Fraunhofer
3 | 25

Fraunhofer

The magazine for people shaping the future

The Circular Economy
How we can keep raw materials in the loop

Michael Hudecek, Fraunhofer IZI

Open the Door!

New solutions for medicine

Bomb Threat
Fraunhofer software helps to defuse the situation

Cybercrime
The search for security becomes a risk for researchers

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

High-Tech Transfer Is Our Core Business

By Holger Hanselka

Holger Hanselka

It is a coincidence, but it is a trend-setting one, that two lines of development intersect in this one week. From Stuttgart, Mercedes-Benz reports a 50 percent drop in profits. Its neighbor, Porsche, reports 95.9 percent lower profits. In Wolfsburg, Volkswagen is faced with a loss of more than one billion euros in the third quarter. That is the somewhat depressing side of this week. But the flip side is inspiring: High-Tech Agenda Germany is picking up speed. After the opening event with 500 guests in the Berlin Gasometer, German broadcaster ARD's Tagesschau news program asked "Can we save the economy with technology?" Let me answer this with the question: What else is there?

We all know the buzzwords. Openness to new technology. The courage to take risks. Speed instead of bureaucracy. Let's use these words to pave our way to the future. We can trust our capabilities. Germany is Europe's innovative driving force. Nearly a third of all European patents involving public research originate from German institutes. A recent study by the European Patent Office has just evaluated patent applications from 2001 to 2020. It attributes an outstanding role to Fraunhofer: Of the 18,276 applications, 7,852–or 42 percent—came from the Fraunhofer-Gesellschaft.

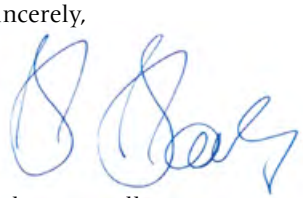
Fear of global upheavals, anxiety about international competition, sentimental recollection of possibly simpler times: None of this will help Germany or Europe out of any crisis. The outlook of High-Tech Agenda is more positive. Planned investments of at least 18 billion euros represent a strong signal for a fresh start. Six key technologies have been defined as targets: artificial intelligence, quantum technology, microelectronics, biotechnology, nuclear fusion and climate-neutral power generation and technologies for climate-neutral transportation. The task at hand is to transform innovations into measurable value creation with a clear concept.

Its understanding of the market makes the Fraunhofer-Gesellschaft the ideal partner for this task. This is no idle claim. It is our tradition. And it is a part of our daily life. With its unique position in the scientific system, Fraunhofer focuses precisely on the commercialization of outstanding research. Following our unique Fraunhofer model, we generate at least two thirds of our funds ourselves through competition. Through the outstanding achievements of our 75 research institutes, the Fraunhofer-Gesellschaft has succeeded in growing industrial revenue even during difficult economic times.

Technology transfer is our core business. Moreover, Fraunhofer's research already covers all the key technologies defined by our High-Tech Agenda. Fraunhofer delivers it all from a single source. Business plus science: Let us take the kickoff of High-Tech Agenda Germany as our common call to action. Now is the time to pool our strengths.

I look forward to our future.

Sincerely,



Holger Hanselka
President of the Fraunhofer-Gesellschaft

Photo: Fraunhofer/Stefan Obermeier

back to page 1

Contents

10
Circular economy
Closing the Loop
Jan Luca Twardzik is improving the recyclability of electrical appliances at Fraunhofer IEM.

26
Working in a Gray Area
Cybersecurity harbors many uncertainties for research. What is permitted? What is not? And: What can be improved?

03 Editorial

06 In Brief

09 Editorial Notes

10 Back to the Beginning
Keeping raw materials in continuous circulation with circular design, digital material expertise and bio-based materials

24 Shredder or Second Life?
Electric transportation: New approaches to battery recycling

26 When Research Becomes a Criminal Offense
Simulated court proceedings improve legal certainty for research scientists

36
Cover story
Opening the Door to Practical Applications
Researchers like Kathrin Held from Fraunhofer ITMP are commercializing medical innovations.

38 "CAR T Cells Detect Tumors Throughout the Body."
An interview with Michael Hudecek, co-developer of CAR T-cell therapy

42 The Industrial Revolution for Cancer Therapy
A highly automated laboratory platform speeds up the production of CAR T cells

44 The Eternal Battle against the White Plague
New approaches to fighting tuberculosis

48 A Gentler Look at Tumors
Radar as a smart supplement to X-ray diagnosis

50 The Next Level in Tumor Diagnostics
Early detection: Researchers develop a blood test for pancreatic cancer

53 Surviving Blood Poisoning
Detecting sepsis with AI-supported sensors

28 Rapeseed Instead of Beef
A novel process transforms this oil crop into protein-rich meat alternatives

30 An Explosive Legacy
How can unexploded aerial bombs be defused with maximum safety?

32 A Trashy Situation
Second life: Heavily soiled plastic waste is transformed into material for 3D printing

34 More from the Moor
Solar installations on rewetted peatlands are urgently needed. Research clarifies the key parameters

54 The Key is in the Data
How Fraunhofer spin-off plus10 optimizes the productivity of machines and plants

56 Poplars Help Fight Climate Change
Improving land use: Agroforestry relies on a mix of arable farming, trees and shrubs

64
Traveling Safely and Sustainably

One material, many forms: Bio-based PLA plastic makes more than just bicycle helmets recyclable.

30
Taming Blasts

Unexploded World War II ordnance: Fraunhofer software helps assess the risk.

58 The Carbon Fiber Revolution
Fraunhofer researchers have developed carbon fibers from cellulose

60 Preventive Medicine for Wind Turbine Blades
Sensors for wind farms: Acoustic detection of damage in wind turbine blades

62 Fraunhofer Worldwide

64 A Helmet for a Smaller Footprint
Renewable raw materials as the basis for sustainable cyclist protection. There is even more potential in bioplastics

66 In the Green Zone
Innovative laser technology provides early detection of trees at risk of falling

68 Electrifying Discoveries
Facilitating brain activity measurement: The EEG goes mobile

70 A Photo & Fraunhofer
Innovative materials for more sustainable fishing gear

66
When Trees Fall...

... they become a traffic hazard. A laser scanner can work preventively.

72 Beeting the System
Compostable plates from residual plant matter

74 But Where's the Crew?
Autonomous, low-emission ships ease the burden on freight transport

76 Sustainably Strengthening Defense Capabilities
Safe and efficient: The Bundeswehr on course for a self-sufficient energy supply

78 This Energy Comes Straight from the Heavens
Solar power for buildings: A smart matrix connection can optimize area utilization

79 Fraunhofer Minds

Sustainability as an economic trend: According to an industry information report from Global Market Insights Inc., the global market for solutions in the circular economy is set to grow from 2.7 billion US dollars in 2024 to 5.8 billion in 2034. This would correspond to an increase of roughly

115 %

Cover photos: Simon Koy, Sven Döring, Havergo/Fotostand/dpa, back cover: Sven Döring;
Content photos: Sven Döring, Laurentiu Lordache / Alamy / mauritius images, Simon Koy, Esteban Felix / AP, Havergo / Fotostand / both from dpa, Tomas Pavlasek / istockphoto

back to page 1

In Brief

The SUPAWheel will soon be rolling on recycled aluminum.

Wheel of the future: rethinking aluminum

Lightweight and non-corrosive: The automotive industry has long used aluminum rims instead of steel. But their production generates high CO_2 emissions. Researchers at the Fraunhofer Institute for Casting, Composite and Processing Technology IGCV are now working on the SUPA-Wheel project to increase the proportion of recycled aluminum to at least 30 percent. The aim is to recycle old rims, saving material and costs: The production of recycled aluminum requires only seven percent of the energy needed to produce primary aluminum.

The challenge: "Impurities can impair the strength and durability of the rims," says researcher Robert Kleinhans at Fraunhofer IGCV. "It is therefore crucial to precisely analyze the interactions between different elements in the alloy. Only in this way we can ensure that the properties of the rims meet the automotive industry's high quality standards." A newly developed matrix helps to identify alloys that are sustainable and have the optimum properties. A patent application has already been submitted for this method. ■

Images instead of banners: better understanding of data protection notices

Data protection banners on the Internet with long, cumbersome texts are often simply clicked away. In a joint study with ETH Zurich, researchers from the Fraunhofer-Gesellschaft's National Research Center for applied Cybersecurity ATHENE have now discovered that real-time feedback and an appealing visual language ensure that they are better understood and perceived. To learn this, the research scientists surveyed roughly 400 people. The result: The study participants not only understood the illustrated data protection policies more quickly, but also found them more pleasant, especially when they were given immediate feedback on their data protection decision with the help of images and symbols. This simplifies informed consent to the processing of personal data as provided for in the General Data Protection Regulation (GDPR). ■

Risks can be communicated more quickly using symbols.

Ground coverage: Solar power from agriculture

Double benefit: the PV modules also protect against hail.

The Fraunhofer Institute for Solar Energy Systems ISE has conducted several studies investigating the potential for agrivoltaics (agri-PV) in Germany. "This is the first study in Germany to look at all types of agricultural land to identify suitable sites, i.e. permanent grassland, arable land and permanent crops such as fruit growing, vines or berries," explains study author Salome Hauger. Up to 500 gigawatts of peak solar power could be installed on the most suitable areas alone, exceeding Germany's expansion targets for 2040. Two scenarios for area assessment show that up to 7900 gigawatts peak are possible, depending on the exclusion criteria. "The data from these studies provide a solid basis for political decision-makers and interest groups to promote the expansion of renewable energies and contribute to achieving climate targets," emphasizes Anna Heimsath, Head of the Analysis Modules and Power Plants department at Fraunhofer ISE. ■

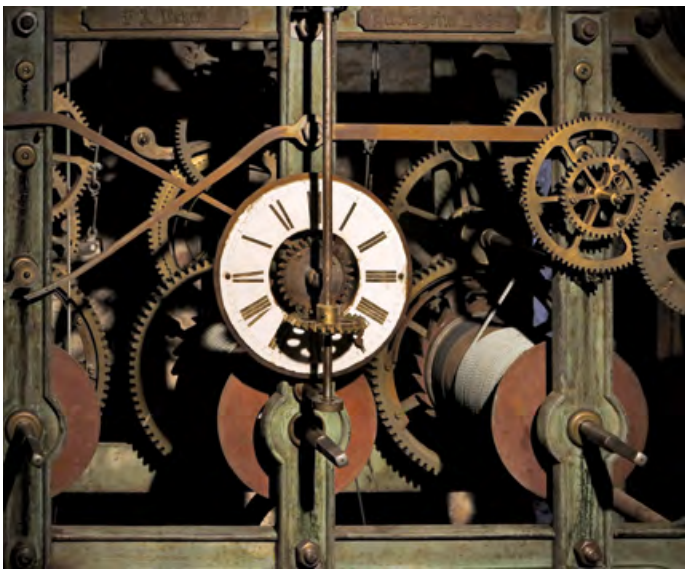
Waste wood: from residual material to raw material

More recycling could significantly reduce the need for fresh wood and conserve resources.

An innovative chemical process enabling the complete recycling of old chipboard has been developed by a research team at the Fraunhofer Institute for Applied Polymer Research IAP in Potsdam together with partners. The research scientists treat the shredded wood from used furniture or structural elements in a novel process with a so-called recycling agent. This is a specially developed chemical agent that partially dissolves and reactivates the adhesives used. The researchers then press new dimensionally stable boards from the wood mass. Roughly 95 percent of the recycling agent can be recovered and can be reused multiple times without losing its effectiveness. This chemical process has already been successfully scaled up to the pilot plant level. The recycled material can be processed in conventional plants. The process developed is especially suitable for producing wood-based materials in the construction industry and in furniture manufacturing. ■

Photos: Bibigon, Bulat Silvia, Marina Lohrbach, Norbert Burger / all from istockphoto

back to page 1



The historic tower clock mechanism from SKD's collection remained intact thanks to the gentle cleaning process.

Restoration made easy

Rust, moss and mold endanger cultural assets made of metal and wood. Using an innovative vacuum suction blast-cleaning process, they can now be cleaned gently, quickly and in an environmentally friendly way. This method was developed by researchers at the Fraunhofer Institute for Electron Beam and Plasma Technology FEP in collaboration with the Dresden State Art Collections (SKD). The project was funded by the German Federal Environmental Foundation (DBU).

In this new process, items are cleaned in a closed chamber. The researchers tested a precise vacuum suction jet with special nozzle shapes and sensors enabling detailed control of the cleaning area. Furthermore, the innovative suction jet does not require any of the usual chemicals. This protects restorers from harmful residues and is also sustainable, as the blasting agent is collected, cleaned and fed back into the process.

Conventional cleaning of the often fragile surfaces of historical objects has previously been very time-consuming. The patina must not be damaged or destroyed, as it tells the story of the objects and is a unique, individual component of the cultural asset. ■

Autonomous surface vessel for underwater analysis

A precise look beneath the surface of the river: in collaboration with the Düsseldorf district government, the Fraunhofer Institute of Optronics, System Technologies and Image Exploitation IOSB has surveyed the Ruhr river. For the first time, an autonomous surface vessel was used for fully autonomous collection of high-resolution data from a six-kilometer stretch of the river. The two-meter-long drone is especially suitable for shallow waters and minimizes ecological impact. It uses sonar and optical sensors to measure the elevation relief both below and above the water surface. The device provided detailed insights into the underwater world of the Ruhr river and thus supports activities such as water maintenance or the calculation of flood events.

"We deliberately entered uncharted territory with the idea of using a lightweight, autonomous platform to survey bodies of water as fully automatically as possible," says project manager Janko Petereit. The Fraunhofer team now plans to optimize the technology in further pilot projects. ■

The battery-powered drone can independently avoid obstacles.

Editorial notes

Fraunhofer. The magazine for research, technology and innovation
ISSN 1868-3428 (print edition)
ISSN 1868-3436 (online edition)

Published by:
Fraunhofer-Gesellschaft
Hansastrasse 27 c, 80686 Munich, Germany
Editorial address as above
Phone +49 89 1205-1301
magazin@zv.fraunhofer.de
https://s.fhg.de/magazine-en

Free subscription:
Phone +49 89 1205-1301
publikationen@fraunhofer.de

Editorial team:
Monika Landgraf
(person responsible for content),
Josef Oskar Seitz (editor-in-chief),
Sonja Endres and Beate Strobel

Editorial assistants:
Janine van Ackeren, Meike Grewe, Sirka Henning, Andrea Kaufmann, Laura Rottensteiner-Wick, Kathrin Schwarze-Reiter, Mehmet Toprak, Yvonne Weiss

Layout and lithography:
Vierthaler & Braun
Circular economy and back cover photography: Sven Döring
Cover image and photography for Medical innovations: Simon Koy

Printed by:
be1druckt GmbH, Nuremberg

Find Fraunhofer on social media:

@Fraunhofer
www.facebook.com/fraunhoferde
www.instagram.com/fraunhofergesellschaft
www.linkedin.com/company/fraunhofer-gesellschaft
www.youtube.com/fraunhofer

Print product with financial climate contribution
ClimatePartner.com/11586-2411-1006

MIX Paper | Supporting responsible forestry FSC® C022647

Photos: Martina Berg/Adobe Stock, Fraunhofer IOSB, Dushlik/istockphoto

Critical to survival in winter: de-icing on the ground and in the air.

Flying more sustainably

Icing on wings reduces lift, increases drag and impairs maneuverability. An innovative Fraunhofer technology saves energy while efficiently removing the ice.

To keep the wings free of ice, aircraft are equipped with thermal systems that draw hot air from the engines and channel it across the surface of the wings. However, this process requires a great deal of energy, and it also impacts engine efficiency.

In the Clean Aviation project, Fraunhofer researchers and partners have developed a much more energy-efficient method: The iced portion of the aircraft wing is vibrated, causing the frozen layer to detach.

In the first step, sensors signal that ice is accumulating on the wings. Then the natural resonant frequency—the frequency range within which the material starts to vibrate—is calculated. Piezoelectric actuators are activated at that point. They trigger low-frequency material vibrations targeted at the spots where the ice has formed. "The vibrations are in the range of just a few kilohertz. They are invisible to the naked eye but very effective. The ice clinging to the wing breaks up and falls off," explains Denis Becker, a researcher at Fraunhofer Institute for Structural Durability and System Reliability LBF. To calculate the vibration frequency, the researchers first needed to study the highly complex interaction of a range of different factors that are responsible for the natural resonant frequency when ice forms.

"The determining factors include the material the wings are made from, the speed, the altitude of flight, the temperature, humidity and how thick the layer of ice is. Algorithms use that information to calculate the natural resonant frequency," Becker explains. Because exterior conditions are constantly changing in flight, the resonance frequency changes as well. Whether the coat of ice thickens or melts is also a factor. For this reason, the sensors continuously supply new measurement information so that the electronics can activate the actuators at the adjusted frequency at any time.

For the research project, the Fraunhofer team went through various steps, including placing a wing inside a special icing wind tunnel and optimizing the way the piezoelectric actuators work. ■

back to page 1

Circular economy

Back to the Beginning

How Fraunhofer institutes use circular design, digital materials expertise and bio-based materials to keep raw materials in continuous circulation.

By Kathrin Schwarze-Reiter; photographer: Sven Döring

A sensitive nose: Helen Haug from Fraunhofer IVV uses a gas chromatograph to test whether recycled packaging still smells good or whether it may even be harmful to health.

back to page 1

A bit musty, fatty, reminiscent of cardboard," says Helen Haug as she puts her nose to a tube and sniffs. "That would be (E)-2-nonenal, a molecule that can be produced by the breakdown of fats." A few seconds later, she notes "cheesy, sweaty" on her sheet—presumably butyric acid, which is formed by bacterial metabolism in waste. Then she writes "flowery, smells of violets"—and suspects beta-ionone, which is often found as a fragrance in cleaning products. At the end it gets really bad: skatol. This is a substance produced by microbial degradation in packaging recycling when food waste or biowaste is involved.

As a sniffer, Helen Haug investigates odorous substances. At the Fraunhofer Institute for Process Engineering and Packaging IVV in Freising near Munich, she investigates materials including plastic recyclates, i.e. materials that are produced when plastics are recycled—with the help of her nose. The tube through which the odor molecules flow is attached to a gas chromatograph: an analytical instrument that slowly heats a sample extracted from recycled plastic and then transports the odorants present in a gas stream to Helen Haug's trained olfactory cells. The stream contains molecules the plastic has brought with it from its past life or that have first formed in the recycling process.

"Odor is a clear quality factor in recycling," says the 30-year-old odor researcher, "especially if the material is to be used again later in an application intended for close use by consumers." It is therefore a challenge to ensure recycling of the yoghurt container is technically stable and, above all, safe. But if it ends up smelling unpleasant, nobody will want to eat from it. Haug and her team are therefore investigating the odors in order to improve the properties of the recyclates. Some substances produced during recycling can even be harmful to health. The researchers at Fraunhofer IVV are also looking for these.

A while ago, Haug's colleague Ludwig Gruber came across an unexpected culprit: burger wrapping paper. "It actually all looked harmless," recalls Gruber, Head of Laboratory for Contaminants Analysis at Fraunhofer IVV. "But when we heated the paper together with water—which is what really happens in the microwave with a juicy burger—fluorotelomers were suddenly formed." These inconspicuous molecules can degrade into PFAS, the "forever chemicals" that accumulate in the environment, have a toxic effect on the liver and are suspected of being carcinogenic. "This," says Gruber, "is precisely why we always have to consider the real-life use when we test plastics: How are they going to be used? Where are the risks?"

