DAV 2004 R guideline tables. Adjustments to current pensions and to applicable income are not taken into account. If there is no reinsurance policy in place, or if the settlement cost of the pension obligations exceeds the capitalized amount calculated by the reinsurer, the amount recognized as a provision is calculated in accordance with an expert opinion based on actuarial evidence. The settlement amount of the pension obligation is calculated using the present value method (method for calculating current single premiums). A 10-year-average actuarial interest rate of 1.87 percent was used in the calculation in accordance with section 253 (2) HGB, along with the 2018 G Heubeck guideline tables.

Other provisions comprise amounts set aside to cover all identifiable risks and contingent liabilities. These provisions are measured in accordance with section 253 (1) HGB on the basis of a reasonable estimate of the most probable outcome. Other provisions for liabilities due in more than one year are discounted at the average market interest rate for loans of a similar maturity as calculated by the Deutsche Bundesbank in December 2021, pursuant to section 253 (2) HGB. Provisions for partial retirement are calculated on the basis of the policies already concluded and on an estimate of those to be concluded in the future.

Liabilities are measured at the settlement amount.

Payments received before the reporting date for benefits to be delivered in a future period are recognized in the balance sheet as deferred income.

Amounts recognized for transactions in foreign currencies are translated at the applicable hedging rates of the respective currencies. In the annual financial statements, foreign currency holdings are translated at the average spot exchange rate prevailing on the reporting date.

Items in transit are noted as trust assets and trust liabilities in a separate line at the foot of the Fraunhofer-Gesellschaft balance sheet.

Convenience translation of the German independent auditor's report

This is a convenience translation of the German independent auditor's report. Solely the original text in German language is authoritative. The independent auditor's report is based on the balance sheet at December 31, 2021, the income statement for the financial year 2021 and the full notes to the 2021 financial statements and the management report 2021.

INDEPENDENT AUDITOR'S REPORT
"To Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V., Munich

Audit opinion

We have audited the annual financial statements prepared by Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V., Munich, comprising the balance sheet as at December 31, 2021, the income statement for the financial year from January 1 to December 31, 2021, and the notes to the financial statements, including the presentation of the applied recognition and measurement methods. In addition, we have audited the management report of Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V., Munich, for the financial year from January 1, 2021 to December 31, 2021.

According to our opinion, as based on the results of the audit:

- The attached annual financial statements comply in all material respects with the provisions of the German Commercial Code (Handelsgesetzbuch, HGB) as applicable to large corporate entities, including the supplementary provisions of the organization's statute, and those of German generally accepted accounting principles (GAAP). Together, this information presents a true and fair view of the organization's net assets and financial position as at December 31, 2021, and of its operating results for the financial year commencing January 1, 2021 and ending December 31, 2021
- The attached management report provides a true and fair view of the organization's current operating situation. In all material respects, the management report is consistent with the annual financial statements, complies with German statutory requirements and provides an appropriate picture of the organization's future opportunities and risks

In accordance with section 322 (3) item 1 HGB, we declare that our audit of the annual financial statements and management report did not lead to any reservation/observations.

Basis for opinion

We conducted our audit of the annual financial statements and the management report in accordance with section 317 HGB and the German generally accepted standards for the audit of financial statements set by the Institute of Public Auditors in Germany. Our responsibilities under those standards are further described below under the heading "Auditors' responsibility for the audit of the annual financial statements and management report." We declare that we are independent auditors as defined by German commercial law and that we exercise our other duties in Germany in compliance with the relevant professional code of conduct, with no other connection to or interests in the Fraunhofer-Gesellschaft. It is our considered opinion that the audit evidence we have obtained is sufficient and appropriate to provide a basis for our opinion on the annual financial statements and the management report.

Responsibility of the legal representatives and the senate for the annual financial statements and management report

The legal representatives are responsible for preparing the annual financial statements in accordance with the provisions of the HGB as applicable to large corporate entities, and for ensuring that they comply with German generally accepted accounting principles (GAAP) and present a true and fair view of the organization's net assets, financial position and operating results.

Furthermore, the legal representatives are responsible for carrying out internal audits to the extent that these are considered necessary to comply with German GAAP, as a basis for preparing annual financial statements in such a way that they are free of material — intentional or unintentional — misstatements.

In preparing the annual financial statements, the legal representatives are also responsible for determining the organization's ability to continue operating as a going concern, which includes disclosing any relevant information concerning this

matter. Moreover, they are responsible for applying methods of accounting that allow assessment of the organization's continuing existence as a going concern, insofar as there are no material or legal circumstances that might contradict this assessment.

Another of the legal representatives' responsibilities is the preparation of a management report, which must be consistent with all material aspects of the annual financial statements, comply with German statutory requirements, provide a true reflection of the organization's financial position and provide a realistic assessment of the organization's future opportunities and risks. In addition, the legal representatives are responsible for such arrangements and measures (systems) as they have considered necessary to enable the preparation of a management report that is in accordance with the applicable German legal requirements, and provision of sufficient appropriate evidence for the statements made in the management report.

It is the senate's duty to present the annual financial statements to the general assembly for approval.

