Fraunhofer
1 | 26

Fraunhofer

The magazine for people shaping the future

Commemorative Year
200th anniversary of the death of Joseph von Fraunhofer

Energy? Of Course!

How research is improving grid resilience



Marco Jung, Fraunhofer IEE

The Global Threat of Drones
How acoustic-based defense systems enhance security

Mission: Future
New Space: space exploration as an opportunity for the economy

Fraunhofer



JOSEPH VON
FRAUNHOFER
1787–1826

Anniversary Year 2026

Joseph von Fraunhofer is regarded as the founder of German precision optics and combined scientific methodology with highly successful entrepreneurship. In 2026, the Fraunhofer-Gesellschaft will commemorate the 200th anniversary of his passing. Fraunhofer's gravestone bore the inscription: *Approximavit sidera* (He brought the heavens closer).

Editorial

Our Origins Shape Who we Are

By Holger Hanselka



Holger Hanselka

Johann Wolfgang von Goethe, born in 1749, was—as we would say today—not amused. He found the Fraunhofer lines discovered by his contemporary Joseph von Fraunhofer "abhorrent," "contrary to the nature of light," and "ultimately unimportant." In a letter to his friend Caspar Graf von Sternberg, the poet and naturalist added: "I am aware of Fraunhofer's efforts; they are the kind that I dismiss."

Perhaps Joseph von Fraunhofer, the self-made man from the small town of Straubing in Lower Bavaria, had touched the great thinker's vanity with his practical insights. Goethe had, after all, spent nearly two decades refining his Theory of Colors. And then along came this young orphan, constructed the finest optical instruments of his time and saw the true colors of the world. Fraunhofer's experimental findings contradicted Goethe's theory of optics. They were later hailed as "the barcode for the chemical elements in the sun's atmosphere."

Theoreticians versus pragmatists: As we mark the 200th anniversary of Joseph von Fraunhofer's death in 2026 with a commemorative year proclaimed by UNESCO, we are working to unite these contrasts. For us in the Fraunhofer-Gesellschaft, research is not an end in itself. Research and knowledge are the raw materials—and unfortunately also the only raw materials in sufficient abundance—that set our country apart and are available to our industry. We put this research and knowledge into practice, a task that we are committed to, day after day and month after month.

Joseph von Fraunhofer wasn't interested in big words but rather in what actually worked. And so, step by step, this simple worker made his way to becoming a world-class research scientist and finally to a company whose instruments were in high demand throughout Europe. This perspective that research and practical application belong together, that science is not an end in itself but benefits industry and society, continues to guide our work to this day, 200 years after Fraunhofer's untimely death on June 7, 1826.

Our origins shape who we are. What really matters, however, is the direct impact of our work today. Year after year, Fraunhofer supports our industry, especially German small and medium-sized enterprises, with some 8,000 projects. Of course many global market leaders are customers of Fraunhofer. This is a clear sign of the trust of leading companies in our expertise. Fraunhofer research makes an impact. And it makes an impact just where it is needed most today, in and for industry.

Our eponym only lived to age 39, dying 200 years ago. His gravestone bore the inscription: Approximavit sidera. In fact, he really did bring the stars closer to us. One of the cover stories in this issue of the Fraunhofer magazine shows just how close the universe has since come to us. In the past, the primary goal of exploring space was to gain knowledge. A new and very practical perspective has since emerged: How can near-Earth space be exploited commercially? Economic forecasts predict annual growth of up to six percent for the New Space Economy.

Gazing up at the stars has brought us a wealth of practical knowledge

Sincerely

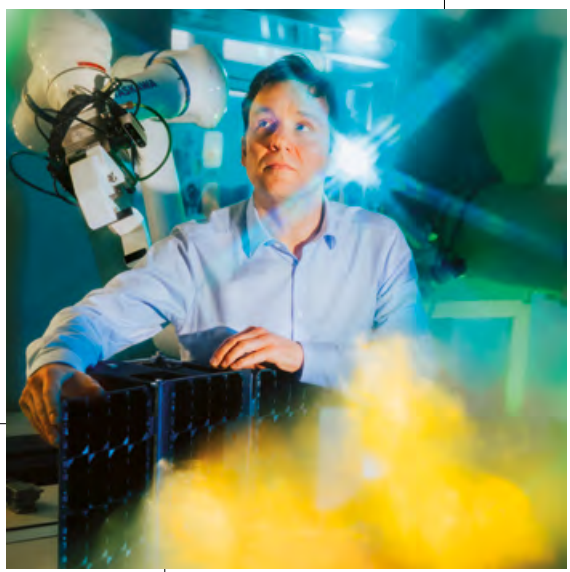


Holger Hanselka
President of the Fraunhofer-Gesellschaft

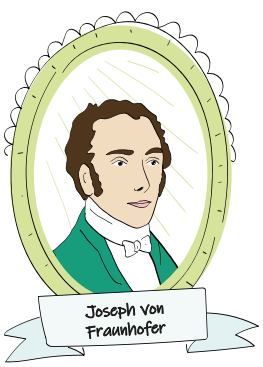
Photo: Fraunhofer/Stefan Obermeier

back to page 1

Contents



10
Aerospace
Mission: Future Market
The New Space Economy is taking off—and offers tremendous opportunities for German industry.



32
If the Fraunhofer-Gesellschaft Didn't Exist Today, We'd Have to Invent It
Holger Hanselka on the 200th anniversary of Joseph von Fraunhofer's death

03 Editorial

06 In Brief

09 Editorial Notes

10 Mission: Future in Space
Why space technology needs to go into mass production now

16 Reaching for the Stars
Fraunhofer technology in space—an overview

22 Helping Agriculture from Space
How global food production can benefit from developments in the New Space Economy



38
Energy transition
Power on!
How can we maintain the long-term stability of our power grids? Fraunhofer researchers are developing innovative solutions.

38 A Secure Energy Future
Artificial intelligence, grid-forming inverters, bidirectional charging and more for improved grid resilience—keeping the lights on in Germany

49 Energy Storage to Beat the Winter Doldrums
Innovative storage technologies can bridge the energy shortfall: Fraunhofer researchers are undertaking projects including commissioning the largest vanadium redox flow battery storage system in Europe to date.

52 Electric Power from Wood
Lignin binds wood fibers together, but it can also be used in manufacturing sustainable batteries. Roughly 50 to 70 million tons of this material are produced worldwide each year as a byproduct from the pulp and paper industry

24 A Voice from the Business World
Science and industry: For DIHK Executive Director Helena Melinkov, curiosity is "the best of both worlds"

26 Save Money by Doing Good!
A navigation aid for companies to implement comprehensive climate change management

28 Racing Against Corrosion
Unexploded ordnance is rusting on the seabed. Smart sensors help to sniff it out

32 If the Fraunhofer-Gesellschaft didn't Exist Today, We'd Have to Invent It
The Fraunhofer-Gesellschaft honors its eponym on the 200th anniversary of his death

36 Under the Skin
Automated documentation of ultrasound images will reduce the workload in everyday hospital practice

54 Where am I, and How Far do I Have to Go?
An innovative optical fiber probe facilitates work in the OR

56 Greenhouse Gases Yield a Palm Oil Alternative
Doubly sustainable: Capturing industrial exhaust gases and using them intelligently to help the environment

74
Mobile Early Detection

A carrier of dangerous pathogens: the American grapevine leafhopper





60
Back into the Loop Instead of Out with the Trash

Most fast fashion cannot be recycled into new textiles—at least not until now.

58 Research for Emergencies
Making crises more manageable

60 Back into the Loop instead of Out with the Trash
Recycling mixed synthetic fabrics into T-shirts, pants and more

62 A Startup is Revolutionizing Dental Prosthetics
Cost-effective 3D-printed prosthetics with gold

64 Drones Incoming
Detecting, identifying, thwarting – researchers know how

66 Protective Foam
An extra-light, thermally robust battery housing

68 A Photo & Fraunhofer
Toxins from Germany's most venemous spider could help to cure cancer

70 Fraunhofer Worldwide

72 Sewage into Sustainable Plastics
Wastewater contains many valuable materials



64
Drones Incoming

Defense systems based on acoustics detect flying objects before they are even visible.

74 Mobile Early Agricultural Pest Detection
A laboratory on wheels helps in the fight against the American grapevine leafhopper and ilk

76 Chips for Europe
The APECS megaproject is improving European resilience in the semiconductor industry

78 Hugo Geiger Prizes
Outstanding work by young researchers

84 Smart Wearables Instead of Cable Spaghetti
A comfortable wearable sensor system warns against heart disease

87 Fraunhofer on the Road

The global space industry reached a record value of 613 billion dollars in 2024. The commercial sector contributed **78%** to overall growth.

Source: The Space Report 2025 / Space Foundation

78 %

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back to page 1

In Brief



For better recycling, paper packaging cannot include any additives.

Easier Recycling of Paper Packaging

Previously, paper packaging could not be closed without additional adhesives or plastic layers that hinder recycling. In the PAPURE project, four Fraunhofer institutes are developing a laser-based process that enables the elimination of adhesives. The research team is working on a sealing process using laser treatment to modify the paper so that it can then be sealed directly with a heat sealing process.

The research scientists are analyzing different types of paper in this project. The paper surface is modified using a carbon monoxide laser. After irradiation, fusible cleavage products remain on the paper surface, which can then be sealed by pressure and heat. The team's preliminary work will be transferred to an industry-oriented demonstrator. This will be a roughly 6 meter long manufacturing system replicating the manufacturing process at the Fraunhofer Institute for Machine Tools and Forming Technology IWU in Dresden. Also participating in the project are the Fraunhofer Institute for Applied Polymer Research IAP, the Fraunhofer Institute for Material and Beam Technology IWS and the Fraunhofer Institute for Process Engineering and Packaging IVV. ■

Quickly Unmasking Food Fraud

Dyed rapeseed oil masquerading as olive oil, oregano mixed with cheap plant scraps—food fraud is a lucrative business. A mobile sensor system will help to quickly detect fraud in the future. In the Fraunhofer PUMMEL project, research teams at the Fraunhofer Institute for Photonic Microsystems IPMS, the Fraunhofer Institute for Molecular Biology and Applied Ecology IME and the Fraunhofer Institute for Process Engineering and Packaging IVV are combining their core expertise in gas chromatography measurement methods, sensor development and chemical sensors. Their goal is to develop a gas chromatography sensor system for rapid on-site detection of volatile organic compounds (VOCs). VOCs are chemical compounds that are characteristic for specific compositions and can be correlated to changes in product characteristics. The portable system, which will be roughly the size of a shoulder bag, includes a silicon chip-based gas chromatography column (GC column), a detector or sensor, integrated sample preparation, control and analysis electronics and a power supply. ■



Olive oil is among the top ten most frequently counterfeited foods.

Sustainable Gaming

How can we reduce electronic waste and make electronics manufacturing more sustainable? Young people can learn about this in the new serious game ICT. factory. This browser-based computer game was developed by experts from the Fraunhofer Institute for Reliability and Microintegration IZM and the Research Fab Microelectronics Germany (FMD) in collaboration with game designers, teachers and secondary school students. In test play with school classes special attention was given to motivation, understandability and enjoyment of the game.

In ICT.factory, the players take over an aging electronics factory with the task of sustainably modernizing the outdated enterprise and ensuring its future viability. The goal is to make strategically intelligent decisions along the entire value chain from sustainable raw materials procurement to efficient and resource-saving manufacturing, to modernization of the production facilities and to the implementation of different sustainability concepts and recycling. The game takes up real challenges such as dealing with the scarcity of resources. The online game runs on all current devices with no installation and is intended for youths of 13 years and above. ■



A fun learning game: ict-factory.de.

3D-Printed Finger Prostheses



The joint structure can be easily bent by up to 90 degrees.

In the ProFi project, researchers from four Fraunhofer institutes have developed fingers for a prosthetic hand that consist of single 3D printed parts. The usual bolted construction of multiple parts is replaced with a programmable multistable metamaterial that can be fixed in three positions. This new passive (i.e. non-functional) aesthetic prosthetic should be more cost-effective and easier to handle in production.

The Fraunhofer solution is implemented with a joint structure with only one rotational degree of freedom and with bistable unit cells. The metamaterial has already been used as a substitute joint for an elbow. The researchers adapted the joint structure in order to transfer it to the significantly smaller available space in a finger and to provide a small bending radius. It exhibits low stiffness in the bending direction and can take on nearly any desired external contour. Fingers can thus be replicated individually and true to life.

Project participants include researchers from the Fraunhofer Institute for Structural Durability and System Reliability LBF, the Fraunhofer Institute for Mechanics of Materials IWM, the Fraunhofer Institute for Industrial Mathematics ITWM and the Fraunhofer Institute for Applied Polymer Research IAP. ■

Photos: Davizro, TKphotography64/both istockphoto, Lily Solopova/ Westend61/mauritius images, Fraunhofer LBF

back to page 1

Reliable Communication

The cellular network can be quickly overloaded in the event of a disaster. In the 5G Opportunity project, a research team has now developed a software-based wireless and ad-hoc capable communication system for authorities and organizations charged with security tasks. In collaboration with their partners, research scientists at the Fraunhofer Institute for Applied Information Technology FIT have tested the mobile, self-organizing communication network based on Fraunhofer WiBACK technology (wireless backhaul). This enables emergency services to remain in contact with each other, deployment management and the internet. The WiBACK communication network uses 5G/Open RAN (radio access network) and WiFi for smartphone access and multi-hop routing for backhaul. "A WiBACK network can be set up in a very short time and be operated immediately in compliance with regulations," says project manager Mathias Kretschmer, a research scientist at Fraunhofer FIT in Sankt Augustin near Bonn. "The hardware consists of self-sufficient, portable components. All you need to do is connect the batteries, align the antennas, and the network is ready to go." ■



Coordination is crucial in a crisis, but communication is often difficult.



Underwater robots are designed to help protect wind farms from damage.

Autonomous Inspection of Offshore Plants

Researchers from the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM are working on fundamental improvements in the inspection, maintenance and cleaning of floating offshore energy platforms. In the FORE-PAIR project, they are collaborating with partners on autonomous underwater vehicles (AUVs) that can reliably inspect the support structures of offshore installations even at great depths and can detect damage at an early stage, even in strong currents or under limited visibility conditions. The team is also developing high-resolution 3D sensor systems and digital twins that represent the condition of the platforms in real time, automatically detect changes, and enable data-based maintenance decisions. The research scientists are investigating sustainable protection solutions that reduce biofouling and thus extend the service life of the systems. This is supplemented by AR-VR based tools that enable maintenance personnel to realistically plan deployments in the digital twin, optimize procedures and efficiently prepare for repair or inspection scenarios. ■

Editorial notes

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Free subscription:
Phone +49 89 1205-1301
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Editorial team:
Monika Landgraf
(person responsible for content),
Josef Oskar Seitz (editor-in-chief),
Sonja Endres,
Beate Strobel

Editorial assistants:
Janine van Ackeren,
Mandy Bartel,
Meike Grewe,
Sirka Henning,
Andrea Kaufmann,
Dr. Monika Offenberger,
Iris Röll,
Kathrin Schwarze-Reiter,
Mehmet Toprak,
Yvonne Weiß

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Mulch films promote a good harvest. There's even enough to share.

Worry-Free Indulgence

Enjoy German strawberries already in early May? Mulch films make it possible, but they place a burden on the environment. Researchers in EU project CELLAGRI are working on ecologically compatible alternatives.

Mulch films suppress weed growth, reduce evaporation and heat the soil. They are therefore often used in fruit and vegetable cultivation. European agriculture uses more than 80,000 tons of these thin plastic sheets every year. Up to 30 percent of this material ends up as microplastics in the soil. Most of the rest is sent to landfills or is incinerated. In EU-funded project CELLAGRI coordinated by the Fraunhofer Institute for Electron Beam and Plasma Technology FEP, researchers from seven European countries are working to create biodegradable alternatives offering high functionality while still remaining affordable.

In this interdisciplinary project, the research scientists are first developing high-performance substrates of various cellulose blends as the base material. A fully biodegradable surface coating made from bio-based monomers enables rapid and controllable decomposition in soil. Innovative microfluidic structures embossed in the coating enable passive water management. The system directs water specifically to the planting holes, thereby increasing water availability. An atmospheric plasma treatment creates hydrophilic and hydrophobic areas that further improve water management and also prevent the formation of mold. A sophisticated manufacturing process combines coating, microstructuring and plasma functionalization in a single step and is implemented in a roll-to-roll process at Fraunhofer FEP. ■

back to page 1

Mission: Future in Space

Understanding and shaping space exploration as an economic opportunity: The new space economy is taking off. Prerequisite for success is a technological paradigm shift.

By Beate Strobel; Photographer: Max Slobodda



Aerospace



Ensuring space superiority: Together with his team, Martin Schimmerohn from Fraunhofer EMI developed the ERNST research satellite, which is now detecting rocket launches from space.

back to page 1

What happened after the Big Bang? How do galaxies evolve? And is there other life out there in space? These are the big questions in astronomy to which the James Webb Space Telescope (JWST) is designed to provide answers. Launched on Christmas Day 2021, it awes us with images of galactic beauty. And this is in part thanks to Fraunhofer technology. The mirrors with which MIRI gazes out into space were fabricated and coated at the Fraunhofer Institute for Applied Optics and Precision Engineering IOF in Jena. Serving as both a camera and a spectrograph, MIRI is the only instrument on the JWST that can cover the mid-infrared range. This enables it to detect even objects that are hidden by interstellar dust. This technology is also of tremendous help in studying the first galaxies from the early universe.

Until now, space exploration has primarily served to advance our knowledge. Now a new perspective has emerged: How can near-Earth space be exploited commercially? What markets and services are emerging for and as a result of the space industry? The New Space Economy: This term captures the shift in space exploration from government backing to commercial interests. Private companies such as SpaceX, launched by tech billionaire Elon Musk, and Blue Origin, started by Amazon founder Jeff Bezos, have become drivers of innovation with their own rockets, satellites and technologies. In Germany, startups such as Isar Aerospace near Munich and Rocket Factory Augsburg plan to develop launch vehicles and spacecraft.

Economic forecasts predict annual growth of up to six percent for the New Space Economy. This has also captured the interest of established commercial enterprises such as automotive supplier Brose SE. At the end of 2025, this family-owned company entered into a strategic partnership with the Fraunhofer Institute for High-Speed Dynamics EMI, the Fraunhofer Institute for Silicate Research ISC and the BERLIN SPACE Consortium. Their goal: to jointly develop and manufacture small satellites, key components for space technology and electric drive systems on an industrial scale. Researchers at Fraunhofer IOF and SPACEOPTIX, a spin-off from Fraunhofer IOF, are collaborating with TESAT, one of the leading companies in satellite telecommunications. In the European Space Agency (ESA) ScyLight program, the research scientists have developed a telescope for laser terminals that not only serves as both a transmitter and receiver but can also be mass-produced.

Why space technology needs to go into mass production now

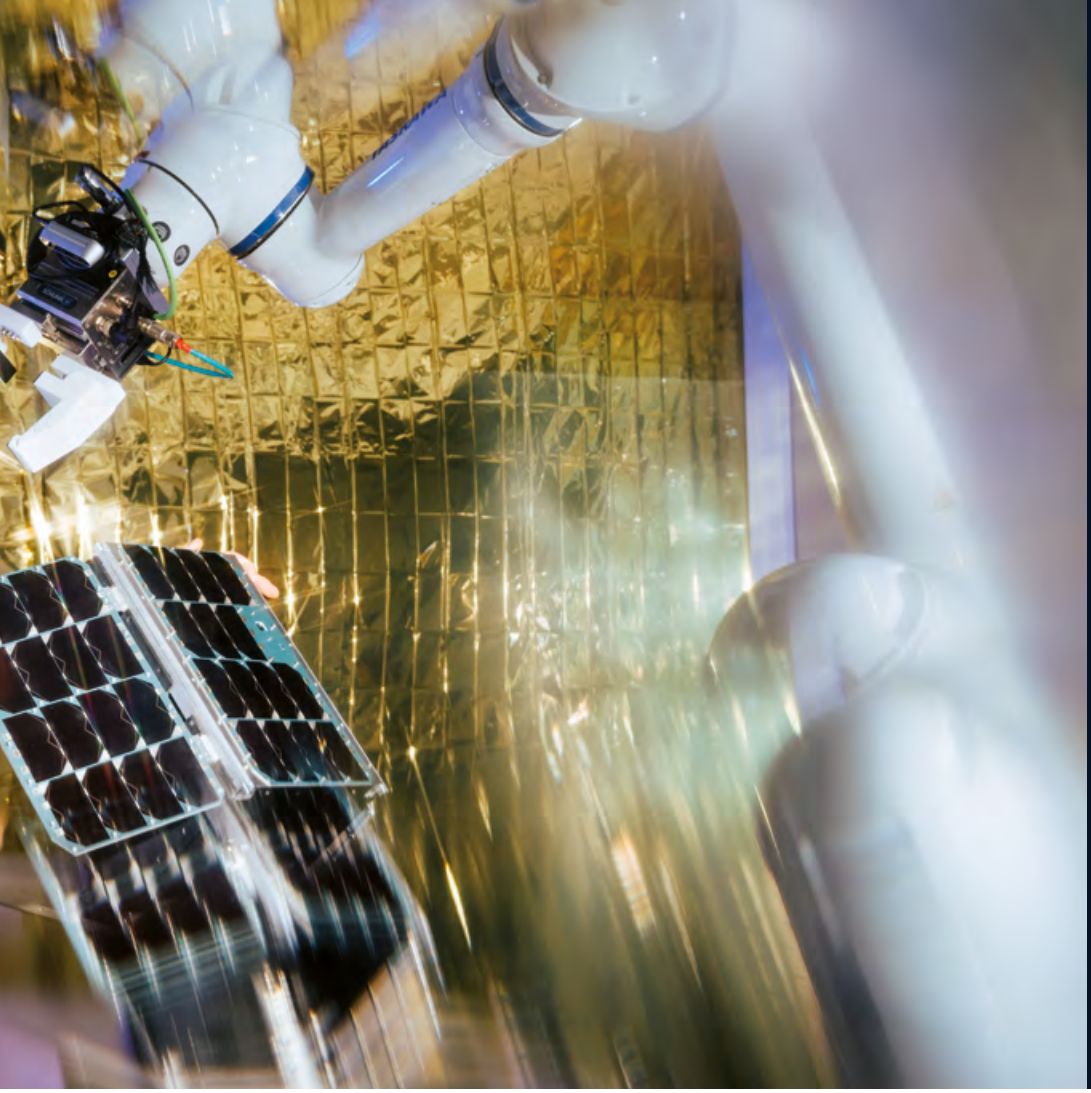
The transition to the New Space Economy requires a change in thinking in both research and industry. "The New Space Economy urgently needs robust, digitally integrated, cost-effective solutions that can be mass produced," explains Stephan Busch, a computer scientist and expert in small satellite technology at Fraunhofer EMI. Within Fraunhofer, these efforts are driven by Fraunhofer AVIATION & SPACE, a group of 37 Fraunhofer institutes. The goal is to provide commercial enterprise with access to Fraunhofer's expertise in the SPACE section and to build bridges between industry and applied research. "As a neutral enabler, Fraunhofer's interdisciplinary approach is convincing. The institutes include not only experts in space technology but also specialists in traditional fields like process optimization, digitalization, automation, materials development, logistics and supply chain management," says Busch. "These skills are extremely valuable for the industrialization process we need for the New Space Economy."

The Fraunhofer NewSpace Innovation Lab (FRANSI) in Würzburg will soon be establishing the infrastructure for agile innovation and test processes for this purpose. A Production Acceleration Center is also planned. This facility is primarily designed to help small and medium-sized enterprises with industrial manufacturing and quality-assured testing within the European New Space ecosystem, accelerating industrial space activities. The importance of small satellites for the New Space Economy is addressed by the KSaRo project, commissioned by the German Space Agency at the German Aerospace Center (DLR). Fraunhofer AVIATION & SPACE, the Fraunhofer Institute for Technological Trend Analysis INT and Fraunhofer EMI have developed a corresponding roadmap for small satellite technologies in Germany through 2030. A survey in the context of the project clearly showed that companies especially regard access to adequate testing capacity as too complex and cost-intensive. The German New Space sector thus still has some work to do in this area.

The effort will be worth it, however. "Small satellites in particular can be produced quickly and cost-effectively, and their low mass enables them to be launched into orbit at a relatively low cost," explains



Faster out of the starting box: Computer scientist Stephan Busch wants to speed up the mass production of satellites.



"The New Space Economy urgently needs robust, digitally integrated and cost-effective solutions that can be mass-produced."

Stephan Busch, Fraunhofer EMI

Nadya Ben Bekhti-Winkel, a research scientist at the Fraunhofer Institute for Communication, Information Processing and Ergonomics FKIE and head of the business office SPACE of Fraunhofer AVIATION & SPACE. Small satellites are also well-suited for use in satellite constellations to provide broader coverage. The astrophysicist is convinced: "The industrialization of small satellite manufacturing is contributing to the democratization of access to space. This means that even smaller companies and universities can afford their own space projects."

Smaller, faster and more affordable: In 2024, eight Fraunhofer institutes and three industry partners formed an interdisciplinary consortium to advance the optimization of satellite production and testing in the NET pioneer project. This project was also funded by the German Space Agency at the German Aerospace Center (DLR). Central to this is the idea of a digital test bed that is modular, automated and easily accessible to both industry and research. "NET pioneer shows how we can improve testing in the New Space sector with digitalization, standardization, automation and robotics, modularization and remote assistance," summarizes Stephan Busch, who led the project along with Nadya Ben Bekhti-Winkel. A significant lever here is the use of digital, standardized data sheets to streamline the flow of information between development, testing and production. In the future, this will enable the provision of test procedures as off-the-shelf products via digital platforms: preconfigured, standardized and ready for immediate use.