> "When testing plastics, we always have to keep the real-life use in mind: How will they be used? Where are the risks?"
>
> Ludwig Gruber, Fraunhofer IVV

Gruber's specialty is mass spectrometric screening. The mass spectrometer is an analytical counterpart to Helen Haug's sniffer port. Instruments like this can detect molecules that are not perceptible by their odors, so they can be precisely identified. The molecules are first separated from each other. The connected detector—the mass spectrometer—reveals their inner life: antioxidants, UV stabilizers from old garden furniture, dye residues from packaging films or decomposition products from the recycling process. "We compare the peaks from the analysis with a database of more than 80,000 substances," says Ludwig Gruber. "This enables us to determine what is in the recycled material at concentrations below the parts-per-billion level." Together with the odor tests, this establishes a double portrait of each plastic. This combination makes it possible to reliably assess whether a recyclate can actually be reused in the form of high-quality, safe products.

The cycle as a model for the future

Earth Overshoot Day comes earlier every year. This is the day when we have used up the renewable resources

that the earth can regenerate in a year, after which we have to live on credit. While it was celebrated on September 23 25 years ago, this year it was already on July 24. Our global population is growing rapidly and its hunger for raw materials knows no bounds.

Our linear "take-make-waste" model is reaching its limits: Natural resources are becoming scarcer, the mountains of waste are growing and the production of new materials generates enormous CO_2 emissions. According to the United Nations International Resource Panel, roughly 90 percent of global biodiversity loss and around half of all greenhouse gas emissions can be attributed to the extraction and processing of natural resources.

By implementing circular principles, European companies could save over **600 billion euros** a year in material costs by 2030.

The shampoo bottle contains valuable crude oil, while the smartphone contains raw materials such as palladium, tantalum, tungsten and dysprosium. Batteries require zinc, manganese or lithium. And last but not least, construction waste: This is growing into the largest mountain of waste in Europe, harboring rare earths, steel, copper and natural stone. This is precisely where the circular economy comes in: it aims to minimize the use of materials, keep recyclable materials in circulation and massively reduce industry's ecological footprint. The circular economy is thus much more than just recycling—it requires us to rethink design, production, consumption and policy. It also offers many opportunities: according to the Ellen MacArthur Foundation, circular principles could save European companies over 600 billion euros a year in material costs by 2030.

Searching for the yogurt lid in plastic waste

An important future-oriented topic at Fraunhofer is innovative solutions for the circular economy—from resource-conserving production and intelligent sorting methods to new recycling processes and bio-based materials. In the Waste4Future project, eight Fraunhofer Institutes pooled their expertise to improve plastic waste retention in the cycle. The flagship project considered the entire value chain from collection and sorting to mechanical and chemical recycling, solvent-based recycling and the evaluation of ecological and economic effects. The goal is to determine the best recycling route for different waste streams, developing a model for a sustainable circular economy.

One of the focal points of the project was the sorting of plastic waste. Georg Maier, Group Manager for Sensor-based Sorting Systems in the Visual Inspection Systems department at the Fraunhofer Institute of Optronics, System Technologies and Image Exploitation IOSB. "The crucial factor is clean separation," says Maier. "Only if the waste streams are reliably separated by their type of plastic can they be turned into materials that meet the stringent demands of industry."

To achieve these qualities, the team has established a prototype sorting plant that is testing various sensor technologies in the Waste4Future project. As most current recycling plants use infrared cameras, they reach their limits in problematic cases, such as with black or heavily aged plastics. "This is like looking into a dark room through sunglasses," says Maier. "You simply can't see anything." These weaknesses can be overcome with new processes such as terahertz sensors: For the first time, black plastics can be reliably distinguished and cleanly separated from one another.

In initial practical tests, the Fraunhofer IOSB sorting system demonstrated the ability to differentiate even materials that are difficult to distinguish, such as black polypropylene and black polyethylene, both plastics that are frequently used in the automotive industry. Until ▶

back to page 1

The good ones go in the pot: In the Waste4Future project, Georg Maier from Fraunhofer IOSB is using a sorting system to better separate plastics—including, for the first time, black and heavily aged plastics.

now, these often ended up in low-grade applications after recycling because they had not been sorted cleanly enough. "If we can separate these materials cleanly, they can be reused for high-quality components," says Maier. "This will enable us to keep more valuable raw materials in Europe."

Less is more

How much packaging is necessary, and how little is enough? This question is posed every day in the food industry, where millions of yogurt containers, films and bottles roll off the production lines. Every packaging item has several tasks: It protects the product from oxygen, moisture, light or germs and ensures safe storage and transportation, while at the same time not costing too much. "This is a tightrope act," says Marek Hauptmann, Head of the Packaging and Processing Technology department at Fraunhofer IVV in Dresden. "If the container wall is too thin, it will not be stable enough for transport. If it is too thick, we are wasting valuable raw materials." The situation becomes even more difficult if the packaging is to be recycled. The shampoo bottle quickly ends up next to the yogurt container, the cleaning agent runs out over the food residue, and dyes or mold create additional problems. For example, food packaging falls under sorting fraction 324, for which more stringent requirements apply than for other recycling products.

Furthermore heat can cause new substances to form during recycling, compounds that are undesirable and, in the worst case, toxic ones that have to be traced. Until now, packaging design has often been based on gut feelings and with large safety reserves. This is precisely why the KIOptiPack project applies artificial intelligence in production and evaluates data collected by sensors directly on the packaging lines: Forming pressures, sealing temperature or the gas atmosphere during processing and later in packaging.

Algorithms can detect relationships and make suggestions as to how machines should be operated to use the thinnest possible films with recycled content. Or which parameters have to be changed to achieve a stable sealing seam despite the reduced material. Hauptmann: "Previously, the material properties were constant. Now, the machine learns to differentiate precisely without compromising on safety."

In the future, AI will not only suggest variants, but will also implement them directly in the machine controls in production environments. The result is a type of adaptive packaging technology that dynamically adjusts to different products and conditions. This saves packaging material. "Every tenth of a millimeter of film," says Hauptmann, "means less plastic, less energy and less waste, multiplied millions of times.

> "Every **tenth of a millimeter of plastic film** means less plastic, less energy, less waste—multiplied a millionfold."
>
> Marek Hauptmann, Fraunhofer IVV

More closed circles instead of lines

At its core, the circular economy is actually an age-old idea with a new twist. For thousands of years, people worked with closed material cycles: Kitchen waste was used for fodder, materials were repaired or reused and nothing was lost. It was the industrial revolution that introduced the linear principle of "take-make-waste"—and with it our throwaway society. The circular economy then resurfaced on the scientific agenda in the 1970s.

David W. Pearce took up these principles in the early 1990s and explicitly coined the term "circular economy" as an alternative to the resource-intensive linear economy. However, little has changed since then: according to the 2024 Global Circularity Gap Report, only 7.2 percent of the world's materials currently circulate in a closed ▶

back to page 1

"We want to think about recyclability right from the development stage instead of waiting until the product ends up in the trash."

Jan Luca Twardzik,
Fraunhofer IEM

Hand in hand with industry: In the ZirkuPro project, Jan Luca Twardzik from Fraunhofer IEM in Paderborn shows how electrical equipment can be kept in circulation for longer.

back to page 1

AI-powered sorting: At Fraunhofer IIS, Johannes Leisner uses artificial intelligence and digital twins to improve the sorting of plastics.

loop. This is even lower than in previous years: in 2020, the rate was 8.6 percent and in 2018 it was 9.1 percent. The rest ends up as waste.

This development is not only fatal from an ecological standpoint. It also poses economic risks. Supply chains are becoming increasingly fragile and geopolitical dependencies are growing, such as in the case of rare earths or lithium for batteries. The circular economy provides a strategic response to this: it can decouple resource consumption from growth and prosperity. The framework conditions for this were adopted by the EU in 2020 with the Circular Economy Action Plan. This plan stipulates that the circular material use rate in the member states must increase to 23.2 percent by 2030.

> "Entire recycling plants are represented and simulated virtually, meaning that sorting processes are no longer based solely on empirical knowledge, but can be optimized based on data—in real time."
>
> Johannes Leisner, Fraunhofer IIS

Starting recycling on the drawing board

But what if products were designed from the start so that they could be easily repaired, reused or recycled? This is exactly the goal of ZirkuPro, a research project of the Fraunhofer Institute for Mechatronic Systems Design IEM in Paderborn, working in collaboration with partners such as Miele, WAGO and Diebold Nixdorf. "Many products today are extremely sophisticated from a technical standpoint, but pose a real problem at the end of their service life," says project manager Jan Luca Twardzik. "We want to think about recyclability right from the development stage instead of waiting until the product ends up in the trash."

The approach is simple but effective: 80 percent of a product's environmental impact is already predetermined in the design phase. Whether a device can later be repaired, reused or recycled therefore depends on decisions that are made long before production. ZirkuPro is therefore developing a set of tools to show engineers in the early development phase which materials and design methods are resource-efficient and which could cause problems later on. Data on the carbon footprint, energy consumption, recyclability and ease of repair are input directly into the development process.

The work in the project is practice-oriented. Research and industry partners meet regularly in workshops and test their ideas on real products, such as a modern, networked oven, a cash register system, an industrial touch panel and a component for electric car charging stations. Equipment like this is used to test how housings can be made from recycled aluminum, how electronic modules can be standardized and how components can be positioned so that they are easily accessible. Twardzik is intimately familiar with hurdles like these: "My washing machine at home stopped working because two carbon brushes in the motor were worn out. Cost: two euros. The repair would have taken ten minutes, but to get to it you had to turn the entire appliance upside down. Factors like these hinder repairs. Things end up in the trash."

ZirkuPro not only examines technology, but also new business models. Because a simple repair is of little use if spare parts are too expensive or there are no return systems. The project is therefore also investigating service offerings, spare parts programs and reconditioning concepts. "Resources are finite. If we keep them in the cycle, companies and consumers win—and so does the environment," summarizes Twardzik.

The Fraunhofer Institute for Manufacturing Engineering and Automation IPA is also working on designing products so that they can become a resource rather than a problem at the end of their service life. Under the motto of "Design for disassembly," the researchers are developing design guidelines in a workshop to define, during the design phase, how devices or components can later be disassembled. Screws instead of adhesives, modular construction methods instead of integral components—principles like these make it easier to replace individual parts, recover valuable materials and reuse components. ▶

back to page 1

The Fraunhofer Institute for Industrial Engineering IAO in Stuttgart is developing a digital tool that makes the circularity and ecological footprint of vehicle components measurable as early as the concept phase. In the CYCLOMETRIC project, a model-based software was developed that shows how material and design decisions affect the carbon footprint, reusability and recyclability. An example is the center console in a car. This can be made from different fiber composites, connected together by screws, clips or adhesives. CYCLOMETRIC compares these variants and immediately shows how each decision affects the environmental balance and costs. Sustainability is thus directly integrated in the development process. An initial prototype of the digital tool has already been implemented and will soon be transferred to industrial practice.

But digital tools can make a difference not only in the design process, but also in actual recycling. While CYCLOMETRIC and ZirkuPro are brining sustainability to the drawing board, the K3I-Cycling project shows how artificial intelligence can optimize the path from the recycling bin back into the cycle. A team at the Fraunhofer Institute for Integrated Circuits IIS is working on using artificial intelligence and digital twins to improve plastics sorting. In the K3I-Cycling project, researchers have developed a system that virtually maps entire recycling plants and simulates how sensors, machines and material flows interact. Johannes Leisner from Fraunhofer IIS explains how this means that sorting processes are no longer based solely on empirical knowledge, but can be optimized based on data—in real time. The algorithms use multimodal sensors such as X-rays or hyperspectral imaging to automatically recognize the material, shape, weight and any missing items such as batteries.

AI-supported systems control various sorting mechanisms such as diverters and robot arms and distribute air blasts to precisely separate the different plastics. A yogurt container goes to the left, an aluminum bowl to the right. This combination of sensors and artificial intelligence ensures that high-quality recyclates are returned ▶

The goal is to separate plastics so precisely that they can be returned to industry as high-quality raw materials.

Starting from straw: In the RUBIO project, Antje Lieske from Fraunhofer IAP has demonstrated that a high-performance, climate-friendly plastic can be produced from straw and plant residues.

back to page 1

There and back again: Marcus Vater converts plastic waste into its original building blocks at Fraunhofer IAP in Schkopau. Then the cycle starts back at the beginning.

to the cycle. The goal is to separate plastics so precisely that they can be returned to industry as high-quality raw materials and do not have to be incinerated.

Finding true treasure in garbage

The Fraunhofer Institute for Applied Polymer Research IAP is working on chemical recycling at the PAZ pilot plant center in Schkopau to enable plastic to be recycled as a raw material. "We convert plastic waste into its original building blocks (monomers) and recover them in this way," explains project manager Marcus Vater, responsible for scale-up and pilot implementation. "The clean monomers can be processed into new, high-quality plastics."

Specifically, Vater's team is collaborating with industry to test processes for recovering terephthalic acid, the key molecule on which polyethylene terephthalate (PET) is based, from polyesters such as PET as known from drink bottles, textiles or plastic film. This is Fraunhofer IAP's response to increasing legal requirements, such as the stipulation that PET packaging must contain up to 30 percent recyclate in the future. "We offer the technology platform to make this possible," says Vater. "Here, industrial partners can test on a pilot scale whether their process actually works, and whether the material can be turned back into high-quality plastic products." This reduces dependence on fossil raw materials, conserves resources and preserves material quality. Or as Vater puts it: "In an ideal future, plastic is not waste, but a recyclable material, and it will be recycled in an almost completely closed loop by 2050."

> "In an ideal future, plastic is not waste but rather a building block, and it will be recycled in an almost completely closed loop by 2050."
>
> Marcus Vater, Fraunhofer IAP

Spinning gold from straw

Bioplastics made from straw and other plant residues—this was the idea behind RUBIO. 18 research institutions and industrial partners have demonstrated that agricultural byproducts can be used to produce a high-performance plastic that is climate-friendly and does not compete with food. At its core is polybutylene succinate (PBS): a bio-based, biodegradable polymer that can be processed like conventional plastic—but returns to natural cycles at the end of its life cycle.

What makes it special: RUBIO focuses on regional sources instead of imports. Straw or pulp from sugar production come from local agriculture. This biomass is broken down and is converted into monomers in a biotech process that uses microorganisms. Completely new types of PBS are synthesized from the monomers at Fraunhofer IAP. The process has already been transferred to the 100-kilogram scale at the Fraunhofer Pilot Plant Center PAZ in Schkopau. "We start with straw and end up with everyday products—it's like spinning straw into gold," says Antje Lieske from the Fraunhofer IAP. The project, which ran from September 2021 to August 2024, has now been completed. Many of the processes and products developed are being continued in new research projects and collaborative efforts.

The first marketable applications have been developed: Packaging films, recyclable monomaterial bags, nonwoven fabrics for textiles or paper coatings. These have withstood practical testing in modern machines, from tear resistance and barrier effects to workability. This process certainly had its hurdles: raw material purity, processing stability, surface defects—the researchers had to make constant adjustments. But the effort is worth it: RUBIO not only takes the bioplastic PBS to a new level, it also serves as a proof of concept for the circular economy—less CO_2, fewer fossil raw materials and more regional value creation. And it shows that the potential of bio-based materials is growing—if science and industry work closely together. ■

back to page 1

Shredder or Second Life?

As electric mobility advances, the need for efficient battery recycling becomes increasingly urgent. A new development plant aims to make fully automated disassembly of various battery systems and recycling approaches a standard practice.

By Janine van Ackeren

Although electric mobility is progressing slowly on German roads, the volume of used batteries in the EU is expected to increase more than tenfold by 2030. Until now, traction batteries—despite retaining 70 to 80 percent of their capacity—have typically been shredded, incinerated, or at best reduced to raw materials. Attempts to repurpose used battery cells into large storage systems for businesses, households, or grid operators have failed for economic reasons: reuse is simply too costly due to the high expense of manual disassembly. This is set to change starting July 2026.

Breaking the Disassembly Bottleneck

The research team led by Rico Schmerler at the Fraunhofer Institute for Machine Tools and Forming Technology (IWU) is betting on automation to achieve cost efficiency.

"Together with EDAG Production Solutions GmbH & Co. KG, we are building a development plant that uses robotic hands to dismantle batteries into individual components. These components are then analyzed for further usability using various methods—all controlled by artificial intelligence," explains Schmerler.

The project focuses on two example battery systems: a high-voltage storage unit from an electric car and a battery from an electric commercial vehicle. If both systems can be successfully disassembled in July, the research will move to the next stage. The plant is expected to answer a critical industry question: How can automation be adapted to different battery types so companies can dismantle them cost-effectively?

Robots, Analysis, and AI

Optical cameras serve as the eyes of the disassembly robots, while AI acts as their brain—because the tasks are highly complex. First, the vehicle battery must be opened. The robot removes the cover and then targets the electrical contacts to reduce the overall voltage and improve safety. Mechanical barriers such as cables, busbars, and connectors must also be removed to enable further disassembly. "The first step is to ensure mechanical accessibility and minimize hazards," summarizes Schmerler.

Artificial intelligence plans the robot's path, determining where and when to screw, press, pull, or cut. The condition of both dismantled and remaining components is continuously monitored. Optical methods detect cracks, while electrochemical impedance spectroscopy deliberately charges and discharges the battery to measure its storage capacity. This helps answer a key question: Is the remaining battery pack suitable for reuse, or does it contain cells that are too degraded and must be removed?

One of the greatest challenges is the sheer variety of battery designs. "We need tools that are as flexible as possible and can handle different battery types with minimal adjustments," Schmerler explains. Fraunhofer IWU researchers evaluate available market options and select the most suitable ones, while EDAG is responsible for design and implementation. Safety considerations, such as fire prevention, are also crucial. "If cells overheat, we can detect it early with a thermographic camera. If excessive heat is released, we notice it before a fire can start," says Schmerler.

Navigating Legal Complexities

Alongside technical solutions for cost-effective automated disassembly, numerous details regarding hazardous goods and waste legislation must be clarified. Although battery recycling laws exist, their wording leaves room for interpretation—and few companies have experience in this area. The researchers aim to provide guidance and ensure clarity.

Ultimately, the plant is designed to help industrial customers optimize the process of keeping battery cells and modules in circulation—making a significant contribution to sustainable electric mobility. ■

Mercedes-Benz plans to recover cobalt, nickel, and lithium in a pilot plant for recycling batteries.

Photo: Mercedes-Benz Group AG

back to page 1

No Escape: Personal data processing must be in compliance with the GDPR.

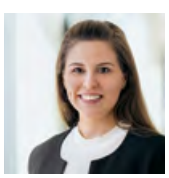
When Research Becomes a Criminal Offense

Cybersecurity researchers quickly find themselves in a legal gray area. What is permitted, and what is not? Simulated trials provide clarity.

By Janine van Ackeren

"We need legal certainty for cybersecurity researchers."

Annika Selzer, Fraunhofer SIT



August 27, 2025. Clad in black robes, a judge, prosecutor, and two defense attorneys sit in court. A common enough picture. And yet so much in this trial is different: The court is considering a fictional case, which starts with the sentence "Call for criminal case XX from Simulation City." Nor does the trial take place in a real courtroom, but rather in the premises of the Fraunhofer Institute for Secure Information Technology SIT in Darmstadt. The "defendants" are research institute employees. They are portraying two cybersecurity researchers who have detected a vulnerability in the online photo storage system of a counseling center for victims of violence. The charges: violation of personal privacy by recording images and data spying.

One foot in prison

"Many laws are written in such a way that they apply to everyone, so they don't include any specific rules just for researchers," explains Annika Selzer, coordinator of the "Legal Aspects of Privacy & IT Security" research area at the National Research Center for Applied Cybersecurity ATHENE, a research center of the Fraunhofer-Gesellschaft. Selzer organized this trial with her team.

The problem: Even though their motives are completely different, cybersecurity researchers use the same tools and methods as hackers. Hackers attack companies to steal data or to prevent access to data and extort money. Cybersecurity researchers want to detect vulnerabilities in order to identify and implement possible countermeasures, thereby enhancing cybersecurity. Criminal law does not always draw a clear line here.