Auditor's responsibility for the audit of the annual financial statements and management report

Our objectives are to obtain reasonable assurance about whether the annual financial statements as a whole are free from material misstatement — be it due to fraud or error — and whether the management report as a whole provides an appropriate view of the organization's position and, in all material respects, is consistent with the annual financial statements and the knowledge obtained in the audit, complies with German legal requirements and appropriately presents the opportunities and risks of the organization's future development as well as to issue an auditor's report comprising our audit opinion on the annual financial statements and on the management report.

Reasonable assurance implies a high level of confidence but does not guarantee that an audit conducted in full compliance with the provisions of section 317 HGB and of the generally accepted accounting principles set by the Institute of Public Auditors in Germany will always detect a material misstatement when it exists. Misstatements may result from fraud or error and are deemed to be material if it can be reasonably expected that they might individually or severally influence business decisions taken by the reader on the basis of the annual financial statements or management report.

Throughout the audit process, we exercise professional judgment and maintain a neutral but critical attitude. We also:

- Identify and assess the risks associated with material — intentional or unintentional — misstatements in the annual financial statements and management report, plan and carry out our auditing activities in response to these risks and collect sufficient, appropriate documentary evidence to substantiate our audit opinion. The risk of not discovering material misstatements is higher in the case of fraud than in the case of error, because fraud may involve fraudulent collusion, deception, deliberate concealment of facts, or false representation or the invalidation of internal checks and controls

- Familiarize ourselves with the internal control system and other instruments and measures insofar as they affect the auditing of the annual financial statements and management report, in order to design audit procedures that are appropriate in the given circumstances. However, it is not the purpose of the audit to judge the effectiveness of the organization's control system

- Assess the appropriateness of the accounting principles applied by the legal representatives and the extent to which their estimated values and the associated information they specify are backed up by documented evidence

- Draw conclusions as to the appropriateness of the accounting principles applied by the legal representatives to determine the organization's ability to continue as a going concern and, on the basis of the audit evidence, to determine whether material uncertainties exist about events or conditions that may cast significant doubt on the organization's ability to continue as a going concern. If our investigations lead to the conclusion that material uncertainties do exist, it is our duty to comment on this fact in our independent auditor's report, providing references to the relevant disclosures in the annual financial statements and/or management report. Alternatively, if such comments are inappropriate, it is our duty to modify our audit opinion accordingly. Our conclusions are based on the audit evidence obtained up to the date of our auditor's report. However, future events or conditions may cause the organization to cease to continue as a going concern

- Verify that the overall presentation, structure and content of the annual financial statements, including the disclosures and the presentation of underlying business transactions and events, comply with German generally accepted accounting principles (GAAP) and present a true and fair view of the organization's net assets, financial position and operating results

- Confirm that the management report complies with the annual financial statements, meets legal requirements and conveys a true image of the organization's financial situation

- Perform audit procedures on the prospective information presented by the legal representatives in the management report. On the basis of sufficient appropriate audit evidence we evaluate, in particular, the significant assumptions used by management as a basis for the prospective information, and evaluate the proper derivation of the prospective information from these assumptions. We have not provided an independent audit opinion on the prospective information or the data on which it are based. There is a substantial unavoidable risk that future events will differ materially from the prospective information.

We communicate with those charged with governance regarding, among other matters, the planned scope and timing of the audit and significant audit findings, including any significant deficiencies in internal control that we identify during our audit.

Nuremberg, March 25, 2022

Rödl & Partner GmbH
Auditors, tax consultants

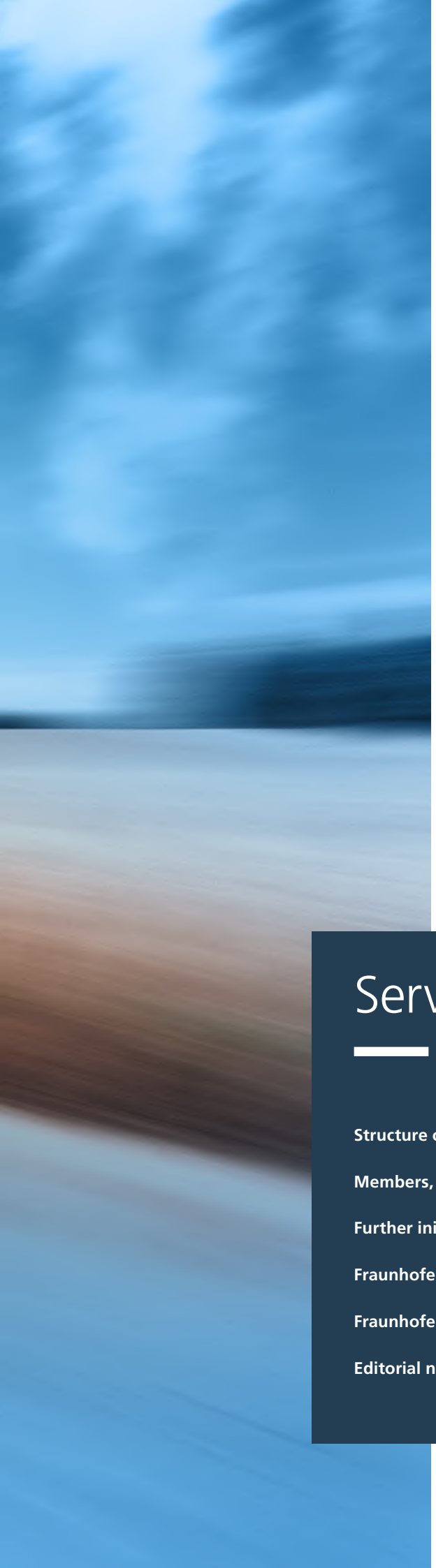
Signature: Vogel
Auditor

Signature: Hahn
Auditor

(End of convenience translation of the German independent auditor's report.)"

