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The magazine for people shaping the future

Savor in safety

Food: Supplying the future

Kevin Bregler of Fraunhofer IPA developed the CURT robot (left).

An interview with Friedrich Merz, leader of the Christian Democratic Union of Germany

"Potential for new value creation is everywhere."

One metaverse, many opportunities — how digital twins are already changing the industry sector

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Editorial

We need expertise in Europe

Prof. Reimund Neugebauer

Artificial intelligence is one of the most important digital future-oriented fields. Today, AI is already taking on many tasks, such as steering self-driving vehicles, making medical diagnoses and defending against cyberattacks. As such, it is causing radical change in numerous sectors and playing a decisive role in our industrial and societal transformation.

The decisive factor in the future of AI systems will be how we manage collaboration between humans and artificial intelligence. Because if machines — whether AI-driven or autonomous — are to be used on factory floors or in hospitals, they cannot simply operate based on models that have been pre-trained on large datasets. Instead, they must also be able to take human observations into account and understand context. Hybrid AI could offer a promising solution — it combines human expertise with data-based approaches that use machine learning methods to analyze statistical correlations.

The Fraunhofer-Gesellschaft is already using hybrid AI for potential industry solutions. One example is RoboGrind, a flexible, semi-automatic AI system for restoring surfaces. The system's robots restore equipment components, such as rotor blades from wind turbines and gears from electric engines, in a cost-effective way, providing an efficient alternative to producing new components.

AI algorithms could also empower the metaverse. Smart glasses and extended reality technologies create a doorway for "entering" the 3D internet, allowing seamless interaction between the digital and analog worlds. This is also an important development for the industry sector — the industrial metaverse is an evolutionary stage in digital transformation, as the addition of immersive technologies will bring Industry 4.0 to the next level. When combined with artificial intelligence, digital twins and data spaces, the industrial metaverse makes it possible to play out and analyze a variety of virtual production, development and maintenance scenarios. An example of this is the "5G Troisdorf IndustrieStadtpark" (Troisdorf 5G industrial park) project, which is making huge advancements in remotely controlling and servicing machines. In this initiative, production machines are connected to a digital twin and the digital manufacturing data is displayed on smart glasses. Despite being in different locations, operators and service desk workers can stand "at" the machine and actively discuss it through 5G video and audio communication. They are displayed as avatars, and each can see what the other person is looking at in virtual space, use virtual hands to point, and move or highlight individual machine parts.

The global race to harness the industrial metaverse and AI technologies as strategic industrial resources has long since begun. This is why building up German and European expertise in developing safe, trustworthy, resource-efficient AI and metaverse technologies will be crucial to ensuring our competitiveness and technological sovereignty.

Sincerely,

Reimund Neugebauer
President of the Fraunhofer-Gesellschaft

Learn more about the main research topics of the Fraunhofer-Gesellschaft:
Prof. Reimund Neugebauer on LinkedIn

Photo: Fraunhofer/Stefan Obermeier

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A medical breakthrough: A recently discovered antibiotic could effectively fight off much-dreaded hospital infections.

According to UNO, 38 percent of global CO_2 emissions come from the building and construction industry. Not only is it falling well short of the targets set out in the Paris Climate Agreement, but the industry's emissions are actually increasing. Sustainable materials and innovative technologies could turn things around.

38 %

Front and back cover photos: Sven Döring, Maya Claussen, Michael Kappeler/dpa
Photo content: Sven Döring, Maya Claussen, Andreas Chudowski, Axel Griesch/Fraunhofer IBP, Rolf K. Wegst/Fraunhofer IME, istockphoto

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Brief report

In 1897, British troops seized the Benin bronzes from the former Edo Kingdom in what is now Nigeria. Today, around 1,100 of these objects are in German museums.

World heritage under the X-ray

The Fraunhofer Institute for Integrated Circuits IIS has collaborated with the Staatliche Museen zu Berlin (Berlin state museums) to digitalize valuable Benin bronzes. Germany is in the process of coming to terms with its colonial past, and as such, it is returning these stolen historic, cultural artifacts to Nigeria. The bronzes were previously displayed in around 20 museums. The scientists want to preserve these important bronzes in digital form for research purposes.