"We need legal certainty for cybersecurity researchers," says Selzer. "As long as they operate in a legal gray area, they are legally vulnerable, even to the point of criminal prosecution." How severe is the penalty if I do something wrong? Would it be a prison sentence or a fine? And who would pay it? Questions like these hobble cybersecurity research. At the same time, it is more necessary than ever, as the number of attacks on IT infrastructure is steadily increasing. For example, the Bavarian State Office for Information Security alone recorded roughly 5,800 suspicious activities against Bavarian state authorities in 2024,

more than ever before. In its report for 2024, the German Federal Office for Information Security assesses the cybersecurity situation in Germany as "worrying."

A clear legal framework is essential

Many real-world scenarios in cybersecurity research are not adequately covered by current legislation. For example, the General Data Protection Regulation assumes that it is always known in advance of any data collection whether, when and which personal data will be processed. But when researchers search the darknet for new tools that hackers use for their attacks, it is entirely possible that they will download documents containing stolen login details without realizing it beforehand. In this instant, they have already collected personal data. Data protection law does not have any instrument that allows for the legally compliant planning of potential undefined data collection. This places cybersecurity researchers in a difficult position." Selzer reiterates: "We need a clear legal framework. Researchers should not be treated in the same way as malicious hackers."

Fictional cases, realistic trials

So far, it is left up to judges to clarify matters for cybersecurity research, and they have to do this in each individual case. Many questions surrounding the legal admissibility of cybersecurity research activities remain unanswered. The simulated court proceedings, which are being conducted annually from September 2024 to 2027, are therefore intended to provide further guidance and show researchers which research activities are considered legally compliant in the opinion of the simulated court. This is why the trials are made as realistic as possible. The defendants testify in court and an expert witness explains complex processes and gives an assessment of the extent to which the procedure can be considered justifiable. Based on this information, the prosecutor argues for sentencing, and the defense attorneys present opposing arguments.

In the trial of August 2025, simulated justice is dispensed. The court warns the two researchers and gives them a suspended fine of 100 euros per day for thirty days. Furthermore, they must each pay 500 euros to a victim counseling center that had made sensitive photos available for affected parties to download without providing adequate protection. The primary determining factor was that the photos were stored for documentation purposes on the research group's server, which was also accessible to researchers who were not involved in the specific research activity.

"With these simulated trials, we want to establish legal guidelines for cybersecurity researchers and their actions in the most realistic possible manner," says Selzer. This will enable researchers to better assess which actions could increase the risk of prosecution in the future. ■

2024 saw roughly

5,800

suspicious activities against Bavarian state authorities—more than ever before.

For more information about the ATHENE project, scan:

Photos: mauritius images / Alamy Stock Photos / Laurentiu Iordache, Fraunhofer SIT

back to page 1

Rapeseed Instead of Beef

Germany is the largest rapeseed producer within the EU. But this bright yellow plant can be much more than just a source of cooking oil, animal feed and biodiesel: Fraunhofer researchers are applying a new process to transform them into protein-rich meat alternatives.

By Yvonne Weiss

Bright yellow, tall and indispensable: Roughly 4.3 million tons of rapeseed were harvested and processed in Germany in 2023. Rapeseed oil is in especially high demand. With roughly 86 million liters consumed in 2024, it ranked first among favorite cooking oils for German citizens, ahead of sunflower and olive oil. However, hexane, which is produced in mineral oil processing, has been used as a solvent in rapeseed oil production until now. This is problematic due to its harmful effects on health.

A processing method that uses no hexane at all is therefore the goal of researchers at the Fraunhofer Center for Chemical-Biotechnological Processes CBP in Leuna. "We are focusing on ethanol in order to get the most out of rapeseed as a renewable raw material and to bring new food products such as naturally protein-rich meat alternatives to market," explains Robert Hartmann, head of the Biomass Fractionation research group at Fraunhofer CBP.

The researchers in Leuna built a special processing plant for this purpose. The rapeseed is first harvested and dehulled. The seeds are broken open by a roller and a stream of air separates the light hulls from the yellow kernels. The hulls contain bitter substances that protect the kernels against parasites such as beetles. The hulls can then be recycled, such as for packaging material.

In current conventional production units, rapeseed plants are fed into screw-type presses together with their hulls. Most of the oil can be extracted by mechanical pressure; the remainder is extracted from the concentrate using hexane, which dissolves oils but is harmful to humans and the environment. Limits and residues in the oil are therefore strictly controlled. In the future, the use of this chemical could be further restricted in the EU or possibly even banned altogether. Because of the pressed hulls, the rapeseed concentrate is also so bitter that no more than five percent can be used in animal feed.

Furthermore, the high pressures and temperatures in conventional processing plants denatures functional proteins naturally contained in rapeseed, thereby greatly reducing their nutritional value. "The result is rapeseed meal that contains many bitter compounds, hexane residues, and denatured proteins," says Hartmann. "We want to intervene here and take advantage of the enormous potential of rapeseed."

In 2024, rapeseed oil captured first place as the most popular cooking oil with roughly

86

million liters

consumed.

The spherical black seeds from the rapeseed plant are one to two millimeters across.

At the new plant in Leuna, the team therefore uses 96 percent ethanol with no bitter substances to process the kernels and preserve their taste. "Ethanol also keeps temperatures constant during pressing and prevents peaks higher than 70 degrees," explains Hartmann. "The natural proteins in the rapeseed therefore stay intact and the nutrients are retained." After pressing, fresh ethanol not only extracts the remaining oil from the rapeseed concentrate, but also fatty acids and lecithins. These are unwanted substances that previously had to be removed by complex chemical processes and were only reused in isolated cases. The researchers wish to process and reuse the byproducts, such as in cosmetics and pesticides.

The result: A neutral-tasting, easily digestible, regional rapeseed concentrate with a natural protein content of over 50 percent. According to Hartmann, this can provide a promising basis, especially for increasingly popular meat alternatives, and can serve as an alternative to soy, which has mostly been used for this purpose up to now but is dependent on imports and supply chains.

The team has already tested the first animal feed produced by the plant, as well as plant-based alternatives to burger patties, eggs, and ground beef. The feedback? Entirely positive. The researchers are currently optimizing the products in order to further increase their protein content. They are also collecting data that will be needed in the future for applying for initial approval for new foods.

Hartmann is pleased with this success: "We can get so much more out of rapeseed than before. I am so glad we can contribute to this—and use food sources sustainably." ■

Photos: Meriç Tuna / unsplash, bin zhu / istockphoto

back to page 1

An Explosive Legacy

Hundreds of thousands of unexploded aerial bombs from the Second World War are still buried underground in Germany. Software from Fraunhofer helps to precisely identify hazards.

By Sonja Endres

The evacuation of one of Cologne's largest hospitals in October of 2024 was a challenge even for the experienced Rhineland experts. A 100-pound American bomb was found in the middle of the Merheim Hospital grounds and had to be detonated in a controlled explosion. 287 patients were evacuated, 1,200 emergency personnel and rescue services from across North Rhine-Westphalia were deployed and the airspace was temporarily closed.

The ground beneath Cologne is explosive: 21 explosive bombs were discovered here in 2024 alone. Unexploded World War II ordnance is usually detected during soil surveys for planned construction projects. It must be defused, and residents must therefore be brought to safety. But the danger is not always as clear as it was in Merheim. Over the past five years, risk analysis software VC Blastprotect, developed by researchers at the Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institut, EMI, in collaboration with Virtual City Systems GmbH and the Explosive Ordnance Disposal Service of North Rhine-Westphalia, has been assisting with the often difficult decision on the actual necessity of an evacuation. This software simulates the propagation of pressure waves in the air and the trajectory of flying fragments in virtual 3D cityscapes based on physical models. It can thus help to avoid unnecessary, costly, and, in the case of medical facilities, often risky evacuations.

The researchers at Fraunhofer EMI now want to further develop the physical models of the software in the "Shockanalyst" project. In the future, the simulations will account for the effects of underground shock waves as well as the effects of the safety measures taken by explosive ordnance disposal services before defusing a bomb.

Working together with the explosive ordnance disposal services of Mecklenburg-Vorpommern, Brandenburg, and North Rhine-Westphalia, the research team conducted a large-scale test in May on an old military site of the National People's Army (Nationale Volksarmee, NVA) near Rostock. Over a

Rural areas were not immune from attacks. Unexploded ordnance is brought to light by activities including plowing.

period of six days, six 500-pound World War II bombs were buried in the ground and subjected to controlled detonation under different conditions.

"It makes quite a bang," explains Christoph Grunwald from Fraunhofer EMI. He and his team had set up the measuring station in a dilapidated former staff building just a few meters away from the explosions. Using numerous sensors, the researchers recorded data including the vibrations caused by the detonations and the intensity of the shock wave under fully realistic conditions. These included protective covers for the bomb and aluminum rings supporting the blast pit.

"VC Blastprotect currently assumes the worst-case scenario and calculates the maximum possible damage in the event of an unprotected explosion," explains Grunwald. "Our forecasts are therefore always on the safe side." The data now not only help to refine the simulations, identify specific danger zones, and reduce the evacuation radius. They also include important information for the explosive ordnance disposal service regarding the effectiveness of their safety measures. One of the detonations was conducted without any containment measures as a reference to compare how these individual measures affect the destructive power of the bomb. "We all took shelter a good kilometer away," says Grunwald. "Still, our car shook noticeably during the explosion."

Among other things, the measurement results revealed that a giant water bag placed over the bomb dampens flying debris and the shock wave just as effectively as sand. "This made the bomb disposal service very happy," says Grunwald with a smile. The water bag has the advantage that it can be filled from a safe distance using a fire hose. Water can also be transported more quickly and easily to the site where a bomb is found.

The disadvantage of covering the bomb: The energy that can no longer escape into the air is distributed in the ground, amplifying the so-called ground shock. "You can imagine this shock wave as a very strong, fast-moving earthquake." says Grunwald. Until now, there has been little knowledge about the damage this can cause to foundations, subway tunnels, gas lines or data cables. Here as well, the research scientists collected important data in a large-scale experiment. Despite these issues, according to Grunwald, unprotected detonation is not an alternative, as bomb fragments in particular form deadly projectiles that can fly several kilometers and even penetrate windows into apartments. "The warheads are deliberately designed to fragment as effectively as possible. Without any damping measures, a significantly larger area would have to be cordoned off."

The researchers want to supplement their measurements with data obtained in the laboratory, where they are specifically investigating different soils such as sand or clay and the effects of parameters such as moisture, density, and shock wave intensity. "It's all very complex," admits Grunwald. The team is currently working on an initial physical model to simulate the ground shock in sandy soils. This is an important decision-making aid for cities when determining whether they have to secure underground infrastructure or shut down gas lines. Grunwald: "In the future, we could use our models to calculate whether a gas line actually needs to be temporarily shut down or whether it might be sufficient to reduce the pressure in the line." This can save companies high costs due to production outages. ■

A giant water bag placed over the bomb dampens flying debris and the shock wave just as effectively as sand.

Photo: Havergo/Fotostand/dpa

back to page 1

A Trashy Situation

Each year, more than 5.6 million metric tons of plastic packaging is discarded after being used just once. In partnership with Hochschule Bremen—City University of Applied Sciences (HSB), Fraunhofer researchers are transforming this dirty waste into high-quality material for 3D printing.

By Yvonne Weiss

Germany collects plastic waste for recycling. But less than one-third of the yogurt cups, plastic moisturizer jars and cream cheese tubs that are sorted out for later recycling after single use actually end up being recycled—so far, at any rate. A new feasibility study from researchers at the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM and Hochschule Bremen—City University of Applied Sciences (HSB) shows that there is a solution.

"Post-consumer waste is especially tough to recycle, since it is generally very dirty and highly heterogeneous," explains Silke Eckardt, professor of future-proof energy systems and resource efficiency at HSB. "Our goal is to reprocess these difficult-to-recycle plastics from private households and turn them into high-quality material for 3D printing," adds Dirk Godlinski, project manager in the Composite Technology working group. He explains the challenge: "Waste used as recycled material in additive manufacturing has to meet extremely stringent requirements for aspects such as purity, shape and size in particular."

To meet these criteria, Eckardt and her team prepared the output from the sorting system. Working at the HSB Laboratories for Circular Economy, they ground the plastics down, washed them and separated undesired material from the primary stream. Any remaining unrelated and unusable plastics were identified using near infrared technology and removed as well. After that, the researchers reground the material to

"Our goal is to reprocess difficult-to-recycle plastics from private households and turn them into high-quality material for 3D printing."

Dirk Godlinski, Fraunhofer IFAM

Making new from old: Researchers give dirty plastic waste a second life.

Photo: DEEPOL by plainpicture/Larry Washburn

the size needed for further processing and dried it. The result was material with a purity of more than 99.8 percent.

Godlinski and his team took over after that. At Fraunhofer IFAM, they produced a solid plastic strand of polypropylene, a material that is durable, resistant to breaking and relatively flexible. In an extruder, the researchers first combined the pieces of prepared waste, mixed them thoroughly and melted them at a temperature of about 200 degrees Celsius. Then they pressed the material through a nozzle.

"The expertise consists in precisely adjusting the temperatures, pressures and speeds along the production process, depending on the various mechanical screw geometries, so that the final product is homogeneous polypropylene," Godlinski explains. For use in 3D printing, the strand must be round and consistent in diameter over its entire length, with a smooth surface.

As far as results go, it was a success: The gray plastic strand, about two millimeters thick, was able to be used directly as a filament in the 3D printer, and Godlinski's team has already successfully printed a number of components.

That marked the conclusion of the feasibility study; the project partners are currently optimizing the production process. Godlinski explains that the recycled plastics can be further refined, and that other substances such as fiberglass can be added during the production process. That means even very high-value 3D-printed components for use in aviation or the automotive industry would be conceivable. ■

The result? Material with a purity of more than

99.8

percent

back to page 1

Unlocking the Power of Peatlands

Achieving climate targets while also generating energy: Solar panels positioned above rewetted peatlands are urgently desirable from the policy perspective. Now researchers are on the task, working to make peatland solar a success.

By Beate Strobel

Important reservoirs of water and carbon sinks: Long ago, peatlands accounted for 4.2 percent of Germany's area.

The six-hectare plot of land in the northeastern state of Mecklenburg-Vorpommern is still being used for agriculture right now. But soon it will look more like a booth at a solar panel trade show. Under the watchful eye of researchers from the Fraunhofer Institute for Solar Energy Systems ISE in Freiburg and the University of Greifswald, various types of solar modules will be installed here at different heights and on different foundations, converting sunlight to electricity as part of the MoorPower project launched in 2024. Meanwhile, the ground beneath them will slowly get wetter and wetter.

Peatlands act as natural carbon sinks, as peat is more than 50 percent carbon. Germany's remaining peatlands store some 1.3 billion metric tons of the element right now. But when these lands are drained for agricultural use, the carbon stored in the peat reacts with the oxygen present in the air to produce carbon dioxide (CO_2), which escapes into the atmosphere. Microbial decomposition processes also produce nitrous oxide (N_2O) gas, which has an even bigger climate impact.

All of this means that preserving and restoring peatlands is an important part of Germany's push to achieve its climate targets. Right now, some 70 percent of Germany's peatlands have been drained, accounting for 44 percent of total greenhouse gas emissions from agriculture in the country. The National Peatland Protection Strategy adopted by the German federal government in 2022 stipulates that annual emissions from peatlands are to be reduced by five million metric tons of CO_2 equivalents by the year 2030. However, reaching the long-term climate goal set by the Paris Agreement would require significantly more. At least 50,000 hectares of land would need to be converted back to peatlands each year.

To make restoring peatlands worthwhile to agricultural operations, peatland solar—an arrangement in which rewetted peatlands are used to produce solar energy—became eligible for funding when the German government adopted Solar Package I in 2023. Fraunhofer ISE notes that with 1.4 million hectares of peatland nationwide being used for agriculture and a density of 0.25 to 0.6 megawatt peak per hectare, peatland solar has technical potential of 321 to 771 gigawatts of rated output per year.

Generating energy from wetlands that can no longer be used for conventional crop growing or livestock operations sounds like a plausible idea. But there's a catch: "Putting in solar panels while also rewetting peatlands is uncharted territory," says Agnes Katharina Wilke, an environmental scientist with Fraunhofer ISE. And that is not only true of Germany. Internationally, too, there is almost zero experience with peatland solar. "We see Germany as a pioneer in this field," Wilke says.

The Fraunhofer ISE research site in Mecklenburg-Vorpommern is intended as a way to build on that role. "One of our goals in the MoorPower project is to find out which technologies are suitable for peatland solar in the first place," Wilke explains. After all, there are a few factors that set wet peatlands apart. "Rewetted organic soils are constantly moving, and their load-bearing capacity is lower. Aside from that, preserving peat is central to the restoration efforts. The thicker the depth of the unstable peat layer extending from the surface of the soil down to the solid mineral substrate, the more complicated and more expensive it gets to anchor the solar modules."

One idea involves building joints into the stands that hold the solar panels so they can flex with movements in the soil. Another alternative for areas that are always underwater is "floating PV," in which the panels are not anchored deep in the soil but rather float on the surface, where they are held in place by ropes. "But that means that the solar panels and the anchor structures in the soil are constantly moving. There is a decent chance that this would prevent the formation of vegetation cover that would protect the soil and the carbon stored in it while also increasing the load-bearing capacity and thus accessibility of the soil itself," Wilke cautions. The project is also studying how the foundations affect the soil's chemical composition.

In addition to exploring the various technological questions, the researchers working on MoorPower are also studying how to make peatland solar a winning business proposition. One prospective incentive for agriculture involves paludiculture solar: generation of solar energy while the land beneath the solar panels develops into a wetland where species such as sedges can become established and then used for things like producing biomass for conversion to energy. But this approach only makes sense ecologically if the peat that is crucial to carbon storage forms and is preserved at the same time that rewetted areas are used for energy and agriculture. Whether that is possible is another question for the researchers.

At any rate, findings from conventional agrivoltaics, in which solar energy is produced above agricultural land, indicate that shading the peatland should reduce the amount of water lost to evaporation, thereby increasing the likelihood of successful rewetting.