The auditor's report issued in German refers not to the foreign language version of the balance sheet and income statement, which are enclosed hereto as appendices, but to the original version of the complete financial statements and management report prepared in the German language.

Photo: Jan Kopřiva



Cycling benefits your body and mind.
Rubber from dandelions grown in Germany is currently being used to produce "green" bicycle tires, and will also be used in car tires in the future — this will benefit the environment right across the planet (p. 100).

Services

Structure of the Fraunhofer-Gesellschaft

Constituent bodies and their duties

The executive board consists of the president and several other full-time members. Its duties include managing the Fraunhofer-Gesellschaft and representing its interests both within and outside of the organization. It formulates the basic principles of the Fraunhofer-Gesellschaft science and research policy, plans its growth and its finances, acquires its base funding, organizes the distribution of funds among the individual institutes and appoints the institute directors.

A total of **76 institutes and research units** at locations across Germany operate under the umbrella of the Fraunhofer-Gesellschaft. Each cultivates its own market presence and manages its own budget. They are organized into nine **Fraunhofer groups**, each with a dedicated research focus, and tasked with coordinating this research within the Fraunhofer-Gesellschaft and harmonizing the market presence of the respective group members. The chairs of the Fraunhofer groups, together with the members of the executive board, make up the presidential council of the Fraunhofer-Gesellschaft. The presidential council participates in executive board decision-making processes and, as such, is entitled to make proposals and recommendations to and has the right to be heard by the board.

The **senate** has around 30 members, comprising eminent figures from the worlds of science, industry and public life, representatives of the federal and state governments, and members of the scientific and technical council (STC). The senate's duties include appointing members of the executive board, defining the outlines of Fraunhofer's science and research policy, and formulating decisions concerning the establishment, transformation, or dissolution of research entities belonging to the Fraunhofer-Gesellschaft.

The **general assembly** is made up of the members of the Fraunhofer-Gesellschaft. Official membership is open to members of the senate and the executive board, institute directors and senior management, and members of the advisory boards. Ordinary membership is open to individuals and legal entities who wish to support the work of the Fraunhofer-Gesellschaft. Honorary members may be elected from among the research staff and patrons of the Fraunhofer-Gesellschaft in recognition of outstanding services to the organization. The general assembly elects the members of the senate, discharges the executive board of its functions and formulates decisions concerning amendments to the statutes.

The **scientific and technical council** (STC) is the organization's internal advisory body. It consists of the directors of the institutes and an elected representative of the scientific and technical staff of each institute. The STC provides advice to the executive board and other constituent bodies in matters of fundamental importance. It makes recommendations concerning research and HR policy, expresses its opinions regarding the establishment of new institutes or the closure of existing institutes, and participates in the appointment of new institute directors.

The **advisory boards** are external advisory bodies of the institutes. They consist of representatives of science, business and public life. For each institute, approximately 12 members are appointed to the advisory board by the executive board with the approval of the director(s) of the institute. The advisory boards act as advisors to the institute directors and the executive board on matters concerning the research focus and any structural changes to the institute.

Structure of the Fraunhofer-Gesellschaft

Although the Fraunhofer-Gesellschaft is basically a decentralized organization, its structure also allows for a centrally agreed strategy and effective centralized management. Various constituent bodies and committees are responsible for coordination, consultation and leadership across the organization as a whole.

Members, constituent bodies, committees

Members

The Fraunhofer-Gesellschaft has 1,202 members, comprising 221 ordinary members, 973 official members and 9 honorary members. Some members have multiple functions.

Honorary members
Dr.-Ing. Peter Draheim

Dr. Alfred Hauff

Dr.-Ing. Horst Nasko

Dr. Dirk-Meints Polter

Prof. Dr.-Ing. Dr.-Ing. E. h.
Dr. h. c. Ekkehard D. Schulz

Dr. Markus Söder

Prof. Dr. rer. nat.
Erwin Sommer

Prof. Klaus-Dieter Vöhringer

Dr. rer. pol. Hans-Ulrich Wiese

Senate

Members representing science, industry and public life
Prof. Dr.-Ing.
Heinz Jörg Fuhrmann
Chair of the senate of the Fraunhofer-Gesellschaft

Prof. Dr. phil. habil. Dr.-Ing.
Birgit Spanner-Ulmer
Deputy chair of the senate of the Fraunhofer-Gesellschaft, director of production and technology at Bayerischer Rundfunk

Oliver Zipse
Deputy chair of the senate of the Fraunhofer-Gesellschaft, chairman of the board of management of BMW AG

Dr. Oliver Blume
Member of the board of management of Volkswagen AG, chairman of the executive board of Porsche AG

Dr. Roland Busch
President and chief executive officer of Siemens AG

Anja-Isabel Dotzenrath
Executive vice president of gas and low carbon energy and member of the board of directors of bp p.l.c.
(as of March 1, 2022)