To do this, experts at the Development Center for X-ray Technology EZRT at Fraunhofer ISS are using state-of-the-art X-ray computed tomography to create three-dimensional models of the valuable bronze reliefs. These models are then translated into digital data sets. The size and solidity of the objects pose a challenge for the X-ray machine, as does the material used, brass. In order to produce tomography images with optimal quality, the project researchers are employing the largest CT scanner in the world, which is located at EZRT in Fürth. Since 2008, Fraunhofer IIS has been working with partners to develop new processes for preserving cultural heritage. ■

Accelerating the transportation transition

As part of the eMobiGrid project, the Fraunhofer Institute for Integrated Systems and Device Technology IISB is working with partners from science and industry to develop a comprehensive charging system for various vehicle types. Growth in electromobility is creating new challenges for infrastructure: Stations for charging batteries must be optimally integrated into stationary energy networks already in the locality, and must be available for all vehicles, from cars and trucks through to tractors and construction machinery. The project partners also want to work together to increase the use of renewable energy. To do this, they are focusing on local direct current networks — these allow for the low-loss integration of storage batteries, photovoltaic systems, wind turbines and hydrogen technologies. This relieves the burden on power grids that are less well developed. They also serve as a buffer against the overproduction of renewable energies, since the electric vehicle batteries can be used to charge other devices. ■

The eMobiGrid project aims to improve infrastructure for electric transportation.

In the developed world, access to clean drinking water is normally a fact of life — but according to UNICEF and the WHO, one in three people worldwide do not have access to this vital resource.

Smart water sources

The Smarte UV-Systeme (smart UV systems) research group at the Systems Technology (AST) of the Fraunhofer Institute for Optronics, System Technologies and Image Exploitation IOSBAdvanced has developed a faucet that disinfects water directly as it flows out. In contrast to classic UV disinfecting systems, it uses state-of-the-art UVC LEDs. These work better for disinfection than conventionally used mercury lamps, as they have a broader emission spectrum that can be adapted as needed; they also turn on very quickly without needing to heat up.

When the faucet is turned on, disinfection starts instantly; when it is turned off, the LEDs also switch off — which saves energy. Backflow contamination into the pipe is also prevented: The disinfection module is located directly behind the faucet's outlet. ■

A personal assistant on two wheels

The Fraunhofer Institute for Material Flow and Logistics IML has developed an agile robot on two wheels that can balance by itself and carry items such as packages. Called evoBOT, the robot even has two arms that can fold out to grab, carry and deposit objects. While robotic systems have previously been limited to performing simple tasks such as pushing and pulling goods in logistics, evoBOT will be able to combine these capabilities and go even further. Its more advanced skills will include passing objects and turning them over.

This means it can not only support logistics work, but also operate in urban spaces. In hospitals, evoBOT could move beds and serve food; in industrial settings, it could load conveyor belts; it could help with everyday tasks such as carrying groceries and helping to load and unload cars and trucks.

evoBOT is a dynamic, stable system that is particularly light and compact. Its design is based on the principle of an inverted compound pendulum without an external counterweight. Unlike conventional models, the robot stays in a constant state of balance. This means that it can navigate varied and uneven surfaces, even on a slope. ■

The evoBOT robot has two arms that fold out, allowing it to provide as much help as possible.

Photos: Staatliche Museen zu Berlin (Berlin state museums), Ethnologisches Museum (Ethnological museum)/Fraunhofer IIS, Simon Skafar/istockphoto, Thomas Imo/photothek/picture alliance, Michael Neuhaus/Fraunhofer IML

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An audio-based testing system monitors whether electrical connectors in cars engage correctly.

It just clicks

In automotive construction, individual components are no longer attached with screws, glue or through welding. Instead, they are joined together with electrical connectors. Researchers at the Fraunhofer Institute for Digital Media Technology IDMT's Oldenburg Branch for Hearing, Speech and Audio Technology HSA have developed an audio-based testing system for these connectors. In the future, this system will make it possible to check whether the connectors are properly engaged. Microphones record the clicking sound they make; and algorithms then analyze it. As soon as it identifies that a connector has not been connected correctly, the testing system gives a warning.