The MoorPower research project is schedule to end in 2028, but project manager Wilke is already thinking about possible follow-up projects. Because it takes decades for drained cropland to be restored into a functioning peatland ecosystem, time is pressing, she says: "Projects focusing on peatland solar make multiple critical contributions to crucial topics of the future, such as global warming, energy security, biodiversity and sustainable agriculture." ■

Photo: Erhard Nerger/imageBROKER/dpa

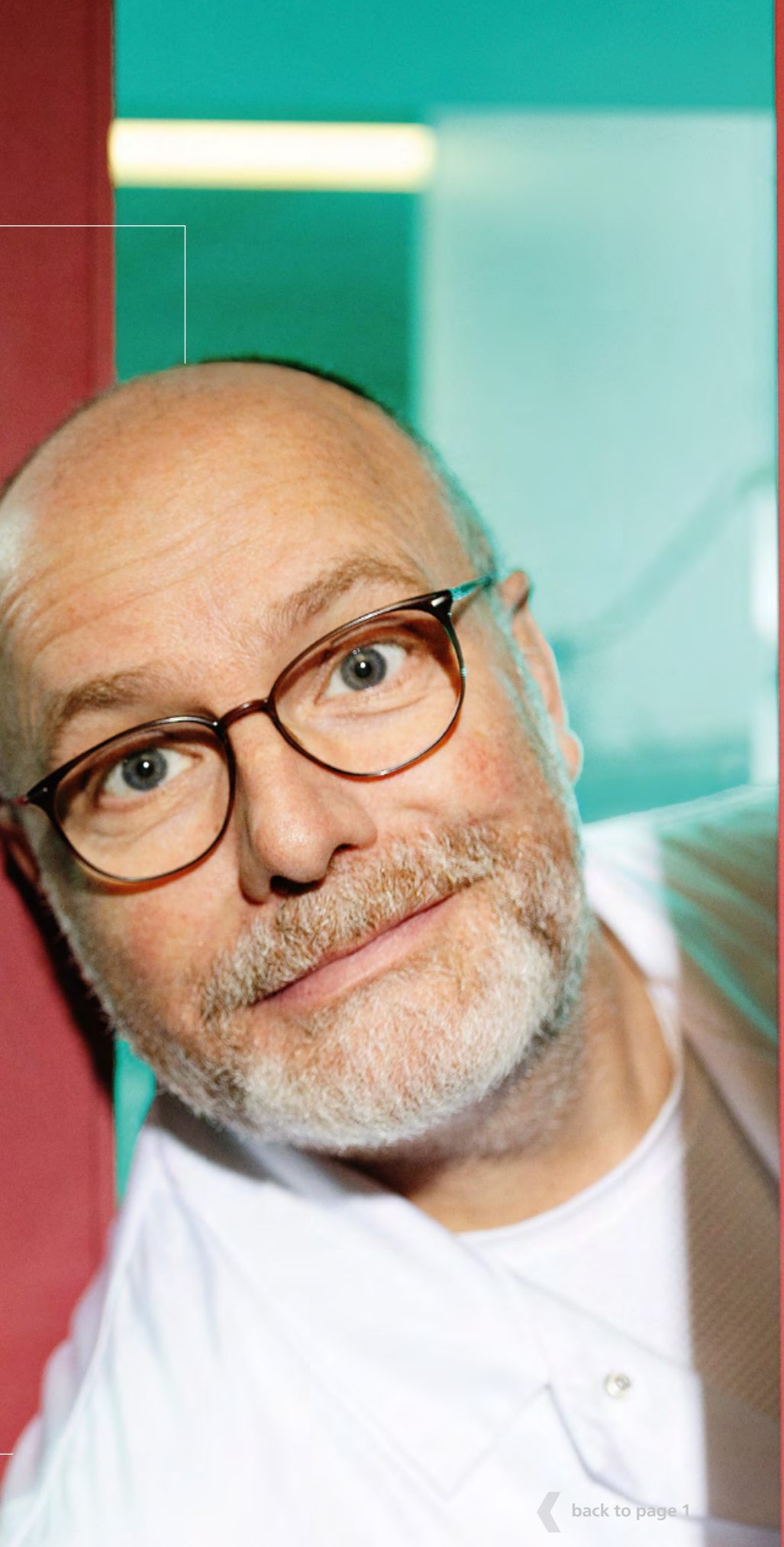
back to page 1

Medical innovations

Opening the Door to Practical Applications

Artificial intelligence and innovative blood tests make it possible to detect cancer, sepsis and tuberculosis earlier and earlier. We can combat these effectively with new substances and personalized therapies. Fraunhofer researchers are now opening the door to the application of medical innovations.

Photographer: Simon Koy



Caught in time: Kai Sohn from Fraunhofer IGB and his team have developed a non-invasive method to diagnose dangerous pancreatic cancer at an early stage.

back to page 1

Medical innovation

"CAR T Cells Detect Tumors Throughout the Body."

The therapy still costs up to 400,000 euros. But costs can be reduced by improved production methods. The new variant of CAR T immune cell therapy is now also targeting solid tumors. The modified immune cells can even track down metastases. This gives hope to many patients. Fraunhofer helps to put scientific excellence into practice.

Interview with Mehmet Toprak

Michael Hudecek is one of the pioneers of cellular immunotherapy, and co-developed the first wave of CAR T-cell therapy in the USA. Now he is working on an optimized version. He is also improving the manufacturing processes for CAR T cells at the Fraunhofer Institute for Cell Therapy and Immunology IZI. The goal: making the therapy accessible for more patients.

Professor Hudecek, what first brought you to the subject of cancer?
As a young physician, I was fortunate enough to work at the Fred Hutchinson Cancer Research Center in Seattle from 2007 to 2012. That was the cradle of bone marrow transplants. We developed the first CAR T cells in the laboratory there, and then one of the first clinical trials was conducted where CAR T cells were used in patients with hematologic cancers, generally called blood cancers. The project resulted an approved CAR T-cell product that is now being used to successfully treat many patients.

The new generation of CAR T cells could also be effective against solid tumors such as breast cancer or pancreatic cancer. How can this be achieved?
CAR T cells have to be much more effective for solid tumors than for blood cancers because they have strong resistance mechanisms. We have to give the CAR T cells special properties to get around this. We have to make them more efficient and extend their survivability. A second receptor that can recognize additional cancer structures could also be added to make the effect more specific. This demonstrates an advantage of immune cell therapy: We can combine properties and incorporate almost any number of qualities into a cell product. This distinguishes it from other therapies where a single substance works—or does not work.

How does this work against cancers that have already spread?
CAR T cells have a special quality here. A single tumor can be surgically removed, but the procedures become more complex where metastasis is involved. The new therapy could especially benefit patients with metastatic tumors. CAR T cells can recognize and fight metastases in the body.

Why are radiotherapy and chemotherapy used first instead of using CAR T-cell therapy right from the start?
We also get this question from patients. Despite all the euphoria, certain basic principles of medical practice have to be followed. A key rule is that the established therapy is used first, because we have many years of experience with it. Only then is the more experimental treatment used. Although it is very promising, it is also associated with risks. We must continue with this cautious approach, even though this is often difficult for patients with an unfavorable prognosis. ▶

Green is the color of hope: Michael Hudecek continues to develop avenues for CAR T-cell therapy in the fight against cancer at Fraunhofer IZI.

back to page 1

But we are making progress. Many studies indicate clear advantages for CAR T-cell therapy over chemotherapy and radiation. This therapy is now already being used in the second line of therapy for certain forms of lymph node cancer and multiple myeloma. This means that it is used if the initial treatment was not sufficiently effective or if the disease returns. There are already studies evaluating CAR T-cell therapy as part of the first line of therapy.

The therapy costs up to 400,000 euros per patient. Why is it so expensive?
First of all, the process is complex. Blood is first drawn from the patient in the clinic in a circulation procedure. The white blood cells it contains, the leukocytes, are enriched, hence the name leukapheresis. The material is then transported to a clean room laboratory where the cell product is manufactured under strictly controlled, sterile conditions.

That doesn't sound especially complicated...
Oh, but it is. We are working with extremely sensitive reagents and need highly specialized personnel, technology, equipment and procedures. Finally, the cells are checked, frozen, released and transported to the clinic. The CAR T cells are not administered until after a preparatory treatment, a modified chemotherapy that reduces the patient's existing immune cells. The choreography is complex. Every step has to be perfect. And the timing has to be right.

And this is where Fraunhofer IZI comes in? Optimizing production processes is a Fraunhofer specialty.
Right, yes. We are working on simplifying and standardizing the infrastructure with automated processes and logistics, without compromising medical quality. This has enabled us to almost halve the production time from the previous 12 to 14 days down to 7 to 10 days. Soon it will only be 3 or 4 days. We also use a novel method for genetic programming of the immune cells. Instead of using modified viruses as usual, we use non-viral mRNA and DNA vectors. This makes the therapy more tolerable for patients and also helps to reduce costs, as mRNA and DNA vectors are much easier to scale up and certain safety precautions are no longer necessary.

Michael Hudecek, pioneer and bridge builder for CAR T-cell therapy

In CAR T-cell therapy (chimeric antigen receptor, CAR), the body's immune cells, known as T cells, are genetically modified and equipped with a receptor that recognizes and specifically attacks tumor cells. Until now, the therapy has only been used for hematological malignancies such as leukemia, lymphoma and multiple myeloma. A new variant also targets solid tumors such as breast cancer. Fraunhofer helps to put scientific excellence into practice: The research teams cover the spectrum from the design of cell products to clinical trials.

Michael Hudecek is one of the pioneers of cellular immunotherapy and co-developed the first wave of CAR T-cell therapy at a renowned cancer research center in the USA. He is now working on the new version of CAR T-cell therapy. With a team of nearly 70 employees, he leads a research program at the University Hospital of Würzburg. He also heads the Würzburg branch of the Fraunhofer Institute for Cell Therapy and Immunology IZI. The CAR T cell production process is being researched and optimized there. The goal is to improve, accelerate and scale up the complex production of the immune cell preparation, enabling patients to receive their therapy more quickly.

But the procedure is still expensive. Can our healthcare system handle it?
If we balance the costs with the benefits and the healing success of the therapy, and then compare that with other therapies, CAR T-cell therapies perform well. Combined therapies involving up to three or four drugs are used for cases of lymphoma or multiple myeloma, resulting in very high annual therapy costs. Patients have to go to the clinic every month. In comparison, the costs of treatment with CAR T-cells are in many cases even lower than those of conventional therapy.

What does the future hold? What are the next steps?
We are already researching the next stage, which is in vivo gene transfer. The gene transfer vector is administered intravenously directly into the patient's body. The CAR T cells are then produced in the body.

So the human patient is their own cell factory?
Exactly. Initial case reports indicate that this can work well.

A single tumor can often be surgically removed, but this is no longer the case for

20

metastases.

Patients with metastatic tumors in particular will therefore benefit from the new therapy.

"CAR T cells are currently the most exciting form of cell therapy."

Michael Hudecek,
Fraunhofer IZI

Could CAR T cells also be used preventively?
Yes, we are already working on corresponding ideas. Many things are possible using AI. Our vision for the future is of AI being able to generate a risk profile for each person using data from medical examinations, such as blood counts, imaging procedures and genetic tests. Based on this, we could then determine whether the risk of a particular cancer is so high that it is appropriate to treat it with CAR T cells, That is preventive medicine.

Will CAR T cells become the dominant cell therapy?
CAR T cells are currently the leading and most exciting form of cell therapy. The potential is enormous. CAR T-cell therapy can in principle be used for any form of cancer and also for treating non-malignant diseases such as infections and autoimmune diseases. Thus far, we have clear clinical proof of efficacy and approvals for treatment of certain forms of leukemia, lymph node cancer and multiple myeloma. We are still conducting intensive research and are working together with colleagues from the research community on new clinical trials and increasingly optimized products and processes. I am quite certain that we will soon see further approvals in various areas of medicine.

How does the avant-garde of cancer research fit in the Fraunhofer model?
Perfectly! The transfer to medical practice has always been important to me, to give as many people as possible the chance of a cure. That wish led me to Fraunhofer. Scientific excellence is not visible or meaningful for society until it is put into practice. ■

back to page 1

Pioneer: Bastian Niessing at Fraunhofer IPT relies on automation in cancer therapy.

"In the end, we always obtain a patient-specific, high-quality and safe product."

Bastian Niessing, Fraunhofer IPT

Medical innovation

The Industrial Revolution for Cancer Therapy

Artificial intelligence instead of manual labor:
Highly automated production aims to make CAR T-cell therapy affordable. An initial production platform already exists.

By Beate Strobel

CAR T-cell therapy is a ray of hope in the dark chapter of cancer. But this new approach comes at a price: Manufacturers charge up to 400,000 euros for the production of individual gene-modified immune cells for people suffering from cancer.

Until now, this treatment has only been approved for specific forms of leukemia and lymphoma. However, intensive research into CAR T-cell therapy means it could soon also be considered for other types of cancer, or could even be used preventively. That is good news for the afflicted, but is a financial burden for an already struggling healthcare system.

Researchers at the Fraunhofer Institute for Production Technology IPT are therefore working together with the Fraunhofer Institute for Cell Therapy and Immunology IZI, companies and institutions from seven countries in the EU-funded AIDPATH project (AI powered, Decentralized Production for Advanced Therapies in the Hospital) to develop a system for the highly automated production of CAR T cells. A prototype laboratory platform for this has been in place at the University Hospital of Würzburg since the summer of 2025.

From the T cell to the finished product, ready to send

What previously had to be done manually by specialists is now done by the machine: "In the first step, the T cells are separated from the patient's blood and activated so that they multiply," explains medical engineer Bastian Niessing, head of the Bio-Adaptive Production department at Fraunhofer IPT and project coordinator. "In the next step, the appropriate CAR receptor is incorporated in the T cells. This is done either by using a virus or through electroporation, which electrically induces permeability of the cell membrane." The CAR T cells are then multiplied in a bioreactor and finally harvested, purified, filled in vials and checked. The end product is already frozen and is thus ready for transport.

Not only does the high degree of automation reduce personnel costs in production, but also the error rate. Niessing: "Many of the activities involved in manually producing CAR T cells are highly repetitive and are therefore prone to errors. In contrast, the machine works around the clock at a consistent quality level." The COPE software developed at Fraunhofer IPT makes the platform easy to operate.

The use of digital twin cells also enables AI-supported production planning. Artificial intelligence is used to optimize aspects such as the parameters in the bioreactor, ensuring that the cell cultures grow at the ideal rate and are harvested at the best possible time. "This ensures that I always get a patient-specific, high-quality and safe product, regardless of the number or quality of the cells at the start of the process," explains Niessing. The AI is continuously improving through the integration of patient data, production parameters and therapy monitoring.

The CAR-T cells are not produced any faster with the production platform. "The process is biologically limited and takes two to three weeks," explains Niessing. The scaling potential of the technology is therefore not one of speed, but rather of quantity over time. The prototype platform can already produce cells for up to twelve cancer patients in parallel. Fraunhofer IPT is also working with a licensee on a system that can produce up to 10,000 products per year. Niessing believes that, over the long term, this will reduce production costs by a third compared to manual production.

To what extent will this savings be reflected in the final price of CAR T-cell therapy? Niessing suspects that the therapy costs will level off at 150,000 to 200,000 euros, thus putting it at the price level of chemotherapy. This would already be a benefit for patients. ■

back to page 1

Detecting tuberculosis earlier: Kathrin Held searches for telltale substances in the blood at the Fraunhofer ITMP.

Medical innovation

The Eternal Battle against the White Plague

Tuberculosis is treatable. Despite this, over one million people die from this disease every year. This can be mitigated by new diagnostic tests and active substances. The danger is close at hand. The proportion of multidrug-resistant pathogens is especially high in Ukraine, among other countries.

By Sonja Endres

Norbert Heinrich's decision to go into research came 17 years ago. The place: in a bush hospital in Malawi. The pediatrician had to watch helplessly as his little patients became thinner and weaker. They were wasting away because of consumption, as tuberculosis used to be known. The extreme deterioration of muscle and fatty tissue is characteristic of the disease. In the 19th century, roughly a seventh of the population in Germany died from the "White Plague", which is spread by droplet transmission. The disease became rare in Germany due to improved living conditions, the establishment of tuberculosis care centers and, from the mid-1940s, antibiotics. However, it is one of the most common causes of death in some regions of Africa and Southeast Asia. Tuberculosis is the infectious disease that claims the most lives worldwide. The toll was 1.25 million in 2023 alone.

Heinrich returned from Malawi with the will to fight this disease. He knows that early diagnosis and rapid, effective treatment are crucial. Heinrich and his colleagues at the Fraunhofer Institute for Translational Medicine and Pharmacology ITMP and the LMU Klinikum München (University Hospital of the Ludwig Maximilian University of Munich) are working on both. They have just filed a patent application for one of the results of their research.

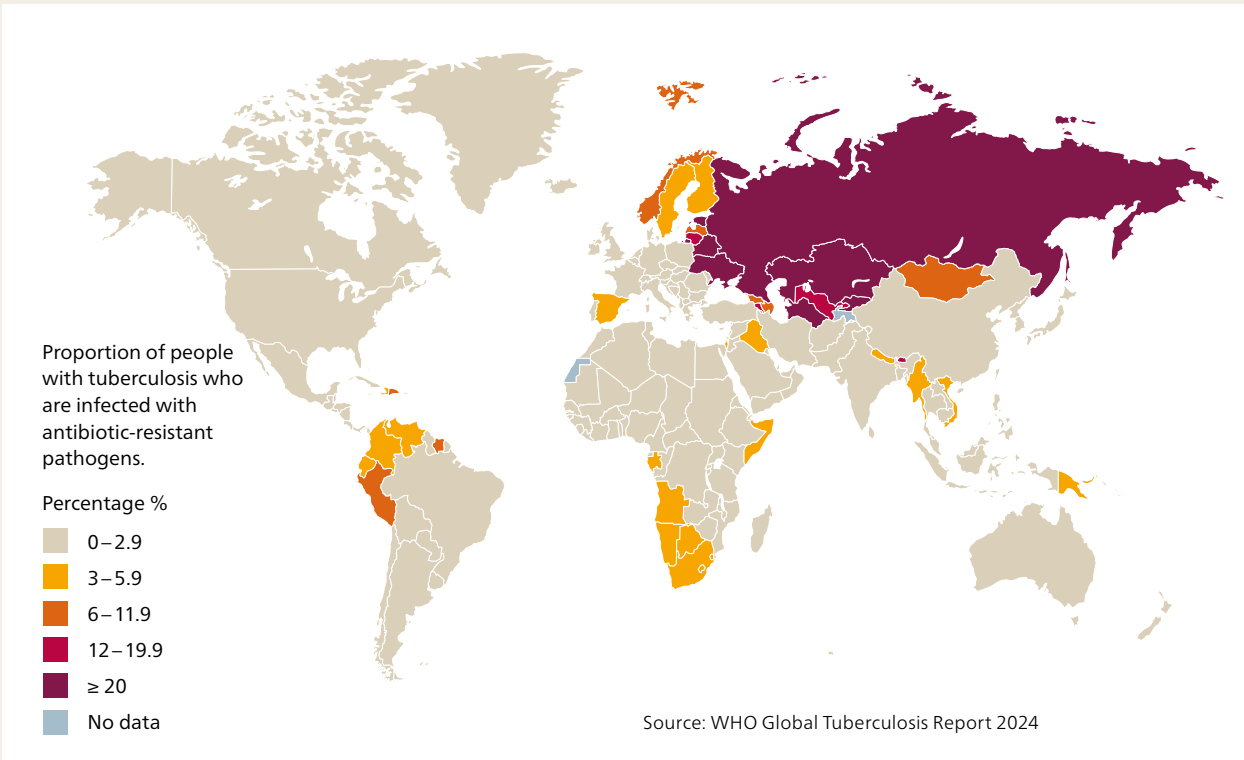
> "More than **200,000 children worldwide die** every year because the disease is not detected."
>
> Dr. Norbert Heinrich, Fraunhofer ITMP

The diagnosis of tuberculosis has hardly changed since the time of Robert Koch. In 1882, Koch, who went on to become a Nobel laureate, discovered Mycobacterium tuberculosis in the sputum of patients. The viscous secretion collects in the deep regions of the lungs and is expelled by coughing. Even today, tuberculosis is still detected by a sputum specimen.

"But try getting sputum from small children," Heinrich points out. The younger the children, the higher the probability of so-called extrapulmonary tuberculosis, in which the bacterium migrates to other organs. The lungs then often remain asymptomatic. "More than 200,000 children worldwide die every year because the disease is not recognized," says Heinrich.

Heinrich's colleague, pediatrician Laura Olbrich, explains how difficult it is to process the highly infectious sputum specimen. The pathogen can only be detected by microscopy at a very high bacterial load of roughly 10,000 pathogens per milliliter of sputum. That quantity is only present in cases of severe disease. The gold standard for diagnosis is therefore a bacterial culture, which can also be used to identify potential antibiotic resistance. The laboratories must comply with stringent safety requirements, and the procedures and machines must be specially controlled for successful culturing. "But the necessary medical infrastructure, also including ▶

back to page 1



Source: WHO Global Tuberculosis Report 2024

the appropriate specialist staff, is lacking precisely in many of the poorer countries with high numbers of tuberculosis cases," says Olbrich. Furthermore, the culture only grows slowly; it can be two to eight weeks before the final proof is available.

Only one in ten becomes ill.

In the DisTB project, Olbrich is therefore developing new diagnostic tests together with an interdisciplinary team and with the participation of pharmaceutical company Roche. They want to facilitate a quick, simple and early diagnosis of tuberculosis. This is crucial to ensure that infected people do not spread the disease and are spared serious harm to their health as well as complications. The researchers are looking for highly sensitive specific biomarkers in blood, urine and saliva, such as specific immune signaling molecules or antigens.