Kerstin Grosse
Managing director of DEROSSI invest GmbH

Sabine Herold
Managing partner of DELO Industrie Klebstoffe GmbH & Co. KGaA

Reiner Hoffmann
President of the German Trade Union Confederation

Pär Malmhagen
Chief operation officer of ABC Technologies

Natalie Mekelburger
President and CEO of Coroplast Fritz Müller GmbH & Co. KG

Bernard Meyer
Managing director of MEYER WERFT GmbH & Co. KG

Tankred Schipanski

Dr.-Ing. Katrin Sternberg
Member of the executive board R&D and QRM of Aesculap AG

Dr.-Ing. Karl Tragl
Chief executive officer of Wacker Neuson SE

Grazia Vittadini
Chief technology and strategy officer of Rolls-Royce

Dr.-Ing.
Anna-Katharina Wittenstein
Member of the management board of WITTENSTEIN SE

Members representing government institutions
Representatives at the federal level
Deputy director general
Dr. Ole Janssen
German Federal Ministry for Economic Affairs and Climate Action (BMWK)

Parliamentary state secretary
Dr. h. c. Thomas Sattelberger
German Federal Ministry of Education and Research (BMBF) (as of March 9, 2022)

Ministerial councilor
Dr. Dirk Tielbürger
German Federal Ministry of Defence (BMVg)

Representatives at federal state level
State secretary
Dr. Sabine Johannsen
Ministry of Science and Culture of Lower Saxony

Deputy director general
Günther Leßnerkraus
Ministry for Economic Affairs, Labour and Tourism of Baden-Württemberg

State councilor
Tim Cordßen-Ryglewski
Bremen Senator for Science and Ports

Members delegated by the scientific and technical council (STC)
Prof. Dr.-Ing.
Albert Heuberger
Managing director of the Fraunhofer Institute for Integrated Circuits IIS

Stefan Schmidt
Deputy chair of the scientific and technical council of the Fraunhofer Institute for Material Flow and Logistics IML

Prof. Dr. rer. nat. habil.
Andreas Tünnermann
Chair of the scientific and technical council, director of the Fraunhofer Institute for Applied Optics and Precision Engineering IOF

Honorary senator
Prof. Dr.-Ing. Dr.-Ing. E. h.
Dr. h. c. Ekkehard D. Schulz

Permanent guests
State secretary Carsten Feller
Thuringian Ministry for Economic Affairs, Science and Digital Society

Prof. Dr.-Ing.
Anke Kaysser-Pyzalla
Chair of the executive board of the German Aerospace Center (DLR)

Dr. Susanne Reichrath
Representative of Saarland's Minister-President for Higher Education, Science and Technology

Dipl.-Inform. Stefan Rughöft
Deputy chair of the Fraunhofer-Gesellschaft central works council, Fraunhofer Institute for Open Communication Systems FOKUS

Prof. Dr. Martin Stratmann
President of the Max Planck Society for the Advancement of Science e. V.

Dipl.-Ing. Dominik Toussaint
Chair of the Fraunhofer-Gesellschaft central works council, Fraunhofer Institute for Systems and Innovation Research ISI

Prof. Dr. Dorothea Wagner
Chair of the German Science Council

Deputy director general
Dr. Manfred Wolter
Bavarian Ministry of Economic Affairs, Regional Development and Energy

Advisory boards

In total, the advisory boards of the institutes consist of 851 members, some of whom hold seats on the advisory boards of more than one institute.

Scientific and technical council (STC)

The STC has 181 members, 109 of whom are delegated institute directors or senior managers, while 72 are elected representatives of the scientific and technical staff of each institute.

Chair of the STC:
Prof. Dr. rer. nat. habil.
Andreas Tünnermann
Director of the Fraunhofer Institute for Applied Optics and Precision Engineering IOF

Presidential council

The presidential council of the Fraunhofer-Gesellschaft is made up of the members of the executive board, the chairs of the nine Fraunhofer groups and the chair of the segment, named below:

Prof. Dr.-Ing. Wilhelm Bauer
Fraunhofer Group for Innovation Research

Prof. Dr. Karsten Buse
Fraunhofer Group for Light & Surfaces

Prof. Dr.-Ing.
Welf-Guntram Drossel
Fraunhofer Group for Production

Prof. Dr. Dr. Gerd Geißlinger
Fraunhofer Group for Health

Prof. Dr. Peter Gumbsch
Fraunhofer Group for Materials and Components

Prof. Dr.
Hans-Martin Henning
Fraunhofer Group for Energy Technologies and Climate Protection

Prof. Dr.-Ing.
Albert Heuberger
Fraunhofer Group for Microelectronics

Prof. Dr.-Ing. Boris Otto
Fraunhofer ICT Group

Prof. Dr.-Ing.
Eckhard Weidner
Fraunhofer Group for Resource Technologies and Bioeconomy

Presidential council members that serve in an advisory capacity
Prof. Dr.-Ing. Jürgen Beyerer
Fraunhofer Segment for Defense and Security VVS

Executive board

Prof. Dr.-Ing. habil. Prof. E. h.
Dr.-Ing. E. h. mult. Dr. h. c.
mult. Reimund Neugebauer
President