Why closer is sometimes better

Potential players in the New Space Economy can especially benefit from the opportunities offered by satellites in very low Earth orbits (VLEO). Their proximity to the Earth enables highly precise Earth observation as well as the establishment of high-performance communication services. VLEO satellites orbit the Earth in just 90 minutes, meaning that a smaller total number of satellites are needed to provide global coverage. This all makes the technology ideal for applications such as agricultural and environmental monitoring, as well as for future 6G networks. A bonus: VLEO objects are quickly slowed down and then burn up, reducing the risk of space junk.

"VLEO is currently a major focal point for the New Space Economy," says Nadya Ben Bekhti-Winkel. Forecasts by Juniper Research indicate that there will already be more than 600 satellites in VLEO by 2030. They estimate that global investment in this sector will reach up to 220 billion dollars by 2027. However, this region does require special satellites, since oxygen ▶

back to page 1

"Small satellites in particular can be produced quickly and cost-effectively, and their low mass enables them to be launched into orbit at a relatively low cost."

Nadya Ben Bekhti-Winkel, Fraunhofer FKIE



A vision for future markets: Astrophysicist Nadya Ben Bekhti-Winkel has just been appointed vice president of the European Association of Space Technology Research Organisations (EASTRO).

atoms and other aggressive particles in low Earth orbit cause accelerated material wear. In the VLEO Demonstrator project, the Fraunhofer Institute for Silicate Research ISC and the Fraunhofer Institute for Integrated Circuits IIS are collaborating with Fraunhofer EMI and Fraunhofer IOF to seek out solutions to these challenges. With funding from the Bavarian Ministry of Economic Affairs, Regional Development and Energy (StMWi), the researchers are conducting the first studies on VLEO satellite design and are developing materials, tools and test procedures.

With a focus on cost and efficiency, teams at the Fraunhofer Institutes IIS and INT (now Fraunhofer FKIE) have been identifying, since 2025 and within the ESA ARTES program, as part of the SatCom Spin-In project, existing technologies that can be adapted with minor modifications for use in the satellite sector. Development of these satellites has never relied solely on space-specific innovations. Technological advances from other industries have always been crucial, especially in high-frequency and microwave technology, semiconductors and microelectronics, digital signal processing and modern network architectures such as software-defined networking.

Why the space industry needs more projects like ERNST

ERNST is a perfect demonstration of the potential of small satellites in low Earth orbit. This miniature orbiter developed at Fraunhofer EMI, which is about the size of a beverage crate, has been orbiting Earth since August 16, 2024. Unlike ground-based radars, an infrared camera enables ERNST to detect missiles as soon as they are launched. This is especially useful for security reasons. "Detecting missiles as early as possible is essential for initiating timely countermeasures against potential threats," explains Martin Schimmerohn, a research scientist who helped develop the research satellite.

Checking the images from ERNST has become a cherished morning routine for Schimmerohn and his team. For example, in July 2025, the satellite observed the launch of a Falcon 9 rocket in the United States and tracked it during its ascent. This is important infrared data that had not previously been available. "We've been extremely satisfied with ERNST so far," the Fraunhofer expert says proudly. This is not only because the satellite works so reliably. ERNST also serves as an excellent example of the success of the New Space approach: The agile platform was deliberately developed quickly and cost-effectively based on pragmatic solutions.

ERNST is scheduled to orbit Earth for five years. This will be plenty of time to



learn and improve, according to Schimmerohn. Results to date are already being incorporated in the development of ERNST's successor, to be developed at Fraunhofer EMI in cooperation with the Brose Group. For Schimmerohn, the automotive supplier is an ideal New Space partner. "It makes more sense to teach an expert in mass production how to build satellites than to try to move a satellite manufacturer from the 'Established Space' world to industrial production," he says. Overall, he sees this initiative as the perfect Fraunhofer project: "We are putting cutting-edge technology to practical use as quickly as possible, advancing the transformation of industry." The research scientist sees industry's interest in the New Space sector almost every day: "It's a gold rush atmosphere. And the opportunity to help take space exploration to the next level is incredibly exciting."

How things get from A to B in space

Logistics is also entering a new phase in the New Space Economy, according to Michael Henke, Institute Director of the Fraunhofer Institute for Material Flow and Logistics IML in Dortmund: "A whole new growth market for logistics companies is emerging here." While the market volume for the Space Economy is expected to triple by 2035, forecasts for Space Logistics are predicting a fivefold increase. A world in which value creation extends into space needs properly functioning logistics. This is true whether it's a matter of transporting raw materials, constructing and supplying space stations, refueling and maintaining spacecraft and satellites or missions to the Moon and Mars.

The Exploration Company (TEC), founded by Airbus executive Hélène Huby, has already established a strong presence in this field, with offices in Germany, France, Italy and the USA. With the Nyx space capsule, TEC is launching a flexible, reusable, cost-effective logistics system for Earth orbit and the Moon—with the goal of better positioning Europe in competition with US-based companies like SpaceX. Fraunhofer IML consults regularly with The Exploration Company on the continuing development of Nyx.

"The basic idea of TEC is the same as that of any logistics company: facilitating transport from A to B," explains Henke. "The difference being that B is now in space and that its position is continuously changing. "And that, ideally, everything leaving A, i.e., our Earth, should either be brought back or reused up there." His colleague Axel T. Schulte, Department Head for Space Logistics at Fraunhofer IML, adds: "In terrestrial logistics, the current focus is heavily on topics such as automation and networked intelligent logistics." These approaches to automation in combination with AI can be very effectively applied to space exploration. There as well, much will have to proceed autonomously, as there aren't always people on site."

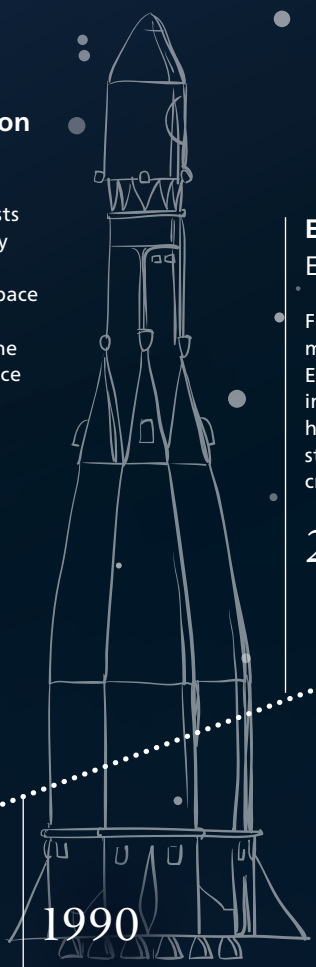
As part of the EU-funded STARFAB project, a team at Fraunhofer IML is currently working with international partners to develop an orbital "warehouse": a kind of automated space service center designed to support missions and operations in space with services including maintenance, inspection, refueling, assembly, manufacturing and even recycling. A demonstrator at a technology readiness level of 4 to 6 is scheduled to be presented already in summer 2026. This is to be a functional laboratory-scale model with a roadmap outlining the path to an international space refueling station.

According to engineer Schulte, the challenge associated with projects in New Space logistics is in transferring existing technologies, concepts and solutions to the conditions of space. Will they work in zero gravity, at extreme temperatures, far away from Earth and without human assistance? "The materials we use on Earth often behave differently in space," adds ▶

back to page 1

Reaching for the Stars

Materials development, optics, sensors, energy, communication and navigation, automation, digitalization and AI: Since the 1980s, Fraunhofer researchers have been supporting the European and international space industry with innovations from a wide range of fields—and are thus "on board" with virtually every space mission.



MIR space station
FHR

Fraunhofer FHR assists Russian space agency Roscosmos with the reentry of the MIR space station by providing radar images from the Fraunhofer TIRA space observation radar.

1986

1990

HUBBLE
EMI

Researchers at Fraunhofer EMI investigate damage to the Hubble Space Telescope from space junk and micrometeorites.

ENVISAT
EMI | FHR

For the ENVISAT mission, Fraunhofer EMI investigates impact damage due to high-speed projectiles striking the spacecraft's structural walls.

2002

2007

Ariane 4, 5, 6
ICT | EMI

Fraunhofer ICT develops a spray-coating process to stabilize ammonium nitrate with additives for the rocket's propulsion system. Fraunhofer EMI conducts impact tests on helium tanks.

ATV-1
FHR | INT | EMI

After separation of the ATV from the rocket's upper stage, technology developed at Fraunhofer FHR enables the TIRA radar to distinguish the two components from one another despite near-identical orbits. Fraunhofer INT performs radiation tests and Fraunhofer EMI performs activities including impact tests.

2008

2011

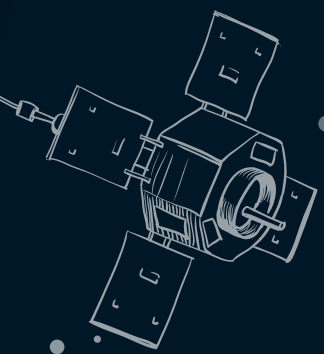
Galileo
EMI | IIS | INT

Fraunhofer EMI leads the development of a ground station system. Galileo receivers are developed at Fraunhofer IIS. Fraunhofer INT conducts radiation tests on components of the Galileo satellites.

GAIA
EMI | IOF

Structural vibrations due to high-speed impacts on spacecraft are measured at Fraunhofer EMI.

2013



James Webb Space Telescope
IOF

Researchers at Fraunhofer IOF manufacture parts including high-precision metal mirrors for the space telescope's Mid-InfraRed instrument.

2021

ERNST
EMI | INT | IOSB

The ERNST nanosatellite from Fraunhofer EMI is equipped with an infrared detector, a camera for Earth observation in the visible spectrum and a radiation detector developed at Fraunhofer INT.

2024

Exomars Rover
IOF | FKIE | IPA

A cleanroom is designed at Fraunhofer IPA in which the Mars rover will be sterilized in a specially developed process for the second phase of the planned ExoMars mission.

2028

BepiColombo
EMI | IST | IOF | INT

Work includes thermal management optimization for the BepiColombo probe using software developed at Fraunhofer EMI.

2018

2023

Heinrich-Hertz
INT | IIS

The Fraunhofer On-Board Processor (FOBP) is developed at Fraunhofer IIS and serves as a space-based laboratory for satellite communication systems on the Heinrich Hertz satellite.

2025

HiVE SkyBee-1 and SkyBee-2
EMI

Fraunhofer EMI contributes its Data Processing Unit (DPU) as the central computer for the HiVE satellite payload. HiVE is operated by Fraunhofer spin-off constellr.

2035

ATHENA
IWS | IWU

Fraunhofer IWS is already fabricating an optical bank as one of the three main components of the ATHENA telescope, while Fraunhofer IWU is developing the associated cyber/physical production process.

2014

Sentinel-1
IOSB | IST | ILT | HHI | EMI

Fraunhofer IOSB researches strategies for integrating data into continuously operating monitoring systems, while Fraunhofer IST manufactures antennas for the Sentinel satellites. Fraunhofer ILT develops laser pump modules, and Fraunhofer EMI develops measures to minimize the risk of component failure due to impacts.

2020

NASA Mars Rover 2020
IST

Bandpass filters for the Mars rover's sensors are coated at Fraunhofer IST.

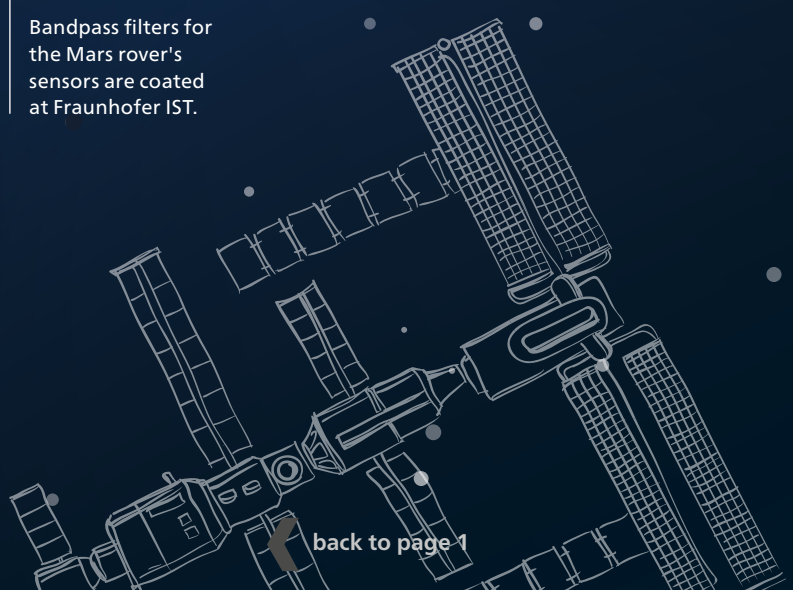


Illustration: Vierthaler & Braun, Owljeans, Vladimir Kazakov / both from istockphoto

Scan for more information about missions with Fraunhofer

back to page 1

Henke. Even so: "We already have the key technologies that will be valuable for space logistics, even including token-based payment processes." When things are manufactured, repaired or transported in space, there also has to be a transfer of money. At Fraunhofer IML, we are already working on that as well."

The role of recycling in space

The opportunities presented by this galactic expansion in the traditional concept of logistics also come with responsibilities. "We have to assign a high priority to the issue of recycling right from the start, not least because of the opportunities it presents," cautions Schulte. This is the case whether it involves recycling the materials used, on-site repairs or the return transport of defective spacecraft. "Service providers are already emerging here that focus specifically on the issue of space junk," the Fraunhofer logistics expert explains. German companies could play a leading role in this area and tap into enormous business potential. However, this is only the case if they take action as soon as possible instead of waiting for predefined standards or becoming hampered by overly stringent regulations.

According to Henke, though, this actually applies for the entire logistics industry in Germany: "Germany is one of the leading logistics nations in the world." "At the same time, however, Germany is always at risk for overregulation." Of course binding guidelines are important in matters such as data security or responsibility for space junk. But those who focus only on the risks miss out on opportunities that then devolve to others. Henke cites the ISO container as a positive example. This container was invented by American shipping magnate Malcolm McLean in the mid-1950s to improve the efficiency of shipping goods. "This container became the standard without any prior regulatory requirements," he says. Similarly, solutions for space logistics must now be created that quickly offer real added value and, for that reason alone, establish themselves as the de facto standard, such as in the form of a standard space container that is not only reusable but is also smart and networked.

Neither Michael Henke nor Axel T. Schulte were thinking about space when they opted for a career in logistics. Now, they see expanding into orbit as the next logical step. "Space is a growing market that we want to develop for logistics," says Schulte. The reason is simple: "Without logistics, nothing works up there either."

Moondust is the substance of more than just dreams

At first, Andreas Dietz also followed the space industry merely as an interested observer. Then, in the late 1990s, Airbus commissioned his team at the Fraunhofer Institute for Surface Engineering and Thin Films IST in Braunschweig to develop a coating for CFRP satellite antennas for the ESA's Sentinel-1 program. This opened the door to space for Fraunhofer IST.

Now, Andreas Dietz deals with space-related topics that still sound a lot like science fiction to most people: Can humans live on the moon—and how can it be done? "There's nothing up there," says the electrochemist. Separately flying in raw materials or even equipment is extremely expensive. "At present, every kilogram of payload costs at least 15,000 euros." Every single gram is haggled over."

So it would be better to use the locally available resources. In the space industry, this is known as in-situ resource utilization (ISRU). What is available on the Moon is primarily regolith, which is loose rock made up of substances including silicon, iron, titanium, aluminum and magnesium oxides. But how can we use these materials to build homes, tools, vehicles and infrastructure? And where does the energy to do that come from? "The day-night cycle on the Moon is different from that on Earth, with 14 days of light and 14 days of total darkness," says Dietz. "Relying only on solar power isn't possible without an efficient energy storage system." ▶





We deliver. Anywhere: Michael Henke (l.) and Axel T. Schulte, both from Fraunhofer IML, develop concepts for logistics in space.

back to page 1



"Lunar processes have to be extremely robust and low-maintenance, operate essentially autonomously and produce virtually no waste, so that materials can be fully recycled."

Georg Pöhle, Fraunhofer IFAM

As part of the DLR-funded Ferrotherm project, Dietz and his team collaborated with the Fraunhofer Institute for Chemical Technology ICT in investigating ways to use the iron oxide in regolith for a type of power plant. "Imagine sparklers from New Year's Eve," explains the research scientist: "They are mostly burning iron powder." The principle developed in the Ferrotherm project is the electrochemical reduction of iron oxide. The resulting iron powder from this process is then burned along with the oxygen that is also released. This produces heat and electricity as well as solid iron oxide that can be easily collected and split back into iron and oxygen in the next step. Dietz: "This is the perfect circular economy." Another advantage of this process is that, unlike power generation using coal, gas or oil, it does not release any carbon dioxide. Dietz believes this also makes the process interesting for terrestrial applications. After all, iron is the fourth most abundant element in the Earth's crust.

According to Dietz, however, it may be some time before iron power plants supply the world's population with electricity, as it is currently easier and more cost-effective for industry to stick with the existing energy infrastructure. But he sees the New Space Economy as an opportunity here: "Startups with unconventional approaches can implement new solutions." His prediction: We'll see iron power plants operating here on Earth before we see them on the moon.

How to produce oxygen on the Moon and on Mars

Lunar processes actually have to fulfill a whole range of specific requirements, explains Georg Pöhle, Group Manager Medical Technology and Functional Materials at the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM in Dresden: "They have to be extremely robust and low-maintenance, operate essentially autonomously and produce virtually no waste, so that materials can be fully recycled. We therefore want to use gaseous or liquid media as little as possible, because it's extremely difficult to handle them under conditions in space." Systems must also be very compact and still lightweight—and able to withstand extreme temperature fluctuations. For example, daytime temperatures on the Moon can reach up to 130 degrees Celsius, plummeting to an average of –170 degrees Celsius during the long nights. "Meeting all these challenges while still developing a highly efficient process—these are the issues that sometimes cause us headaches," admits Pöhle.

The researchers at Fraunhofer are focusing on the so-called ROXY process.



A man for the Moon: Georg Pöhle from Fraunhofer IFAM is working to develop solutions for extraterrestrial production.

This is a method developed by Airbus in collaboration with Fraunhofer IFAM and Boston University by which oxygen and metals can be extracted from lunar dust. To do this, the regolith is chemically reduced in a reactor, i.e. oxygen is separated out from the metal oxides. What remains is pure metal, which can be used to make items such as tools. The ROXY process is considered a key technology for future lunar bases, as well as for sustainable metal production on Earth.

For this reason Pöhle and his team are now developing Mini-ROXY—a compact, very lightweight and hence lunar-capable version of the ROXY process. The demonstrator looks like a bee skep with a height of 30 centimeters, a diameter of 50 centimeters and a weight of 36 kilograms. Earth-based testing of Mini-ROXY is not only about automated continuous operation during the lunar day and lunar night. "As it's difficult to replicate the extreme lunar vacuum in our laboratories, we work under an inert gas. This prevents the materials from reacting with oxygen, hydrogen or nitrogen in the atmosphere," says Pöhle. Parabolic flights or drop towers that briefly create microgravity through controlled free fall can be used for testing in low-gravity conditions. Because sufficient lunar dust is not available on Earth, researchers use regolith simulants that closely resemble the original in terms of particle size, geometry and mineral composition.

The first goal is to produce roughly a liter of pure oxygen under lunar conditions—something that no one has yet managed to do. This is necessary not only to supply future lunar residents with breathable air but also to be able to produce the necessary O_2 for rocket launches on site.

Mini-ROXY could also be useful on Earth, Pöhle foresees: "In an ongoing project, we are already exploring whether we can adapt this process to extract of rare earth elements." Production conditions on Earth are simpler, but here the competition involves all established processes in terms of cost and efficiency: "A process that has an excellent environmental footprint but is three times as expensive will not prevail."

It will be decades before Mini-ROXY will be able to autonomously produce oxygen on a large scale on the Moon or Mars. However, Georg Pöhle and the other Fraunhofer researchers believe it makes sense to address these issues today and develop solutions for extraterrestrial life. "Every technology we are currently using has a long history," Pöhle sums up. "We are developing the technologies now that will be needed in the future. And we are benefiting along the way from many exciting ideas and valuable partnerships that can inspire and improve our lives today." ■

back to page 1

Help on the Farm From Space

What sounds like high-tech for far-away worlds and futuristic scenarios also affects our daily lives: Developments from the New Space Economy are increasingly improving life on Earth. This not only includes more precise satellite systems to improve national security and sovereignty as well as for navigation and weather forecasting. Agriculture and hence global food security also benefit from advances in space technology.

For example, satellites have long been used to monitor fields from high above. In addition to the Sentinel missions, notable examples include EnMAP, Germany's first environmental satellite, and the DESIS hyperspectral instrument on the International Space Station (ISS), for which Fraunhofer IOF developed and fabricated high-precision mirror optics and the telescope system including binary grating optics. However, other than these hyperspectral imaging instruments, most current satellites detect far too few colors in the visible spectrum. They therefore overlook subtle changes due to by factors such as nutrient or water deficiency or stressors such as heat or disease.

This is where the RAINBOW research project comes in with a new technology based on satellite research that also bears the potential to make agriculture more sustainable and resilient in times of climate change. In the RAINBOW project, Fraunhofer IOF is collaborating with Airbus Defence & Space, VISTA GmbH and the Fraunhofer Institute for Surface Engineering and Thin Films IST to develop a new generation of hyperspectral sensors. The goal: an extremely compact, cost-effective spectrometer that can even fit aboard small satellites and provides precise data on agricultural areas.

At the heart of RAINBOW is a telescope that can be used to demonstrate a spectrometer-on-a-chip concept. Designed for series production in small lot sizes, this system provides high image quality despite its miniaturization and achieves a spatial resolution of less than 20 meters. This concept enables integration of all the key functions of a spectrometer into a single chip and analysis of hyperspectral data. "The compact hyperspectral optics enable a detailed analysis of vegetation and soil characteristics from space and could enable functions such as early detection of whether fields are receiving too little or too much water," explains Stephanie Hesse-Ertelt. The physicist is a research manager at Fraunhofer IOF, where she serves as the point of contact for Fraunhofer AVIATION & SPACE. Instead of complex opto-mechanical components, optical filters are used to select the required wavelengths without compromising analytical quality. The hyperspectral filter selects more than 30 spectral bands between 400 and 1,700 nanometers and combines three linearly variable bandpass filters on a glass substrate measuring just one centimeter on each side. This is barely larger than a fingernail but is robust and highly precise.

"The sensor technology, which is based on a telescope with an integrated filter chip, is ideally suited for small satellites and enables scalable applications in future space missions," says Hesse-Ertelt. Beyond the agricultural sector, this instrument could also prove valuable for general Earth observations, such as for monitoring climate-related changes.

Scan for more information about Fraunhofer AVIATION & SPACE



"The sensor technology, which is based on a telescope with an integrated filter chip, is ideally suited for small satellites and enables scalable applications in future space missions."

Stephanie Hesse-Ertelt, Fraunhofer IOF

back to page 1

A voice from the business world



Helena Melnikov, 45, sees a strong common theme between science and industry: For the DIHK chief executive, curiosity is "the best of both worlds."

Hope Is Called Curiosity

The German economy is in crisis. This country was once a beacon of innovation and progress. We can achieve this again: with new ideas and closer collaboration between research and industry.

A perspective from Helena Melnikov, Chief Executive of the German Chamber of Commerce and Industry (DIHK)

New inventions and groundbreaking discoveries are often the basis for economic growth, enriching start-ups as well as small and medium-sized companies and large corporations. One special quality lies at the beginning of every innovation, every advancement and every new technology: curiosity. It is the driving force behind science and the lifeblood of a productive economy. When curiosity in research meets curious companies, the best of both worlds come together: a spirit of discovery and a bias for action. This is precisely the combination that every progressive economy needs to continue developing and remain competitive on the global stage.

Germany has always been a country of innovation. The light bulb, the telephone, the dynamo and the tram, the motorcycle and, of course, the automobile, the 35 mm camera, television, the computer and the chip card: These are all inventions and designs that can be traced back to German pioneering spirit—and which have led to enormous (economic) progress. Curiosity is one of the few renewable resources our country has, and over the centuries we have known how to nurture it and exploit it wisely. This enormous potential should be leveraged especially in the education system so that it can develop into innovative strength. In addition to the sustainable promotion of STEM education, there is also a need for more support for lifelong learning and an efficient higher education system.

However, those who are curious and enthusiastic about progress in this country are continually confronted with new obstacles and setbacks. The economy is no longer growing—for the third year in a row. Investment is not increasing. According to the DIHK economic survey, only 19 percent of companies intend to invest in expanding capacity. This is the lowest figure for this investment objective since 2003. Investment plans for product innovations are also below average. This is not the way for Germany to return to the forefront of progress and innovation.

Bureaucracy and regulations do the rest, qualified specialists are in short supply and talented individuals are migrating abroad. German and European legislation often slows down innovative technologies before they can develop and mature. Risk tolerance is on the wane in politics and society. Exciting innovations are now frequently coming from the USA and China, especially those for future markets such as AI, electric mobility and communication technology. Competition is intensifying in those industries where Germany is still a world leader.

To create new jobs and maintain our prosperity, it is essential that the results of domestic research and development also be applied in our own country. Synergy between research and industry opens up one of the paths that can lead to renewed economic prosperity. Let's embark on this route with curiosity! We advocate for policymakers to ensure freedom and an innovation-friendly environment so that companies can once again focus more intensively on tinkering, experimenting and further development in the future. Along with reducing bureaucratic burdens in the innovation process, living laboratories are a promising tool. They offer companies (and cooperation partners from the scientific community) a low-threshold opportunity to drive innovation more quickly under simplified regulatory conditions, creating new products "Made in Germany."

Consistent collaboration between business and science means that disruptive ideas, efficient processes and innovative services can once again become our strength. The Chamber of Commerce and Industry actively supports this partnership: 140 innovation and technology consultants build bridges between companies and research institutions, share their broad expertise on current developments and innovations and support companies in technology transfer.

In addition to favorable location conditions, a true new beginning requires not only courage and a spirit of optimism but above all that which forms the basis for both science and entrepreneurship: the freedom to give free rein to productive curiosity. Those who can and want to engage must also be allowed to! ■

"140 innovation and technology consultants build bridges between companies and research institutions."