There is an IGRA test, a blood test that can prove that the patient's immune system has been in contact with the tuberculosis bacterium. "But the IGRA test does not tell us whether a person has tuberculosis," explains immunologist Kathrin Held, who is conducting research alongside Olbrich in DisTB. This is because the disease only manifests in roughly one out of ten infected individuals, especially in those with compromised immune systems. Olbrich: "A healthy body is normally able to encapsulate the bacterium and render it harmless." Doctors speak of latent tuberculosis, which is not infectious. However, if the immune system is severely stressed by another pathogen such as HIV or is artificially compromised, such as due to chemotherapy or rheumatological treatment, the tuberculosis bacterium can gain the upper hand and the person can fall ill, even years after infection.

The researchers have now succeeded in finding biomarkers in the blood that are not only highly specific for tuberculosis, but are also easy to detect. They have even identified a specific combination of biomarkers that can be used to diagnose an active disease and measure the success of treatment. A patent application has since been filed for this so-called signature.

The research scientists want to implement their findings in a test that is as simple as possible and does not require complex laboratory diagnostics or specialists. "The ideal solution would be a type of finger prick test," says Olbrich, "such as those used by diabetes patients to measure their blood sugar levels." All that would be re-

quired is a drop of blood, a test strip and a small reading device. Held adds: "With sufficiently sensitive tests that show us how active the tuberculosis is in the body, we could provide more targeted preventative treatment than has been possible to date and prevent the disease from manifesting." With this, the two researchers hope to shorten treatment times and reduce the number of new infections.

Severe side effects

Tuberculosis is currently treated with a combination of four antibiotics. This combination therapy is necessary because the bacterium very quickly develops mutations that confer resistance to individual drugs. "In this way," says Heinrich, "we reduce the risk of some bacteria surviving the therapy and continuing to multiply." The therapy lasts at least four months, but usually six or more. The side effects are severe, with patients often suffering from nausea, vomiting and diarrhea, and occasionally also from skin rashes, dizziness and liver dysfunction. The side effects are even more serious in the treatment of multidrug-resistant tuberculosis, when the so-called first-line antibiotics no longer help because the bacteria have become resistant to these agents, necessitating the use of reserve antibiotics. Multidrug-resistant pathogens are especially widespread in the WHO's European region, which also includes Russia, Belarus and Ukraine. They account for roughly 24 percent of all newly diagnosed cases. During treatment, a quarter of patients with multidrug-resistant tuberculosis suffer neuropathy, i.e. nerve damage, as well as bone marrow suppression. This results in anemia, which weakens the immune system and makes the patient susceptible to serious infections and bleeding. The harm to health can be permanent. Sometimes the therapy has to be discontinued, which promotes the development of further resistance.

An especially problematic agent in the mix of antibiotics is the highly toxic but also highly effective linezolid. Heinrich and his colleagues hope to replace it soon with two new substances: Sutezolid and Delpazolid. These antibiotics belong to the same class, but are significantly less toxic. In two Phase IIb trials, the researchers and their African partners have now tested these drugs for the first time in combination with the other three tuberculosis antibiotics. The drugs were studied in patients with multidrug-resistant tuberculosis in South Africa and Tanzania. The results indicate significantly better tolerability and, in the case of Delpazolid, also very good efficacy. These results were published in high-impact journal "The Lancet Infectious Diseases" and attracted significant attention among experts, as they could enable significant progress in therapy.

New beacons of hope

The research team hopes to build on its success in a Phase III trial, coming one step closer to approval of the innovative active ingredients. BTZ-043, a new antibiotic developed at the Institute of Infectious Diseases and Tropical Medicine at the LMU Klinikum München and the Hans Knöll Institute in Jena, is to join Delpazolid here, replacing another problematic agent in the quadruple combination therapy: Bedaquiline. The bacterium is becoming increasingly resistant to that former beacon of hope, which revolutionized the treatment of multidrug-resistant tuberculosis roughly 20 years ago by making the therapy significantly more tolerable and reducing the treatment time by two thirds. This development is especially threatening in many countries in southern Africa.

Heinrich is also very concerned about the USA's withdrawal from global prevention and treatment efforts. Until now, the US government has been the heaviest funder of tuberculosis research. "I must say, our American colleagues are quite desperate." The funding cuts also mean that many aid programs can no longer be continued and supplies are at risk in numerous countries. Heinrich fears a significant increase in tuberculosis cases and deaths. As antibiotic treatments have to be discontinued prematurely due to a lack of medication, new, even more resistant pathogens could emerge, posing a serious threat to global health. "We urgently need new tools to get this disease under control," says Heinrich. And that before the white plague conquers Europe and other regions around the world because none of our drugs help any more. ■

Multidrug-resistant pathogens are especially widespread in the WHO's European region, which also includes Russia, Belarus and Ukraine. They account for roughly **24 percent of all newly diagnosed cases.**

back to page 1

Medical innovation

A Gentler Look at Tumors

Lower radiation exposure in the diagnosis and treatment of cancer: Fraunhofer researchers are drawing on a technology from a completely different field.

By Beate Strobel

X-rays are fascinating for Victoria Heusinger-Hess: They tell us quickly and in detail what is present or taking place under a surface. Nor can she avoid this topic as a research scientist at the Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institut, EMI: X-rays play an important role at the Efringen-Kirchen site. For example, the research scientists are able to use high-speed X-ray imaging to study dynamic processes taking place over periods of milliseconds or microseconds. They can do this at speeds of up to 1000 frames per second. "An X-ray video like this," explains the mathematician, "enables us to directly observe what happens inside a vehicle and what happens to the occupants during a high-speed car crash, for example."

"By integrating additional information from a previous X-ray scan, the subsequent radar image can be enhanced to a higher level."

Victoria Heusinger-Hess, Fraunhofer EMI

In contrast, X-ray examinations in medicine are both a blessing and a hazard: the longer and more frequently a person is exposed to the ionizing radiation used, the greater the probability of damage to cells and tissue. In just a single CT scan, a person receives two to five times the average radiation dose that they naturally experience in a year.

"As little as possible, as often as necessary" is therefore the medical motto when using imaging procedures such as X-rays or computer tomography. The benefits and risks must be weighed especially carefully for people who are genetically predisposed to cancer or already have a tumor. So researchers at Fraunhofer EMI asked: Is there a technical solution that provides meaningful image data while simultaneously working so quickly and effectively that the patients are exposed to as little X-ray radiation as possible?

Electromagnetic waves provide a glimpse inside

In a joint project with researchers from the Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR and the Fraunhofer Institute for Digital Medicine MEVIS, the Fraunhofer EMI team decided on a surprising solution: radar. This technology has thus far been used more in shipping and air traffic or for gathering weather data. The principle is simple: A radar unit emits electromagnetic waves that cannot penetrate certain materials (such as an airplane), but are instead reflected back to the radar. Based on the time of flight and the change in frequency of the reflected waves, conclusions can then be drawn about the shape, material and movement of the detected object. The so-called "body scanners" at the airport also work with radar waves: They make the body and any suspicious objects under the clothing visible.

An enhanced view: Victoria Heusinger-Hess combines X-ray and radar at Fraunhofer EMI to benefit breast cancer patients.

The advantage of radar technology is that electromagnetic waves can also penetrate the body at a suitable frequency and image tissue changes without being harmful to health. The disadvantage: Image resolution is somewhat coarse. "If we limit ourselves to radar, we could see that a tumor is there," explains Heusinger-Hess. "But precise localization is not possible."

To compensate for this drawback, the Fraunhofer researchers are combining radar and X-ray technology. "By integrating additional information from a previous X-ray scan," says Heusinger-Hess, "the subsequent radar image can be enhanced to a higher level." For example, in practice, an X-ray CT scan of a tumor would be taken at the start of cancer treatment, as has been the case up to now. Subsequent examinations could then be replaced by less harmful radar technology, using intelligent algorithms to incorporate prior information from the initial X-ray image.

A phantom breast made from gelatine and fat

The research at Fraunhofer EMI is currently focusing on breast and lung tumors. There are very practical reasons for this. Unlike the abdominal region, for example, breasts and lungs are relatively compact areas of the body where there are not too many different organs and types of tissue. And unlike in the skull, for example, there is no massive bone plate to impede the passage of radar waves.

The patent for combined radar and X-ray tomography has already been granted, and the next step is to further develop the technology. To achieve this, Heusinger-Hess and her team have developed so-called breast phantoms made primarily of gelatine and fat. The algorithms are being further developed on the one hand, but different scan variants are also being tested. For example, can X-ray and radar images be created simultaneously, or does it make more sense to capture images with a time delay? Can radar measurements be used to change or compensate for artifacts in X-ray images? And can artificial intelligence, trained with simulation data and real measured values, enable neural networks to draw the right conclusions from the image data in a further step?

Applications outside medicine are also conceivable, such as for a quick check of containers in a shipping port or for hand luggage scanning at an airport. This takes the Fraunhofer team full circle back to the initial question of their research in security: "X-ray technology gives us the quick information that there is a square object in a suitcase," explains Heusinger-Hess. "But the radar gives us the important details: Is it explosives, or just a bar of chocolate?" ■

back to page 1

Medical innovation

The Next Level in Tumor Diagnostics

Fraunhofer researchers have developed a highly effective method for the early detection of pancreatic cancer. This approach could bring huge advances to precision medicine.

By Beate Strobel

Feathers, rapeseed, lignin: In the "Circular" display in the foyer of the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB in Stuttgart, various materials hang from the ceiling, fixed between glass panels. But in area, only four narrow rows of black lines and dots can be seen. "A reminder from my doctoral thesis," explains Kai Sohn, who holds a doctorate in biology—fragments of human DNA, genetic information made visible. Two decades ago, sequencing just one human genome cost 100 million dollars. Now, the latest technologies enable it to be done for as little as 100 dollars. And science has since grasped what options a deep dive into the genome actually holds: This information can save lives!

Tumors that are based on changes to not just one chromosome, but entire chromosome complexes, pose a special diagnostic challenge. Pancreatic cancer is one such ultimate adversary: With a survival rate of less than ten percent within the first five years after diagnosis, pancreatic cancer is considered the most dangerous cancer. This type of tumor has an especially high rate of growth and undergoes early metastasis to neighboring organs in the abdomen.

> "There are currently no screening tests or instruments enabling the early diagnosis of pancreatic cancer. And this is precisely why we chose this disease for our research."
>
> Kai Sohn, Fraunhofer IGB

However, the mortality rate is also so high because pancreatic tumors grow unnoticed: symptoms such as abdominal pain, weight loss or digestive problems only occur in the later stages. "There are currently no screening tests or instruments enabling the early diagnosis of pancreatic cancer," says Kai Sohn, summarizing the situation. "So far, it can only be diagnosed when it is too late. And this is precisely why we chose this disease for our research."

In collaboration with Georg Weber from Erlangen University Hospital and Genedata, a Fraunhofer research team led by Kai Sohn has developed an innovative method that can detect pancreatic cancer at an extremely early stage—without any biopsy. All that is required is a blood sample.

Cleverly wrapped—but with a predetermined break point

In his office, Kai Sohn places a white plastic model on the table, representing a DNA double helix that is carefully wrapped around a sponge-like internal structure. "In our cells," the researcher explains, "the DNA is compressed as best as possible in a packaged unit like this—the nucleosome." "The core ▶

What's next? Biologist Kai Sohn at Fraunhofer IGB is banking on precision diagnostics as a game changer in medicine.

back to page 1

"My dream is that one day we will be able to detect the diseases of tomorrow and beyond at an early stage, simply by analyzing tiny DNA fragments."

Kai Sohn, Fraunhofer IGB

of the nucleosome is made up of histone proteins around which the DNA strand is wrapped. This results in the most compact possible structure." The individual nucleosome units are in turn connected to each other by so-called linker DNA. These are the predetermined break points of the complex.

Nucleosome complexes can break apart at precisely these weak points. This can occur in natural cell decay, for example, but also in the development of tumors or through inflammatory responses in the body. Fragments like this, also known as cell-free DNA (cfDNA), are present in the blood of every human being. "We search for these DNA fragments in the plasma," explains Sohn. Or more precisely, they search to determine whether methyl groups have attached themselves to the DNA fragment. This is because tumor-derived DNA has different biochemical signatures, distinguishing it from healthy DNA. And there's more. "Depending on where the methylation took place, we can tell whether this nucleosome originates from an immune cell, the intestine, the liver or the pancreas."

An angular device the size of a desktop printer sits in the basement of the Fraunhofer IGB, with a soft pink luminescent band around its midsection and on which someone has glued two cheerful googly eyes. This is where the detailed analysis is done. The Illumina NextSeq2000 performs high-throughput sequencing, also known as next-generation sequencing (NGS). This technology now enables researchers to analyze genomes at high speed, says Sohn. "We can currently sequence 30 million DNA fragments overnight, meaning we can determine the exact sequence of nucleotides and search for methylation patterns."

Not only do the biomarkers discovered by researchers in the In-vitro Diagnostics department at Fraunhofer IGB make it possible to distinguish between healthy patients and patients with tumors, but also to differentiate very precisely between pancreatitis and a malignant pancreatic tumor, for example—two diseases with nearly identical symptoms. Using AI-based algorithms, the researchers were even able to show in some example cases that their diagnostic procedure can also classify preliminary stages of pancreatic cancer. Kai Sohn is optimistic: "I am convinced that this technology is a true game-changer in the fight against pancreatic cancer."

The next step is to conduct further clinical tests, followed by technology transfer to routine hospital use. Sohn underscores that Fraunhofer has a special advantage here: "By working closely with future producers and users, we develop technologies that account for user needs right from the start."

Genome analysis as the key to personalized medicine

NGS is also used at Fraunhofer IGB to identify new biomarkers for diagnosing other cancers as well as certain infectious diseases. For example, the DISQVER diagnostics platform developed at Fraunhofer IGB—now operated by Fraunhofer spin-off Noscendo—can identify more than 16,000 microbes (bacteria, DNA viruses, fungi and parasites) within 24 hours and can thus provide the fastest and best possible support for treatment decisions. Here too, all that is required is a blood sample from the patient.

According to Sohn, the rapid, effective and inexpensive analysis of genomes using biochemical and bioinformatic methods such as NGS are the key to patient-specific medicine—with the potential to herald a paradigm shift from diagnostic to preventive medicine. Development is still in its infancy, but the progress achieved over just a few years has already been enormous. "We are gradually beginning to understand the wealth of information available from fragmentomics, the analysis of DNA fragments," the researcher explains. "My dream is that one day we will be able to detect the diseases of tomorrow and beyond at an early stage, simply by analyzing tiny DNA fragments." ■

Medical innovation

Surviving Blood Poisoning

Sepsis is one of the most common causes of death worldwide. An early warning system employing AI-supported sensors can save lives. How Fraunhofer researchers want to enable the detection of health risks.

By Beate Strobel

A throbbing finger wound, a tooth infection, a urinary tract infection: Blood poisoning always starts with an inflammation. If pathogens enter the bloodstream, sepsis can develop in a heartbeat. The immune system releases a flood of inflammatory mediators that dilate and damage blood vessels. Fluids enter tissue, blood clotting goes out of control, the risk of thrombosis increases and organs fail. Only one in two people survive a septic shock. This disease is one of the most common causes of death worldwide.

Because every minute counts in sepsis cases, researchers at the Fraunhofer Institute for Computer Graphics Research IGD have been looking for a solution in the HealthView project to detect typical symptoms as early as possible. "Our project partner, Hypros GmbH in Stralsund, sells a device that uses optical sensors to detect critical clinical situations such as restlessness or the onset of delirium," explains Mario Aehnelt, Deputy Site Manager at Fraunhofer IGD in Rostock. "To expand its functions, we have jointly evaluated AI-supported contactless sensors that can determine key vitals such as body temperature, respiratory rate and pulse rate," adds project manager Gerald Bieber.

Sensors providing a three-dimensional image of people in bed are ideal. Algorithms can determine respiratory rate from the raising and lowering of the blanket by only millimeters. Pulse rate can also be measured indirectly: Every heartbeat causes a minimal change in blood flow to the facial skin. Pulse rate can be derived from this alone. "Body temperature, on the other hand," says Bieber, "is a very good estimate based on the data from thermal imaging cameras and the daily temperature measurement by the caregiver." The vitals are processed locally and are only provided in evaluated form, minimizing data protection concerns.

The feasibility study at Fraunhofer IGD is the basis for further development into a marketable system. This is tantalizing for startups looking for an innovative product, for example. In the next step, the research team wants to bring doctors on board to teach the AI the clinical interpretation of the parameters collected: How should the escalation levels be defined?

The Fraunhofer team is simultaneously examining further ideas for scaleup. "Continuous data acquisition and precise analysis without personnel expenses can be interesting not only for other disease processes, but also for the sensory monitoring of animals, in occupational health management, in professions where safety is a concern or in autonomous driving," says Bieber. Further development of digital patient twins is also being accelerated. "Continuous data collection acquisition improves our knowledge of the boundary between health and illness," emphasizes Mario Aehnelt. "This development is still in its infancy. But it is already clear that there are exciting opportunities here." ■

Sepsis emergency: warning signs
The symptoms are similar to those of the flu—except for low blood pressure, confusion and a high respiratory rate.

Fever (> 38 °C) or **low temperature** (< 36 °C)

Shortness of breath and **hyperventilation** (accelerated breathing)

Nausea and/or **vomiting**

Tachycardia (elevated heart rate) in combination with low blood pressure

Changes in state of consciousness Confusion or disorientation

Skin changes Moist, warm or reddened skin; cold extremities

back to page 1

Fraunhofer start-ups:
Applying research in industry

More is Always Possible

The key is in the data: As a spin-off of Fraunhofer IPA, plus10 uses AI software solutions to optimize the productivity of highly automated machines and systems.

By Beate Strobel

Trade fairs are more than just places serving up the tried-and-true. They can also showcase new breakthroughs like start-up plus10. The history of this company began in 2016 at Automatica, the leading international trade fair for intelligent automation and robotics. "Felix Müller, who was a group manager and project manager at the Fraunhofer Institute for Manufacturing Engineering and Automation IPA at the time, presented his exhibit at the main Fraunhofer booth, while I was in a different hall with an EU research project," recalls automation expert Pablo Mayer, now COO of plus10. "We would meet at the Fraunhofer stand for a beer in the evenings. Felix and I got to talking, discussed our research, and exchanged ideas." This after-work meeting had far-reaching consequences.

One of the ideas we discussed was data-driven production optimization using intelligent software tools: to what extent can AI increase efficiency and productivity in the manufacturing industry? Felix Müller, now CEO of plus10, already had specific plans for a spin-off and had applied for funding from the exist start-up grant program of the German Federal Ministry for Economic Affairs and Energy. Together with Pablo Mayer and Thomas Hilzbrich (now CTO at plus10), Müller developed a prototype of the analysis tool while still working at Fraunhofer IPA. The software collects high-frequency data from the machine control system, evaluates these in real time using self-learning algorithms and then reports whether there are any faults in the manufacturing system and to what extent they may be related. A second tool, the Shannon® intelligent worker assistance system, uses the data to provide step-by-step instructions on how to correct or even prevent production faults.

The third software tool is an intelligent machine benchmarking system called Darwin, which compares the production performance of similar machines and uses this information to develop an ideal process flow. Darwin performs an automated comparison for early detection of a machine running slower than intended, for example, and indicates possible technical causes and potential for optimization.

A launch and a pandemic

Once the tools they had developed had proven themselves for pilot customers, Müller, Mayer, and Hilzbrich took the plunge into self-employment in 2019. plus10 GmbH (the name conveys productivity improvement by intelligent optimization) started with one office each in Augsburg and Stuttgart. A scant six months later, the first Covid lockdown began.