Prof. Dr. rer. publ. ass. iur.
Alexander Kurz

Dipl.-Kfm. Andreas Meuer

List of committee members as of January 31, 2022

Further initiatives and research infrastructures

Impact Goals

The purpose of the Impact Goals is to help Fraunhofer improve its profile in the eyes of policymakers, industry and society. The goals address social and cross-industry challenges and highlight the areas in which Fraunhofer can contribute significant solutions by taking an interdisciplinary approach:

- Affordable healthcare
- Energiewende accomplished
- Digitalized value creation
- Fully circular economy
- Security and resilient society

Fraunhofer Strategic Research Fields

The Fraunhofer Strategic Research Fields define the system-relevant research focus areas that make up the portfolio of the Fraunhofer-Gesellschaft. Taking relevance, strategy and priorities into account, Fraunhofer has firmly positioned itself in the following research fields (see also the "Projects and results" section, p. 72 et seq.):

- Artificial Intelligence
- Bioeconomy
- Digital Healthcare
- Hydrogen Technologies
- Next Generation Computing
- Quantum Technologies
- Resource Efficiency and Climate Technologies

Addressing lead markets through the Fraunhofer alliances

In line with our research fields, Fraunhofer has defined strategic customer segments, which we call "lead markets." The objective of these lead markets is to use innovations to achieve a global competitive advantage for Germany, safeguard the technological sovereignty of Germany and Europe and generate sustainable value creation for society. The strategic customer segments, or lead markets, provide customers with access to Fraunhofer's range of industry-oriented services.

- Plant, mechanical and vehicle engineering lead market (Fraunhofer Automobile Production Alliance)
- Construction industry lead market (Fraunhofer Building Innovation Alliance)
- Chemical industry lead market (Fraunhofer Chemistry Alliance)
- Digital economy lead market (Fraunhofer Big Data and Artificial Intelligence Alliance BIG DATA AI)
- Energy sector lead market (Fraunhofer Energy Alliance, in collaboration with the Battery Alliance and the Water Systems Alliance (SysWasser))
- Food industry lead market (Fraunhofer Agriculture and Food Industry Alliance)
- Healthcare sector lead market (Fraunhofer Group for Health, in collaboration with Fraunhofer Assisted Healthy Living Alliance)
- Aerospace economy lead market (Fraunhofer Space and Aviation Alliance)
- Mobility sector lead market (Fraunhofer Transport Alliance)

Fraunhofer groups

Within the Fraunhofer model, groups represent both places of solidarity and the joint utilization of resources. Their mission is to safeguard and advance scientific excellence in their respective areas of research.

Institutes with goals that involve the security of people, society and the state coordinate their activities within the Fraunhofer Segment for Defense and Security VVS. Expertise-based groups are currently active in the following fields:

- Energy Technologies and Climate Protection
- Health
- Information and Communication Technology
- Innovation Research
- Light & Surfaces
- Materials and Components
- Microelectronics
- Production
- Resource Technologies and Bioeconomy

Fraunhofer clusters of excellence

The Fraunhofer clusters of excellence were created in 2017 to drive outstanding applied research in future-oriented fields at a world-class standard and with an international focus. The clusters support long-term collaboration between Fraunhofer institutes with strategic road maps aimed at creating innovations that are of systemic importance and have the potential to be disruptive. They are driven by a specific research focus for an initial duration of five years, led by a responsible management team. The clusters are integrated into existing (infra) structures and are usually spread across several locations. They therefore operate like a virtual institute.

At the beginning of 2021, all six current clusters underwent an interim evaluation with external specialist evaluators, where they showed excellent potential for developing long-term collaborative structures. As of 2021, a second funding phase has been initiated to drive the expansion of the clusters of excellence and to integrate them into the Fraunhofer-Gesellschaft in the long term.

- Integrated Energy Systems CINES — integration of a greater proportion of renewable energy sources with variable output into the energy system at both a market and system level
- Circular Plastics Economy CCPE — ways of achieving a knowledge-based plastics circular economy for industry and society
- Advanced Photon Sources CAPS — ultrashort-pulse laser systems with exceptionally high power output
- Cognitive Internet Technologies CCIT — key technologies for the cognitive web; with the Research Centers Machine Learning, IoT-COMMs and Data Spaces
- Immune-Mediated Diseases CIMD — personalized treatment and diagnostics for immune dysregulation
- Programmable Materials CPM — materials with reversible functionalities, which could replace sensor-actuator systems

Lighthouse projects

By pooling its capacities in lighthouse projects, the Fraunhofer-Gesellschaft sets strategic priorities for pre-competitive research. Fraunhofer institutes work together in consortia to quickly turn original scientific ideas into marketable products.