Helena Melnikov

- has been Chief Executive of the German Chamber of Commerce and Industry since January 2025. The DIHK represents the interests of more than three million companies in Germany and is the umbrella organization for the 79 chambers of commerce and industry.
- grew up in Uzbekistan until the age of eight. After moving to Germany with her family, she graduated from high school in Recklinghausen and studied law in Cologne and Bremen. She earned her doctorate in business law in 2009.
- after starting her career as a legal advisor at Neelsen Agrar GmbH, took on a head of department position in the Federation of German Wholesale, Foreign Trade and Services (BGA).
- went on to hold further positions as Chief Executive of Waren-Verein der Hamburger Börse e.V. (commodities association of the Hamburg Stock Exchange) and as Chief Executive and Executive Board Member of the German Association for Supply Chain Management, Procurement and Logistics (BME).

Photo: Werner Schuering

back to page 1

Save Money by Doing Good!

Decarbonization as a business opportunity: Customized roadmaps lead to climate strategies that pay off—for the environment and for the company.

By Beate Strobel

"Decarbonization offers real opportunities for SMEs and large corporations alike, not only to reduce costs but also to reach new markets and customers."

Michael Rentschler, Fraunhofer IPA

The will is there: Nearly all of Germany's largest publicly-listed companies (90 percent) already transparently disclose their direct and indirect greenhouse gas emissions. More than 66 percent have set themselves the long-term goal of reducing Scope 1 and Scope 2 emissions. And a good third is even planning to reduce greenhouse gases occurring indirectly in the organizations' upstream and downstream value chains (Scope 3). This was the finding of the 2024 decarbonization study, for which auditor KPMG analyzed the sustainability reports of the 160 largest companies listed on the DAX, MDAX and SDAX exchanges.

However, the study also revealed that more than half of the companies surveyed (57 percent) are lagging behind their own targets. 63 percent are currently unwilling to predict when they will become climate-neutral or emission-free. Willpower alone is not enough—the path to net zero must also be clear.

A scientific navigational aid for climate targets: In the KliMaWirtschaft project in 2024, the Berlin-based Fraunhofer Institute for Production Systems and Design Technology IPK supported small and medium-sized companies in measurably reducing their CO_2 emissions through holistic climate protection management. "More than 300 small and medium-sized companies have participated in the three-year project and explored climate management solutions," reports Felix Budde, research scientist in the Corporate Management division at Fraunhofer IPK and expert in sustainable business and sustainability management. One of the results of the project is a toolbox (www.klimaschutz-wirtschaft.de/klimaschutztoolbox) that is now freely accessible online and contains more than 90 individual measures to help SMEs develop the right solutions for their own climate strategies.

But we can also take it up a notch. This has been demonstrated by Fraunhofer researcher Felix Budde in a new project: In collaboration with the Fraunhofer Institute for Manufacturing Engineering and Automation IPA and the Fraunhofer Institute for Surface Engineering and Thin Films IST, he advised an international electrical appliance manufacturer in developing a decarbonization strategy for its entire value chain. "At the start of the project, this large industrial company had already identified and implemented a number of individual measures, such as introducing a product class with higher energy-efficiency and using more sustainable materials," explains Budde. "However, they lacked an overall strategy based on practical and reliable data." This situation is currently a reality in many companies.

What is so special about a consortium of three Fraunhofer institutes charting a company's path to decarbonization? "It's probably our scientific approach, which is very strategic and analytical," says Budde. In the project, the researchers not only identified suitable measures but also calculated the costs of avoiding emissions: How will the use of a technology with lower CO_2 emissions affect the bottom line? The individual measures that were already in progress contributed significantly to the complexity of the project, according to Michael Rentschler, research scientist in the Sustainability Modeling and Analytics research team at Fraunhofer IPA. "In the validation phase, we not only had to check the data that had already been collected for compliance with standards,

we also had to evaluate the effectiveness and efficiency of the measures that had already been implemented." The costs were then presented in marginal abatement cost curves (MACCs) and compared with each other: Where does not only the environment benefit from reduced greenhouse gas emissions, but also the company financially?

The researchers advised that the company starts with those measures promising the greatest efficiency. This specifically involved potential materials savings, as eliminating metals or plastics that do not have to be produced in the first place is especially effective in reducing emissions and costs. However, material substitution also plays an important role, such as the use of low-emission steel or secondary aluminum. The Fraunhofer team also presented alternatives with a lower greenhouse effect for the coolants previously used in the electrical appliances manufactured. This highlighted another benefit of using Fraunhofer as a scientific partner for decarbonization, emphasizes Michael Rentschler. "The 75 Fraunhofer institutes have experts for almost every technical question and every industrial process—and we are right there where innovation is taking place in areas such as materials."

The question of transport was also raised: How do the raw materials get to manufacturing and how does the end product get to the customer? "We worked together to identify points in the supply chain where solutions like air freight could be replaced by ships, as well as those points where this would not make sense because the customer might then have to wait too long for the goods," explains Rentschler. The catalog of measures even included recommendations for more generous work from home arrangements in order to manage emissions from commuter traffic.

The Fraunhofer researchers are already working on their next consulting project, developing a decarbonization strategy for the Brazilian steel and cement industry. Their hope is that the approach of viewing climate management as a business case and climate protection measures as an economic option will prevail in the long term. Because: "Decarbonization offers real opportunities for SMEs and large corporations alike, not only for reducing costs but also for reaching new markets and customers," emphasizes Rentschler. Felix Budde adds: "We want to help companies discover these opportunities for themselves—always accounting for economic feasibility and operational reality." ■

Learn more about Fraunhofer's approach to developing decarbonization strategies:

A key point in decarbonization is replacing fossil raw materials such as petroleum.



Photo: peterschreiber.media/istockphoto

back to page 1

Racing Against Corrosion

Two world wars have left their mark on the North Sea and the Baltic Sea. Bombs, mines and grenades are decaying, releasing more and more toxic explosives. Fraunhofer researchers are helping to find them quickly.

By Sonja Endres



The rusting masts of the Richard Montgomery rise high out of the water off the small British coastal town of Sheerness. The American ammunition ship ran aground and broke apart on a sandbar in the Thames Estuary during a storm in 1944. Most of its cargo remains unrecovered: approximately 9,000 explosive devices, including more than 2,500 cluster bombs—and 286 so-called blockbuster bombs, which can weigh several tons.

What is normally hidden beneath the surface is visible in Sheerness. Some 1.6 million tons of unexploded ordnance are decaying at the bottom of the Baltic and North Seas, hidden in shipwrecks or under silt, piled up in heaps or scattered individually across the seabed. The explosive legacy of two world wars threatens not only the marine ecosystem but also people and infrastructure. Recovery is becoming increasingly difficult because the ammunition casings are rusting and becoming brittle. Toxic substances and some carcinogens are released, including TNT, mustard gas, white phosphorus and mercury.

But these ticking time bombs must first be found before they can be retrieved from the water and disposed of. Smart sensor systems are designed to scan the seabed as quickly as possible and identify munitions with a high degree of accuracy. Once their protective casing has completely disintegrated, it is nearly impossible to detect ordnance such as grenades and mines. Expert Sascha Krohmann warns: "It is urgent that we make the search more efficient by significantly increasing the coverage rate, in other words, by surveying a greater area per unit of time."

A unique underwater test site

The marine engineer heads the "Digital Ocean Lab," a unique underwater test site operated by the Fraunhofer Institute for Computer Graphics Research IGD. The site covers an area roughly the size of 1000 soccer fields in the Baltic Sea off the coast of Nienhagen near Rostock. This is where sensor manufacturers, research institutions and salvage companies are performing underwater tests of their latest technologies and the operational capabilities of their systems. There are two so-called UXO gardens available for this purpose, one near the coast and one in deeper water. UXO stands for unexploded ordnance. Dummy munitions as well as real defused bombs and mines provided to Fraunhofer IGD by munitions clearance services and the German Bundeswehr are scattered over and under the seabed in this area. Obstacles are intended to make the area as realistic as possible and provide an additional challenge for the sensors being tested. Krohmann and his team provide a variety of underwater vehicles,



Toxic and explosive: Ships in the heavily trafficked Thames Estuary must give the wreck of the Richard Montgomery a wide berth.

Photo: Krisztian Elek/ZUMAPress/dpa

diving robots and ship-towed instrument platforms into which they integrate sensor systems. "We provide support with our infrastructure and expertise so that the systems can be tested in the water as quickly as possible," says Krohmann. This saves both time and money."

The Bionic RoboSkin team brought their own vehicle along for testing. Research scientists at the Fraunhofer Institute for Reliability and Microintegration IZM joined forces with their project partners, robotics company EvoLogics and salvage company Baltic Diver, in testing a flexible, autonomous underwater robot that looks and moves like a manta ray. It glides over the seabed with its broad wings. It incorporates highly miniaturized, pressure-resistant sensors developed by Fraunhofer IZM that enable mapping of the terrain and can detect metal. Fraunhofer IZM research scientist Marcus Voitel explains: "The principle is the same as that of a metal detector used to search for buried coins." The sensors can detect objects hidden in the mud at depths of up to 50 centimeters. The modules sit on the wings of the robotic manta ray like buttons, each encased in a small housing. They can be easily exchanged depending on the desired measurement function.

Its maneuverability also enables the manta ray to explore tight and difficult-to-reach places. An entire swarm of these devices could autonomously scan the seabed over a large area to detect ferromagnetic objects. "But then we still don't know if someone dropped an old iron beam or if there's actually ammunition there?" remarks Voitel's colleague Karl-Friedrich Becker. "But at least it's a point to start investigating. Additional data sources and technologies have to be added to get a clearer picture."

Examples of this are innovative electrochemical sensors developed by the Fraunhofer Institute for Chemical ▶

Roughly **1.6 million tons** of unexploded ordnance are decaying at the bottom of the Baltic and North Seas.

back to page 1



A team from Fraunhofer IZM used a robotic manta ray to search for bombs.

"The underwater environment places similar demands on sensor technology as in space, perhaps even greater ones."

Sebastian Geiger, Fraunhofer ICT

Technology ICT in Pfinztal near Karlsruhe. Sensor systems engineer Sebastian Geiger clarifies: "I like to compare our system to a bloodhound that can detect explosives underwater." Any suspicious find could then be quickly investigated. The electrochemical nose is currently still mounted on a rover, a remotely operated underwater vehicle. However, it can also be mounted on autonomous underwater vehicles such as the manta ray to complement the existing sensor system. It must be as small as possible but also extremely robust in order to fit as much as possible onto a support system. "The underwater environment places similar demands on sensor technology as in space, perhaps even greater ones," says Geiger. Saltwater is corrosive and contains suspended particles that can contaminate electrode surfaces and block lines. Sometimes there are strong currents, and there are significant fluctuations in pressure and temperature.

Even so, the sensor system developed by Fraunhofer ICT performed well in practical testing in the Bay of Kiel. Here, just two kilometers from the beach in the Baltic Sea resort area of Heidkate, lies one of the largest officially designated munitions dumping sites. After World War II, mines, grenades, bombs and small arms ammunition were disposed of en masse in the Kolberger Heide dumpsite. The intention was to render Germany's stockpiles of weapons unusable as quickly and irreversibly as possible. Geiger reports: "The seabed is contaminated with munitions over an area of about 1,200 hectares." The researchers systematically approached mines with their rover in this restricted area. It is important here, says Geiger, that the electrochemical sensor mounted at the front of the underwater vehicle approach the target against the current. "A bloodhound is best able to detect scents carried to it by the wind."

Sniffing out TNT underwater

Geiger and his team use the cyclic voltammetry method for chemical analysis. "Many substances have their own electrochemical fingerprint," explains Geiger. This can be measured by cyclic voltammetry." The researchers do this by applying a constantly changing electrical voltage to the water sample that is automatically pumped into the sensor head, while simultaneously measuring the current with high precision. Electrical voltages can cause chemical substances to absorb or release. The more electrons migrate back and forth, the stronger the current. The measured current/voltage curve is characteristic for each material.

The electrochemical sensor can detect TNT and other known powerful military explosives such as RDX or HMX at concentrations down to few micrograms per liter. The unit can take a sample roughly every

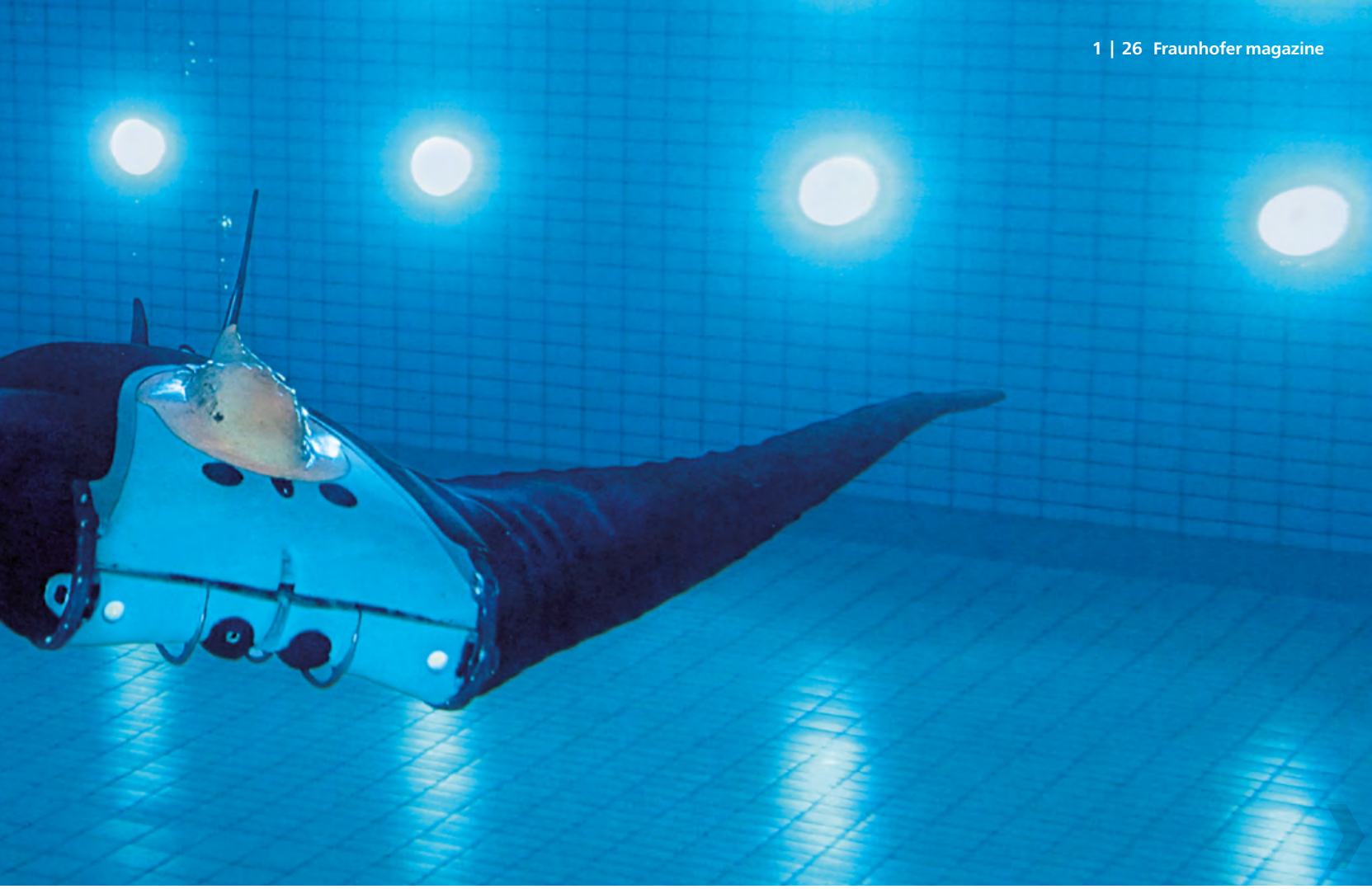


Photo: EvoLogics GmbH

five minutes for over twelve hours without having to resurface. "This would enable surveying and monitoring of larger underwater areas at various measurement points," says Geiger. The research team is currently working on further improving the sensitivity of the sensors.

However, the electrochemical bloodhound can only detect explosives if they are already leaking and are thus present in the water. Geiger explains: "It's like the human body. We don't use only our sense of smell but also other senses, such as hearing, i.e. sonar, to better perceive the situation."

Fraunhofer IGD researcher Sascha Krohmann adds: "Sound waves from sonar travel very well through water. If they are powerful enough, they can even penetrate the seabed." If they encounter objects along the way, the sound waves are reflected and picked up again by underwater microphones known as hydrophones. Depending on the frequency used, the strength and characteristics of the echo can be used to determine the location, material, size or surface structure of the object.

Krohmann and his team are currently collaborating with Danish partners to test equipment including an extremely powerful side-scan sonar, not in the UXO fields this time but off the Danish coast. It is incorporated in an innovative device equipped with numerous other sensors and towed across the seabed by a specialized ship. "This sonar gives us a high-resolution scan of the area around the ship for about 200 meters in every direction, twice as far as with conventional equipment," says Krohmann. It is combined with a multibeam sonar the researchers use to map large areas of the seabed before each search operation and can already detect larger objects and mounds in the sediment. Finally, sub-bottom sonar provides a view beneath the seabed, as does a magnetometer that complements the sonar systems by detecting magnetic objects even behind the edges of inclines or in murky water where sonar images are often difficult to interpret.

"We want to combine and analyze all the data we are collecting here and have already collected in the UXO gardens to narrow down the number of suspicious objects as much as possible," says Krohmann. AI-supported analysis tools should help here. In the future, these tools could determine not only whether clearance is necessary but also the type of grenade or mine, how severely damaged it is and whether it is still capable of exploding. Krohmann and his team have already created 3D images of roughly 20 percent of the unexploded ordnance, with which they are training their AI models. The images also show how the ammunition changes as it corrodes or if parts are already missing. "The more data we have, the more accurate we become," says Krohmann, "and the faster we can rid our oceans of these toxic and hazardous pollutants." ■

back to page 1

If the Fraunhofer-Gesellschaft didn't Exist Today, We'd Have to Invent It

In 2026, the Fraunhofer-Gesellschaft is commemorating the 200th anniversary of Joseph von Fraunhofer's death. The eponym of the Fraunhofer-Gesellschaft will also be remembered during a commemorative year at the initiative of the German Commission for UNESCO. This gives us the opportunity to look into the future from our historical perspective and ask ourselves: What does Germany need to ensure that scientific research becomes value creation and that we remain internationally competitive?



Holger Hanselka,
President of the Fraunhofer-Gesellschaft

Joseph von Fraunhofer was never a research scientist in the traditional sense. He was a craftsman and entrepreneur, a pragmatist who put knowledge to use. He developed optical instruments because they were needed. He always saw a close connection between research and the market. And it is precisely this approach that continues to shape the identity of the Fraunhofer-Gesellschaft to this day. Under competitive conditions, we systematically apply research to create marketable technologies, working in close collaboration with industry and the public sector. In a time when Germany needs to retain its innovative strength while speeding up implementation, this is not merely an end in itself. It is a crucial location factor.

In this sense, I see Fraunhofer as more than just a person or a research organization. The name is also bound to a philosophy and to the personal commitment to understanding scientific curiosity, not merely as a self-justifying goal but instead applying it in a focused manner for impactful benefits and progress. It stands for the conviction that knowledge only realizes its full potential when it reaches and serves society. The questions that motivated our eponym more than 200 years ago are still highly relevant: How can knowledge be put to practical use? How can knowledge become value creation? And how can we organize research such that it benefits Germany as an industry hub and society in general?

Driven by responsibility for our future

I am convinced that if the Fraunhofer-Gesellschaft didn't exist today, we'd have to invent just such an institution. Not out of reverence for the past but out of responsibility for the future.

The consistent focus on implementing scientific findings in real-world applications for business and society is reflected today in the unique Fraunhofer Model. This is what sets the Fraunhofer-Gesellschaft apart in Germany's highly specialized scientific system. In contrast with other non-university research institutions funded almost entirely by base funding from the government, the Fraunhofer-Gesellschaft receives a maximum of one-third of its budget from base funding and must independently generate at least two-thirds of its total business volume in contracts from industry and from public sector clients.

"Joseph von Fraunhofer inspires me in my day-to-day work because his life story—starting as a humble glass grinder to become a visionary researcher and successful entrepreneur—so clearly demonstrates how scientific excellence and market-driven action belong together." This combination of a spirit of discovery and value creation continues to shape our identity at the Fraunhofer-Gesellschaft to this day and is a daily inspiration for me."

We at Fraunhofer are intentionally operating in an economic environment. This promotes an entrepreneurial approach in our thoughts and actions. It also continuously ensures demand-driven solutions to the economic and social challenges of today and tomorrow. This is entirely in the spirit of our eponym, who saw knowledge as the starting point for a successful path toward marketable products, processes and standards.

The need to measure applied research against the competition every day promotes a keen sense of practical application, speed and adaptability. Successful technology

transfer is the backbone of our innovation system. It is our core business and what sets us apart.

We are living in a time when technological, geopolitical and economic challenges are manifestly compounding, innovation cycles are accelerating rapidly and competition is intensifying. Businesses are calling out for speed, government is demanding effectiveness and society needs solutions.

We have every reason to be optimistic

While it's true that Germany is still lagging in some areas, we also have key strengths and every reason to be optimistic, if we can efficiently, effectively and quickly implement our ideas and abilities in real-world benefits.

For the economy to catch up and get ahead, we need close collaboration between scientific research, business and government. We also need to establish conditions that reward speed, investment and boldness. We all have to pull together, and we especially have to pull in the same direction! We need to focus on key technologies, including artificial intelligence (AI), microelectronics and biotechnology, where we can play to our strengths and establish a leading international position.

Let me illustrate this with two examples. One of these is digital sovereignty and AI. Language-based AI systems hold enormous disruptive potential for the economy, for industry and for society. This sector is currently dominated by the USA and Asia. Especially in security-critical industries, however, it is important that the data remains within the company, following the highest security and compliance standards. And it is precisely here where non-European solutions often fail to live up to European market requirements. AI applications in areas such as law, public administration, medicine, industry and security also require an extremely high level of quality, precision, trust and reliability. A national AI language model, or at least a European one, is therefore absolutely necessary to ensure digital sovereignty and economic independence in Europe, as it will enable our economy to utilize the innovative potential of AI systems while remaining digitally independent.

We have partnered with Teuken 7B in the OpenGPT-X project to release the first open-source language model made in Germany. Teuken 7B is above all else a technology that must be put to use. Deutsche Telekom is already showing how this works in practice. It has integrated Teuken 7B in its Business GPT product, with which companies can operate their own AI with a high level of data confidentiality and data security.

The second example is in energy storage, which is also covered in this issue of Fraunhofer Magazine. Battery technology is a key technology for Germany, equally promoting CO_2 reduction, outage resilience, economic growth and technological autonomy and is indispensable for a sustainable future. The energy transition in its current form can only succeed through the use of safe, reliable, high-performance battery storage systems. The need for suitable technology for electrical energy storage will therefore grow exponentially.

Achieving the goals we have set will also require a sustainable circular economy, especially considering global volatility in the accessibility of raw materials. In December of 2025, the Fraunhofer Research Institution for Battery Cell Production FFB demonstrated how Germany can successfully apply its research strength by implementing the first end-to-end process chain using exclusively European plant equipment to produce fully functional lithium-ion battery cells. This is a key milestone on the path to competitive battery production. When the pressure is on, innovation has to respond more quickly. ▶



"The way I see it, Joseph von Fraunhofer stands for combining scientific ways of thinking and world views with a pragmatic entrepreneurial spirit. This is an ideal that is very important to me both in teaching and in my work as a manager."

Axel Müller-Groeling, Executive Board Member for Research Infrastructures and Digital Transformation

"Joseph von Fraunhofer inspires me in my day-to-day work because he had a sharp eye for details and he successfully implemented his visions with dedication and pragmatism."

Sandra Krey, Executive Board Member for Finances and Controlling



Photos: Fraunhofer / Stefan Obermeier

back to page 1

Ingenuity is our country's most important raw material. Our research scientists have never been found wanting in creativity or quality. However, it must be clearly pointed out that ideas are often implemented as innovations in spite of and not because of existing conditions. Far too often, structural hurdles block the implementation of research findings as marketable applications. We need a change in mentality that prioritizes boldness and a spirit of innovation over hesitation and overregulation. Ideas have to be implemented quickly before others beat us to it. Conditions should facilitate this and not impede it or, even worse, prevent it.

What makes us a driving force for value creation

Fraunhofer's core business is knowledge transfer. Every year, our Fraunhofer institutes and research institutions collaborate with thousands of companies ranging from mid-sized market leaders to global corporations to quickly bring innovations to the market, opening up new value creation routes for clients and partners. The Fraunhofer-Gesellschaft works here as an innovative driving force for value creation and job creation in Germany and Europe. Day by day, we work at the interface between research and the market, and we fully understand the associated challenges and processes. We must realize that if we want to be an internationally competitive hub, we urgently need policy conditions that better promote innovation.

"Joseph von Fraunhofer's legacy continues to inspire us today to remain curious, push boundaries and shape the future with openness and team spirit."

Elisabeth Ewen, Executive Board Member for Human Resources, Corporate Culture and Legal Affairs





"Joseph von Fraunhofer has proven that scientific excellence and market viability are inextricably connected." Not only did he establish groundbreaking technology, he also created real added value to the world. We are carrying on this legacy today by boldly transferring knowledge into action, ensuring our technological sovereignty for the future."

Constantin Häfner, Executive Board Member for Research and Transfer

With its High-Tech Agenda, the government has set the right course to strengthen Germany's innovative capacity and sovereignty in global technology competition. We lack the resources to achieve world class results everywhere. The agenda's promotion of development in key technologies such as artificial intelligence, microelectronics and biotechnology is precisely the right approach to ensure that Germany becomes a global leader in these key new technologies. This is an essential step toward achieving technological sovereignty, reducing economic dependence and strengthening international competitiveness. Fraunhofer will fully support the agenda through cutting-edge applied research, regional innovation partnerships and technology transfer into real-world applications. Collaborating closely with industry and the government, we can strengthen Germany's position as a technological powerhouse and ensure its long-term success.