"There were days when we stood in production halls for hours wearing FFP2 masks and ate ten meters apart in company canteens," recalls Pablo Mayer. "Of course we were also hit by the economic downturn during and after the pandemic." This was hardly an ideal time to start

On average, the smart tools from plus10 enable improvements of between **5 and 20 percent.**

Yes to improvement: Start-up plus10 helps companies get the most out of their automated production lines.

a business. "But we survived," adds Mayer, "because, in spite of it all, demand was solid." Thanks to their time at Fraunhofer IPA, the entrepreneurs did not have to start from scratch, and were able to build on existing company contacts. The special mindset the founders acquired over their time at Fraunhofer also helped: "Working on a variety of projects not only gives you valuable insights into different production processes, but also teaches you to constantly deal with new things and to implement them quickly," explains Mayer. This all continues to contribute to the success of plus10 GmbH to this day. The team now includes employees from AI, software development, automation and control technology as well as production engineering.

A further benefit is that DataCollector, Shannon® and Darwin can be applied across all industries, from classic machinery and equipment to the automotive industry, pharma and medtech, to manufacturing consumer goods. Hopper, the latest AI tool, was developed specifically for injection molding of elastomers and thermoplastics. It analyzes the various parameters influencing the raw materials processed on machines and systems and optimizes the machine settings on a case-by-case basis to minimize scrap and cycle time.

Improving productivity and shortening ramp-up times

Over the past six years, plus10's expertise has benefited prominent companies such as Freudenberg, Roche, SCHOTT, YPSOMED, and Aumovio, as well as hidden champions from the machinery sector such as ZAHORANSKY, Arburg, and Hosokawa. M10 Solar Equipment, an emerging solar module company with associated manufacturing technology, has relied on its partnership with plus10 since its launch. Working in fully automated electronics assembly, Continental used plus10-Shannon® to improve the availability of its systems by 18 percent.

Among the top 3 worldwide: plus10 (2nd from right: Felix Müller, CEO) at the 2025 Industrial AI Awards.

On average, the smart tools from plus10 enable improvements of between 5 and 20 percent. The tools are now also being used to shorten the ramp-up phase of new production facilities. For example, feedback from medical syringe production indicates a reduction of 20 percent. This corresponds to savings in the millions for major production facilities.

As a general rule, the more complex the production process, the greater the potential for improvement. Human operators can no longer handle the many dynamic factors influencing a process and have difficulty optimizing the systems manually, whether by following instructions or based on their own experience. Tools such as Shannon®, Darwin, and Hopper not only look at all the data, they are also on the job 24/7 as assistants. "This minimizes fluctuations in production between shifts or on weekends," says Mayer.

At the 2025 Industrial AI Awards, SIEMENS announced that, after evaluating more than 60 global AI start-ups in the manufacturing sector, plus10 was among the top three. It is also the only company worldwide that develops intelligent optimization tools that provide a true benefit in regulated critical production areas such as safety-related automotive components, pharmaceuticals, and medical technology. ■

Photos: greenbutterfly / istockphoto, plus10

back to page 1

Poplars Help Fight Climate Change

Agroforestry combines trees and farming. This historical form of land use could be the future—for both farmers and the construction industry.

By Sonja Endres

Softly, the summer snow drifts down. Starting in May, the white fluff that protects poplar seeds falls from the trees, often forming a thick carpet on the ground. But Moira Burnett-Barking is fascinated by a different property of these trees, which are members of the willow family. The head of a research group at the Fraunhofer Institute for Wood Research, Wilhelm-Klauditz-Institut, WKI, Burnett-Barking is especially enthusiastic about how fast they grow: "The trunks can reach a diameter of 20 centimeters in just ten to 15 years. Other tree species take five times as long on average. That's what makes poplar so interesting to the lumber industry."

In the PappelWERT project, Burnett-Barking is working with her team and partners to unlock the benefits of poplar for various applications—while at the same time reshaping agriculture to be ready for the future. To achieve this, the researchers are looking to a historical form of land use: agroforestry systems, a way of combining farming, trees and bushes. These practices were widespread in Germany right up to the end of the 19th century. Rows of poplars showed where one field ended and another began, acting as windbreaks. Hedges were an important refuge for many animal species, and the soils of meadow orchards were kept rich in nutrients by falling leaves and fruit. But as agriculture was mechanized, the woody plants were increasingly in the way. Trees, bushes and shrubs were removed, which had an adverse impact on soil quality and field microclimates, among other effects. Farmers tried to make up for the loss by increasing their use of fertilizer and artificially irrigating the land. Burnett-Barking explains: "But agriculture has reached its limits on that score. As extreme weather becomes more common due to climate change—meaning long periods of drought along with unusually heavy precipitation—there is an urgent need to change how we use land. This is the only way to safeguard yields in the long term."

Now, researchers are looking to the past to secure the future with modern agroforestry systems, optimally adjusted to present-day agricultural production technology. The PappelWERT team is developing best practice examples and studying six poplar agroforestry systems across Lower Saxony, Schleswig-Holstein, Mecklenburg-Vorpommern and Brandenburg, all regions where the impact of climate change is already readily apparent. Strips of poplars three to four rows deep cut across the fields every 25 meters. The trees are planted in rows with plenty of space in between, making it easy to manage the fields and the areas where the trees are growing and move machinery around them. Combining crops and trees has benefits for the local environment, the climate—and people's wallets.

More water, nutrients and protection

Through capillary action, the poplars' roots pull water upward like pumps, drawing dissolved nutrients to the surface from deep underground. The shade cast by the trees slows the evaporation process, so the soil does not dry out excessively even during periods of drought. The poplars function as a windbreak and keep seeds from being blown away while also preventing soil erosion. Fallen leaves and thinner, threadlike roots that have died off enrich the humus and improve soil quality. The areas where the poplars are planted are also teeming with animals and insects, increasing biodiversity. Burnett-Barking explains: "There is a whole chain of effects with positive results for the field." The researchers are still gathering data on how exactly those effects play out, such as the degree to which the benefits are limited to crops right near the poplars or also extend to those farther away.

But poplars aren't just making for a brighter future for farmers; the construction industry can benefit as well. "Poplar is an outstanding wood for use in furniture or

Photo: DEEPOL by plainpicture

Rows of poplars are easy to manage while also having beneficial effects on neighboring crops.

home construction. It is very strong, comparable to spruce or pine," Burnett-Barking says. The Fraunhofer WKI team plans to make higher-value wood products from the poplar. As the first step, the experts are looking at production of OSB, veneer and plywood panels.

Oriented strand board (OSB) consists of longitudinally oriented wood strands known as flakes, which are joined with resin and compressed. Laminated veneer lumber is sturdier, as it involves gluing several layers of wood veneer—thin layers of wood—together. To produce types of board, Burnett-Barking and her team need to tweak the conventional wood processing methods to accommodate the young poplar wood. Veneer production usually involves trunks 50 to 60 centimeters in diameter. "These trunks are peeled in the machine like an apple," Burnett-Barking says. The 10- to 15-year-old poplar trunks are only half as thick at most, so they need to be changed more frequently and yield much smaller sheets of wood. Poplar also has different desired characteristics and does not grow to be as strong as oak or beech. More caution is thus needed when removing the bark. "But we can do it. After all, this is our specialty here at Fraunhofer WKI."

Poplar on the rise

The laminated veneer sheets can be used for the outward-facing panels of doors, for example, and OSB can be used as wall elements in modular homes. "A lot of wooden buildings in the United States are made from OSB," Burnett-Barking says. It can also be used to make roof boards, ceiling panels or furniture. The sturdier plywood panels, which are made from sheets of wood glued together, can even be used as load-bearing elements in structures, such as beams or supports. "We believe the construction industry has the greatest potential for profitably marketing poplar wood," Burnett-Barking says. She is a firm believer: "Demand for these products will rise sharply in the future."

Her confidence seems justified. More and more homes in Germany are already being built from wood today—in spite of a slump in the construction industry. In 2023, wood rose to account for some 22 percent of new construction. The lightweight wood is especially suitable for expanding existing buildings in cities affected by housing shortages, plus it is sustainable. Wood does not take a lot of energy to produce like steel, brick or concrete does; it simply grows with light, air, soil and water. In the process, it extracts carbon dioxide, a known greenhouse gas, from the atmosphere and binds it in the wood. In this way, the poplars from the test areas not only help to protect crops such as wheat and rye from the effects of climate change but also to further curb those effects. ■

back to page 1

The Carbon Fiber Revolution

Researchers at Fraunhofer IAP have developed a cellulose-based carbon fiber with a high degree of functionality that gives it the potential for a wide range of applications.

By Beate Strobel

The reinvention of carbon fiber has been the goal of fiber expert Jens Erdmann at the Fraunhofer Institute for Applied Polymer Research IAP in Potsdam for over a decade. A project of almost historical significance: "For a good 50 years, scientists have been working on developing a competitive carbon fiber from biogenic raw materials," explains the materials scientist. Now the time has finally come: Erdmann's research team has succeeded in producing a highly functional carbon fiber based on cellulose.

But why bother reinventing something that has become the darling of industrial production since the 1950s? After all, traditional carbon fiber is something of a magic bullet among materials: It is light, extremely stable and simultaneously highly resistant to heat and chemicals. Composite materials made from carbon fiber produce high-performance materials that are extremely robust in terms of tension, compression, bending and impact, even under the most demanding conditions. Carbon fiber, which is produced by pyrolyzing organic pitches, also exhibits extraordinarily high electrical and thermal conductivity. The range of potential applications is correspondingly diverse.

Versatile cellulose as an ideal starting point

But fossil-based carbon fiber also has its drawbacks. This is because the industry draws 95 percent of its precursor material from the petroleum-based polymer polyacrylonitrile (PAN), which is processed into carbon fiber in a highly energy and resource-intensive process. Up to 20 tons of carbon dioxide are produced per ton of carbon fiber—roughly equivalent to the annual CO_2 emissions of two German citizens. And: the PAN used by the carbon industry comes primarily from the USA and Asia. This is a difficult raw material dependency in view of the volatile geopolitical situation.

The approach of replacing the fossil-based raw materials used to date with cellulose is therefore highly attractive: as the main component of plant cell walls, this biogenic polymer is not only the most common organic compound found in nature, but is also one of the most important natural stores of carbon. "However, a major advantage of cellulose is its ability to form filaments. Spun fibers made from this material exhibit amazingly high mechanical stability—they can really withstand a lot," says Erdmann. "I don't know of any other biogenic material with such a wide variety of technical applications." In addition, the entire cellulose value chain could be based in Germany: it has sufficient forests on the one hand, while on the other, the paper and pulp industry as well as carbon fiber spinning mills can provide a suitable industrial environment.

Temperatures of over 2500 degrees Celsius are required in parts of the carbonization process, i.e. conversion of the spun precursor into high-modulus (HM) carbon fibers. This removes volatile organic components and retains a high carbon content in the end product while simultaneously improving the mechanical properties. Jens Erdmann's research team has developed a production system for cellulose as a precursor that uses suitable catalysts and additives to lower the carbonization temperature by up to 1000 degrees Celsius while still accelerating the process and improving yield from 15 to up to 45 percent by weight. The researchers are capitalizing on the fact that the threads spun from cellulose can absorb the requisite additives and catalysts almost like a sponge. The fiber can thus be specifically optimized for the subsequent carbonization process.

Round, elliptical, kidney or flower shapes

By adapting the spinning process and parameters such as temperature, mechanical prestretching and residence time during the subsequent carbonization process, the researchers at Fraunhofer IAP have achieved bio-based, ultra-thin carbon fibers with a diameter of well below four micrometers—which is nearly down to half the diameter of conventional carbon fibers. But Jens Erdmann is also enthusiastic about the variety of shapes of the cellulose-based fibers can assume: "Round, elliptical, kidney-shaped, lobulated, i.e. almost flower-shaped—

with our special spinning methods, we can generate the most diverse geometries and internal structures."

And this in turn, the materials scientist says, enables the precise production of fiber types for a broad range of applications: such as in lightweight construction, aerospace, defense technology, robotics, wind turbines or medicine, for shielding sensitive electronics or as components in batteries and fuel cells. Erdmann: "The mechanical properties of our biogenic carbon fibers are on par with PAN-based high-performance carbon fibers. At the same time, it exhibits electrical and thermal performance similar to that of pitch-based fiber." Interest in sustainable materials is growing, says Erdmann. "But ecological benefits alone are not enough to win over the market. Economic performance must also be convincing."

Increasingly more inquiries from carbon fiber users are now coming in to Fraunhofer IAP, asking when the cellulose fibers will be available. "But the processing industry needs this new fiber material at least by the kilogram. We can't manage those quantities in the laboratory," explains Erdmann. The production technology will therefore be transferred to pilot scale in the Carbon Lab Factory Lausitz in Guben and Boxberg (Lausatia) in a cross-state initiative of Brandenburg and Saxony in collaboration with Chemnitz University of Technology and Brandenburg University of Technology Cottbus-Senftenberg. The systems, which will be up to 90 meters long, will represent the entire value creation process from the raw material, through carbon fiber production to the component—thus serving as a bridge to industrial scaleup. ■

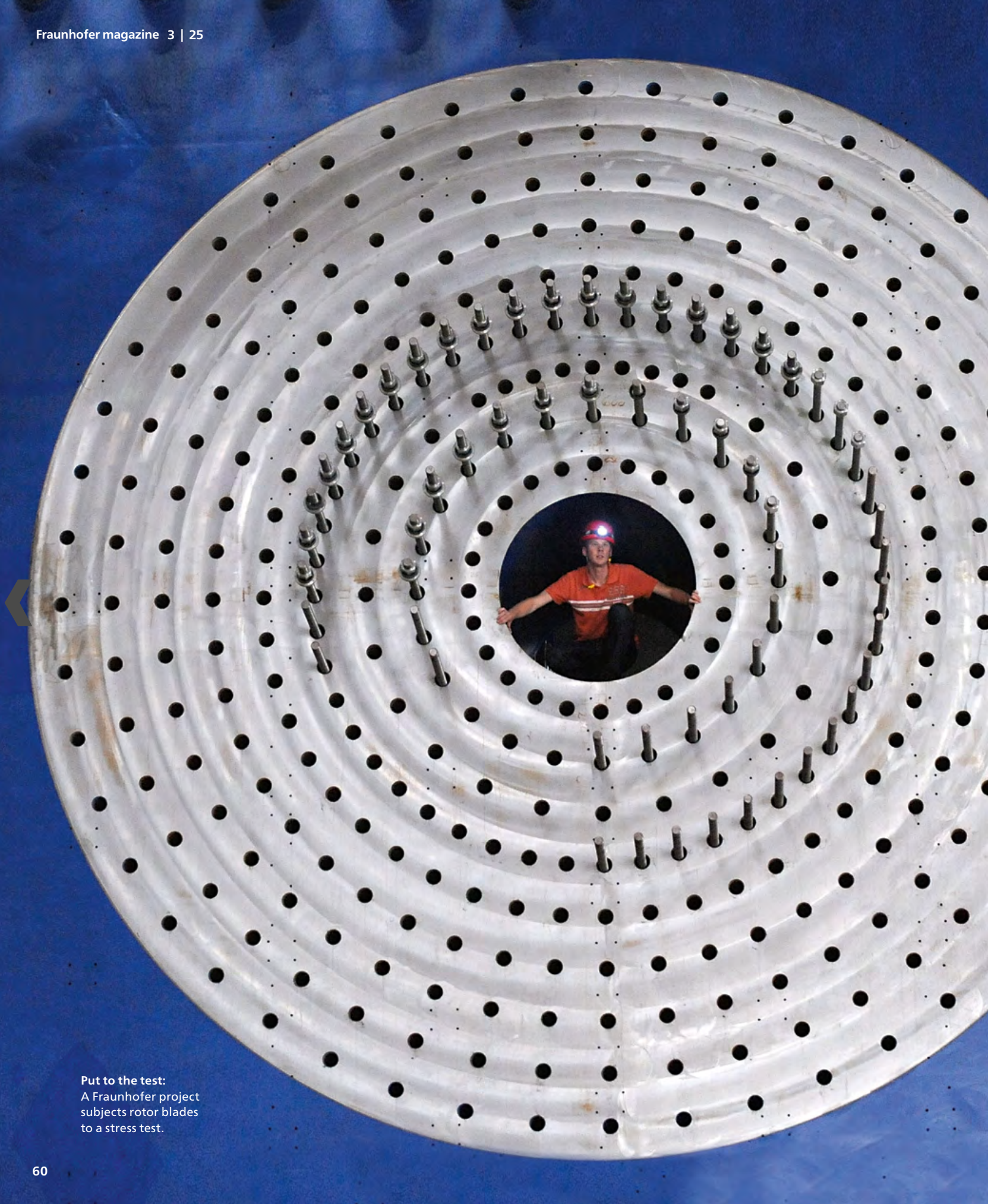
"Ecological benefits alone are not enough. Economic performance must also be convincing."

Jens Erdmann, Fraunhofer IAP

Photo: Fraunhofer IAP / Kristin Stein

Thin as a wisp and immensely strong: The diameter of bio-based carbon fibers from Fraunhofer IAP can be well below four micrometers.

back to page 1



Put to the test:
A Fraunhofer project subjects rotor blades to a stress test.

Photo: Ingo Wagner / dpa

Preventive Medicine for Wind Turbine Blades

Maintaining wind turbines and identifying potential vulnerabilities is expensive and time-consuming, especially when they are located offshore. Fraunhofer research scientists are developing a solution for the remote detection of hazardous damage at an early stage.

By Yvonne Weiss

It could start with a tiny crack. Allowed to propagate unnoticed in the fiber-reinforced plastic of the rotor blade, it could cause failures and expensive repairs to a wind turbine. Offshore wind farms are particularly affected, as they are exposed to exceptionally strong winds, rain and other severe weather conditions at sea.

Wind turbines are regularly inspected and maintained to identify such damage early enough. If damage is already significant, repairs are usually costly and are not always possible on site, and rotor blades may therefore have to be completely replaced. Depending on the rotor blade and the damage, the costs can reach hundreds of thousands of euros.

Researchers at the Fraunhofer Institute for Integrated Circuits IIS and for Wind Energy Systems IWES are working on a solution: "With the help of structure-borne sound sensors, we aim at detecting hidden damages in rotor blades at an early stage and monitor it remotely," says Björn Zeugmann, group manager at Fraunhofer IIS in the field of analog integrated circuit design. "In this way, we want to help ensure the availability and reliability of wind turbines."

The sensors, which are attached to the inside of the individual rotor blades, detect sound waves going through the structure of the blades. The rotor material poses a particular challenge. Unlike materials like steel beams, it is not homogeneous, since rotor blades are made up of different layers.

The research scientists at Fraunhofer IIS have developed a new chip for use in the structure-borne sound sensors. It detects so-called surface waves that occur in the event of damage. The system then transmits these signals via mobile communications.

A key advantage of this development is that, unlike conventional measurement methods such as radar systems or drones that record and transmit a large amount of raw data, the chip developed by the Dresden-based researchers only transmits conspicuous data. "We use an acoustic system that detects damage based on the sounds it makes," explains Björn Zeugmann. "This enables it to distinguish between a crack that is just forming inside the rotor blade and an actual fracture."

The researchers already developed this acoustic solution in a previous project. Because only relevant features are transmitted, the data quantity can be significantly reduced, which is what makes their transfer via mobile networks possible in the first place. Zeugmann: "Our chip is constantly listening. It can therefore efficiently classify and transmit information on potential damages directly in the rotor blade."

In the future, it will be possible not only to determine whether any damage has occurred at all, but also to monitor existing cracks over an extended period of time. If the recorded sound indicates that the damage has worsened, technicians can perform targeted repairs. This avoids costly service deployments and minimizes downtime.

A prototype of the new chip is already in use. In the follow-up project, which has been running since June, the team wants to expand the overall system. In the future, they want to also be able to detect lightning strikes and their possible consequences. This has not been feasible thus far, but especially for offshore wind farms, this additional information is crucial.