Current lighthouse projects

- RNAuto — automated production of mRNA therapeutics
- SUBI²MA — sustainable, biobased and biohybrid materials
- NeurOSmart — high-performance computing for sensor systems
- 6G SENTINEL — next-generation mobile communications
- FutureProteins — high-quality protein worldwide
- ALBACOPTER® — experimental platform for vertical gliders
- ShaPID — Green Deal for the chemical industry
- WASTE4FUTURE — from waste to raw material
- SWAP — hierarchical swarms as production architecture with optimized utilization
- MaNiTU — materials for sustainable tandem solar cells with extremely high conversion efficiency
- ElKaWe — electrocaloric heat pumps
- QMAG — quantum magnetometry
- EVOLOPRO — evolutionary self-adaptation of complex production processes and products
- COGNAC — cognitive agriculture
- MED²ICIN — digital patient model for cost-intelligent medicine

Completed lighthouse projects

- ML4P — machine learning for production
- QUILT — quantum methods for advanced imaging solutions
- ZEPOWEL — towards zero power electronics
- eHarsh — sensor systems for extremely harsh environments
- Future AM — next-generation additive manufacturing
- Go Beyond 4.0 — digital printing and laser processes in mass production
- Combustion Engines for Tomorrow's Mobility — new drive systems, fuels and AI
- Electricity as a Resource — electrochemical processes for fluctuating energy and raw materials systems
- Theranostic Implants — approval-relevant development of key technologies for medicine
- Critical Rare Earths — efficient use of strategic high-tech metals
- E³ Production — paradigm shift in production technology: Focusing less on maximizing profit using minimum capital investment and more on maximizing added value using minimum resources
- Electromobility — innovative technologies and components for hybrid and electric vehicles
- Cell-free Bioproduction — developing an industrial process for cell-free protein production

High-performance centers

Fraunhofer already organizes collaborations between university and non-university researchers and industry in 21 high-performance centers based in Germany, as well as others abroad.

Universities, higher education institutes, Fraunhofer institutes and other non-university research institutes work closely with businesses and stakeholders from civil society at a single location to carry out research on specific topics in order to rapidly bring innovations into practical application. High-performance centers provide best-of-breed, cross-organizational, practical infrastructure, vocational training programs and expertise.

They bring together like-minded partners and act as innovation guides to help bring ideas to the market.

From 2022, high-performance centers will advance in their role as regional innovation ecosystems by means of more precise program management. The refined model is intended to promote a dynamic system that rewards exemplary transfer activities and makes the direct impact of research at a regional level visible (see p. 57).

- Chemical and Biosystems Technology, Halle-Leipzig region
- Digital Transformation, Berlin
- DYNAFLEX — Dynamic and Flexible Processes for Energy and Raw Materials Transitions, Oberhausen
- Electronic Systems, Erlangen
- Functional Integration in Micro- and Nanoelectronics, Dresden/Chemnitz
- GreenMat4H2 — GreenMaterials for Hydrogen, Hanau/Darmstadt
- Innovative Therapeutics, Frankfurt am Main
- Integration of Biological and Physical-Chemical Material Functions, Potsdam-Golm
- Intelligent Signal Analysis and Assistance Systems — InSignA, Ilmenau
- Logistics and IT, Dortmund
- Mass Personalization, Stuttgart
- Medical and Pharmaceutical Engineering, Hannover/Braunschweig/Lübeck
- Mobility Systems, Karlsruhe
- Sustainability, Freiburg
- Photonics, Jena
- Sensor Intelligence, Saarland
- Secure Intelligent Systems, Munich
- Simulation- and Software-based Innovation, Kaiserslautern
- Smart Production and Materials, Chemnitz/Dresden
- Sustainable Subsea Solutions, Rostock/Lübeck
- Connected Adaptive Production, Aachen

High-performance centers with international participants

- Additive Technologies for Medicine and Health, Warsaw, Poland
- Systems Research and Transfer for the Automotive Supply Industry, Liberec, Czech Republic

Collaborations

Fraunhofer Research Institution for Battery Cells FFB

The aim of the Fraunhofer Research Institution for Battery Cell Production FFB is to accelerate the innovation and commercialization process of production technologies for existing and future battery cell formats. The objective is to produce high-quality battery technologies more efficiently and more cheaply, and thus avoid international dependencies on other energy storage technology markets in the long term.

The initiative focuses primarily on gaining experience in operating a large-scale research factory in order to expand expertise in this area and close any gaps in knowledge.

Research Fab Microelectronics Germany (FMD)

As the largest cross-location R&D association for micro- and nanoelectronics in Europe, the Research Fab Microelectronics (FMD) offers a unique range of expertise and infrastructures. The FMD also bridges the gap between basic research and customer-specific product development.

The research fab sees itself as an international driver of innovation. As a one-stop shop, it offers SMEs and start-ups easier, more extensive access to advanced technologies and equipment and technology pools for testing new products.

Eleven Fraunhofer institutes from the Fraunhofer Group for Microelectronics are collaborating with two Leibniz institutes, the Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik (FBH) (Leibniz institute for high-frequency technology) and the Leibniz Institute for High Performance Microelectronics (IHP).

Cybersecurity Training Lab

Seven Fraunhofer institutes and selected universities of applied science across Germany have joined forces as part of the further education program, Cybersecurity Training Lab. In high-grade laboratories with real work environments, training participants can experience the effects of hacking attacks first hand, for example, on the control center of a power plant or on a production line used in industrial manufacturing.

Max Planck School of Photonics

The German Federal Ministry of Education and Research (BMBF) is funding the Max Planck Schools as a new type of graduate training. The Max Planck School is led by the Fraunhofer Institute for Applied Optics and Precision Engineering IOF in Jena.

Collaboration partners also include the Fraunhofer Institute for Applied Optics and Precision Engineering IOF (leader), the Fraunhofer Institute for Laser Technology ILT, the Max Planck

Institute for Biophysical Chemistry (BPC), the Max Planck Science of Light (MPL), the Max Planck Institute of Quantum Optics (MPQ), the Deutsches Elektronen-Synchrotron (DESY), the Helmholtz Center for Heavy Ion Research in Jena (GSI HIJ), as well as the Leibniz Institute of Photonic Technology (IPHT).