The technology was very challenging to develop, owing to the clicks' similarity to each other. "For decades, we have been developing acoustic methods for detecting and analyzing sounds. Our system is now able to reliably differentiate and examine acoustic signals that are very similar to each other," explains Danilo Hollosi, group manager for Acoustic Event Detection at Fraunhofer IDMT. Even surrounded by the noise of a factory floor, the algorithms can isolate and analyze individual clicks.

The audio-based technology not only fits in with the trend of controlling manufacturing steps in production with sensors to make them safer and more reliable — it also helps to significantly increase efficiency and lower costs. ■

Less food waste

Due to manufacturing errors and overproduction, up to 15 percent of industrially produced bread rolls, pretzels and the like never make it to the breakfast table — instead, they are destroyed. In the future, an intelligent system will help avoid this by using sensors to continuously monitor the quality of products on the bakery production line. As part of the SensoBack project, a team from the Fraunhofer Institute for Mechatronic Systems Design IEM developed this system in collaboration with partners from research and industry. The sensors are deployed at multiple points in the production line to record whether the products meet quality requirements in terms of shape, weight and the properties of the dough. For the first time, it will be possible to monitor every step of the baking process along the bakery production line, check whether each product meets the quality requirements and quickly make adjustments to the individual processes.

In conventional systems, process parameters such as temperature have always had to be manually adjusted for raw materials with different properties, such as different types of flour.

This new system will help bakers to optimize product quality while also making better use of the available resources. ■

On the table instead of in the trash: Fraunhofer IEM is making bakery lines smarter with an intelligent sensor system.

Editorial notes

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In the future, fishermen in the Kenyan village of Mwazaro will be able to give their goods a longer shelf life.

Solar-powered ice

In rural areas of Kenya, up to 30 percent of food is thrown away due to a lack of options for cooling and drying. Fraunhofer researchers want to change this.

As part of the SolCoolDry project, the Fraunhofer Institute for Solar Energy Systems ISE has collaborated with a German engineering company and Kenyan partners to develop a solar-powered system for producing ice and drying food.

This system consists of two parts: a photovoltaic system and two solar-powered food drying tunnels. The photovoltaic system, which has an output of 15 kilowatts, feeds the power it generates into a three-phase isolated grid that is backed up by batteries. This grid powers an ice machine and a cold room. The excess solar power flows into batteries, where it is then stored.

The air in the two drying tunnels is constantly heated up. Fans then distribute this air over the food to dry it. The products can also be dried during the night, as one of the fans is fitted with heating pipes. A flat-plate solar thermal collector and a hot water tank supply these pipes with heat. The system has been made available to fishermen and farmers in Mwazaro, a village on the south coast of Kenya. Up to 30 percent of the food produced there is thrown away due to insufficient electricity infrastructure.

"The goal was to develop a system that the local people could operate themselves," explains project manager Dr. Alexander Morgenstern of Fraunhofer ISE. By making their fish, vegetables and other foods last longer, the farmers and fishermen will be able to sell more products — even out of season. This will provide them with additional income.

The project partners installed the SolCoolDry system during an on-site workshop. "The system has been very well received by the local people. Fishermen are driving up to 50 kilometers to collect the ice," says Dr. Morgenstern. The drying equipment is also already in constant use.

The Kenya Industrial Research and Development Institute KIRDI will be operating the plant together with the local Beach Management Unit, with the support of a technician who is currently in training. The fishermen are also being trained to conduct quality assurance and carry out hygienic product processing. ■

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The industrial metaverse — fact or fiction?

So long to the 2D internet? Already, we are seeing the enormous advantages that the metaverse holds for development and production.