Zeugmann is pleased with what the new technology has achieved so far: "I'm fascinated by working in a field of the future like the energy transition and creating value for society that way." ■

back to page 1

AUSTRIA

Smarter timber transport

In collaboration with industry and logistics partners, Fraunhofer Austria has developed a digitally networked container system to make timber transport more efficient, flexible and sustainable. The standardized roll-off transport system (ACTS, Abroll-Container-Transport-System) transports both tree trunks and other wood products such as wood chips for the first time and are suitable for intermodal use on roads and railways. In contrast to conventional, time-consuming processes, this system enables reloading between trucks and freight cars in just a few minutes without an additional loading crane. This makes rail transport economically viable for distances as short as 140 kilometers, and transports can be better combined, reducing empty runs by nearly half. Modern sensors detect the weight of the load already in the forest, preventing overloading. Intelligent IoT technology also enables real-time container location tracking. This system must be further tested to generate additional practical data. Interested application partners are still being sought for this.

Reloading individual tree trunks onto the train is time-consuming. The solution is an innovative container.

Fraunhofer Worldwide

Locations of the Fraunhofer-Gesellschaft

Ice rinks require enormous amounts of energy—and are therefore harmful to the climate.

SWITZERLAND

Skating on plastic

Rising energy costs and climate change are making traditional ice rinks increasingly uneconomical. The Fraunhofer Institute for Mechanics of Materials IWM in Freiburg has developed a sustainable alternative together with Glice AG from Lucerne: synthetic ice with gliding properties to rival those of frozen water.

To achieve this, Fraunhofer IWM analyzed the frictional forces between the skate blade and artificial ice with a specially constructed ice gliding simulator. These data were used to optimize material formulations and surface structures. The result is plastic sheets made of refined polyethylene and a surface layer with ultra-low resistance, on which skaters glide just as effortlessly as on real ice.

The panels have a service life of roughly ten years on each side and require neither water nor coolant—a plus for the environment and for the operator. The innovative, robust material could also replace toxic PFAS in machinery and equipment manufacturing in the future.

SPAIN

German-Spanish Alliance for Biomedical Innovation

The new Fraunhofer Center for Applied Theranostic (Fraunhofer CAT) in Barcelona is striving for significant advances in personalized medicine. The aim of the researchers is to develop innovative technologies that advance diagnostics, prognosis and therapy selection, paving the way for precision medicine. Under the umbrella of the Fraunhofer Spain Research Foundation, Fraunhofer CAT acts as an interface between research laboratories, clinics and the biotech industry. Josep Samitier will head the center. The renowned research scientist is the director of the Institute for Bioengineering of Catalonia IBEC and a professor at the Faculty of Electronics and Biomedical Engineering at the University of Barcelona. The grant authorities are the Fraunhofer-Gesellschaft, the Spanish government, the Catalan Government and Barcelona City Council.

Holger Hanselka, President of the Fraunhofer-Gesellschaft, (2nd from right), with Spanish and Catalan government representatives in Barcelona.

EUROPE

Amplifier chips for more precise weather forecasts

The MetOp-SG mission of the European Space Agency (ESA) aims to make weather forecasts significantly more accurate and improve long-term climatological data. The first of six satellites has now been placed in a near-Earth polar orbit. Also on board are extremely low-noise amplifier chips from the Fraunhofer Institute for Applied Solid State Physics IAF. These are installed in the microwave sounder (MWS), which measures temperature and humidity profiles in different atmospheric layers, and are based on metamorphic high-electron-mobility transistors (mHEMT). The especially high electron mobility in these devices enables them to precisely amplify even very weak microwave signals. The satellite's modern instrument packages—including infrared and microwave sensors as well as instruments for chemical atmospheric analysis—cover the entire globe within 24 hours and provide high-resolution data on temperature, precipitation, cloud formation and wind conditions.

The MetOp-SG satellites can self-destruct at the end of their service life.

USA

Rapid detection of antibiotic resistance

Researchers at the Fraunhofer USA Center for Manufacturing Innovation CMI in Boston, in collaboration with the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB and the Fraunhofer Institute for Microelectronic Circuits and Systems IMS, are working on a novel rapid test method that detects antibiotic resistance within a few minutes instead of several hours. The µFLOWDx platform analyzes whether bacteria from patient samples are responding to antibiotics. This is done by adhering the pathogens to special surfaces in a microfluidic cell and bringing them into contact with antibiotics. Highly sensitive optical sensors based on fluorescent carbon nanotubes measure how the bacteria respond in real time. Based on their metabolic stress responses—measurable changes in metabolism as a result of the antibiotic effect—the system quickly identifies which antibiotics are effective. The goal is to avoid misdiagnoses, provide more targeted therapy and thus reduce deaths, complications and long hospital stays.

Beautiful but potentially deadly in blood: MRSA bacteria.

back to page 1

A Helmet for a Smaller Footprint

Fraunhofer researchers have developed a bike helmet made from recyclable bioplastic. But their real goal is much bigger.

By Beate Strobel

The history of bike helmets, as we know them today, stretches back to the 1960s, when a new discovery was made in the Trott family basement in Radevormwald, a town in the German state of North Rhine-Westphalia. There, Karl-Heinz Trott, a police officer, developed the "Trott helmet" out of concern for the safety of his sons, all amateur racing cyclists. Designed much like a hard hat, the Trott helmet featured a plastic shell supplied by a local toy manufacturer. Inside, a spiderweb-like design created at least a minimal distance between the outer shell of the helmet and the wearer's head, and with it a tiny crumple zone in case of a crash. Those who wanted greater air flow could drill small holes in the rigid outside of the helmet.

While the Trott helmet looked like a hardened swim cap—which may have been part of the reason it disappeared from the market at some point—today's cyclists have a dizzying array of models to choose from. Similarly, a wide range of different materials are used to make them: polycarbonate for the outer shell, expanded polystyrene foam for the core, polypropylene for attachments like visors and nylon for straps. "All these different fossil-based plastics are inseparably connected during the helmet production process, so they can no longer be taken apart once the helmet reaches the end of its useful life," explains Janne Constantin Albrecht, a chemical engineer with the Fraunhofer Institute for Chemical Technology ICT in Pfinztal, near Karlsruhe. The mix of materials makes it nearly impossible to recycle the product. This means discarded helmets typically end up being incinerated—which increases the environmental footprint of a sport that is otherwise viewed as very ecofriendly.

Material with great design potential

In the PIMMS project, Albrecht and his team, with support from the Fraunhofer Future Foundation, have set out to design a bike helmet made from a single material, so the product is recyclable. The centerpiece of their helmet innovation is a type of plastic that is already environmentally friendly in itself because it is made from renewable raw materials: Polylactide, also known as polylactic acid (PLA), is typically made from cornstarch or sugarcane, so it falls within the bio-based plastics category. Because no fossil sources such as petroleum are used and it is highly recyclable, PLA has a significantly smaller material footprint than traditional plastics although its technical properties are comparable. "Another factor in PLA's favor is that it is highly available," Albrecht notes. "That means the conditions are perfect for transferring this idea to industry."

Over the project's 18-month term, the Fraunhofer researchers worked with several industrial firms to dramatically expand the range of PLA use cases, developing particle foams, deep-drawn films, fibers and composite materials consisting of PLA. This is a considerable achievement, since if the exterior shell and the protective inner foam are made from the same biopolyester, for example, then those parts also soften at the same temperatures, making processing much more complicated. "Quite a bit of process know-how went into solving the problem of how to connect all the components without them losing their shape," Albrecht explains.

"Our monomaterial helmet's environmental footprint is 66 percent smaller."

Janne Constantin Albrecht, Fraunhofer ICT

Coming full circle: 3,000 people gathered in Santiago de Chile in 2023 to attempt a Guinness World Record for the world's largest bicycle made out of human figures. They weren't wearing helmets, though—just baseball caps.

Photo: Esteban Felix/AP/dpa

The PLA helmet the researchers created has already passed the first material tests of shock absorption and resistance to environmental influences with flying colors. Albrecht is also confident as he looks ahead to the upcoming crash tests at an external testing lab: "Initial tests have already demonstrated that our version is equal to traditional bike helmets in terms of protection and safety." One especially positive aspect is the results of the life cycle analysis of the PLA helmet: "Our monomaterial helmet's environmental footprint is 66 percent smaller," Albrecht says. That is because the bioplastic helmet can simply be put through an industrial shredder at the end of its useful life, processing the PLA into granulate so it can be reused.

From helmet to surfboard to car

Initial negotiations with potential manufacturers are under way now, but Albrecht is already thinking one step ahead. "Above all, this helmet is proof that many other multi-material products would also be conceivable as recyclable monomaterial versions," he explains. Plus, they wouldn't even require much investment from industry, since PLA can be processed using the same machinery and tools as conventional plastic.

As the next product, Albrecht is thinking about a PLA surfboard, for example. Car seats could also be made entirely from the bioplastic, though: "If you think about the EU's regulations on end-of-life vehicles, for example, which call for a significant increase in the recycling rate for motor vehicles, innovations like these are urgently needed." Albrecht sees bright prospects for the PLA foam developed at Fraunhofer ICT in particular: "From insulation to transportation containers and packing materials, basically any product that is traditionally made from expanded polystyrene now could also be made from PLA." ■

back to page 1

Lush green:
Trees are a valuable source of shade, especially in summer.

Photo: Myslitel/iStockphoto

In the Green Zone

Fallen trees cause a lot of damage year after year in Germany, with railways being an especially prominent example. Fraunhofer researchers are using a smart laser scanner to make traffic routes safer.

By Yvonne Weiss

The asphalt? Hot. The air? Dusty. The sunlight? Painfully bright. This summer has shown all too clearly that if not for trees, quality of life would decline rapidly, especially in cities. Trees produce oxygen, filter toxins out of the air, dampen street noise and provide habitats for insects, birds and squirrels. They also create shade, a natural contribution to cooling sidewalks and buildings.

But drought is a danger to trees—and it makes them dangerous in turn. Together with embankment fires and floods, fallen trees and branches caused more than 8,000 disruptions in Deutsche Bahn rail service in 2022, and that figure is rising.

Researchers from the Fraunhofer Institute for Physical Measurement Techniques IPM and the University of Freiburg have teamed up on the TreeVitaScan project, working to reliably identify weakened trees and make transportation routes safer. "We've developed a multispectral laser scanner that uses not one but two wavelengths," explains Alexander Reiterer, a department head at Fraunhofer IPM. "That lets us take distance measurements while also determining how dry a tree is, which is an important parameter in gauging the possible risk that the tree will fall."

Traffic safety involves manual labor: In the current practice, city employees run a rope around the tree's trunk and pull with a set amount of force. The amount the tree inclines is then used as an indicator of its state of health, and thus the potential risk of falling. The trees tested in this way are then manually charted using a GPS receiver and entered in existing tree registers.

Reiterer and his team intend their smart laser technology to be a substitute for this testing method: "Our multispectral laser scanner is part of a box mounted on the roof of a test vehicle. As the vehicle drives by, the instruments automatically collect information on every tree the vehicle passes on the road, measuring its moisture content and providing a picture of its health," Reiterer says. "Our long-range goal is a complete vegetation register, a sort of Google Maps that shows each and every tree's risk of falling."

As with conventional laser distance measurement, the laser source first transmits a beam of light that strikes a rotating mirror and is then sent outward from the rooftop box. The combination of the rotating laser beam and the moving vehicle creates a helix of light that scans the environment around the car.

The two different wavelengths used in the new scanner provide the crucial information: "Depending on the wavelength, laser light is absorbed by water, reflected or scattered," Reiterer explains. "If we scan a moist surface with two different red wavelengths, for example, one of which is reflected by water and the other absorbed, we can measure how much of the respective light comes back and then use that ratio to conclude how much moisture there is in something like a tunnel wall, facade or tree."

Because both the mirror and the vehicle are moving when the measurements are taken, the overlay between the two wavelengths has to be perfect; that is the only way to hit exactly the same point on the object even from a distance of 100 meters. The researchers are currently fine-tuning this aspect. A measurement system has already been built, and initial test drives are in progress in Freiburg.

In the long term, Reiterer and his team are also planning to integrate the moisture scanner into a sensor system that is being developed by Fraunhofer IPM in a separate project. It is only about the size of two shoe boxes together. Thanks to artificial intelligence, this system enables complete analysis of laser scanner, camera and GPS data within the measurement box, all in real time. Going forward, it could be used to automatically analyze more than just the condition of trees in seconds. It could also detect damp spots in tunnels, bridges and asphalt even more efficiently, so dangerous cracks could be identified in time to take action. And infrastructure monitoring would be much simpler and easier.

Reiterer sees a wide range of possible applications and a wealth of potential: "I'm excited to think that our new method lets us capture about two million measurement points a second, determining not only an object's geometry but also other parameters in the process. This represents a huge leap forward compared to existing laser scanner technology." ■

back to page 1

EEG without the “shower cap” and cable spaghetti: Innovative adhesive electrodes can be used to measure brain activity during everyday activities, including over a longer period.

Electrifying Discoveries

Electroencephalogram (EEG) technology has afforded amazing insights into the human brain for some 100 years now. Now, EEGs are going mobile, taking diagnosis of sleep disorders and neurological disorders to a new level.

By Sonja Endres

Psychiatrist Hans Berger, working in the German city of Jena, set out to find out whether there was a connection between feelings and brain activity, and in 1924 became the first to measure electrical currents in the cerebral cortex. A century on, Fraunhofer technology makes it possible to conveniently use electroencephalogram (EEG) technology under everyday conditions as well as in clinical settings, unlocking a whole new range of insights.

Electrical signals in the brain arise when cerebral nerve cells transmit stimuli. Electrodes can be used to read these signals from the scalp and visualize them as a chart. The shape, frequency and height of the waves show characteristic patterns, for example when a person's eyes are closed or when they are asked to think of something in particular.

EEGs let us understand how people learn, think or perceive the world around them. They are also crucial to diagnosis and treatment of neurological disorders or sleep problems, an area of focus for Karen Insa Wolf in her research. Wolf, who manages the Mobile Neurotechnologies group at the Fraunhofer Institute for Digital Media Technology IDMT, explains: "The hallmark of EEG technology is that we can use it to watch how the brain works in real time." Advanced imaging methods such as computed tomography (CT) and magnetic resonance imaging (MRT) are more accurate at pinpointing exactly where something is happening inside the brain. "But there's always a delay, which we don't have with an EEG."

Beyond that, EEG systems are significantly less expensive than CT scanners and MRI units, which can cost two to three hundred times as much depending on the configuration. They also have another crucial advantage in that they can increasingly be used on a mobile basis—especially thanks to miniaturized electronics and innovative flexible adhesive electrodes that also work reliably when movement occurs. Wolf continues: "When people think of an EEG, they picture the typical shower cap with cords coming out of it every which way. Although those kinds of units are still necessary for certain applications in clinical settings, there are now alternatives suitable for long-term observation in everyday life or while people sleep."

Wolf and her team have developed unobtrusive EEG systems that require only a few small electrodes adhered behind the ear and on the face. They are comfortable to wear while still achieving high data quality. Another advantage of this solution compared to helmet-like dry electrode systems is that there is no need to exert pressure to press the often brushlike electrodes through the hair and onto the scalp, as this is the only way to create adequate signal quality. In many cases, this ends up causing a headache after a certain amount of time. These kinds of devices can hardly be used for 24-hour EEG monitoring, quite aside from the fact that people cannot very well be asked to go about their everyday lives wearing what looks like a shower cap or helmet.

> "The hallmark of EEG technology is that we can use it to watch how the brain works in real time."
>
> Karen Insa Wolf

The versatile new adhesive EEG electrodes from Fraunhofer IDMT hardly restrict the wearer at all. This is beneficial where EEGs are used to diagnose sleep disorders, among other things. The goal is to allow patients to monitor their sleep from home using electrode patches they can stick on themselves. Supplemented by further technologies from Fraunhofer IDMT that log vital signs without contact, this could make it possible to do without disruptive overnight stays at a sleep lab involving cables and intrusive technology worn on the body. "Our systems not only offer freedom of movement and greater comfort but also ensure better data quality, as they collect data on natural sleep in a familiar environment," Wolf points out. The data collected in a sleep lab is of limited significance in this regard, because there are so many contact sensors, few people can sleep as well there as they do in their own beds.

The innovative adhesive EEG systems are supplemented by artificial intelligence. The researchers train AI algorithms to identify characteristic patterns and determine sleep phases. AI is essential to analyzing the large volumes of data generated during mobile long-term monitoring—especially when interpreting the signals is more challenging than in the case of a sleep EEG, where external influences are limited and interpretation rules are known.

Epilepsy patients are among the groups that could benefit from this. Seizure activity, a crucial criterion for individual treatment planning, could be recorded using mobile sensors located at the patient's ear as they go about their daily life. Wolf and her team train AI-based algorithms for automated seizure detection. The accurately recorded signals at the time of the seizure help to better understand epilepsy as a disease and tailor the patient's treatment on an individual basis. The goal is to prevent seizures or, at a minimum, reduce their frequency and at the same time limit medication side effects. Early warning systems could also be developed based on the data collected, helping to prevent injuries from falls in this group of patients, for example. Wolf is currently still looking for industry partners to continue her work on developing these kinds of systems. She is a firm believer in one thing: "Mobile EEGs still have a lot to teach us." ■

Photo: Fraunhofer IDMT/Leona Hofmann

back to page 1

A Photo & Fraunhofer

Fished away

Fish is not only essential for survival for these two hunters. This fast-paced food chain earned photographer Qingrong Yang the title of Wildlife Photographer 2025. Roughly 800 million people around the world are considered dependent on fishing and fish production and sales. In addition to overfishing, pollution of the oceans also threatens stocks. The fishing industry is one of the primary contributors to marine litter. According to estimates, roughly 29 percent of all lines and up to 40 percent of nets used are lost at sea. Equipment abrasion and wear also introduce large quantities of microplastics into the oceans.

To reduce environmental pollution in the ocean, the Fraunhofer Institute for Environmental, Safety, and Energy Technology UMSICHT is working with partners in the SEARCULAR project to develop new materials for fishing gear. Recyclable solutions such as recycled polyamide for ropes and biodegradable ground lines and fish aggregating devices are intended to help reduce microplastics in the sea. A management system also helps to ensure that disused fishing equipment is recycled properly. With this project, the researchers wish to contribute to sustainable fishing and a healthy marine ecosystem.

On the hunt:
Herons usually strike in the early hours of the morning.

Photo: Qingrong Yang, courtesy Wildlife Photographer of the Year

back to page 1

Naturally sweet: Sugar beets contain up to 20 percent sucrose at harvest.

Beeting the System

Single-use plastic tableware has been banned in the EU since July 2021. However, more environmentally compatible reusable solutions are not always suitable for events such as trade shows. Together with partners, Fraunhofer researchers are developing compostable alternatives based on regional sugar beet residues.

By Yvonne Weiss

Plastic is polluting the oceans. To reduce quantities of plastic, the EU already banned plastic dishes, cutlery and drinking straws in 2021. The problem: more environmentally friendly reusable solutions are only suitable for events to a limited extent; paper plates are often not sufficiently stable and they also degrade slowly. Researchers at the Fraunhofer Institute for Wood Research, Wilhelm-Klauditz-Institut WKI are working on an alternative. Research scientist Arne Schirp at Fraunhofer WKI describes the goal as follows: "We are developing compostable single-use tableware based on regionally available plant-based residues from sugar production."

There are currently about 150 million tons of plastic in the world's oceans, forming garbage patches such as the Great Pacific Garbage Patch in the North Pacific, which is roughly four times the size of Germany. This new material could help prevent a further increase, as it degrades completely both in seawater and on land.

> "We are developing compostable single-use tableware based on regionally available plant-based residues from sugar production."
>
> Arne Schirp, Fraunhofer WKI

The new compostable plates, knives and forks are based on beet residues from the local sugar industry, provided by project partner Pfeifer & Langen. More than one million tons of this residual material are produced every year during the beet harvest in Germany.

Previously, this byproduct has only been reused to a limited extent, such as for animal feed. Arne Schirp sees much more potential here: "Together with natural polymers such as corn starch or pectin from sugar beets, beet residues serve as an ideal basis for compostable, environmentally friendly single-use plates and cutlery."