National Research Center for Applied Cybersecurity ATHENE
Under the umbrella of ATHENE, over 500 scientists are researching the challenges posed by cybersecurity.

For example, ATHENE is researching how Germany's critical infrastructures (power, transportation, etc.) can be reliably protected and how IT systems can be secured in the long term, even in the face of new technologies such as quantum computers. On top of that, the center makes continuous, comprehensive and predictive efforts to identify important, practical issues related to cybersecurity and privacy.

ATHENE is a research center established by the Fraunhofer-Gesellschaft (Institutes for Secure Information Technology SIT and for Computer Graphics Research IGD) with participation by the Technical University of Darmstadt and Darmstadt University of Applied Sciences. The national research center represents an innovative collaboration model for university and non-university research that enables cutting-edge research for the benefit of society, industry and the state.

International initiatives

Fraunhofer Innovation Platform for Applied Artificial Intelligence for Materials & Manufacturing FIP-AI@VSB-TUO, Ostrava, Czech Republic
June 2021 marked the beginning of a collaboration between the Technical University of Ostrava, the Fraunhofer Institute for Machine Tools and Forming Technology IWU and the Fraunhofer Institute for Chemical Technology ICT. The objective of the collaboration is to research innovative approaches to resolving heat recovery challenges in industry through the use of modular energy storage and heat exchange systems. These approaches will then be combined with solutions for digital production technology and process chain integration.

Fraunhofer Innovation Platform for Smart Shipping FIP-S2@Novia, Turku, Finland
The Fraunhofer Center for Maritime Logistics and Services CML and the Novia University of Applied Sciences in Turku have been conducting joint research on intelligent maritime technology since 2021. Specific areas of focus include maritime simulations and digital twins, i.e., virtual copies of a ship, ship component or port. These digital twins can then be used to investigate the operation of various systems or to study energy consumption, for example.

Other initiatives

International Data Spaces Association
Digitalization both drives and enables innovative business models. In this context, data is growing in significance as a commercial asset.

The International Data Spaces initiative (previously: International Data Spaces e. V.) is aimed at creating secure data spaces and giving organizations of all sizes in a wide range of sectors sovereign control over their data assets. The International Data Spaces are not limited by geographic borders; instead, they extend their focus across European borders and beyond. As of the end of 2021, the association has 133 members from 22 countries.

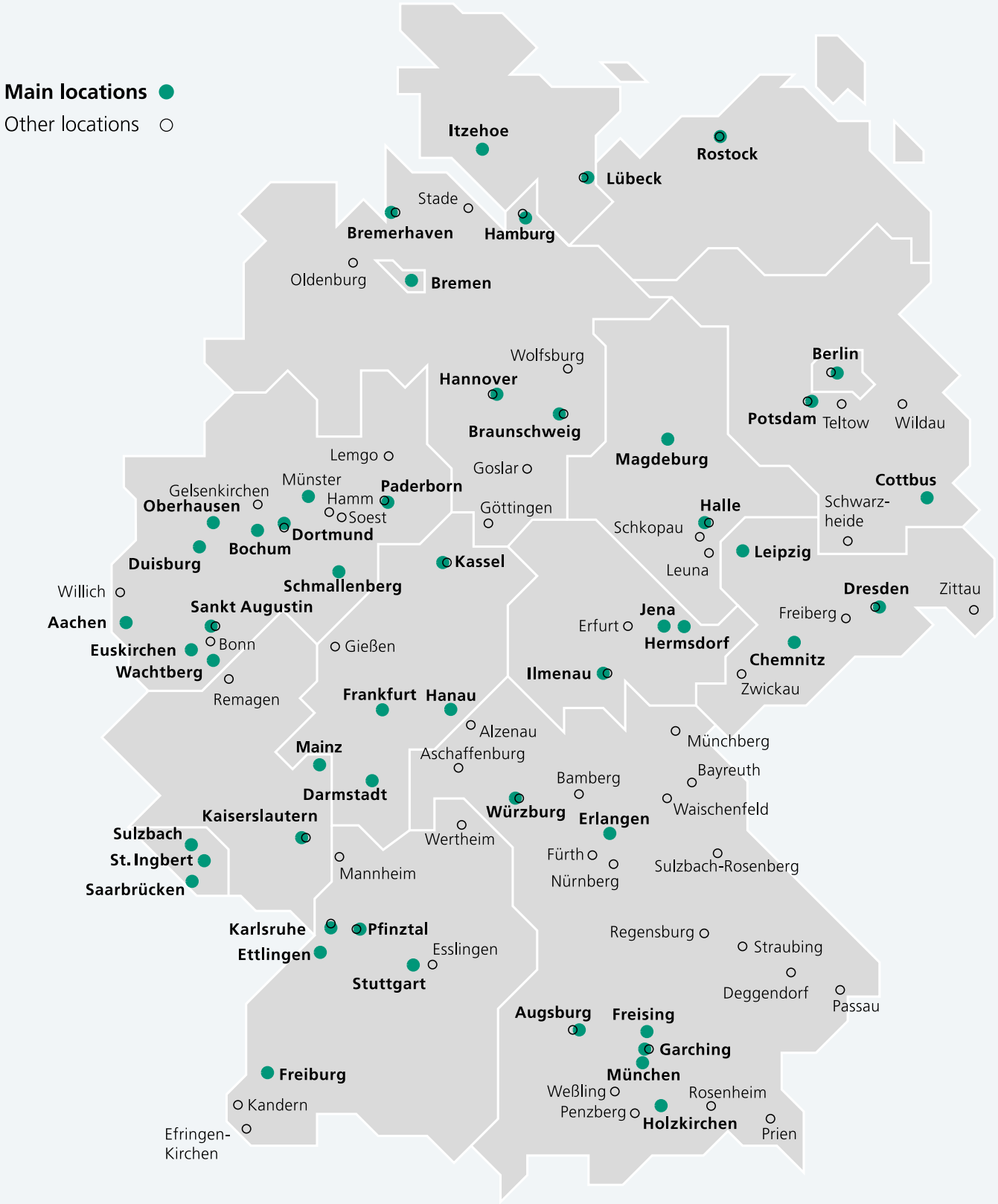
Proof-of-concept initiative for translational medical research
Since 2017, the Helmholtz Association, the Fraunhofer-Gesellschaft and Deutsche Hochschulmedizin (association of German university hospitals and medical faculties) have been running a proof-of-concept initiative to test a cross-organizational strategy for promoting the quick and efficient transfer of pre-clinical research to clinical development. The aim is to accelerate the process of translating highly innovative approaches from basic research into medical practice, i.e., whereby the industry sector develops new, potentially beneficial substances and processes to turn them into therapeutic agents and medical devices that could potentially see use in practical applications.