For Germany's High-Tech Agenda to reach its full potential, we can no longer have structural and legal frameworks that hamper the knowledge and technology transfer.

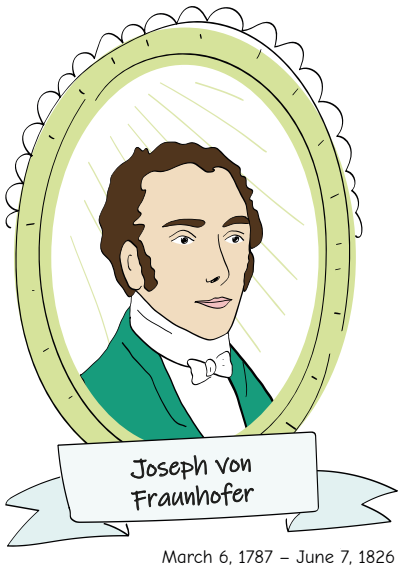
The proposed political reforms aimed at radically reducing bureaucracy and the Freedom of Innovation Act are headed in the right direction and must be implemented swiftly and resolutely. We also need a culture that facilitates spin-offs and entrepreneurial activity, as well as spaces for experimentation and low-bureaucracy test environments where new technologies can be efficiently tested and scaled. The success of historical figure Joseph von Fraunhofer would be more than questionable under our current level of bureaucracy.

Our land of ideas must become a land of action

This commemorative year is thus a task for the present and with a view to the future. Joseph von Fraunhofer became the eponym of a research organization because he put into practice the combination of scientific excellence, artisanal precision and entrepreneurial implementation.

This is a legacy we should build upon. If we take a comprehensive view of research and applied science, industry and politics, we can achieve great things—for our economy and for our future.

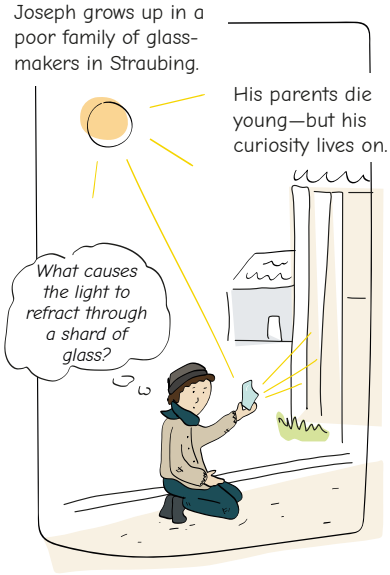
We are a land of ideas. We must also again become a land of deeds and of innovative pioneers with the boldness to turn ideas into reality. That is what Fraunhofer stands for—both the historical person and now the research organization. ■



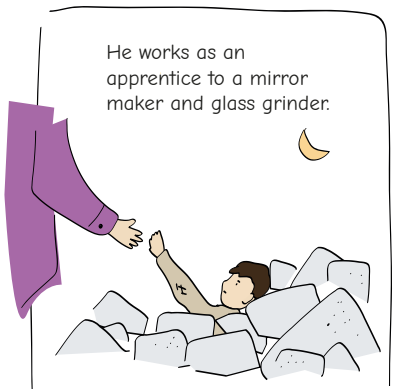
March 6, 1787 – June 7, 1826

Joseph grows up in a poor family of glass-makers in Straubing.

His parents die young—but his curiosity lives on.



He works as an apprentice to a mirror maker and glass grinder.

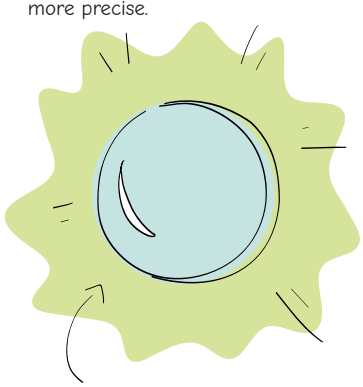


Rescued from a collapsed house, his talent is discovered, and he receives vital support including from Elector Maximilian. A stroke of fate turns into luck.

He joins the Optical Institute in Benediktbeuern in 1806, where he quickly rises to a leadership position.

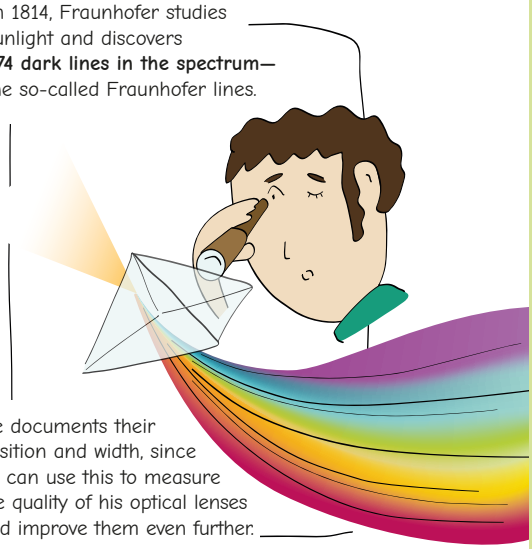


He develops new machines and improves the quality of the glass. This makes the lenses much more precise.



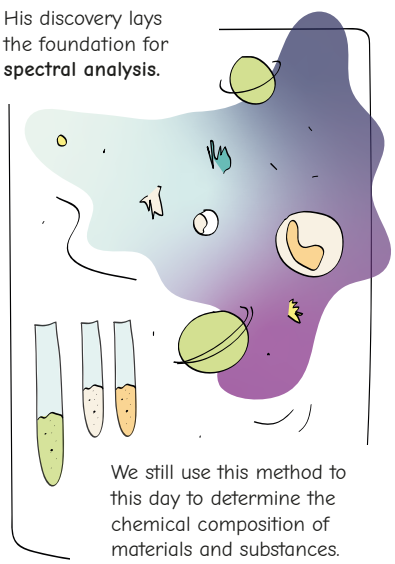
A revolution in manufacturing technology!

In 1814, Fraunhofer studies sunlight and discovers **574 dark lines in the spectrum—** the so-called Fraunhofer lines.



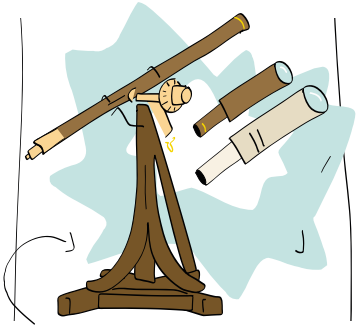
He documents their position and width, since he can use this to measure the quality of his optical lenses and improve them even further.

His discovery lays the foundation for **spectral analysis.**



We still use this method to this day to determine the chemical composition of materials and substances.

He produces the **most powerful astronomical telescopes** of his time and sells his inventions throughout Europe.



Fraunhofer's **Dorpat refractor** was considered the pinnacle of precision engineering and optical technology of its time.

Fraunhofer dies far too young at the age of 39—a successful research scientist and entrepreneur, honored and ennobled.

Yet his work still affects us to this day and serves as a model for many innovations from the **Fraunhofer-Gesellschaft** that have a lasting impact on our lives.

Illustration: Fraunhofer-Gesellschaft / Vivian Ellermeyer

back to page 1



Scanning children: Fraunhofer technology facilitates ultrasound examinations.

Under the Skin

Ultrasound is a popular image modality in pediatrics, as it does not expose patients to radiation. Fraunhofer researchers are now working on automatic spatial documentation of ultrasound images, with the goal of reducing the workload in hectic everyday hospital practice.

By Yvonne Weiss



Photo: Westend61 / Ezequiel Giménez / mauritius images

"Our system reduces the workload for doctors, meaning they have more time for their patients."

Oliver Gölz, Fraunhofer IPA

They show what is happening under the skin, in a patient's thyroid gland, abdomen or lymph nodes—painlessly and without radiation. Several million ultrasound examinations are performed in Germany every year. Sonography is used especially frequently in pediatrics.

But how are the scans documented? It's a time-consuming task. For example, if doctors discover a cyst, they first have to measure it and manually record its position in a 2D pictogram. The position of the ultrasound transducer on the patient's body has to be transferred to the screen of the ultrasound system. Not only is this step potentially inaccurate—it also takes up about a quarter of the treatment time.

Researchers at the Fraunhofer Institute for Manufacturing Engineering and Automation IPA in Mannheim are working on a more efficient solution. In the SonoMap project, they are developing a system that can automatically document the recording positions of ultrasound scans and visualize them in three dimensions.

A 3D camera is used for this: In addition to color information, it also calculates the spatial distance of each pixel. Unlike conventional cameras that only provides a flat color image, 3D cameras enable depth perception. So far, 3D cameras have been used in products such as smartphones, VR glasses and agricultural robots. They are a novelty on the ultrasound market.

In the new documentation method, the system automatically determines the recording position of the ultrasound probe using the 3D camera and records it in a three-dimensional image. The camera also documents the angle from which the image was taken. This is a crucial advantage, says Oliver Gölz, project manager and research scientist at Fraunhofer IPA: "The side and angle from which an object is scanned makes a visible difference. The additional tilt and angle information in the 3D image could help to locate tumors or cysts more quickly, making follow-up examinations more efficient."

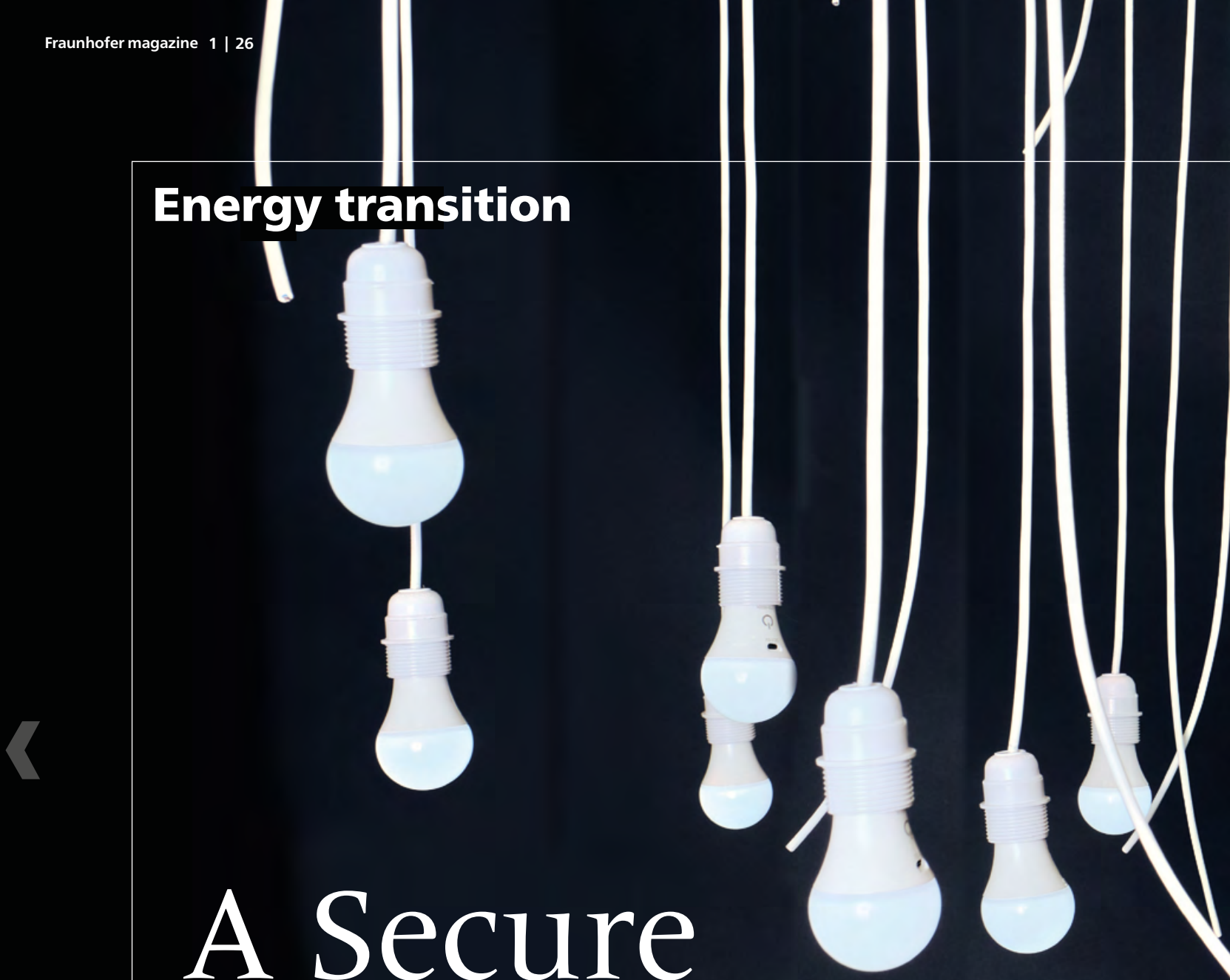
Once the 3D camera has identified the ultrasound probe and measured the surface of the patient's body, AI-based image processing algorithms determine the position of the ultrasound device relative to the abstracted body. The new system uses this data to create a 3D visualization. This allows the patient's body to be viewed from different angles.

"Using our new system, doctors only have to save the ultrasound image and the spatial documentation is generated automatically," explains Gölz. "This makes the process potentially faster and more accurate."

A demonstrator for the new technology has already been developed and will be used in an upcoming study. Later on, the researchers want to work with industry partners to equip ultrasound systems with the new function.

The team is currently ensuring that the 3D camera only takes secure images, ensuring patient data protection. Gölz is looking forward to what lies ahead: "I'm excited that we can tackle problems from everyday clinical practice head-on. Our system reduces the workload for doctors, meaning they have more time for their patients." ■

back to page 1



Energy transition

A Secure Energy Future

The power grids are old and the energy sources are new—not an ideal mix. Fraunhofer researchers have developed innovative solutions for keeping the lights on in Germany.

By Janine van Ackeren; Photographer: Heinz Heiss



Digital solutions: Christof Wittwer from Fraunhofer ISE wants to improve the resilience of the power grid with an early-warning system for grid operators.

"Expanding the grid infrastructure to include renewable energy sources should be a clear priority."

Christof Wittwer,
Fraunhofer ISE

back to page 1

Berlin, January 3, 2026: An arson attack cripples parts of the power grid, leaving 45,000 households and over 2,200 businesses in the southwest of the capital in the dark. It takes four days before power is restored. France and Great Britain, January 9, 2026: Storm "Goretti" sweeps across the country overnight with winds of up to 200 kilometers per hour, leaving 55,000 households in Great Britain and more than 380,000 in France without power in its wake. Spain and Portugal, April 28, 2025: Voltage surges, frequency fluctuations and a complex chain reaction trigger a twelve hour long power outage in Spain and Portugal—the largest disruption in the European power grid in 20 years.

> "We are living in a new situation—we never anticipated attacks like this many years ago."
>
> Kerstin Andreae, Chair of the Executive Board of the German Association of Energy and Water Industries

As widely varying as the causes of these power outages may be, they all have one thing in common: They show just how vulnerable our power grid is. For example, the German power grid contains numerous bottleneck power poles that are easily located and even easier to damage—and whose failure would have serious consequences. Fire-resistant enclosures would be required but are still not available. "We are in a new situation—no one anticipated attacks like this many years ago," explains Kerstin Andreae, chair of the executive board of the German Association of Energy and Water Industries. "Physical protection of critical infrastructure must therefore be a top priority on the political agenda." The German Federal Cabinet is responding with a draft bill for the KRITIS Umbrella Act, which takes an overall federal and cross-sector approach to protecting critical infrastructure. In the future, every operator must take appropriate measures to respond to the specific risks to its facilities.

The monumental task of ensuring stability

This is far from the only challenge facing grid operators. "Every protection measure for a line costs money—we are trapped in a dilemma between economics, cost-effectiveness and system robustness." "Expanding the grid infrastructure to include renewable energy sources should be a clear priority," says Christof Wittwer, Head of the business unit Systemintegration at the Fraunhofer Institute for Solar Energy Systems ISE. "The entire energy transition currently hinges on our aging power grid." This transition continues apace: In the third quarter of 2025, 64.1 percent of electric power domestically produced in Germany was already from renewable sources—two percent more than in the third quarter of 2024.

The sticking point: In their current form, renewable energy sources do not provide the instantaneous reserve needed to act as a buffer for short-term fluctuations in the power grid. Until now, these fluctuations have been absorbed by the inertia of the heavy generators and turbines in large coal-fired or nuclear power plants. They have been able to balance out load peaks and stabilize the grid frequency by transferring rotational energy into or out of the grid. However, the new decentralized systems lack these heavy flywheels—so the necessary instantaneous reserve must be provided by other means. The rule of thumb: The fewer large power plants, the fewer flywheels, the greater the instability. "Expansion of the power grid and the associated changes are highly complex," says Wittwer. "Where grid operators used to have to intervene in grid operations once or twice a day, roughly 500 interventions are now necessary every day." This means higher costs for customers.

The weapon in fighting fluctuations: AI

Artificial intelligence should provide support in the monumental task of maintaining grid stability and preventing chain reactions and power failures. In the eKI4DS project (Explainable AI for dynamic stability), Simon Eberlein from the Fraunhofer Institute for Energy Economics and Energy System Technology IEE and his colleagues are investigating just how this could look at the transmission grid level, i.e., at the highest voltage levels. Chip manufacturer NVIDIA and grid operator TransnetBW are involved as associated partners.

The scene is in the grid operator's control room. The AI should immediately detect critical situations, alert human operators and provide them with suggestions for possible corrective measures. All this in a way that it is easy to understand, which is hardly always the case for typical AI systems. This is made possible by AI methods such as machine learning, the necessary architectures for which are available. The challenge lies especially in feeding the AI model with current data on the state of the grid: consumption, generation and the type of energy, i.e., renewable or conventional. The AI is extremely voracious: Thousands or even millions of simulations are necessary to prepare it for all eventualities. This is a high-performance computing task that pushes conventional commercial software to its limits. ▶



Automated grid analysis: Dennis Rösch at Fraunhofer IOSB-AST is developing an AI agent solution to help grid operators make operational decisions to ensure that the kettle is always ready to make hot water.

"GridCompanion should help limit power failures like those in Spain to smaller regions or even prevent them entirely."

Dennis Rösch, Fraunhofer IOSB-AST

back to page 1



"An exchange of information on the European level is essential. We must have coordination and a shared understanding."

Diana Strauss-Mincu,
Fraunhofer IEE

A united Europe:
In the EU InterSCADA project, Diana Strauss-Mincu is working to detect anomalies throughout Europe at an early stage.

Open-source software developed by the team helps lighten this load. At its heart is a complex, massive model of the German transmission grid with 1,500 nodes. The distribution grids leading to end users are represented in simplified form by a load on each node. "The open-source software is essentially the toolbox used to train the AI model and then to run it," says Eberlein. The AI has already shown its mettle on smaller test grids in a control room prototype developed by Fraunhofer IEE.

Digital colleague analyzes voltage spikes

AI always needs people to keep the grid stable. However, it is becoming increasingly difficult to find well-trained staff. "The training period for operators in grid control centers is one to two years. This is a challenge given current high employee turnover rates," explains Dennis Rösch, Group Manager at the Fraunhofer Institute for Optronics, System Technologies and Image Exploitation – Advanced System Technology branch IOSB-AST.

An AI agent solution named GridCompanion that Rösch and his team are developing is intended to assist grid operators with operational decisions in the future. "GridCompanion allows data storage and analysis systems to exchange data and automates the analysis," says Rösch. As for eKI4DS, this is by no means a black box despite the use of AI. An AI agent is at work here, calling up and operating the various deterministic analysis tools. This is a type of digital colleague that performs the standard analysis steps and provides the results to the operator for a decision—automatically, of course. "The human operator receives both the prepared analytical data and a usable list of potential causes for the current faults," explains Rösch. A pilot project involving three German grid operators was started in February 2026. The researchers want to use this to define and develop a specific use case for each operator. An example is fault prioritization. If multiple faults occur at the same time, which one should the operator deal with first? The system could already be supporting human colleagues in the control rooms within one or two years. "Of course this doesn't grant immunity to attacks such as the one in Berlin, since it won't help to optimize work processes in the control center if the functioning communication lines are gone," explains Rösch. "In the future, however, GridCompanion should help limit power failures like those in Spain to smaller regions or even prevent them entirely. Such outages are due primarily to grid fluctuations and could be resolved through active intervention by the control center."

> "The open-source software is essentially the toolbox used to train the AI model and then to run it."
>
> Simon Eberlein, Fraunhofer IEE

Open-source platform strengthens European cooperation

Of course grid stability is not just a problem in Germany; it represents a challenge for all of Europe. After all, the power grid operates as an interconnected system in Europe. It is thus wholly conceivable for a fault in the Spanish grid to propagate through France and on to Germany. "An exchange of information within Europe is essential. We must have coordination and a shared understanding," says Diana Strauss-Mincu, group manager at Fraunhofer IEE. The EU InterSCADA project with 18 partners from 9 EU countries and from Taiwan is intended to strengthen cooperation among European grid operators. The researchers are developing an open-source platform for data collection, remote monitoring and power grid control for advance detection and correction of anomalies throughout Europe. Experts refer to a supervisory control and data acquisition platform (SCADA). The system is modular, enabling grid operators to customize the platform themselves and add additional modules.

Contributions from the Fraunhofer team include a module for monitoring and estimating synchronous inertia. This is based on measurement systems that are already integrated at various points within the grid. The remaining parameters are approximated by the state estimation module. "Our algorithm filters the measured data, processes it and uses it to calculate the inertia of the grid," says Strauss-Mincu. Adjusting the algorithms is especially tricky. Fraunhofer laboratories are also providing the decision support module. A digital twin of the grid enables the analysis of various faults and their effects on the grid with no risk to the real grid, as well as investigation of the results of different stabilization measures. The inputs to the digital twin are the current inertial monitoring data and the state estimation data. In the future, the new module should provide grid operators with a prioritized list of stabilization measures. Strauss-Mincu: "InterSCADA should help improve grid stability and reduce the probability of outages in the future."

Promise for the future: grid-forming inverters

The grid itself also offers some possibilities for ensuring stability as further renewable energy capacity is added. Grid-forming inverters offer great promise. The ▶

back to page 1

background: Renewable energy systems such as solar panels and wind turbines need an inverter to convert the direct current they generate into alternating current before feeding it into the grid. The same is true for battery systems. Thus far, this has been implemented to follow the grid. The system synchronizes with the grid frequency so as not to cause any significant fluctuations. But the result is that even slight fluctuations in grid frequency will force solar installations as well as, increasingly, battery systems, to follow suit. Grid-forming inverters can actively stabilize the frequency and voltage and help to maintain them at target levels. In this way, they can replace the inertia of conventional power plants that are taken offline, thereby improving resilience to grid faults. The first grid-forming inverters are already on the market, although standardized behavior on the grid remains an issue. The system must be positively damped and standards must be established across manufacturers. Starting this year, there is also a market for instantaneous reserves on which this capability can be traded.

Fraunhofer ISE researchers are taking on this issue from multiple angles. Grid faults can be simulated in the in-house multi-megawatt laboratory and the response of the test systems analyzed at extremely high time resolution. In collaboration with the four German power transmission system operators, the researchers first developed a suitable measurement and analysis procedure as well as a catalog of requirements to enable comparison of the devices. They then tested as many grid-forming inverters as possible. How effective are they at stabilizing the grid under various conditions? Wittwer's requirements: "The system design must be highly efficient, compact and scalable, and it must be possible to manufacture it competitively in Germany as a cutting-edge technology."

In the SUREVIVE project, the team is going a step further in collaboration with partners, investigating for the first time



Communication: Marc Richter and Christoph Wenge have developed a type of control center at Fraunhofer IFF to network grid operators, fire departments and other agencies.



the degree to which grid-forming inverters stabilize the German power grid. Who needs these systems, where, and how many? How do they have to be controlled and parameterized to achieve the optimal effect throughout the entire interconnected grid? As part of this study, project partner

> "We want to reduce and compensate negative effects on the grid, improve the quality of supply, reduce the load on operating equipment and make optimal use of the existing grid infrastructure."
>
> Christoph Wenge,
> Fraunhofer IFF

Schoenergie has, for the first time, directly connected a grid-forming battery system with a 20-megawatt power capacity and a 55 megawatt-hour storage capacity in Föhren in Rhineland-Palatinate to a substation operated by distribution grid operator Westnetz. To minimize the risks of this field test, researchers at Fraunhofer ISE first analyzed the grid-forming characteristics and behavior in the multi-megawatt lab. In the future, battery storage ▶

back to page 1

systems with hundreds of megawatts of storage capacity could balance the energy supply as needed, while also stabilizing the grid and providing the necessary instantaneous reserve capacity that was previously supplied by conventional power plants. This will all have no effect on the end consumer.

A digital twin with sensing eyes

Researchers at the Fraunhofer Institute for Factory Operation and Automation IFF are also working on integrating grid-forming inverters into the grid as a stabilization action in combination with battery systems. They are developing suitable intelligent algorithms and power electronics systems in the joint research project ALene, a collaborative partnership of industry, grid operators and research organizations. "We want to reduce and compensate negative effects on the grid, improve the quality of supply, reduce the load on equipment and make optimal use of the existing grid infrastructure," explains Christoph Wenge from Fraunhofer IFF. In short, to improve grid resilience.

Innovative measurement technology represents one step toward this goal since an appropriate response first requires knowledge of what is happening in the grid. "Our online impedance measurement (a measurement of electrical resistance) enables us to monitor grid status continuously in real time. That's unparalleled," says Wenge. Changes and destabilization are immediately apparent." If taken at all, such measurements currently have a one-minute scan rate maximum, that is, one measurement per minute. Disruptions can manifest themselves within milliseconds, though, continuous online monitoring and automated processes are needed to regulate them. That is why the measurement systems immediately relay their data to the control center where algorithms model grid status, ascertain the optimal setpoint and transmit it to the inverters so that they can work to stabilize the grid.