Together with plasticizers such as water and glycerin, the researchers put the mixture of beet residues and natural polymers into a compounder, in which different raw materials can be mixed and processed into granulate. After melting, the materials are first crushed into pellets. These are then pressed to form films. In the final step, the researchers coat the films and then reshape them into plates. Knives and forks will also be produced in this way in the future. The current developments are part of the project "Development of disposable products with bio-based coatings from regional agricultural residue streams from the food industry" (EBRA).

"Natural polymers have the advantage of a low melting point or in some cases no melting point at all," says Schirp. "They can therefore be used to create wonderful new materials—with very little energy input."

The use of domestic residue also keeps transportation routes short, lowers CO_2 emissions and strengthens regional markets. The new plates are to be produced in existing plants.

The material also speaks for the alternative: "Over a twelve-week test," says Schirp, "we found that the new products decompose more quickly, with higher mass losses than conventional paper plates, for example." The materials can therefore be readily disposed of in a home composting system and pose no health issues.

The project partners are currently fine-tuning the optimum quality of the new tableware. Grilled food such as meat requires that the new plates be sufficiently mechanically stable, while greasy foods such as sausages and oily dishes like salads with dressing require a material that is resistant to water and grease. The researchers aim to achieve this with a bio-based coating currently under development by project partner RWTH Aachen University.

The environmentally friendly single-use plates are being developed as part of the Competence Center for the Biological Transformation of Material Science and Production Technology (Bio-4MatPro). This project is funded by the German Federal Ministry of Research, Technology and Space (BMFTR). The first prototypes have already been produced. In the next step, the project partners want to transfer production to an industrial scale and then launch it on the market. ■

Photo: Niclasbo/istockphoto

back to page 1

But Where's the Crew?

The EU plans to boost cargo traffic on inland waterways by 25 percent between now and 2030 in a bid to ease the burden on the road and rail infrastructure and reduce environmental impact. Small, autonomous ships with zero emissions could be just the ticket.

By Laura Rottensteiner-Wick

Small ship, big impact: In the EU's AUTOFLEX project, Jonathan Weisheit and his international team plan to revive currently unused old inland waterways to strengthen inland shipping operations. "Using smaller ships would make it possible to expand the existing waterway network in our area of study in the Netherlands by about 45 percent, for example," explains Weisheit, a research scientist at the Fraunhofer Center for Maritime Logistics and Services CML. Weisheit, which means "wisdom" in German, is certainly a fitting name for a scientist. "People definitely have high expectations when they hear my name," he jokes. A coastal engineer, Weisheit is also formally trained in shipbuilding. Helping to develop an autonomous, emission-free ship for inland trade is certainly a good step toward meeting those expectations.

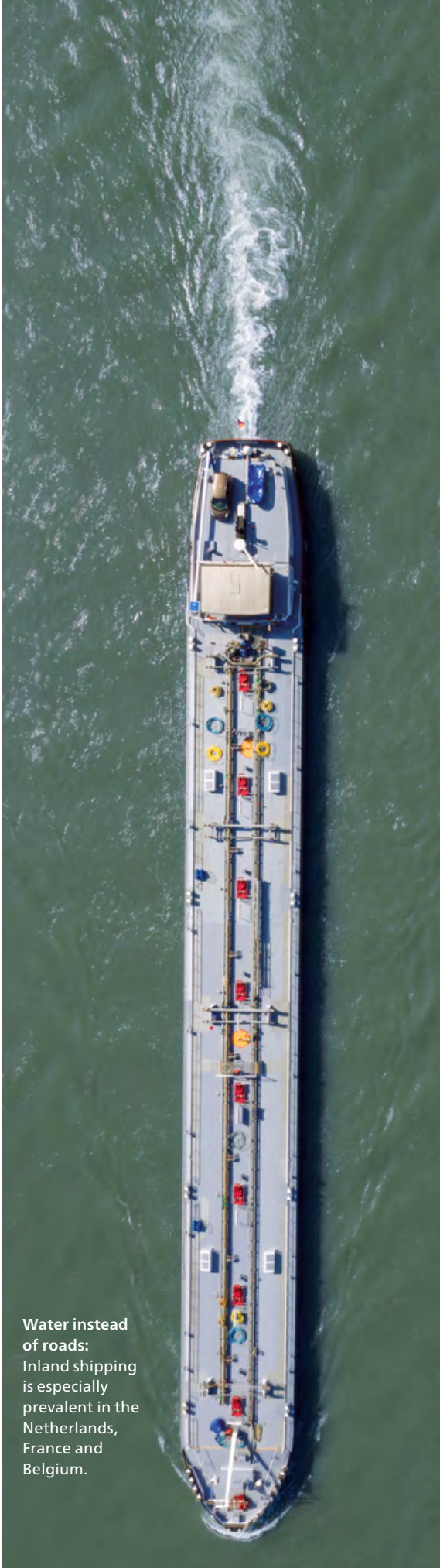
The EU plans **to boost** cargo traffic on inland waterways by

25 %

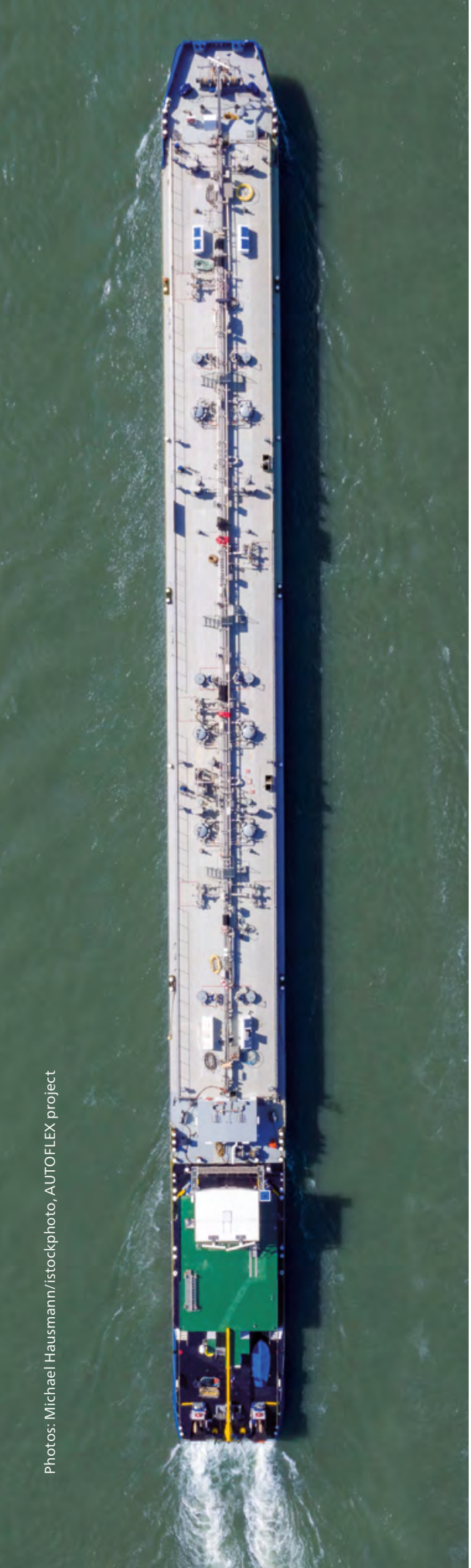
by 2030.

Reviving unused waterways

"In Northern Europe in particular, there are a lot of historical canals that cannot be used for conventional large-volume inland cargo shipping, whether because the locks are too narrow or for other reasons," Weisheit explains. "To help with this situation, we are developing a modern uncrewed inland cargo



Water instead of roads: Inland shipping is especially prevalent in the Netherlands, France and Belgium.



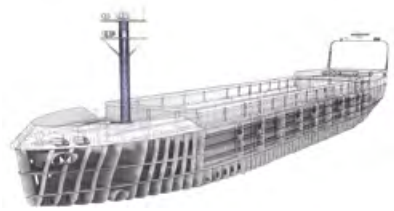
Photos: Michael Hausmann/istockphoto, AUTOFLEX project

ship that can provide reliable transportation services even in smaller or narrow waterways and with low water depth, with less environmental impact than a truck." If needed, the autonomous zero-emission ship can also be used to move smaller volumes of freight, while traditional cargo shipping generally involves very large volumes for emission and cost reasons. This could reduce truck traffic by about ten percent. New distribution nodes are also being designed to connect with road transportation.

These ships have a number of special features. At 6.6 meters wide and 53 meters long, they are not only significantly smaller and more maneuverable than conventional ships used on inland waterways but also operate autonomously—no crew means additional cost savings. Plus, they are electric. That is why two of the ship's 24 available stowage slots for standard 20-foot containers are reserved for battery containers. "In theory, the ship could also be used for mobile energy storage," Weisheit says, describing one possible secondary use. Together, the batteries have a capacity of 5.8 MWh.

Ship design published—test phase underway

The project was launched in early 2024 with 4.5 million euros in funding over a three-year term. "We're just about at the midway mark right now. We published the ship's design in early May, and we've made good progress on digitally charting the available canal networks as well, along with all the potential bottlenecks, like bridge crossings and locks, depths and speed limits," Weisheit says. The challenges ahead now include further developing and refining the business models used, ensuring cybersecurity and testing the design in a pilot project in the Netherlands and Belgium. "We plan to demonstrate an autonomous lock crossing in the Netherlands in late 2026," Weisheit says, looking down the road. According to global data and business intelligence platform Statista, inland shipping accounts for about seven percent of all cargo shipping spending, so it has tended to play a minor role. "It's high time we changed that," Weisheit says. ■



The model of emission-free, autonomous inland shipping has already been created.

"To help with this situation, we are developing a modern uncrewed inland cargo ship that can provide reliable transportation services even in smaller or narrow waterways and with low water depth, with less environmental impact than a truck."

Jonathan Weisheit,
Fraunhofer Center CML

back to page 1

Sustainably Strengthening Defense Capabilities

The Bundeswehr is increasing its reliance on renewable energies and batteries for its energy supply. Sustainability and green visions are only a side effect here: The primary objective is a secure, self-sufficient and crisis-proof energy supply.

By Mehmet Toprak

Soup time: German Federal President Frank-Walter Steinmeier at the Weiden-Frauenricht military training area. Mealtimes are classic load peaks that challenge the power supply on deployments.

It converts chemical energy to electrical energy and has served well for over 100 years in industry, construction, hotels, computer centers and hospitals: the diesel generator, the untiring workhorse of the electrical age.

It is also indispensable for the Bundeswehr. On deployments, such as in camps, it supplies power for field kitchens, sanitary facilities, floodlights and communications equipment. But now there are efforts to give this career soldier modern assistance and eventually even muster it out.

Researchers at the Fraunhofer Institute for Chemical Technology ICT in Pfinztal are working on electrical energy storage systems based on iron/iron redox flow technology, which enables flexible adaptation of storage and performance capabilities. These batteries relieve the generators during load peaks and reduce diesel fuel consumption. If available, the battery storage systems are charged using renewable energy from photovoltaics and wind power.

But the Bundeswehr's energy transition is not just about sustainability; it primarily serves one goal: strengthening defense capabilities. The storage systems are intended to end dependence on fossil fuels, improve resilience of the energy supply, and provide greater flexibility in the Bundeswehr's power supply.

Noisy and inefficient

Diesel generators have to be designed specifically to cope with load peaks. As soon as the field kitchen has provided food for hundreds of soldiers, less power is needed. The large generators are then overdimensioned. "In a Bundeswehr camp with several thousand soldiers, such as was the case in Afghanistan, the generators consume up to 50,000 liters of diesel fuel per day. And their efficiency is only around 30 percent," explains Karsten Pinkwart, Deputy Section Head at Fraunhofer ICT.

Another problem is that the deployments are often far from major roads, meaning that the diesel fuel for the generators often has to be transported over long distances and across rough terrain. Tanker trucks and diesel tanks must also be protected against attacks. "A generator-based power supply is essential, but it harbors many incalculable risks," is Pinkwart's sober conclusion.

> "A generator-based power supply is essential, but it harbors many incalculable risks."
>
> Karsten Pinkwart, Fraunhofer ICT

Compact and powerful

Pinkwart has served as an expert advisor to the Bundeswehr on energy supply for many years. Together with experts at Fraunhofer ICT, he is researching the potential of innovative energy storage systems such as redox flow batteries and lithium-ion batteries. These batteries relieve the load on generators, making the power supply more resilient.

Research operations recently began with Europe's largest redox flow battery at the institute's site in Pfinztal. Its electrolytes are made of non-flammable vanadium salts. This modular battery was implemented using components and expertise developed entirely in Germany. It is characterized not only by high operational reliability and scalability, but also by a significantly longer service life in comparison with conventional battery technologies.

Output performance and energy capacity can be scaled independently of each other, which is a huge benefit for use in camps of widely differing sizes. Jens Noack, Team Leader for Flow Batteries at Fraunhofer ICT: "The redox flow test platform represents a step towards a stable, flexible and resilient power system."

But these qualities alone are not enough for use in the Bundeswehr. "The power supply must also be extremely robust and reliable, and must withstand cold, heat and sand," says Fritz Bruch, battery expert and research scientist at Fraunhofer ICT. His work focuses on lithium ion batteries and on potential successor technologies such as sodium-based systems. This is no easy task, as the inner workings of the battery cells are extremely complex and correspondingly sensitive, with electrode sheets that are only a few micrometers thick and have to be precisely stacked. The Fraunhofer researchers are addressing these issues as well.

Nor is the Fraunhofer Institute working alone. It is part of the EU Nomad project with 18 partners from 9 EU countries and Norway. The aim of this project, with a budget of roughly 22 million euros, is to test existing energy storage systems for their suitability for defense purposes and to develop them further. For example, they are investigating standard formats for battery cells. This would make batteries interchangeable and compatible within their respective performance classes.

Silent and efficient

Vehicle drive technology could also benefit from batteries in the future. The vision: "Patrol vehicles approaching a deployment site cover the last mile under electric power. At the deployment site, the battery powers all of the vehicle's functions, such as radio, air conditioning, navigation and reconnaissance sensors. Because the batteries operate silently, emit no exhaust gases and radiate no heat, the vehicles are difficult to detect," says Bruch.

Pinkwart also wants to give hydrogen its chance. A hydrogen-powered fuel cell could supplement or possibly even completely replace the drive system in applications such as drones or other autonomous systems used for reconnaissance. That fuel cells can do this is proven by their use in Bundeswehr submarines for more than two decades. These ghostly, elusive underwater giants are valued by many friendly nations for precisely this reason. The Fraunhofer researcher also has a vision for heavy equipment on land: The combination of fuel cells and lithium batteries could one day serve discreetly here as well—with no engine noise, no exhaust fumes and no heat generation. ■

Photo: Armin Weigel/dpa

back to page 1

Arranging solar cells like bricks in a wall increases the energy yield.

This Energy Comes Straight from the Heavens

Improving surface utilization: The innovative matrix shingle technology from Fraunhofer ISE easily integrates solar cells into the building envelope—whether on the roof, on the house wall or on balconies and fences.

By Laura Rottensteiner-Wick

Free, inexhaustible and no emissions: "Especially in a resource-poor country like Germany, solar energy is literally heaven-sent," jokes Achim Kraft, Head of the Interconnection Technologies Group at the Fraunhofer Institute for Solar Energy Systems ISE. The energy technology and renewable energy engineer knew early on what his career path would be. "My goal from the outset was to work in renewable energy research and development, and above all I wanted to work close to industry," he says. "That is why I'm perfectly at home at Fraunhofer."

The solar technology market is currently dominated by Chinese products, with prices that cannot be economically undercut by European suppliers. In a market environment filled with low-cost offers, the solution is to innovate. "There are still very good opportunities for commercializing specialized, highly innovative PV applications and their industrialization," Kraft explains.

With its matrix shingle technology, Fraunhofer ISE has now brought one of these specialized applications to industrial maturity in collaboration with several partners in the EU SPHINX project. The technology provides crucial benefits, especially for the relevant building-integrated photovoltaics. "We have revolutionized solar cell interconnection," Kraft enthuses. In conventional PV modules, individual solar cells are connected in strings, i.e. in series, and the current can only flow along these strings. If one cell is shaded, the entire string is switched off and no longer produces electricity—this is the current state of the art.

The matrix interconnection combines series and parallel connection of the cells across the entire surface of the module. In this way, not only can the current flow along the strings, but also in lateral directions. Kraft explains the advantage: "The current can simply flow around small areas of partial shading, minimizing the energy loss." As the solar cells are cut into smaller strips before interconnection, utilization of the area can also be optimized. The cells are interconnected like shingles with a slight overlap of roughly one millimeter and are connected using electrically conductive, lead-free adhesive. Because cell connectors are no longer used, the result is a uniform black surface. This has a very high-quality appearance and can also be color-matched or made partially transparent.

Pilot line for industrial production

Fraunhofer ISE has now implemented a pilot line for the newly developed matrix shingle roof tiles at its "Module-TEC" pilot plant in Freiburg. The flexibly automated production enables Swiss project partner Freesuns to manufacture on a pilot scale before the newly developed product goes into mass production.

"Overall, our highly industry-oriented production line has manufactured over 4,000 roof tiles measuring 450 by 510 millimeters with matrix shingle technology. This technology is now also being implemented on several demonstrator roofs," explains Kraft. A significant nominal output increase of 60 percent has already been achieved by replacing the conventional, older technology with the new matrix roof tile modules. This is only the beginning, explains Kraft: "There will certainly be follow-up projects. We have already received several inquiries from industry."

Matrix shingle technology is extremely flexible: In principle, all types of solar cells on the market can be used, and the technology can be implemented in integrated photovoltaics anywhere. Whether on a roof, building wall, noise barriers, fences, balcony balustrades, partially transparent models, lightweight construction or glass-glass modules—everything is possible. Kraft: "Our pilot production now puts us in a position to support the German and European PV industry very well in the often critical step from development to production of such products. In this way, we are lighting a path to commercialization chances for solar modules in Germany—despite the nearly overwhelming competition from Asia." ■

Photo: Leander Baerenz / Westend 61 / mauritius images

Fraunhofer Minds

Innovation transfer for Germany

Holger Hanselka (1st row, 2nd from left) and Chancellor Merz with the new strategy group.

Constantin Häfner

The voice of science and engineering

Constantin Häfner, Executive Board Member for Research and Transfer of the Fraunhofer-Gesellschaft, has been inducted in acatech, the German National Academy of Science and Engineering. As a national academy, acatech is funded by the German federal and state governments and acts as the voice of science and engineering both within Germany and abroad. The German Federal President is the patron of the Academy.

As the director of the Advanced Photon Technologies Program, Fraunhofer executive board member Constantin Häfner was responsible for projects including the development of the world's most powerful laser systems and led research and development projects on groundbreaking laser technologies, especially on applications in high-energy density physics and nuclear fusion. ■

Holger Hanselka, President of the Fraunhofer-Gesellschaft, is a member of the Strategy Group for Technology and Innovation, the technology and innovation policy advisory body of the German federal government. This body comprises members of the German federal government and high-ranking representatives from science and industry.

The Strategy Group is tasked with analyzing trends and new developments in the innovation cycle and developing specific proposals to strengthen the research and innovation system and to promote resilience and technological sovereignty. The aim is to promote the innovative strength and competitiveness of Germany as an industrial location and to leverage +technological potential in various sectors. The focus of the opening meeting in November was on strengthening innovation and competitiveness in the security and defense industry and in artificial intelligence. ■

Photos: Stefan Obermeier / Fraunhofer, Sandra Stein / Federal Chancellery

back to page 1

Benefits for the Economy and the Environment

Economic and ecological interests complement each other perfectly in the circular economy. By 2030, by applying circular principles, European companies will be able to save 600 billion euros in material costs—annually. Fraunhofer researchers present new solutions.

"We start with straw and end up with everyday products—it's like turning straw into gold."

Antje Lieske,
Fraunhofer IAP

Fraunhofer