In 2021, the results gathered from the pilot projects to date were presented to representatives from the worlds of politics, industry and research. The potential for both the translation process in Germany and the further development of the initiative into a national platform was also discussed.

Centers

Fraunhofer centers are single, interdisciplinary locations where multiple Fraunhofer institutes conduct specialized activities. The aim is for these activities to continue at the location on a long-term basis so that the specific research field is well-established there.

- Security of Socio-Technical Systems SIRIOS, Berlin
- Microelectronic and Optical Systems for Biomedicine MEOS, Erfurt
- Energy Storage and Management Systems ZESS, Braunschweig
- Stem Cell Process Engineering, Würzburg
- Lightweight Construction and Electromobility, Wolfsburg


Main locations
Other locations
Itzehoe
Rostock
Lübeck
Stade
Bremerhaven
Hamburg
Oldenburg
Bremen
Wolfsburg
Hannover
Berlin
Potsdam
Teltow
Wildau
Braunschweig
Magdeburg
Lemgo
Goslar
Münster
Paderborn
Gelsenkirchen
Hamm
Oberhausen
Soest
Göttingen
Halle
Cottbus
Schwarz-
heide
Schkopau
Dortmund
Bochum
Duisburg
Kassel
Leipzig
Leuna
Schmallenberg
Willich
Sankt Augustin
Dresden
Zittau
Freiberg
Aachen
Jena
Erfurt
Bonn
Gießen
Hermsdorf
Euskirchen
Chemnitz
Wachtberg
Ilmenau
Zwickau
Remagen
Frankfurt
Hanau
Alzenau
Münchberg
Mainz
Aschaffenburg
Bamberg
Bayreuth
Darmstadt
Würzburg
Erlangen
Waischenfeld
Kaiserslautern
Wertheim
Sulzbach
Fürth
Sulzbach-Rosenberg
St. Ingbert
Mannheim
Nürnberg
Saarbrücken
Karlsruhe
Pfinztal
Regensburg
Straubing
Esslingen
Ettlingen
Deggendorf
Passau
Stuttgart
Augsburg
Freising
Garching
Freiburg
München
Weßling
Rosenheim
Kandern
Penzberg
Holzkirchen
Prien
Efringen-
Kirchen

Fraunhofer in Germany

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info@fraunhofer.de

Address for visitors
Hansastrasse 27 c
80686 München, Germany

Executive board
President, Corporate Policy, Research, International Affairs, Technology Marketing, Business Models (until December 31, 2021)
President, Corporate Policy, Research Management and Communications (since January 1, 2022)
Prof. Dr.-Ing. habil. Prof. E. h. Dr.-Ing. E. h. mult. Dr. h. c. mult. Reimund Neugebauer

Human Resources, Legal Affairs and IP Management (until December 31, 2021)
Innovation, Transfer and IP Management; (acting) Human Resources, Corporate Culture and Legal Affairs (since January 1, 2022)
Prof. Dr. rer. publ. ass. iur. Alexander Kurz

Finances and Digitalization (until December 31, 2021)
Finances and Controlling, Research Infrastructure and Digital Transformation (acting) (since January 1, 2022)
Dipl.-Kfm. Andreas Meuer

Information on fields of research, contact address for all Fraunhofer institutes and groups, and points of contact for Fraunhofer headquarters are available on both the German and English versions of the Fraunhofer website:

www.fraunhofer.de

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Fraunhoferstrasse 1
83671 Benediktbeuern, Germany


Glasgow
Gothenburg
Dublin
Brussels
East Lansing
Brookline
Munich
Vienna
Budapest
San José
Plymouth
Bozen
Graz
Porto
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