While the partners are focusing on the instrumentation and controls, the Fraunhofer IFF research scientists are creating a digital twin that models the complete system. "We are dealing with the question of how to generate the optimal control signal from the measurements. This covers the entire data processing logic: taking measurements, identifying countermeasures, providing control algorithms and issuing appropriate control commands. In other words, we are developing the interface between monitoring a nd control systems," explains Wenge. The grid-forming inverter has been finished and the battery system is ready at Fraunhofer IFF, too. They will be merged and combined with the metrology in the coming months. How could this system have helped in Berlin? "After the attack, real-time grid status was unavailable," says Wenge. In particular, real-time information on the extent of grid disruption and the limits of functioning areas was lacking—this left everyone blind to an extent." ALene is intended to change this in the future.

> "Optimized coordination processes, are needed, especially to provide consistent information to the public quickly."
>
> Marc Richter, Fraunhofer IFF

Strong in emergencies

Berlin shows that improvement is needed in communication too in an emergency. "The events in Berlin showed that communication between grid operators, the emergency response team, emergency management and the fire department in complex situations can be made even better." "Optimized coordination processes are needed, especially to provide consistent information to the public quickly," says Marc Richter, head of department at Fraunhofer IFF. He and his team have developed a type of control center with the Integrated Operations Center IOC, which merges the data on power generation, transmission, storage and consumption in one unified system. "The IOC functions as a cross-domain information hub. This reduces interpretation errors and prevents teams from working with different overviews of the situation because of contradictory assessments or gaps in communication, for instance." explains Richter.

The IOC is also used as a research and test facility at Fraunhofer IFF. The project being worked on there together with Siemens and grid operator 50 Hertz is ODAL, short for Operator-Centered Digital Assistance Systems in Modular Control Systems." It is essentially about helping control center staff with digital assistance systems and tools in hectic emergency situations. The team is developing training scenarios for this: How does the operator respond to the emergency? Do they do the right thing and do they do it fast enough? Can the process be improved? These data are used in turn to train an AI. For instance, the grid can normally handle a single line failure easily. Things get complicated when multiple lines go down at the same time because of a cyberattack or cascading failures, for instance. One of the distinctive features of ODAL is that the AI autonomously designs and prioritizes such scenarios and develops solutions. In other words, the scenarios are generated automatically. ▶



Electric cars as an emergency reserve: At Fraunhofer IEE Marco Jung is developing methods that can use the batteries in electric vehicles in the event of power failures.

Where can we get electricity from during power failures? Marco Jung from Fraunhofer IEE is working to improve stability in bidirectional charging.

back to page 1

Preventing a domino effect

Ideally, control room staff should never have to face such stressful situations in the first place since the grid infrastructure is resilient to disruptions. But how can the power grid be protected against floods, storms and terrorist attacks? Researchers from Fraunhofer ISE, EMI, IEE, IEG and IOSB are following up on this question in the Resist project, ongoing until summer 2026. They have defined three fault scenarios for this: technical defect, cyberattack and natural disaster. They simulated these scenarios in various configurations on a general digital twin on the level of the distribution grid. "The digital twin helps us understand and represent the grid and identify potential faults as reliably as possible," says Wittwer. To what extent can the power supply be maintained before, during and after a fault? What needs to be improved? The increasing complexity of the grid poses a major challenge, increasing its vulnerability and potentially triggering cascade effects, a sort of domino effect that also causes blackouts in other areas. A decentralized power grid structure with grid-forming battery systems and fallback logic in the IT systems offers a promising outlook here.

The data for the fault scenarios recorded by the researchers using the digital twin is bundled, analyzed and visualized in the resilience monitor. A planning tool enables the identified resilience criteria to be incorporated in the planning of future grid infrastructure in order to prevent power outages as much as possible. "The resilience monitor also serves as a kind of early warning system for grid operators," says Wittwer. It indicates the current stability of the power grid and enables predictions, enabling earlier identification and resolution of critical situations."

To increase the resilience of the power grid in major outages, Wittwer and his team also investigated the use of grid-forming inverters in the distribution grid. These could form local island grids, so-called microgrids, in combination with large batteries, maintaining the power supply to affected areas. In this study, the researchers took a battery inverter they developed in the NETfficient project and integrated it in the Digital Grid Lab, which is a digital twin of the grid. This places real test components, in this case the battery inverter, in a virtual power grid. The virtual grid simulates various faults, calculates their real-time effects on frequency and voltage and then applies these results to the real equipment. "We are studying the interaction between the component and the power grid and how the response of the component affects the grid," explains Wittwer.

> "This would revolutionize the emergency power supply provided by the fire department and THW."
>
> Anton Gorodnichev, Fraunhofer IEE

Emergency power supply from electric cars

"Couldn't we take energy from car batteries instead of large battery storage systems to bridge grid outages?" pondered Anton Gorodnichev and Marco Jung from Fraunhofer IEE. "Prerequisite for this is bidirectional charging, where the car's battery can not only charge but can also feed power back into the grid," says Jung. The idea of drawing on electric car batteries during dark lulls to balance out grid bottlenecks and to then fully recharge the batteries when there is a surplus available is not entirely new. The concept is known as vehicle-to-grid. In the Charging Infrastructure 2.0 project, Fraunhofer IEE researchers have already successfully tested this approach in Munich and Hamburg in collaboration with automotive supplier Vitesco Technologies. Barcelona-based wallbox also relies on this model. An AI developed by the company intelligently uses the energy stored in the batteries while still leaving cars with sufficient reserves for their use. In this way, wallbox saves more than 20 percent on its energy costs—a prime example waiting to be followed.

Fraunhofer IEE is also developing the innovative Vehicle-to-Grid+ system in the CombiPower project. This is not primarily intended for long-term grid stabilization but can be used with grid-forming control to generate emergency power during power failures. "One or more vehicles can form their own island grid—independent of the main power grid." This turns the vehicle into a mobile grid-forming system. Local renewable sources such as solar power or battery storage systems can also be integrated," explains Gorodnichev. A vehicle battery has a storage capacity of 90 kilowatt-hours, while the average household uses roughly 10 to 15 kilowatt-hours a day. A vehicle like this could thus power a household for a week. This time could be further extended by also integrating solar panels or diesel generators.

Researchers in the RuBICon project have demonstrated the essential viability of this approach and that the resulting island grid can later even be integrated in the normal power grid. Gorodnichev explains: "We simulated an entire street block with simulated households and supplied them with power via a grid-forming inverter. We are also thinking ahead here. This would revolutionize the emergency power supply provided by the fire department and the German Federal Agency for Technical Relief (THW)." So there is hope for Berlin—and beyond. ■



Energy Storage to Beat the Winter Doldrums

Dark lulls bring our power grid to its knees. Innovative storage technologies can bridge the energy shortfall. Fraunhofer researchers are undertaking projects including commissioning the largest vanadium redox flow battery storage system in Europe to date. An overview.

By Beate Strobel

Dark lull: the term alone speaks of gloom. It actually refers to the fact that our latitudes experience fewer hours of sunshine in winter, with occasional periods of calm. But because more than half the thirst for energy in Germany is slaked by wind and solar power, these winter circumstances affect the energy market. Energy prices increase rapidly during dark lulls due to the rules of supply and demand.

This situation can be mitigated by a method humans have traditionally employed during the winter months: storing up. However, unlike potatoes or vegetables, electric power is not so easily stored in the basement to cover dark lulls. Because of this, researchers are now focusing more heavily on new forms of energy storage to save the renewable energy from periods of high production for times when hardly any electric power can be generated.

Electrochemical storage

Two words are heard especially often when speaking of the energy transition: batteries and storage. This generally means electrochemical energy storage, ▶

back to page 1



a principle that is in use nearly everywhere today: in smartphones, in electric cars, in home batteries for solar power systems and increasingly also in large-scale storage power plants.

Every battery consists of electrodes of two different materials, separated by a liquid or gel, which is the electrolyte. The materials differ in how readily they accept or release electrons. Charging the battery forces electrons to migrate from one electrode to the other. The energy to do this is stored inside the battery in the form of chemical changes. When the battery is subsequently discharged, this process runs precisely in reverse: The electrons want to return to their origins, and they do so by flowing through an external circuit. This flow of electrons is the current that then operates a device or provides electric power to a building.

No fuel is therefore burned on charging and discharging; all the work is done by atoms and ions migrating back and forth between the electrodes, where chemical complexes are formed or broken down. Batteries also differ with regard to the materials used. For example, lithium ion batteries are light, powerful and can absorb large quantities of energy, explaining their widespread use in smartphones and electric cars. Other systems such as sodium ion batteries, redox flow storage systems or high temperature batteries rely on other materials and are suitable for very different application areas. These can be large energy storage systems for solar installations and wind farms, long service-life storage systems for industrial facilities or cost-effective solutions for areas where lithium is scarce or expensive.

Electrochemical storage systems can be used nearly everywhere. Applications include home systems for overnight use of solar power stored during the day, in industrial operations to smooth out peak loads, in power grids to equilibrate frequency fluctuations and in vehicles of all types. They supply the energy where it is needed and exactly when it is needed. This is crucial in a world that is relying increasingly on renewable energy.

In the summer of 2025, the Fraunhofer Institute for Chemical Technology ICT started research operation for the largest vanadium redox flow battery storage system in Europe to date. A redox flow battery stores energy in liquid electrolytes. The battery includes two large tanks filled with two different fluids for this purpose. Each of these fluids contains chemical substances that can receive or give off electrons. On charging and discharging, these fluids are pumped through a reaction cell in which the actual electric power generation takes place. The storage system developed at Fraunhofer ICT can provide an output of up to two megawatts and can store up to 20 megawatt-hours of electrical energy. This is enough to provide power to several hundred homes for many hours. The facility is located on the institute grounds in Pfinztal and is coupled directly with a two-megawatt wind power plant.

An initial practical test demonstrated that renewable energy can be fed into the power grid from this storage system when the wind is not blowing. This represents a clear step towards a stable power system, says project manager Jens Noack, team leader for flow batteries in the Department of Applied Electrochemistry at the Fraunhofer ICT and associate professor at the University of New South Wales in Australia. A system like this could help provide a reliable supply of clean electricity to remote locations, businesses or entire energy villages, even if they lack a solid connection to a public grid.

Mechanical energy storage

Mechanical energy storage is among the oldest and most robust methods for storing energy for later. Mechanical storage systems rely on simple but highly effective physical principles: potential energy, kinetic energy and deformation energy. In this method, energy is stored in purely physical form, with no chemical reactions, no rare earths and usually with a long service life.

For example, compressed air energy storage systems use excess electrical energy to power compressors that force air into underground caverns. This increases the pressure and temperature of the air. The energy is then held in the compressed air. The higher the pressure, the more energy is stored. As soon as the air expands again, it can drive turbines that in turn run generators to feed electric power into the grid.

In the KompEx LTA-CAES® modular joint research project, the Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT developed a system with a modular design and a combination of turbo and piston machinery that enables location-independent compressed air energy storage systems. The technology draws on the fact that air is strongly heated when compressed and similarly cooled when expanded, storing the resulting process heat and reusing it on expansion. It therefore does not rely on fossil fuels. Yet another aspect: The same machine unit can be used for both storing and releasing energy, while conventional compressed air energy storage systems require separate machine units. This eliminates the need for an entire shaft train, which contributes to reducing costs.

Another interesting approach is the principle of pumped-storage power plants. In the traditional version, excess energy is used to pump water from a lower reservoir to a higher one. When electric power is needed, the water is routed back to the lower reservoir through a turbine that generates electric power in a generator. In the Stored Energy in the Sea (StEnSea project), research scientists at the Fraunhofer Institute for Energy Economics and Energy System Technology IEE want to transfer this principle from land to the oceans: 400-ton hollow concrete spheres are anchored to the seabed and are charged by pumping them dry using surplus energy from offshore wind turbines. To discharge the spheres, water is simply allowed to flow

back in, generating electricity as it passes through turbines. Following a successful test with a three-meter sphere in Lake Constance, another test run is scheduled for late 2026 as part of the StEnSea 2.0 follow-up project, this time off the coast of California and on a significantly larger scale.

Thermal energy storage

Heat is one of the most important forms of energy in everyday life: it heats homes, drives industrial processes and brings our bathwater to a comfortable temperature. However, heat is often available when we don't need it at all, such as solar heat in the middle of summer or waste heat from factories at night. Thermal energy storage systems enable flexible use of this heat over time.

In the simplest form of thermal energy storage, a material such as water, sand or stone is simply heated. It absorbs energy in this process, and it gradually releases this energy again as it cools. Storage systems like this are robust, affordable and are already in wide use in both households and district heating networks. However, as is well known from using a hot water bottle or thermos, these systems lose efficiency over time as they release heat into the surrounding environment, so they are best suited as a storage option over a time frame of hours to a few days.

A more elegant approach makes use of phase transitions. When a substance melts, it stores large amounts of energy with no change in temperature. Its temperature does not begin to rise until it has completely liquefied. This principle is utilized in so-called latent heat storage systems. The materials used—often paraffins or specific salts—are selected for a melting point at exactly that temperature where they will later be heated or cooled. This permits temperature fluctuations to be balanced out and also enables the storage of large amounts of energy in a small space. Although the process is more technically complex, it is ideal in cases where a constant temperature is required or space is limited.

The third variant is thermochemical storage, which embodies the next step towards a thermal battery. Here, heat is incorporated into chemical bonds, such as by heating a substance to remove bound water or to modify its molecular structure. This reaction can later be reversed, such as by adding water. This releases the stored energy. The benefit: These storage systems lose virtually no energy over months or even years because they are not subject to maintaining a constant temperature. This makes them ideal for seasonal storage, such as storing summer heat to make it usable in winter.

In the ISSDEMO project, Fraunhofer UMSICHT is working together with multiple partners to develop a novel heat storage system that responds especially quickly and withstands very high temperatures. This storage system is based on a special metal alloy that can absorb and release large amounts of heat on melting and subsequent solidification. This enables a flexible, environmentally friendly supply of process steam as is needed in many factories, using heat from renewable energy sources instead of fossil fuels.

This thermal storage system works on the principle of phase change: the metal alloy absorbs a large quantity of heat on melting and releases this heat when it solidifies again. In this project, the storage system is being further developed so that it can deliver high temperatures of 250 to 500 degrees Celsius and can store enough energy for reasonable implementation in industry. This would then convert renewable electricity directly into heat for production processes.

Chemical energy storage

This form of energy storage is not based on temperature or pressure but rather on the structure of molecules. Every chemical substance contains a certain amount of energy stored in its interatomic bonds. If a chemical reaction is triggered, these bonds can absorb or release energy. Chemical storage systems thus use energy to change chemical forms. The process then runs in reverse for subsequent energy recovery.

For example, water can be broken down into its components of hydrogen and oxygen by supplying electric power. The hydrogen produced contains energy without heating or motion: It is simply stored in the actual molecules. This energy is released again when the hydrogen reacts with oxygen to form water. This type of storage is especially interesting because it enables far larger quantities of energy to be stored than in conventional batteries.

The Reference Factory.H2 at the Fraunhofer Institute for Machine Tools and Forming Technology IWU has developed so-called hydrogen microgrids to temporarily store electrical energy that is not immediately needed. The core element here is the HyVentus electrolyzer developed at Fraunhofer IWU. These hydrogen microgrids convert and store excess electrical energy from renewable sources as hydrogen. When the energy is needed, fuel cells convert the hydrogen back into electric power. The microgrids installed in shipping containers are especially well-suited for decentralized energy networks.

The container-based solutions store excess solar and wind power in the form of hydrogen, even enabling seasonal storage if necessary. Unlike traditional battery solutions, they can store large quantities of energy over extended periods of time, as hydrogen has a very low self-discharge rate. This aspect makes it ideal for seasonal energy storage. At the same time, the microgrids bridge dark lulls when neither wind nor the sun are available.

Examples of potential users of this technology could include hospitals due to the oxygen produced during electrolysis. This could be used as medical oxygen or for purifying and disinfecting water. ■

back to page 1

Electric Power from Wood

Lignin, a byproduct of pulp processing, has mostly been thermally recycled until now. But now it is a building block in new energy storage systems—made in Thuringia.

By Kathrin Schwarze-Reiter

Saws whine in the sawmill. Trunks are split and wood fibers are exposed. What remains behind cannot be processed for added value: wood chips, bark—and a brown, fibrous substance known as lignin. An estimated 50 to 70 million tons of material are generated worldwide each year. Available in plenty—but hardly used at all thus far. Lignin is generally burned in boilers for power generation.

"Lignin is not waste; it's an exciting byproduct," says chemist Lukas Medenbach at the Fraunhofer Institute for Ceramic Technologies and Systems IKTS in Arnstadt, Thuringia. What was previously incinerated is now the center of the ThüNaBsE (Thuringia Sodium-Ion Battery for Scalable Energy Storage) research project funded by the Free State of Thuringia. Researchers from Fraunhofer IKTS and Friedrich Schiller University Jena, both partners in the Center for Energy and Environmental Chemistry (CEEC), are developing a novel sodium-ion battery in which lignin plays a central role. From byproduct to an energy storage component—the negative electrode of a battery.

Lignin is the substance that holds wood together. While cellulose forms the long fibers with their tensile strength, lignin acts as a natural adhesive: it interlinks the fibers in a matrix, making wood hard, resistant and long-lasting. The chemical makeup of lignin comprises biopolymers made from various aromatic carbon building blocks. These are specifically stored in the cell walls of plants. There, they effect what botanists call lignification: the transformation of soft plant cells into solid weight-bearing structures. These specific properties also make lignin an interesting material for battery research.

The market is currently dominated by lithium-ion batteries. Lithium is recovered from salt lakes in countries such as Chile and Argentina in a process that uses large quantities of water or is mined energy-intensively from hard rock in Australia. "Germany is highly dependent on international trade relations here," says Medenbach. "Although lithium won't become a scarce resource by tomorrow, it is an expensive, highly contested and strategically sensitive raw material."

In contrast, Lignin is abundant. It is available regionally and is bio-based and renewable. Sodium also requires no complex processing. As a component in table salt, it is one of the most readily available elements on Earth. Although the slightly lower energy and power density of sodium-ion batteries limits some

applications, it also makes them cost-effective and robust energy storage systems wherever supply reliability is more important than maximum performance.

"Our project partner Martin Oschatz and his team from the Institute for Technical and Environmental Chemistry at the University of Jena heat the lignin in the absence of oxygen," explains Medenbach. "This removes hydrogen and oxygen from the material. What remains is a carbon material with a special structure." This so-called hard carbon is extremely stable but is internally disordered, containing hollow spaces and voids. This precise structure is a perfect fit for large sodium ions: they can be stored in and removed again from the structure, a fundamental prerequisite for rechargeable batteries.

However, a consistent quality is necessary if sodium-ion batteries are to be mass-produced. Biogenic raw materials can fluctuate in quality depending on the type of wood, growth or weather conditions. "The biggest challenge is reproducibility," says Medenbach. "If the properties vary from one batch to the next, it can be a problem for batteries." The ThüNaBsE project is therefore using lignin produced at an especially high purity and consistency in a patented process by industrial partner Mercer Rosenthal GmbH. Only then does actual battery production begin: carbonization, grinding in high-performance mills and mixing with conductive additives and a binder that is also bio-based. The end result is a negative electrode, ultimately a complete sodium-ion cell on a laboratory scale.

Lignin is deliberately implemented only in the anode. This is where the storage capacity of the hard carbon is required. In contrast, the positive electrode requires materials that can stably take up sodium ions at a higher electrical potential. In this case the researchers are drawing on analogs of Prussian Blue. These are non-toxic iron compounds that were already being used as pigments roughly 200 years ago. They are readily available and environmentally friendly and can reliably store sodium ions. The team intentionally forwent using critical metals such as cobalt or nickel. The fluorine content in the electrodes and electrolyte is also to be kept as low as possible.

An estimated

50–70

million tons of lignin

are generated annually.

A sustainable battery from Thuringia

Although lignin-based sodium-ion batteries are not yet ready for mass production, the project is already much more than just a laboratory-scale experiment. It highlights where such energy storage systems could one day be put to good use: wherever weight and maximum energy density are of secondary concern. These are stationary storage systems for buffering wind and solar power, in forklifts and industrial trucks with clearly defined applications or in microcars for short distances.

The first small demonstration cells are currently being made at the Fraunhofer IKTS battery testing center in Arnstadt, in Hermsdorf and at Friedrich Schiller University Jena. The experiments are supplemented with realistic simulations. The results are promising: "After 100 charge and discharge cycles, the laboratory cell thus far exhibits virtually no signs of aging," says Medenbach. By the end of the project, that number should reach 200 cycles for a 1 Ah full cell.

"We want to demonstrate that we can also think regionally when it comes to a battery value chain," says Lukas Medenbach. The raw materials don't necessarily have to come from remote mines; they can also be obtained from existing industrial cycles. And that materials from the bioeconomy offer more than just a promise of sustainability. They are also technically robust. ■

Photo: Frank Muckenheim / plainpicture

back to page 1



Every move is precise: Fraunhofer technology facilitates work in the OR.

Where Am I, and How Far do I Have to Go?

In minimally invasive heart surgery, large equipment such as X-ray and ultrasound units are currently used to locate the probe inside the body. In collaboration with partners, Fraunhofer researchers have now developed a special fiber-optic probe that can communicate its own position beneath the patient's skin, opening up new possibilities in the OR.

By Yvonne Weiss

The surgeon guides the probe precisely towards the patient's heart. During the operation, she follows the probe live in her VR goggles: just a little further and she'll be there. A dot moves across the lens right before her eyes, showing her precisely where the probe tip is currently located in the patient's body. All without X-rays or ultrasound equipment.

With new technology, this is how minimally invasive heart surgery could be performed in the future. In the QUANTIFISENS joint research project, research scientists at the Fraunhofer Institute for Applied Optics and Precision Engineering IOF collaborated with partners to develop a self-localizing fiber probe for use in the operating room.

"Our probe tracks its own location, so it knows precisely where it is in the body at all times," explains Thomas Schreiber, head of the Laser and Fiber Technology Department at Fraunhofer IOF. Ideally, this will enable doctors to forgo X-ray or ultrasound monitoring equipment in the future, protecting patients from extended exposure to X-ray radiation during surgery.

While one project partner is working on imaging that uses laser to enable doctors to identify different layers of tissue in the body, the Fraunhofer researchers are focusing on developing special optical fibers.

Thomas Schreiber and his team are working on special geometries to produce the fibers. They drill holes in a glass rod through which light will later be precisely guided by reflectors that the researchers integrate in the fiber.

Minute variations in the laser beam can be used to determine how much and in which direction the fiber is bent at individual points. Software can then be used to calculate its position in three-dimensional space, in this case, within the body.

In combination with special calibration procedures and AI-supported data analysis that the project partners are currently working on, the probe finally appears as a dot moving in real time in the VR goggles. "In the future, this will offer entirely new possibilities for less invasive, more precise procedures while simultaneously improving patient safety, quality of treatment and efficiency in healthcare," explains Fraunhofer IOF research scientist Stephanie Hesse-Ertelt, senior research and development coordinator of the joint research project.

A demonstrator unit is already available for this technology, the development of which the researchers have successfully tested on a medical dummy.

Beyond the operating room, the properties of this special fiber could also make it useful in other fields. Because optical fibers are not affected by magnetic or electrical fields and can also detect acoustic signals and temperature changes, they could also be used as sensors in bridges, buildings or wind turbines. Although hidden hazards such as lightning strikes, stresses in concrete or fire can already be identified today, this new technology will also enable early detection with their precise location. Thomas Schreiber is fascinated: "I'm thrilled by the impressive precision we can now achieve using laser and fiber technology. I'm continually impressed by this every day." ■

"Our probe tracks its own location, so it knows precisely where it is in the body at all times."

Thomas Schreiber, Fraunhofer IOF

Photo: David Agüero Muñoz/Westend61/mauritius images

back to page 1



Greenhouse Gases Yield a Palm Oil Alternative

Palm oil is the most widely used vegetable oil in the world. The consequences for the environment and climate are catastrophic. A research team has now succeeded in producing a high-quality substitute—from industrial emissions that harm the climate.

By Sonja Endres

Palm oil is industry's favorite oil: it has a long shelf life, is heat-resistant, has a neutral flavor and is easy to work with. And: It's inexpensive. At least as long as the environmental and social costs are ignored—from rainforest clearing to climate damage.

In collaboration with partners, research scientists from the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB in Straubing have now succeeded in producing a high-quality substitute for palm oil. Their raw material: ethanol produced from industrial exhaust gases. Project lead Vanessa Wegat at Fraun-

"That makes us twice as sustainable."

Vanessa Wegat, Fraunhofer IGB



Oil palms as far as the eye can see: The largest plantations easily encompass 500 to 1,000 square kilometers.

Photo: Anks Rachman/istockphoto

hofer IGB is especially proud of this accomplishment: "That makes us twice as sustainable."

The carbon dioxide, carbon monoxide and methane that are harmful to the climate are captured directly at the plant by Fraunhofer IGB collaboration partner LanzaTech and are fed to bacteria that metabolize them into ethanol. "These gases are essentially sugar for them," says Wegat. It's a completely normal fermentation process, just like we know from processes like brewing beer." The only difference is that here, gases are converted into ethanol instead of the starch contained in the grain.

Special strains of yeast that occur naturally on Camembert and other cheeses then consume the alcohol and convert it into a fat that is similar to palm oil. "We have to take a bit of care with that," says Wegat with a smile. "If the yeast is given too much ethanol, its response is similar to ours if we've had too much. It becomes toxic above a certain level." The process is started by stirring the yeast in a bioreactor together with a nutrient medium and with a supply of oxygen and heat. "We can control the composition of the fat blend by adjusting the process parameters, such as the amount of oxygen or the types of salts and vitamins we feed in," Wegat explains. She and her team have now applied for a patent for the process in collaboration with their industry partner, the Swiss Mibelle Group.

The fat has many applications, with properties similar to and even higher quality than palm oil. "We have adapted the process to produce a large fraction of unsaturated fatty acids," says Wegat. These are especially advantageous for cosmetic products but also for food, because they are healthier." Unsaturated fatty acids in creams protect and strengthen the skin barrier. They also ensure that the active ingredients are better absorbed by the skin.

The Mibelle Group, which has long been working on sustainable alternatives for its raw materials, plans to start using the palm oil substitute as soon as possible. They have already produced and tested the first promising creams and lotions containing the new fat in their laboratories.

To reduce costs in the production process, Wegat and her team intend to use additional components from the biomass produced during fermentation in the bioreactor. "Not only does it include high-quality fatty acids but also proteins with an excellent amino acid profile. These are sure to be interesting for the cosmetics and food industries," says Wegat. The research scientists are currently working on the most environmentally friendly and effective possible method for extracting all the valuable components and to scale up production. Many products that have been based on palm oil could therefore not only become significantly more sustainable but also more independent of supply chains and raw material suppliers. ■

back to page 1

Research for Emergencies

Natural disasters, attacks, power outages—our world is vulnerable. In the SIRIOS Lab in Berlin, four Fraunhofer institutes are working together on research to enable faster crisis response.

By Mandy Bartel



Sabotage, human error, severe weather and cyberattacks: There are many threats to critical infrastructure. In 2025 alone, the German Federal Criminal Police Office (BKA) recorded 321 attempted acts of sabotage targeting power grids, railway infrastructure or cell towers in Germany. Ulrich Meissen at the Fraunhofer Institute for Open Communication Systems FOKUS in Berlin studies the consequences of the resulting system failures: "We absolutely must improve the resilience of our infrastructure, irrespective of the cause." Meissen is researching innovative security solutions at the recently opened SIRIOS Lab.

Resilience has its price

He and his colleagues have already learned the hard way that resilience and security are always a matter of money. And this is in Berlin of all places, which just had the largest power outage in postwar history back in January. The former Fraunhofer Center for the Security of Socio-Technical Systems (SIRIOS) was launched in Berlin in 2022 with public funding. Now, it has no longer received funding from the German federal government since 2024 due to budget cuts. This set the team back in its research right at a time of growing security threats, increasingly complex infrastructure and greater demands on crisis response. But the researchers remain determined: "We have now independently reopened the SIRIOS Lab with support from the Berlin Innensenat, to provide an open platform for critical infrastructure operators, industry and security agencies," says Meissen. "With this step, we wish to demonstrate the potential of research and networking for public safety and security and to exploit this potential in collaboration with our partners for the benefit of all."

The SIRIOS Lab isn't about achieving one-hundred percent security—which doesn't exist—but rather about mitigating the effects and potential cascading consequences of crises or outages. Meissen is convinced: "we are still far from making full use of all the technical resources that research could provide us with." With this, he especially means providing better tools to emergency services in situation centers. This is exactly what four Fraunhofer institutes are working on in the SIRIOS Lab. There they are combining their expertise in simulation, situational awareness, crisis communication and visualization for public safety and security.

A key focus of the researchers is video analytics supported by artificial intelligence for better detection of incidents and ideally preventing disruptions or acts of sabotage. Cameras have long since ceased to be merely devices for capturing images. Intelligent video analytics (IVA) can be used to automatically detect and evaluate conspicuous movements, unusual pedestrian traffic flows or unauthorized access.



Better prepared for crises: Fraunhofer researchers have life-saving ideas.

Photo: Michael Bihlmayer&Chromorange / dpa

This applies to sensitive infrastructure such as substations as well as to major events and transportation hubs. What used to be virtually impossible to follow in dense crowds can now be quantified, also with drone imagery analysis: Where are people gathering? Where are dangerous situations manifesting themselves? "The systems analyze the movement patterns of entire groups and critical situations but can also precisely track individual people in an anonymized manner," says Thomas Golda, Meissen's SIRIOS colleague from the Fraunhofer Institute for Optronics, System Technologies and Image Exploitation IOSB in Karlsruhe. "This enables infrastructure operators or emergency services to react quickly, ideally before any damage occurs."

"But no one can prepare for every eventuality," points out Meissen. Simulation therefore serves as the basis for forward-looking, cost-effective planning. In the SIRIOS Lab, researchers simulate what happens when key nodes fail, communication networks break down or cascading effects propagate through different infrastructures. To do this, they draw on real-world data, such as video analysis of major events or past crises, combined with information on the overall situation. How do crowds move? How do they react to warnings? Which further systems are affected, and in what order? These results are all incorporated in simulation models with which various scenarios can be played out: from power outages to evacuations, until restoration of services. "The goal is not to predict the future in any situation but to provide freedom for decision-making," says Meissen. "Someone who knows what is likely to happen can act more quickly and target their actions." As an example of what went well during the power failure in Berlin, he cites the quick, well-organized evacuation of nursing homes and of people needing assistance. "This is a situation that can be anticipated fairly well and can therefore be prepared for."

Communication under extreme conditions

Communication, however, was far less favorable. The adage that every crisis is also a communications crisis also proved to be true in Berlin. Cell phone networks went down, warning systems only functioned to a limited extent and information was difficult to access. "Organizing communications is key," says Meissen. The experts in the SIRIOS Lab are therefore investigating how communications can be maintained even when traditional networks fail. "Emergency systems with battery buffers can stave off a communications breakdown for about two hours. But it's also clear that I can't equip every cell tower with emergency generators." The goal is therefore to reliably reach as many people as possible using limited resources. Using simulations and data from warning systems such as the Fraunhofer-operated KATWARN and in collaboration with sociologists, the teams are analyzing where information can be disseminated most effectively, such as via specific locations, persons or structures. This enables more efficient use of multipliers and enables more targeted establishment of local emergency and backup networks where they are needed most.

A networked overview for better decision-making

Although there can be an insufficient of information on the one hand, crisis management teams often face a completely different problem: too much confusing information from a wide variety of sources, including infrastructure operators, emergency services, sensors and the populace. What is often lacking is a common and clear understanding of the situation. "We are working on networked systems that bundle, analyze and present information in an understandable form," says Golda. "We can combine real-time data with simulations on our digital map table: What happens if we take action here?" What are the results of shifting resources there? This gives decision-makers an overview and a meaningful basis for their actions." The map table thus becomes the connection between previously isolated systems. A networked safety structure such as this includes systems used by the police and fire departments, as well as by infrastructure operators and government agencies and also integrates elements such as the KatHelfer PRO software that enables authorities to coordinate and make the best possible use of the capabilities of volunteer responders in the event of a disaster. Ulrich Meissen is convinced: "In the power outage in Berlin, it probably would have been easier to get the situation under control more quickly if all the relevant information had been available in the situation center in a form that was more easily understandable, easier to analyze and presented in a standardized overview," He and his colleagues will work together with critical infrastructure operators and emergency services in the newly opened SIRIOS Lab to review and analyze this incident in order to learn from it and work to improve their security solutions. ■

back to page 1

Back Into the Loop Instead of Out With the Trash

A T-shirt for four euros, pants for ten: The fast fashion trend continues unabated. No sooner worn than forsworn, these mostly low-quality items quickly end up in the trash. The textiles have been largely unrecycled—until now.

By Sonja Endres

Nearly 11 million tons of textile waste are generated in the EU every year. Most of it is incinerated or ends up in landfills. Previously, less than one percent has been recycled into new textiles. Thomas Fehn and his team at the Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT intend to change this. In the EU Autoloop project, they are working with 14 partners from 7 countries to route textiles through a closed-loop system. While recycling processes for cotton fibers are already established, there are none for synthetic blended fabrics, which make up about half of the clothing produced worldwide. "Polyester and cotton fibers are so tightly intertwined that it's extremely difficult to separate them," says Fehn.

Finnish project partner Aalto University in Helsinki has now successfully achieved this separation. The polyethylene terephthalate (PET) recovered in this innovative process and from which most polyester fibers are made is not a single type. Instead, it consists of various types of PET. It also contains dyes, impregnating agents, plasticizers and stabilizers. Fehn explains: "We can't simply reuse this PET to produce new fibers. Instead, the basic chemical building blocks have to be extracted individually." He and his team are accomplishing this with pyrolysis, a high-temperature decomposition process in the absence of oxygen. In this process, the starting material is not destroyed but rather is broken down into its molecular components.

Breaking down PET produces crystalline terephthalic acid which often forms tough, waxy deposits in combination with other decomposition products. These can clog pyrolysis reactors or pipes. The Fraunhofer research scientists have developed a solution to this problem. They add steam to the reaction system at a temperature of roughly 400 degrees Celsius. "The steam cuts the molecules apart like a pair of scissors," says Fehn. "We are thus able to break down the PET polymer chain into its



The automated procedure could yield a tenfold increase in sorting throughput and simultaneously reduce costs by

50 to 75

percent.

individual building blocks and completely separate out the terephthalic acid to a very high degree of purity—nearly 100 percent—without anything sticking together."

Terephthalic acid is a main component of PET. It plays a key role in determining the strength, stability and quality of the synthetic textile fibers and is produced almost entirely from petroleum-based raw materials. "Recovery is therefore especially important for the environment." After cleaning and repolymerization into PET, the material can again be spun into fibers.

However, the actual conversion of worn-out sweaters or pants with holes into new goods also requires an intelligent collection and sorting system. The EU has established a key prerequisite for this in the form of mandatory separate collection of used textiles, which has been in effect since January 1, 2025. Under this regulation, these items can no longer be disposed of with general waste and must be sorted separately to promote recycling and reuse. Textile waste is then separated from wearable clothing in sorting facilities. British start-up Zori Tex, another partner in the Autoloop project, uses AI-supported image processing to sort used clothing by fiber type. Fehn explains: "The textiles are transported on a large conveyor belt. The AI detects blended fabrics with a high PET content. A directed air jet blows these specific items off the conveyor belt." This automated procedure could yield a tenfold increase in sorting throughput and simultaneously reduce costs by 50 to 75 percent.

Out of the average of 60 new items of clothing purchased each year 24 are hardly ever worn, if at all.

To further simplify and refine sorting in the future, the Autoloop team is joined by German company TLX in working on an intelligent tracer technology. Lasers will be used to etch invisible markers into the fibers. These will later provide information on the exact composition of the material.

Fehn is convinced: "The ideas and technologies are already available; they just have to be implemented to give us a working closed-loop system." ■

Photo: ronstik/istockphoto

back to page 1



Fraunhofer startups

The Startup Revolutionizing Dental Prosthetics

By Beate Strobel

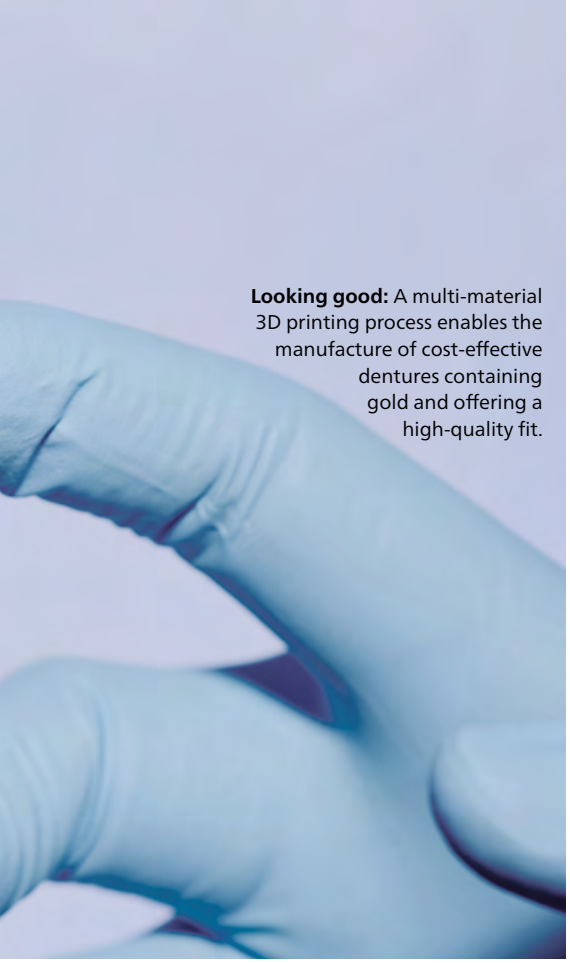
The price of gold is on the rise. Specialists are becoming increasingly scarce. And people are getting older. These three challenges currently affecting society have something else in common: dental prosthetics. As life expectancy increases, so does the need for dental prosthetics. However, the high price of gold, combined with the extensive manual labor required, has resulted in fewer and fewer telescopic dentures being made with this precious metal, despite the fact that it also remains the gold standard in terms of high-precision fit, quality and user-friendliness. Industrial manufacturing has thus far only been possible for dental prostheses without gold or for low-cost alternatives.

Start-up FIDENTIS, a spin-off from the Fraunhofer Institute for Casting, Composite and Processing Technology IGCV in Augsburg, has developed a solution to this problem. Using an innovative multi-material 3D printing process, FIDENTIS manufactures telescopic prostheses that not only minimize the use of gold but are also produced via a fully automated process chain, which is prerequisite for the series production of patient-specific prostheses. "We are bridging the gap between the precision of artisans and industrial efficiency," summarizes Max Horn. The co-founder and CEO of start-up FIDENTIS explains: "This is how we reduce production time while still ensuring consistently high quality."

From nuclear fusion to dentistry

Since 2017, research scientists at Fraunhofer IGCV have been studying additive manufacturing methods for complex multi-material parts. The goal is to bond different metals together in a single printing step. The basic concept behind the technology further developed by FIDENTIS originated as part of the major MULTIMATERIAL Center Augsburg project, which was co-funded by the Bavarian Ministry of Economic Affairs. The initial objective was to develop applications in areas such as nuclear fusion. Josef Schweiger, head of the dental laboratory at the Department of Prosthodontic Dentistry at LMU Munich, brought up the topic of dental prosthetics, explains Max Horn. "He had seen some initial applications of multi-material manufacturing and was of the opinion that if we could manage this with precious metals and achieve a significantly more intricate finish we would have a business case."

Like Timo Schröder and Lukas Langer, the industrial engineer was working at the time on the "MULTIMATERIAL Center



Looking good: A multi-material 3D printing process enables the manufacture of cost-effective dentures containing gold and offering a high-quality fit.

Augsburg" project. They jointly submitted their start-up idea in Phase 1 of the AHEAD program, in which the Fraunhofer-Gesellschaft supports those looking to found spin-offs with funding, networking events, workshops and coaching. "We continued developing the technology after work and on weekends during the COVID-19 pandemic," says Horn. "Right at the close of the pandemic, we were finally ready to produce a prototype for telescopic dentures."

With seed money of 1.62 million euros from the EXIST research transfer program of the German Federal Ministry for Economic Affairs and Energy (BMWE), the founding team—which had since been joined by industrial engineer Johannes Lauer, now CCO at FIDENTIS—then brought the technology to market readiness. This additive manufacturing process based on laser powder bed fusion (LPBF) and found nowhere else in the world now enables the simultaneous processing of two or more different alloys, such as cobalt/chromium alloys for stability and gold alloys for secure seating. A robot precisely deposits the additional powder material in the powder bed. The completely digital process chain also includes automated finish milling of the surfaces based on patient data.

The entire printing process is roughly 20 times faster than previous manufacturing methods for telescopic dentures. However, the FIDENTIS team is also matching this speed with its own development: "Within 14 months, we had already produced semi-finished products that were used as medical devices on the first patients in mid-2025," Max Horn states with pride. "It's rather unusual for a start-up product to reach such a high technology readiness level so quickly in a regulated market."



Putting teeth into entrepreneurship: the FIDENTIS team of Timo Schröder, Johannes Lauer, Max Horn and Lukas Langer (from left to right).

Photos: Leon Laskowski, Rebekka Amann

Fighting through a jungle of bureaucracy

This is especially true considering the bureaucratic challenges confronting the entrepreneurs on their journey to starting their own businesses. "It was difficult just to keep up with the constantly changing requirements, information and processes. A more pragmatic approach in Fraunhofer's spin-off process would simplify some things for start-ups," says Horn. Contract negotiations are somewhat slow, and each individual process involved a lot of paperwork. On the other hand, the Fraunhofer name opened many doors for them. "Everyone immediately understands that this is not just a school science fair project but rather state-of-the-art technology," says Horn.

The founders are now busy preparing for series production. An injection of fresh capital is urgently needed for this since establishing a manufacturing company not only requires equipment and expensive materials but also staff. "By 2028, we intend to grow to ten full-time positions, including students," Lauer stresses. The Fraunhofer name goes a long way in recruiting. But it would not be enough to rely solely on this network. "For example, our manager at Fraunhofer Venture has also gained us strong connections with other founders, supporters and organizations beyond Fraunhofer," says Lauer. "The ecosystem that has developed around FIDENTIS is extremely valuable to us."

Also planned for 2026 is the move out of the pilot plant at Fraunhofer IGCV and the associated separation from the parent organization. FIDENTIS is currently completing the move to its own offices in Munich. "This is the next major milestone," Lauer says: "In-house series production that we can have fully certified in accordance with the Medical Device Regulation. And then ramping up production, including going international."

Max Horn has been working on developing additive multi-material manufacturing technology for nearly ten years. Together with his co-founders, he can also draw on two years of experience as an entrepreneur. Still, he hasn't once regretted taking the plunge into entrepreneurship: "At some point, you just want to get what you're researching out in the real world and let it take flight." The idea of expanding FIDENTIS technology to other industries such as aerospace also follows—especially since the founding team of the start-up includes aerospace engineer Timo Schröder. "These are topics we can continue researching with Fraunhofer IGCV," Lauer concludes. ■

back to page 1

Drones Incoming

Suspicious drones near airports and military bases, inexpensive cobbled-together drones and drone swarms—security agencies are faced with challenges. Research scientists are responding with practical solutions: Acoustic defense systems listen around corners and high-resolution cameras help identify suspicious targets. A new innovation center for drone defense is working on the key technologies of the future.

By Mehmet Toprak



Detect, identify, interdict—Fraunhofer researchers are ready with technologies for every step.

Archibald M. Low was an ingenious inventor, tinkerer and engineer. After presenting Televista, an early precursor to television in 1914, he was serving as a captain in the British Royal Flying Corps when he flew an unmanned aircraft by radio control on March 21, 1917. He also demonstrated a remote-controlled rocket in 1917. Although both only remained airborne for a short time, Low came to be known as the father of the drone.

More than 100 years later, Fraunhofer researchers are once again setting their sights on drone technology. This time, however, the reasons are numerous and mostly unpleasant. However, there's good news from the latest research findings: Protecting critical infrastructure is both possible and feasible.

Sensors that can hear around corners

One example of this is the acoustic sensor system developed by the Fraunhofer Institute for Digital Media Technology IDMT in Oldenburg. It uses sophisticated microphone technology and digital signal processors (DSP) to detect flying objects even before they enter visual range, such as in poor visibility, fog or darkness, when they are still hidden behind a building or flying through a wooded area. All that is needed for initial detection is a single microphone. Up to eight directional microphones are used for more precise tracking.

Christian Rollwage, group manager for audio signal enhancement, describes the deployment scenario: "Our system is no larger than a lunchbox and can be combined with camera-based recognition technologies." "When a drone is detected by the microphones, radar-based systems or cameras are activated and enable more precise tracking and analysis."

Optical drone tracking and identification is being implemented in the Modeas project by the Fraunhofer Institute for Optronics, System Technologies and Image Exploitation IOSB. Multiple installed cameras scan the entire horizon. If a flying object enters the field of view, a pivoting high-resolution camera with a telephoto lens automatically activates and tracks the object. In the next step, the object is classified by AI-based video analysis and its position is determined in 3D. All systems are configured for the practical requirements of security agencies and critical infrastructure facilities. Fraunhofer IOSB is combining all of its expertise in the field of drone defense from multiple departments in an independent task force led by Nico Heussner. The research scientists are also working on drone interdiction.

Drone center in Baden-Württemberg

To ensure the best possible coordination of the different research projects, eleven institutes joined together in 2002 to form the Fraunhofer Segment for Defense and Security VVS. The Baden-Württemberg Innovation Campus for Security and Defense is also establishing the Innovation Center for Drones and Drone Defense. Project participants are the Fraunhofer Institutes for Chemical Technology ICT and for Optronics, System Technologies and Image Exploitation IOSB and the Karlsruhe Institute of Technology.

This planned project has the goal of establishing a research infrastructure and technology platform covering all aspects of this topic, from developing innovative defense technologies to novel drone systems: in the water, on land and in the air.

> "This represents a beacon project for German industry."
>
> Jürgen Beyerer, Fraunhofer IOSB

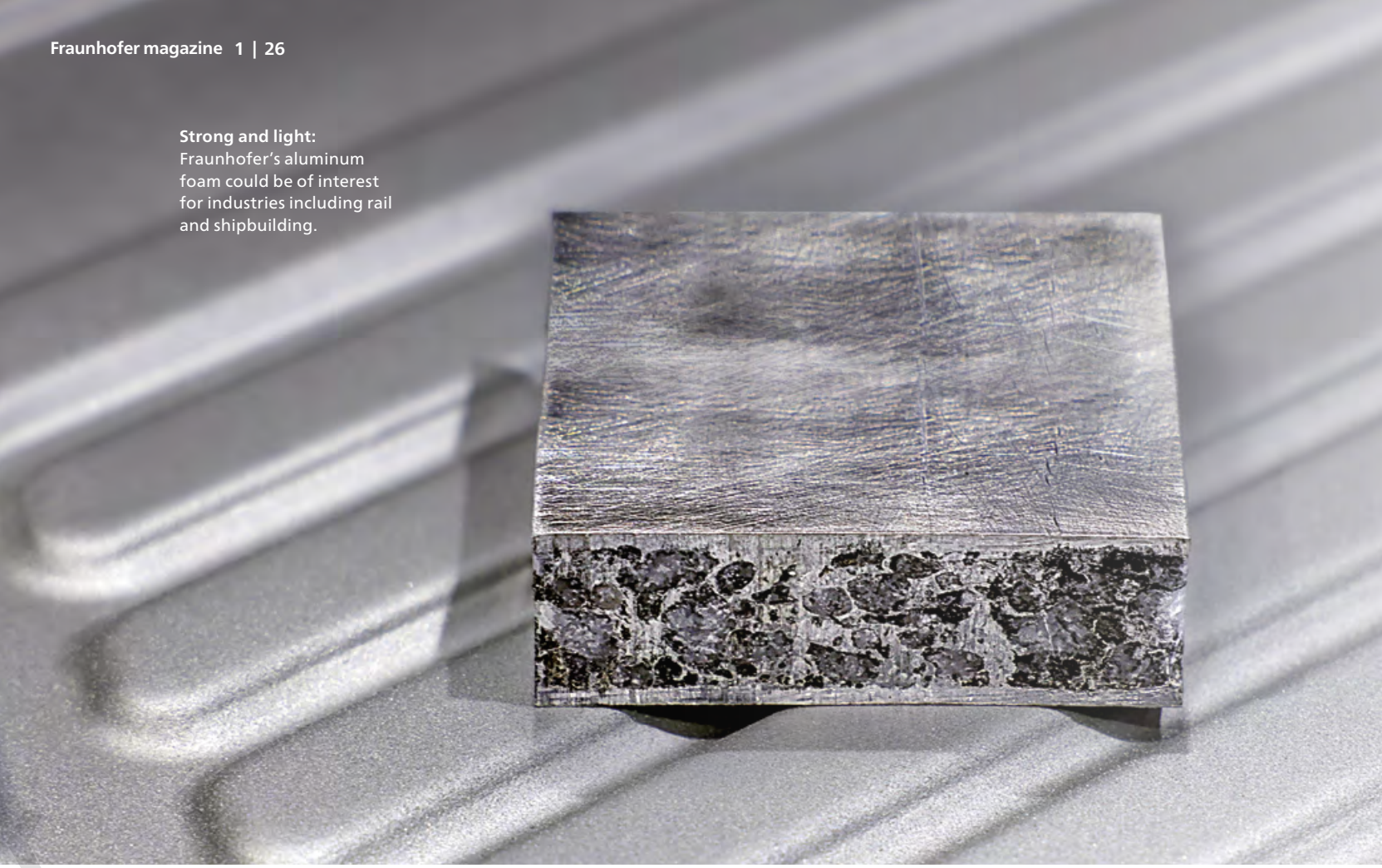
The trend here is not to develop the ultimate super-drone packed full of electronics. Sebastian Wurster from Fraunhofer ICT says: "The key to mastering drone technology is in manufacturing. This has to be cost-effective and also highly flexible and modular. Rapid scalability is also a must. Only if all of these requirements are met will we be able to provide a swift, appropriate response to new threat scenarios."

Fraunhofer IOSB Director Jürgen Beyerer adds: "The planned innovation center in Karlsruhe is a unique opportunity: we are using pioneering technologies and manufacturing processes to combine high-tech with cost-effectiveness, energy efficiency and scalability. This represents a beacon project for German industry. It goes far beyond the areas of security and defense and demonstrates our technological sovereignty."

Flexibility and modular concepts also ensure the ability to more quickly launch practical solutions. Nico Heussner is confident: "We are highly motivated and in optimistic spirits. And we continue to look forward to welcoming motivated new talent ready to contribute to our security." Archibald M. Low, the father of the drone, needs new followers. ■

Photo: Jens Büttner / dpa

back to page 1



Strong and light: Fraunhofer's aluminum foam could be of interest for industries including rail and shipbuilding.

Protective Foam

Innovative pore power for electric cars: Fraunhofer researchers have created a battery housing that is lighter, safer and more thermally robust.

By Iris Röll

Sometimes tiny bubbles can make life so much better—prosecco sparkles on the tongue, a bubble bath lets you sink beneath mountains of white foam and a yeast bun melts on the tongue. Highly advanced bubble engineers are at work at the Fraunhofer Institute for Machine Tools and Forming Technology IWU in Chemnitz. They are working with aluminum foam and have now succeeded in collaborating with US automotive supplier Amsted to use this material in manufacturing housings for electric car batteries. Not only is it lighter and safer than conventional models, it can also keep the battery within its optimal temperature range. The researchers recently presented their prototype at the Battery Show North America in Detroit and engaged with car companies.

"You have to imagine it like baking," begins Thomas Hipke when asked how aluminum foam is produced. The mechanical engineer heads the Lightweight Design, Energy Storage and Circular Economy business unit at Fraunhofer IWU. He developed this innovative battery housing jointly with project manager Rico Schmerler. Aluminum powder is used instead of flour. A rising agent is also added—in

this case, titanium hydride. The mixture goes into the oven, which, at 600 to 650 degrees Celsius, has to be slightly hotter than at home in the kitchen. The heat dissociates the titanium from the hydrogen, which then pushes the pores apart. "The volume increases by a factor of 5," says Hipke, "meaning that the foam has only one-fifth the density and weight of aluminum."

Shockproof, heat-resistant and flame-retardant

In cars, lower weight means lower energy consumption. But battery housings are subject to a whole range of other requirements: They must be highly shock-resistant, heat-resistant and flame-retardant. However, they must also absorb shock loads in the event of accidents, dissipate heat from the battery and protect it from temperatures below the freezing point. For these reasons battery housings in electric cars are already made mostly of aluminum and rarely of steel or plastic. But not aluminum foam.

The foam meets all these requirements—in some cases even outperforming ordinary aluminum. "For example, it can absorb significantly more deformation energy in the event of accidents," says Hipke. The result: greater safety. And it does an excellent job of maintaining a stable battery temperature. This feature is enabled by a new development by the Fraunhofer specialists: They have succeeded in incorporating a phase change material (PCM) into the closed pores of the aluminum foam. PCMs are materials that can absorb and release energy by changing their physical state—the colder they are, the more solid they become; the hotter they are, the more liquid they become. "You can think of it like the transition from water to ice and vice versa. The difference is that we can use the chemical composition of the PCM to select a specific temperature at which the material changes from solid to liquid. In our case, this temperature was 44 degrees Celsius," says the researcher. "We can thus protect the battery from overheating."

But how do the researchers get the PCM into the closed pores of the aluminum foam, which are only one to three millimeters in size? Hipke laughs. "This requires a few tricks that I can't reveal and relatively high pressure to press the PCM in." This is because there are tiny openings between the pores, known as contact points, through which the material can enter. At least this works with the aluminum foam from Fraunhofer IWU: "We also tried this with foams from manufacturers in Korea and China, but it wasn't possible."

In any case, the PCM absorbs excess heat from the battery, stores it and can release it again if temperatures threaten to drop too low. Once installed, this so-called passive cooling functions automatically for its entire service life with no further control. "We have calculated that this is sufficient to manage battery temperature in 95 percent of all regions of the world," explains Hipke. For extremely hot regions, an active cooling structure could be used as an alternative or supplement in their prototypes. This works in a similar way to a refrigerator by pumping a refrigerant through small cooling tubes.

Moving to series production

At the Battery Show in the USA, the Chemnitz-based researchers presented their prototype with a sandwich structure that can be equipped as necessary: as a pure aluminum foam housing without temperature management, with PCM, with active coolant or with both variants. "The car manufacturers and suppliers were very interested," says Hipke. "We'll be continuing to pursue acquisitions here in Europe as well." The goal is to make the move to series production or, initially, to conduct a long-term test in a vehicle to demonstrate the passive temperature control system in real-world operation.

But the possible applications of Fraunhofer aluminum foam are far from exhausted with battery housings. It could be a huge success wherever an extremely stable and lightweight material is needed. "For example, Deutsche Bahn is already a good customer of ours. Aluminum foam also saves a lot of weight in shipbuilding," says the research scientist. "We are already in series production in the machine tool industry based on the material's excellent damping properties." An increasing number of inquiries have also come in from the defense industry over the past several years. The Fraunhofer IWU experts are working on aluminum foam shelters that can be installed in private or public buildings.

Aluminum foam is currently more expensive to produce than conventional aluminum parts. Fraunhofer IWU has therefore developed a recycling method that shreds used aluminum and processes it into powder. "We are currently implementing this technology at a manufacturer," reports Hipke. "This brings the price of the foam closer to that of conventional aluminum parts." The engineer cites two reasons for using the recycled powder: first, cost savings of up to 30 percent, and second, sustainability, which is now important to many manufacturers. "We need to do much more in this area," warns Hipke. "I am absolutely convinced that sustainability technologies offer us a huge opportunity for the future. They enable us to stand out from Chinese manufacturers." The product may be full of holes, but the argument is solid. It's yet another way tiny bubbles can make life that much better. ■

Photo: Fraunhofer IWU

back to page 1



A Photo & Fraunhofer

Do You Like Spiders?

It's only three centimeters tall, lurking in the tall grass of Saarland, Brandenburg and Hesse. The spider will bite if anyone touches its nest hidden among the waist-high stalks. The pain is so severe that most people seek medical attention—and can suffer from the symptoms for up to a week.

The yellow sac spider is considered the most poisonous spider in Germany. However, its venom may not only cause circulatory problems, fever and shock but may also have healing properties. Researchers at the Fraunhofer Institute for Molecular Biology and Applied Ecology IME and Justus Liebig University Giessen have decoded the previously unknown venom of the yellow sac spider, seeing potential for a medical agent:. "Unlike other known spider toxins, the highly potent toxin of the yellow sac spider does not attack the nervous system but rather the cell membrane," explains Tim Lüddecke, project manager and researcher at Fraunhofer IME in Giessen. For him, that's cause for celebration.

The biochemist believes that a modified form of the toxin could potentially be used against cancer cells, thus playing a role in tumor therapy. Decoding of the toxins has been completed and a follow-up study is planned. Tim Lüddecke is enthusiastic: "The yellow sac spider proves that we don't have to go to the Amazon to discover new biomolecules—they're right in our own backyard, as it were. I find that absolutely fascinating!"



On the prowl: The yellow sac spider catches its prey with powerful jaws and injects its venom.

Photo: Andia / Alamy / mauritius images

back to page 1



CHILE

Cosmic Amplifier Chips

To better understand how stars, planets, galaxies and ultimately life itself form, 145 low-noise, high-performance amplifiers from the Fraunhofer Institute for Applied Solid State Physics IAF and the Max Planck Institute for Radio Astronomy complement the ALMA international radio telescope observatory in the Andes in northern Chile. As key components in the ALMA receivers, they amplify extremely faint signals in the millimeter and submillimeter wavelength ranges by more than 300 times in the very first processing step. This enables highly precise measurements of gas and dust clouds, planetary disks and complex organic molecules in far-flung reaches of the universe with unprecedented accuracy. The amplifier chips achieve their unusually low noise level through monolithic integrated microwave circuits with metamorphic high-frequency transistors made of semiconductor indium gallium arsenide.



The heart of ALMA comprises fifty 12-meter diameter antennas that work together to form a single telescope.

Fraunhofer Worldwide



Fraunhofer-Gesellschaft locations



The Colorado potato beetle is voracious—and is resistant to many chemical pesticides.



USA

Protecting Crops Without Poison

Researchers from the Fraunhofer Institute for Molecular Biology and Applied Ecology IME, Justus Liebig University Giessen and U.S. nonprofit GreenLight Biosciences have studied the central active mechanism of a novel RNA spray designed to specifically target the Colorado potato beetle, one of the most significant pests in potato cultivation.

This is the first study to report that RNA-based pesticide Ledprona causes a functional disruption of the proteasome, the cellular recycling system, in Colorado potato beetle larvae. This proteasome dysfunction causes the larvae to die. Independent field trials have shown that this RNA active ingredient is highly specific in targeting the Colorado potato beetle, is biodegradable and leaves no toxic residues. Fraunhofer IME researchers are also currently developing RNA sprays to combat aphids and planthopper *Pentastiridius leporinus*, an emerging pest in sugar beet cultivation.

EU

Faster Diagnosis Using AI

Coughing, fatigue, shortness of breath—these symptoms cover a broad range of lung diseases. The EU project AI4Lungs is developing an AI-based system designed to help doctors identify the correct diagnosis at the earliest possible stage. The Fraunhofer Institute for Industrial Mathematics ITWM is developing the corresponding backend component. Using guideline and data-based models, it analyzes patient data and makes medical recommendations with corresponding explanations. The goal is to develop a Clinical Decision Support System (CDSS) that reduces the workload for physicians and identifies optimal treatments at an early stage. However, the final decision still remains with medical staff.



Respiration sounds provide important diagnostic information.

EU

Strategically Fighting the Increasing Risk of Wildfires



2025 was a record year with more wildfires in the EU than ever before.

Extreme wildfires are a growing threat: They are more intense and more unpredictable and are causing unprecedented damage. Europe's first integrated wildfire risk management strategy (IWRM) is now in place. Its development also included the EU Firelogue project coordinated by the Fraunhofer Institute for Communication, Information Processing and Ergonomics FKIE (formerly Fraunhofer INT). The strategy includes a practical roadmap comprising various measures such as the establishment of fire-tolerant landscape mosaics and incentives for fire-smart bioeconomies. The researchers want to apply existing knowledge and recent innovations in wildfire suppression to improve effectiveness across Europe. The strategy also includes specific policy proposals, including the establishment of an interdepartmental EU coordinating committee and the development of a common wildfire directive, which are intended to significantly reduce risk.

IRELAND/ITALY

Sustainable Agriculture

In the FarmScan project, researchers at the Fraunhofer Institute for Microelectronic Circuits and Systems IMS are working in collaboration with the University of Udine and University College Dublin to develop environmentally compatible soil sensors to provide precise agricultural data to improve crop yields. The sensors continuously monitor key soil parameters such as moisture and nutrient levels, and they fully decompose into harmless materials on reaching the end of their service life. Passive RFID technology enables remote data collection over large areas; this data is then integrated in an AI-controlled platform providing farmers with specific real-time guidance on irrigation and fertilization. The sensors are tested under real-world conditions on test farms to evaluate their usability in practice and their environmental effectiveness. The objective is to bridge the gap between reliable data collection and environmental sustainability and to promote climate-friendly, resilient farming systems.



Precise fertilization and irrigation: Innovative sensor technology makes it possible.

Photos: ESO/B. Tafreshi twanight.org, Tim Ur, Steve Allen Photo, Toa55, skynesher all istockphoto

back to page 1



The way to the future: Wastewater contains a wide range of raw materials for industry.

Sewage into Sustainable Plastics

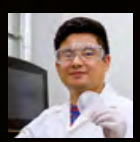
Fraunhofer researchers are working on recovering environmentally friendly bioplastics from municipal wastewater. The research scientists' work is supported by a robust bacterium *Cupriavidus necator*.

By Mehmet Toprak

Pravesh Tamang always starts to smile when talking about his research: "Working in the laboratory, tackling tricky problems, finding solutions—I simply enjoy it." This is especially the case for a topic with much still unexplored: wastewater.

Tamang is a bioprocess engineering expert at the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB in Stuttgart. He is working on the KoalAplan project together with his team and partners. This project is investigating municipal wastewater as a source of ammonium, hydrogen and bioplastics. The task of the Fraunhofer researchers is to microbially produce the bioplastic from the wastewater, more specifically, polyhydroxyalkanoates (PHA). PHA serves as a raw material for biodegradable plastics. And these are increasingly in demand for packaging materials and textile coatings, as well as for use in pharmaceuticals or for medical implants.

"Wastewater contains so many valuable substances. It is high time we got to work."



Pravesh Tamang, Fraunhofer IGB

Bioplastic from Hydrolysate

Once the solids have been filtered out of the wastewater, they can be pretreated at a project partner's plant. The DVGW Research Center at the Karlsruhe Institute of Technology (KIT) Engler-Bunte Institute subjects it to a process known as dark fermentation. In this process, biogas is typically produced through the fermentation of organic matter by bacteria. In the KoalAplan project, however, this process is interrupted and optimized to produce an acidic hydrolysate.

In the Fraunhofer IGB laboratory, Tamang and his team use this hydrolysate to grow the bacteria and convert it to PHA. However, the organic acids such as acetic, butyric and propionic acids in the hydrolysate have a toxic effect on the bacterial strains. Fraunhofer research scientist Tamang explains the solution with a highly satisfied smile: "We have finally identified a tolerant bacterium, Cupriavidus necator, that can survive in this toxic environment and produce PHA intracellularly."

However, the acid concentration in the hydrolysate, which serves as the primary raw material, is highly diluted (approx. 3 – 7 g/L). It takes roughly 300 liters of hydrolysate to produce one kilogram of PHA. The biorefinery tanks must be scaled accordingly. To limit the volume, the Fraunhofer researchers have further developed the so-called perfusion method. This is a continuous process involving cell retention. This process enables retention of the PHA-producing bacteria in the bioreactor while they are supplied with fresh hydrolysate. This concentrates the initially highly diluted hydrolysate in the system in the form of bacterial biomass and PHA. The unusable broth is discarded. "This increases the yield and quantity of PHA without increasing the reactor volume," says Tamang.

Further Action

The Fraunhofer researchers are already taking up the next problem. This one, as Pravesh Tamang would say, is again "particularly tricky." Unlike pure Carbon source like pure organic acids, for example, the composition of municipal wastewater is always fluctuating. This also results in a different PHA variant. The research team is working on AI-supported models to predict which PHA variant will be produced from a given type of wastewater.

Tamang outlines the overall goal: "We need a modular, agile and flexible technology platform that can specifically treat any type of wastewater without requiring extensive preliminary testing. Wastewater contains so many valuable substances. It is high time we got to work."

Pravesh Tamang smiles, because he knows he's in for more fun. ■

Photo: Elise Ortiou Campion/plainpicture

back to page 1

Mobile Early Agricultural Pest Detection



Climate change is enabling the spread of new crop pests in German wine- and fruit-growing regions. Stopping their spread requires detecting them early and reliably. A mobile laboratory, the PhenoTruck, makes this possible.

By Monika Offenberger

Chardonnay and Dornfelder, Kerner and Scheurebe: Scaphoideus titanus loves them all. The American grapevine leafhopper, an insect from the leafhopper family, was introduced to France from its native range 80 years ago. It has been proliferating in Europe ever since, becoming established in Italy and Switzerland and continuing to spread unchecked. The insect was detected in southern Baden for the first time in 2024. Winemakers are now on red alert.

The pest can serve as a vector for single-celled pathogens, aka phytoplasmas, which enter a plant during feeding, transmitting the dreaded grapevine yellows flavescence dorée (FD). Once this disease manifests itself by wilted leaves and stunted shoots, afflicted grapevines are beyond saving. Quick action is required to prevent more extensive damage, and the PhenoTruck makes this possible. The name stands for a mobile analysis platform that can be operated self-sufficiently in the field. It is the product of interdisciplinary collaboration: A team from RLP AgroScience GmbH contributed its expertise in plant pathology and molecular biology. The Fraunhofer Institute for Factory Operation and Automation IFF brought its know-how in AI-optimized monitoring and spectral analysis. The mobile platform was developed by the Fraunhofer Institute for Biomedical Engineering IBMT, which has many years of experience with custom-built vehicles.

The PhenoTruck makes it possible to detect and contain even the smallest sources of infection at an early stage and prevent an FD epidemic. The same is true for other fruit-crop diseases caused by phytoplasmas, such as apple proliferation, pear decline and European stone fruit yellows. This is currently done by trained specialists who perform assessments of suspicious plantations. They look for the specific symptoms of the particular diseases and take samples of infected leaves, sending them to a laboratory for molecular biology analysis. The PhenoTruck can expedite this labor-intensive and time-consuming process significantly.

"Our years of experience developing mobile laboratories for a wide array of applications helps us develop appropriate designs for samples, handling, equipment selection and optimal space and energy use in a dynamic process in collaboration with our project partners," explains Fraunhofer IBMT project manager Sylvia Wagner. Then the vehicle is built in close collaboration with custom-built truck makers. "What makes the PhenoTruck special is its off-road capability. After all, you have to be able to go into the vineyard with it,"



Photos: MediaExpanding/istockphoto, blickwinkel/Alamy/mauritius images

explains Fraunhofer IBMT research scientist Markus Michel. "It houses two full-fledged laboratories, one for molecular biology and one for physical work, cleanly separated by an airlock. Both are reliably climate controlled, even if the outside temperature is 35 degrees Celsius and the humidity is high." The goal is to identify harmful organisms right in the affected growing region. "We can't replace the experts from the plant health services, but we can help them do their work," says Bonito Thielert from Fraunhofer IFF. His research group has developed an assessment app that facilitates recording the features of suspicious grapevines and their location: "Users can customize which data they want to enter and link them with GPS data. This makes it easy to return to symptomatic plants later for sampling."

Wide-area data on the cropland is supplied by drones equipped with multispectral sensors, which overfly the terrain autonomously and take photographs from an altitude of roughly 35 meters. The data is georeferenced down to the centimeter, and the individual drone images are fused into one complete image. The drone camera also scans infrared wavelengths, delivering initial indications of possible grapevine or fruit-tree diseases. Plants that are stressed or infected by harmful organisms suffer from chlorophyll deficiency. Other colors are predominant as a result.

Remote detection can localize unusually colored grapevines and fruit trees precisely but cannot identify the cause of discoloration. Is it drought, nutrient deficiency or other stress factors? Or could phytoplasmas be the cause and if so, which ones? Apart from FD, plant diseases in Germany include bois noir and other grapevine diseases that are also manifested by yellowing of the leaves but are considered harmless. The next step delivers answers. To ensure a clean laboratory environment, suspicious leaf samples are first collected and prepared outside in the weatherproof PhenoTruck tent. Then they go into the laboratory where hyperspectral cameras record their radiation profiles in the short-wave and infrared ranges. The resulting spectra of the suspicious leaves are compared with reference values from visual assessments and molecular biology data. They are interpreted by AI models that have been trained by machine learning to detect phytoplasmosis and to distinguish between dangerous pests and less harmful pathogens.

"What makes the PhenoTruck special is its off-road capability. After all, you have to be able to go into the vineyard with it."

Markus Michel, Fraunhofer IBMT

"Our models can distinguish between infected and healthy tissue with an accuracy of 95 to 99 percent," reports Bonito Thielert, who supervised extensive field trials. "The differentiation between the grapevine diseases FD and BN is 80 percent accurate. With every step, we cut down the number of samples we have to analyze with molecular biology methods." This final determinative analysis is also performed in the mobile laboratory, delivering the results in just under one hour. Wolfgang Jarausch and his colleagues from RLP AgroScience GmbH optimized the underlying rapid test. This test is based on a new form of DNA amplification that works without cyclic heating and cooling of the biomolecules, making it faster than conventional methods. This makes it possible to identify and clearly assign species-specific gene sequences to specific phytoplasmosis pathogens. There's good news: The PhenoTruck showed what it can do in a field test in Rhineland-Palatinate. There's even more good news: At least there, grapevine yellows have not yet appeared. ■



Since it transmits a dangerous pathogen, the appearance of the American grapevine leafhopper can necessitate grubbing up entire vineyards.

back to page 1



Greater independence: The APECS megaproject is improving European resilience in the semiconductor industry.

Chips for Europe

Coordinated by Fraunhofer the first pilot line of its kind in Europe is currently being established, covering the entire development chain in state-of-the-art chip production. The issue is more than just electronic components: Supply security, innovative capacity and economic stability in Europe are at stake.

By Mandy Bartel

Instead of a single chip, tasks are performed by multiple small specialized modular chiplets working together.

It's the largest project ever coordinated by Fraunhofer: 730 million euros in a project spanning more than four and a half years, involving ten European partners from eight countries. Expectations are high: "The project aims to elevate microelectronics in Europe to a new level and thus to strengthen technological resilience and to give major industrial firms, SMEs and start-ups alike an accessible route to microchips," says Dirk Schumann. As head of the mammoth APECs project, he juggles figures, goals and timelines on a daily basis. APECS stands for "Advanced Packaging and Heterogeneous Integration for Electronic Components and Systems." Schumann is responsible for establishing this pilot line, the only one of its kind in Europe, in the Research Fab Microelectronics Germany (FMD). It is intended to cover the entire

development chain from the design of new chiplet components through prototyping and integration to scalable manufacturing.

New technologies for greater competitiveness

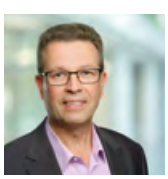
Not only are microchips part of our daily lives, from brushing our teeth to driving or using our phones, they also play a critical role in key areas like AI, quantum technologies, aerospace and medical technology. Most chips are currently manufactured in Taiwan, China and South Korea. For years, experts and associations have warned of dangerous dependencies and the impending loss of Europe's competitiveness. At the same time, new technological approaches are necessary: Electronic systems are becoming increasingly complex, energy-efficient and specialized. This brings traditional approaches to their limits. The focus of the microelectronics industry was long on integrating as many functions as possible in a single chip. However, physical and economic hurdles are making this approach more and more expensive and inflexible. The partners in the APECS project are working on viable alternatives for the future, focusing on heterointegration and chiplet technologies.

Heterointegration refers to different chips and technologies that are combined within a system. Instead of a single chip, multiple small specialized components known as chiplets work together in a modular system, such as memory, sensors and power electronics. This enables more targeted system optimization and more flexible implementation of new functions. This approach also accelerates the development processes that were previously tedious and reduces costs, especially for smaller lot sizes and specialized applications.

Sustainable value for industry

In the APECS pilot line, robust, reliable, and scalable chip systems are to be developed and tested for industrial applications. Dirk Schumann is pulling all the strings. As a physicist, he brings technical understanding and an analytical approach to the role. 30 years of industry experience at companies such as Intel in Ireland, BMW, ASML and Infineon have honed his ability to handle complexity, structure processes and communicate across multiple levels. "My job is to establish a structure with over a hundred individual activities that contribute to a common goal, keeping a handle on the complexity of this project," the project manager says. In the first step, state-of-the-art semiconductor technology systems will be procured and gradually commissioned at various FMD institutes and at European partner organizations. At the same time, the researchers are developing or refining processes and technologies for advanced packaging: integrating chiplets and other electronic components into turnkey systems. A key focus of the project is on sustainability. Resource-efficient designs, circular manufacturing and durable electronic systems can be implemented especially well.

> "My job is to establish a structure with over a hundred individual activities that contribute to a common goal, keeping a handle on the complexity of this project."
>
> Dirk Schumann, FMD



The partners will ultimately share their knowledge and insights with other European companies and research institutions in the form of services and training. "APECS essentially serves as a one-stop shop, bundling expertise, infrastructure, technologies and processes and facilitating the transition from research to applications," explains Schumann. Despite its technical orientation, it is therefore more than just a research project; it is also an industrial and structural policy initiative with strategic relevance. It is part of the EU Chips Act in which the European Union targets investments in semiconductor technologies to strengthen Europe's technological resilience and competitiveness. "APECS is hard work, but it also generates employment," says Dirk Schumann. "A lot of people earn their livelihood from it, and our success will create many more jobs and open up great opportunities for the industry." ■

European collaboration

APECS is designed as a cross-European collaborative project. In Germany, twelve Fraunhofer institutes and two Leibniz institutes are bundling their expertise in APECS. Internationally, the consortium includes partners from Austria, Belgium, Finland, France, Greece, Spain and Portugal, including renowned institutions such as imec, CEA Leti and VTT. This European scope enables networking of existing strengths and helps to eliminate duplicate structures. APECS is co-funded by the Chips Joint Undertaking and with national funding in the Chips for Europe initiative.

Find out more about the project:
https://www.apecs.eu

Photos: Christoph Burgstedt/AdobeStock, FMD

back to page 1



Christopher Spiess is developing a new approach to synchronization in quantum communication networks.

First prize: Christopher Spiess

Particles With a Sense of Timing

Many networked technologies only work when they are perfectly synchronized. That list includes data transmission via quantum communication. Christopher Spiess has developed a synchronization method that uses individual photons as a timing signal. This method is robust, is efficient with resources and is accurate down to the picosecond.

By Mandy Bartel

Whether in 5G and 6G networks, industrial automation or smart power grids: Devices everywhere have to be synchronized, i.e. precisely coordinated with one another. Time acts as a metronome that determines whether information is delivered reliably and systems are operating securely. This precise timing is even more crucial in quantum communication—the high-security counterpart to traditional data transmission for critical infrastructures. In quantum communication, information is exchanged between the transmitter and receiver via entangled photons in a process that is virtually eavesdropping-proof, whether as a beam in free space or via a fiber-optic path. "The state of these light particles and their arrival time at the receiving station are the most important parameters," explains Christopher Spiess from the Fraunhofer Institute for Applied Optics and Precision Engineering IOF in Jena. "In free-space connections, synchronous measurement of arrival times is critical to act as a temporal filter to distinguish the signal from background photon noise such as from sunlight. Also, more precise synchronization also allows for tighter clocking of the qubits, increasing the transmission rate."

An accuracy in the nanosecond range is currently possible with GPS or atomic clocks. However, many pro-

Hugo Geiger Prize

Prize for Talented Young Scientists

Every year, the state of Bavaria and the Fraunhofer-Gesellschaft award the Hugo Geiger Prize to three young scientists that have produced outstanding doctoral work in the field of applied research.

tocols only work if the clocks are synchronized to within picoseconds. That is equivalent to one trillionth of a second, roughly the time it takes for light to pass through a speck of dust. Especially in free-space connections such as between an aircraft and a ground station or between satellites and the Earth, turbulence, vibrations and temperature fluctuations can greatly disrupt timing and increase error rates. Secure, scalable quantum communication requires new, robust and cost-effective methods. And this is precisely where Christopher Spiess's work comes in. "My goal was to develop a method that can manage without additional synchronizing lasers or ultra-stable, expensive atomic clocks and can be seamlessly integrated into existing quantum communication systems," says the researcher. He is therefore combining quantum optics, computer science, electrical technology and engineering in his research.

Synchronization with no additional hardware

Spiess has developed a synchronization method that draws on individual photons—particles of light that are already transmitted as units of information in quantum communication. The underlying protocol functions with no special signal patterns or modifications to the transmitter. Synchronization is achieved solely through the intelligent measurement and analysis of photon arrivals—much like an orchestra without a conductor that continues playing in perfect unison even when all the musicians are following only the soft ticking of a metronome. In Spiess's approach, these clicks are represented by the individual photons. Special algorithms analyze their arrival times and calculate the degree and progression of any disruptions in tight feedback loops. How strongly do turbulence or vibrations affect the beam? How does the signal shift over time? These calculations enable us to compensate for all influencing factors in real time. This results in stable, synchronized timing that makes free-space connections significantly more stable.

Transfer to practice

The field test was also an endurance test for the research scientist. To test his method under real-world conditions, Christopher Spiess had to spend nights outdoors in cold and darkness. The free-space experiments work best without distracting sunlight. Late into the night, he worked with cold fingers to analyze the measurement results on his laptop, tweaked algorithms—and kept himself awake with chocolate.

And had success: In tests over a 1.7-kilometer free-space connection the synchronization was stable despite atmospheric turbulence. In a 70-kilometer fiber-optic link between Jena and Erfurt, integration in the existing infrastructure also worked with no hardware changes.

The results of his research are already being incorporated in several German and European projects developing solutions for secure communication, distributed quantum computing and satellite-based quantum networks. Fraunhofer spin-off Quantum Optics Jena also uses the concept developed by Spiess for synchronization with quantum particles to further improve the reliability of its QKD (quantum key distribution) systems. However, this method also opens up potential applications far beyond this—from telecommunications to aerospace and precision measurement. In the future, satellite communications could use significantly smaller telescopes, as it also works with weaker signals. The performance of precision measurement technologies such as interferometers or quantum optics can be significantly improved, as the use of individual photons eliminates the need for strong reference signals that otherwise generate additional noise. "Looking to the future, synchronization is not just a tool but also a key technology," Spiess is convinced. "Because it enables the seamless integration of traditional communication networks and future quantum infrastructures." ■

Photo: Fraunhofer IOF

Second prize ▶

back to page 1

Second prize: Christian Weber

Hearing What's in the Air

We often don't notice when concentrations of carbon dioxide or nitrogen dioxide reach critical levels until it's too late. Christian Weber uses photoacoustics to construct sensors that are extremely compact, low-power and sensitive for detect these gases early on—at a fraction of the cost of previous devices.

Having difficulty concentrating? Feeling dizzy or unwell? It could be something in the air. Maybe there are high CO_2 levels indoors or too much NO_2 in an underground parking garage. But how much is too much? We no longer feel well when carbon dioxide levels increase from the atmospheric average of 0.04 percent by volume to up to 0.5 percent. The maximum concentration of toxic nitrogen dioxide recommended by the World Health Organization is only five parts per billion (ppb). In other words, five NO_2 molecules per billion air molecules.

Reliable monitoring of these trace gases in the ambient air helps prevent health risks. However, technology for full-coverage monitoring often fails to deliver. "Many measurement systems are large and cumbersome, consume up to 100 watts of power and cost tens of thousands of euros," says Christian Weber, research scientist at the Fraunhofer Institute for Physical Measurement Techniques IPM in Freiburg. "One



Christian Weber's work stands out through a combination of physical finesse and engineering pragmatism.

of the sensor architectures I developed during my dissertation work is the size of a pack of tissues, consumes roughly half a watt of power and has detection thresholds in the single-digit ppb range." This enables Weber to simplify and expand health protection.

Making gas concentrations audible

The physical concept behind Weber's sensors sounds simple: light is converted into sound. "When light shines through a gas at a wavelength that matches its natural frequency, the gas absorbs a portion of the light. The absorbed light energy undergoes a series of processes that convert it into heat energy," explains Weber. "This causes the gas to expand, creating a sound wave that we can measure with a microphone. Pulsing the light—switching it on and off rapidly—produces a periodic signal that corresponds to an acoustic tone. The higher the gas concentration, the louder the signal." Experts refer to the phenomenon of audible light as the photoacoustic effect, which was first discovered in 1880 by Alexander Graham Bell. Now, this old measurement method is experiencing a renaissance thanks to a combination of Weber's work and the availability of new light sources, such as high-power light-emitting diodes (LEDs) and semiconductor lasers, as well as highly cost-effective micromechanical microphone chips developed for smartphones.

Two methods, two innovations

For his doctoral thesis, the research scientist developed two sensor architectures in parallel, each tailored to a specific target gas and application. The objective for the CO_2 sensor was that it be small and energy efficient. In Weber's specially designed two-chamber system, an LED emits infrared light over a short measurement distance into a special photoacoustic detector that is filled with carbon dioxide and hermetically sealed. The trick: The detector registers precisely the narrow absorption lines to which CO_2 reacts. "This makes us four to six times more sensitive than conventional filter solutions and can shorten the optical path to eight millimeters," Weber says. The result is a sensor module measuring $8 \times 7 \times 17$ mm³ that operates for years with minimal calibration and high energy efficiency. This makes it ideal for applications such as interior ventilation in schools and offices.

Meanwhile, toxic NO_2 must be detected already at significantly lower concentrations. This makes measurement a major challenge. Weber's NO_2 sensor, which has a resonant single chamber, uses powerful

> "The gas expands, creating a sound wave that we can measure with a microphone."
>
> Christian Weber

LEDs and a specially shaped cell to "hear" the absorbed light signals in the violet-to-blue spectrum. However, since the emitted tone is very faint at the extremely low gas concentrations to be measured, it must be amplified by an acoustic resonator. The research scientist provides a simplified explanation, comparing it to an organ pipe, where even a weak stream of air produces a loud sound in a resonating chamber. "This resonance changes with temperature, pressure or humidity," says Weber. "However, the excitation frequency must precisely match the resonant frequency of the structure to prevent measurement errors." The solution proposed by the Fraunhofer research scientist is both elegant and practical: "I focus the light from a second LED directly onto the wall of the resonant cell. As the radiation is absorbed, a portion of the heat is also transferred to the gas, generating a sound wave that excites the cell resonance." Not only did this method prove to be completely linear and free of inherent resonances, but it can also be easily and inexpensively integrated into a sensor system at an additional cost of less than one euro. The process is patented and has already been licensed.

Successful technology transfer

The impact of Weber's work can be seen in the numbers: the results have already been incorporated into more than ten industrial projects. His method yields systems that replace existing solutions that are hundreds of times more expensive in specific applications, with unit prices in the low three-digit euro range. Applications range from monitoring greenhouse gases and transcutaneous CO_2 measurement through the skin in medical technology to detecting methane leaks from a moving car. Further applications are in tunnels and underground parking garages, where the higher sensitivity provides more advanced warnings. Other projects involve refrigerant leaks and fuel cell diagnostics. The Fraunhofer research scientist sees future potential for gases such as ammonia associated with the energy transition and in networked, battery-operated sensor clusters for cities and industrial plants. ■

Photo: Fraunhofer IPM

Third prize ▶

back to page 1

Third prize: Anne-Sophie Munser

Fighting Faster Against Bacteria

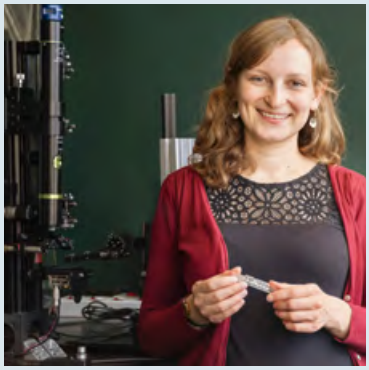
The measurement method is tried and true, but Anne-Sophie Munser has reinterpreted it from the ground up. Scattered light analysis can now be used to detect harmful microorganisms earlier than before. This helps detect diseases and antibiotic resistance more quickly, as well as germs in food and water.



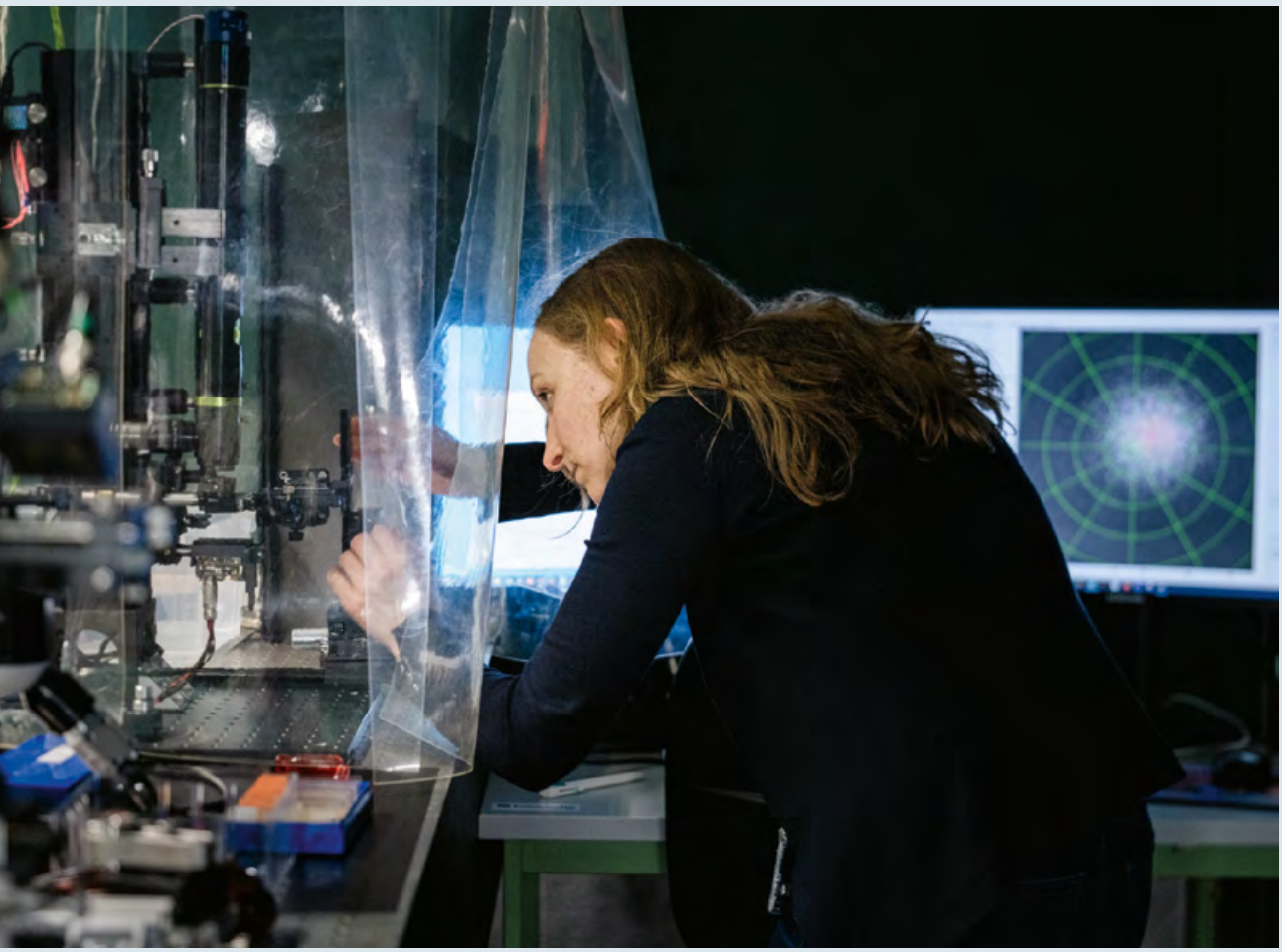
Anne-Sophie Munser is an optical engineer specializing in photonics. For her dissertation work, she also became a biologist: she took a method normally used for testing and measuring the nanostructures of optical systems and applied it to cell biology. "Sensitive measurement methods such as angle-resolved scattered light analysis are needed to detect even the smallest defects or particles on the ultra-smooth surfaces of mirrors or lenses," explains the research scientist from the Fraunhofer Institute for Applied Optics and Precision Engineering IOF in Jena. The idea of testing this measurement method on bacteria came up in a discussion with the neighboring Leibniz Institute for Natural Product Research and Infection Biology Hans Knöll Institute HKI in Jena.

"The combination of speed, non-contacting sensing and extremely high sensitivity motivated me to use scattered light for biomedical studies and to focus on bacteria and fungal spores rather than nano-scale scratches or dust particles." Together with the HKI, she thus set out to solve a relevant problem in medical practice. Harmful microorganisms must be quickly identified in order to reliably diagnose diseases in a timely manner. Previously, this has only been possible by culturing bacteria in an elaborate process over many hours and sometimes even days—often too long for medical emergencies. Measurements using scattered light is both more accurate and faster. "The method is so sensitive that we can detect microbes in the micrometer range in a fraction of a second without using dyes," says Munser. "Conventional methods need thousands of cells." This means that even a small number of individual cells can be analyzed in a very short time—and can thus be fought more effectively.

> "The method is so sensitive that we can detect microbes in the micrometer range within fractions of a second and without using dyes."
>
> Anne-Sophie Munser



In angle-resolved scattered light measurement, a laser beam strikes the cells and—depending on their morphological properties—is reflected by their microstructures and nanostructures and is scattered in corresponding directions or angles. The resulting pattern reveals whether the samples are individual bacteria, cell clusters or other microorganisms and provides information about their characteristics. The research scientist describes one of the challenges of her work: "At first, these patterns are new to biologists." "They are used to seeing images of the cells under their microscopes. I therefore



Anne-Sophie Munser's work at Fraunhofer IOF is making a significant contribution to the fight against antibiotic-resistant pathogens.

developed my own data analysis methods in my work, making it easier to interpret the results." Munser and her team at Fraunhofer IOF are currently using AI in their work on further simplifying the analysis method.

Detecting antibiotic resistance

In her doctoral research, Anne-Sophie Munser was able to demonstrate that scattered light technology can be used to determine the effectiveness of antibiotics against various bacteria within just a few hours. This is a clear advantage for faster and targeted treatment. Munser is pleased: "Instead of waiting for colonies with thousands of cells, we can use a microfluidic sample system after only the first two or three cell divisions to determine whether an antibiotic is effective against a specific pathogen or whether it has already developed resistance." This makes the device, which at present is roughly the size of two shoeboxes, more sensitive than methods previously used in biology. "And we are currently working on making the system even more compact, portable and sensitive, letting us reliably analyze even individual cells." In the future, the system could even be miniaturized to lab-on-a-chip scale. But the speed of the system is not the only innovation. It is also the ability to analyze thousands of samples in a very short time. Because a measurement takes only a fraction of a second, this technology can be integrated in compact, high-throughput systems in laboratories and clinics.

With the close interdisciplinary collaboration of experts in photonics, microbiology and infectious disease biology, the scattered light method is already in use at a research institute for drug discovery and infectious disease diagnostics. But its potential goes far beyond that: "In the future, scattered light sensors will enable simple testing for drinking water quality or food safety," says Munser. "And the method could also prove interesting for stem cell differentiation and biofilms, such as for implants or in dentistry." ■

Photo: Fraunhofer IOF

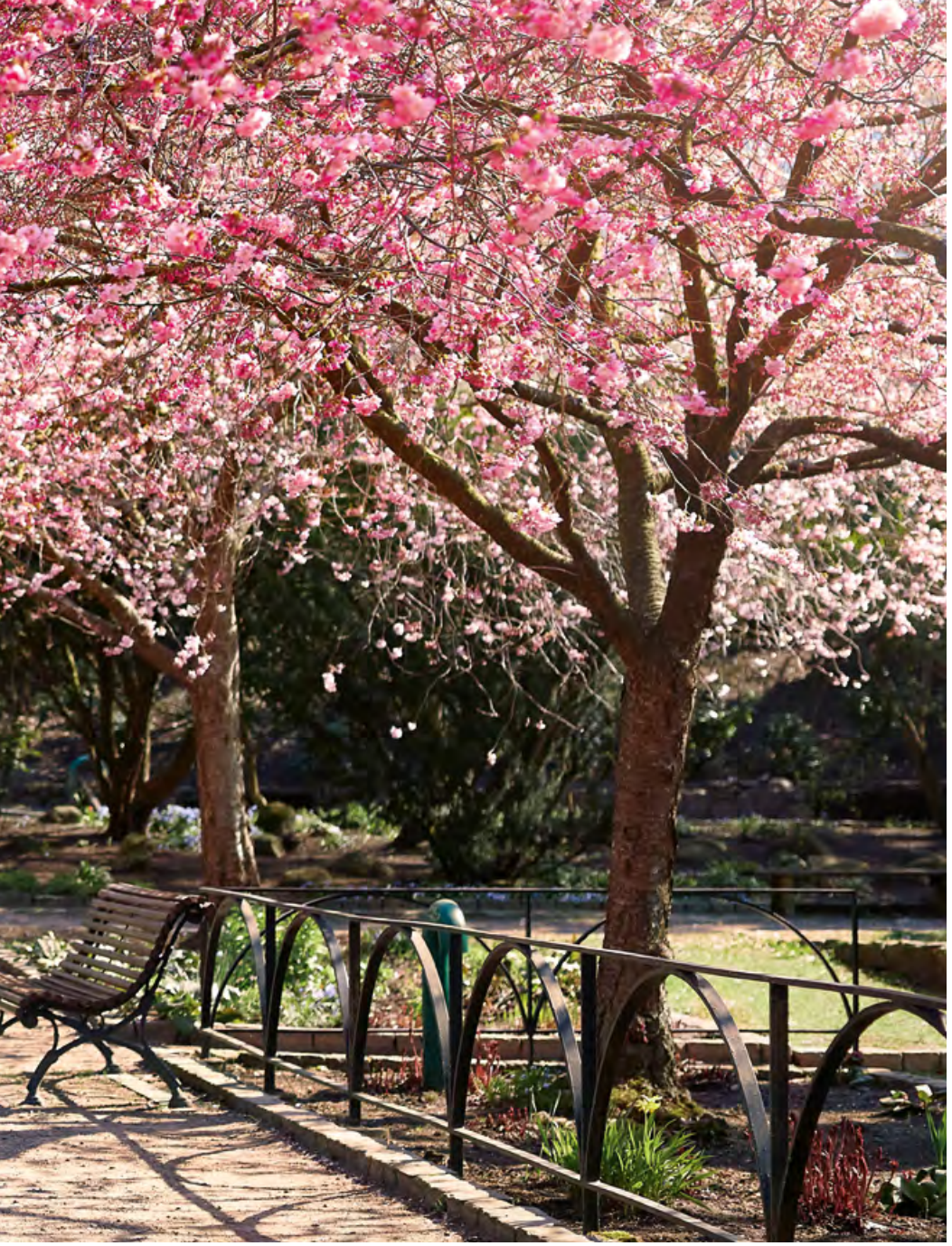
back to page 1



Smart Wearables Instead of Cable Spaghetti

More than nine million people worldwide die each year as a result of heart disease. In Germany, it is responsible for a third of all deaths. An AI-supported sensor system can detect warning signs at an early stage, saving lives.

By Monika Offenberger



The new wearables can synchronously record and compare all this data at a sampling rate of

1,000

points per second.

Convenient heart rate monitoring while jogging: Sensor-equipped patches or vests make it possible.

Photo: Johnér/mauritius images

Exhaustion after jogging, shortness of breath when climbing stairs, anxiety before falling asleep: Most of the first signs of heart failure are nonspecific. Those affected therefore often put off seeking medical help for a long time. "And when they finally do go to the cardiologist, maybe everything looks just fine. But the next day, when they go for a run, the problems come back because the heart doesn't reach its limit until it's under stress," says Basel Adams, team leader at the Fraunhofer Institute for Reliability and Microintegration IZM. Comprehensive heart monitoring is often not available until after a wait of several weeks and involves tremendous effort.

"There must be a better way," thought Adams, a trained electrical engineer and got to work on his dissertation. In the Fraunhofer maia (Medical Artificial Intelligence Applications – Center for Applied AI in Medicine) joint research project at Fraunhofer IZM, he worked together with partners from Charité Universitätsmedizin and TU Berlin to develop an intelligent sensor system that can be worn directly on the body. It measures a large swath of cardiac and circulatory data—wirelessly, in real time and at any time—and uses this data to derive AI-supported diagnoses and treatment recommendations. To date, two types of sensor-equipped wearables have been developed. One is an individually adjustable textile vest designed to be worn once a day for 10 to 15 minutes over an extended period and uses built-in sensors to record physiological data. The other is an ensemble of biocompatible patches that are placed on various parts of the body, over the heart and lungs, on the neck and on the legs to continuously gather data. ▶

back to page 1

Data acquisition in the wearables is performed by multi-channel semi-dry textile electrodes that can distinguish relevant signals from interfering body movements. The biocompatible electrodes are integrated in the washable fabric vest with hook-and-loop fasteners for optimal contact on the body depending on the wearer's size and build, contact the skin directly without any conductive gel.

Whether in the form of a vest or with patches, the smart sensor system measures a wide swath of medically relevant signals, including body temperature, respiratory rate, heart and lung sounds blood pressure and oxygen saturation, stroke volume and cardiac output, a complete 12-channel ECG and much more. The total of 40 acquired raw data signals can be used to derive 110 cardiological parameters. They provide a comprehensive picture of cardiovascular function during various activities, whether the person is awake or asleep, exercising or experiencing stress, feeling happy or upset. To integrate this impressive arsenal of state-of-the-art medical technology into comfortable, everyday wearables, the various instruments first had to be miniaturized and connected together through interfaces. The result is a world first, stresses Basel Adams: "Although there are all sorts of sophisticated devices on the market, they are far too large and generally don't provide any raw data but rather only derived results. Nor do they have any standardized interface because every manufacturer uses its own system."

The new wearables can synchronously record and compare all this data at a sampling rate of 1,000 points per second. But that's not all. "The system also receives input from two additional data sources," explains Adams. A cardiologist first creates a patient profile with all the relevant information about known hereditary conditions, previous surgical procedures and medication used. "We also ask the person how they feel at present, whether they tire easily or if they have noticed any chest pain, difficulty breathing or other irregular symptoms." A chatbot obtains this information by asking questions for five to ten minutes once a day, as would a doctor, and saves the answers along with the other data in the cloud.

Each measurement thus combines more than a thousand data points from three sources, serving as the basis for a diagnosis or risk analysis by the system. "The key is that we record all of these signals synchronously. The AI can thus learn to recognize patterns and draw the right conclusions from them. This is the diagnostic strength," explains Adams. He first obtained the necessary expertise in in-depth dialogue with Charité cardiologists and then used this expertise to train the AI. The guidelines of the German Cardiac Society serve as the basis. "We want to ensure in this way that our system follows the same criteria as a doctor would in practice."

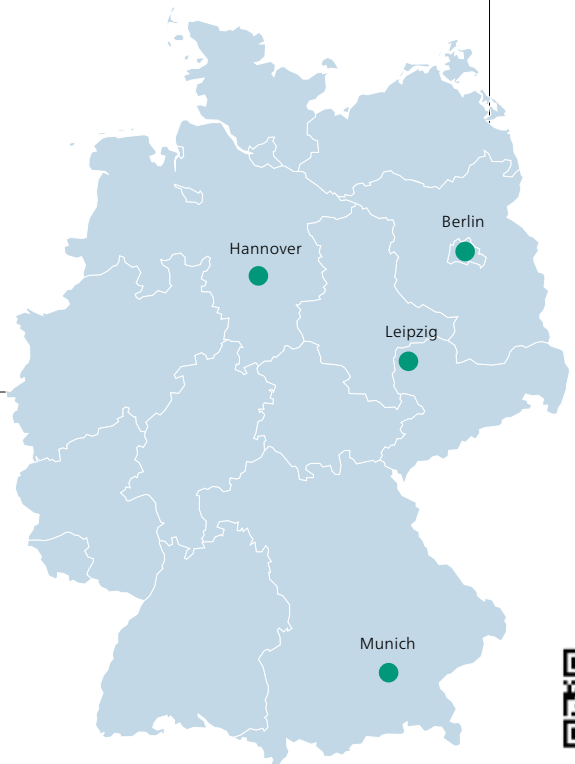
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> Basel Adams, Fraunhofer IZM

Before the sensor-equipped vests and patches can be tested on people with heart disease, their effectiveness has to be demonstrated in clinical trials. The question: Is the AI-supported system correct in its diagnoses and treatment recommendations? Or does it even make more accurate assessments than experienced cardiologists? While Basel Adams looks for partners for studies—the necessary approval from the ethics committee has since been provided—his colleague Lukas Werft is already considering further improvements to the wearables. In the Fraunhofer IZM System On Flex group, the materials engineer played a key role in developing textiles with integrated flexible electronics. In the current model of the vest, the various electrodes transmit their signals via conventional cables that are routed between two layers of fabric. "Once our product is launched on the market, we could consider integrating the electrodes in a T-shirt, for example," he says. "It should be possible to just toss it in the washing machine after wearing it, ideally as often as needed. And of course it would be practical to not have to first remove all the cables every time."

The researcher already has an idea of how to solve this problem: with a printable and washable liquid-metal ink that he developed together with colleagues at Fraunhofer IZM. The main component of this innovative Liquid Metal Ink (LMI) is Galinstan, an electrically conductive alloy of gallium, indium and tin. It can be printed on and encapsulated in thermoplastic polyurethane, a plastic that can be shaped using heat, and then laminated on standard textiles. "If we could replace the conventional leads with this liquid metal, sensor-equipped textiles such as T-shirts or vests could be extremely durable and washable," underscores Werft.

Lukas Werft sees another medical application for this liquid metal ink in pediatrics: "Unfortunately, far too many babies still die from sudden infant death syndrome because they stop breathing unnoticed during the night. Traditional monitoring systems are uncomfortable and awkward. Our approach would be to integrate Galinstan-based strain sensors directly into baby clothes." A prototype of a sensor-equipped garment for babies has already proven its function in a Europe-wide research project called Newlife. ■

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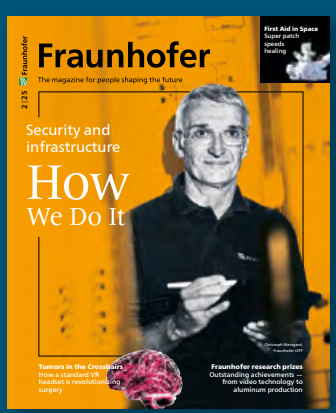
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back to page 1

New Heights for Industry

Space as an economic opportunity: the New Space Economy is bringing about a paradigm shift. Fraunhofer IOF research manager Stephanie Hesse-Ertelt is working on this. Her fascination with space travel has long since become quite personal. “If it becomes possible,” she says, “I would love to join a space flight someday.”



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