By Kathrin Schwarze-Reiter,
Photography: Maya Claussen

Ronja Gaulinger, Fraunhofer IAO

Digital twin

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Frida Santos walks into her office on a Monday morning. The young engineer works for an SME that numbers among the leading companies in the solar cell market, with locations all over the world — but she herself lives in a small German town. Ms. Santos makes herself a cup of coffee, has a quick chat with a colleague and gets ready for her first meeting of the day, which she attends in a special room with no windows and partially sound-proof walls to avoid visual and acoustic distractions. The engineer puts on her VR headset and steps into a digital world. Some avatars are already sitting at a large table in the middle of the virtual meeting room — colleagues of hers, from Darmstadt, Stuttgart, Bologna and San Diego. No one had to fly anywhere or request approval for a business trip: For our fictional engineer, Frida Santos, collaborating with her colleagues is an entirely climate-neutral endeavor.

"Fact or fiction?" asks Dr. Dietmar Laß. The senior research manager from the Fraunhofer ICT Group's central office answers his own question with a definite prediction. "The metaverse is more than just hype. We can be sure that it is coming — it's just a question of how and to what extent." Dr. Laß and his team act as the bridging point between the activities of the various Fraunhofer institutes that are involved in the metaverse field and large companies' increasing interest in the new digital reality. The ICT Group develops metaverse technologies and guides those companies as a reliable partner. "In recent years, we have seen significant investments by large companies, rapidly advancing technological developments and a sense of openness around this style of communication," says Roland Busch, Chief Executive Officer of Fraunhofer's collaboration partner Siemens. That's why he thinks the metaverse has a big future ahead of it: "The industrial metaverse will be a space where we use the speed of software to drive innovations. Its potential for reshaping our domestic economies and industries is enormous."

The metaverse is an important opportunity for Germany to safeguard its position as a technological powerhouse. "We have strong technology know-how in many areas, so there's no need to hide from this new development," points out Holger Graf of the Fraunhofer Institute for Computer Graphics Research IGD. "In the future, extended reality, software solutions for industry business processes, the virtualization and combination of 3D content, and decentralized, interoperable data platforms will have a major role to play. But what we need now is to build up an innovation ecosystem, which means we have to combine industry-based digital technologies in Germany more effectively."

Siemens Energy is already constructing models of power plants in the metaverse, so it can predict when they will require maintenance work. The company expects that this will reduce downtime and save power plant operators 1.7 billion dollars per year. Car manufacturer BMW is planning a digital factory using the Omniverse platform by the graphic processor manufacturer NVIDIA. "The planned machines or structures will only be built in reality once the corresponding digital models have been designed in full and validated," explains Dr. Leif Oppermann, the head of Mixed and Augmented Reality Solutions at the Fraunhofer Institute for Applied Information Technology FIT in Sankt Augustin, North Rhine-Westphalia.

Direct prototype testing with future users

The possibilities for testing are almost endless; for example, in virtual reality driving simulators, metaverse users could try out prototypes directly and then provide feedback that would immediately be taken into account in the design and manufacturing process. Similarly, the Fraunhofer Institute for Material Flow and Logistics IML has developed a simulator for DB Schenker so that their staff can practice driving forklifts. "The German rail company Deutsche Bahn uses artificial intelligence and virtual reality for digital maintenance, both for finding damage and fixing it," relates Dr. Oppermann. When learning how to carry out repairs, mechanics can start by practicing on digital trains. "BASF is also experimenting with metaverse technologies for virtual labs, virtual showrooms and global 3D collaborations."

The Fraunhofer Institute for Industrial Engineering IAO and the Fraunhofer Institute for Manufacturing Engineering and Automation IPA have teamed up with the Virtual Dimension Center (VDC) in Baden-Württemberg to create a large-scale metaverse project called CyberLänd. With funding from the Baden-Württemberg Ministry of Economic Affairs, Labor and Tourism, the initiative will focus on discovering what political, industrial and social potential the metaverse could offer for the south German state. First and foremost, the project team aims to help foster a deeper understanding of this complex topic. "At present, companies still don't have any concrete prospects for development in the metaverse," explains Prof. Katharina Hölzle, director of Fraunhofer IAO and the University of Stuttgart's Institute of Human Factors and Technology Management IAT. "We are exploring what interactive collaboration in the metaverse might look like, how digital twins can be used on a wide scale and how you could pay people and offer on-the-job training in the metaverse." ▶

"The metaverse is more than just hype. We can be sure that it is coming — it's just a question of how and to what extent."

Dietmar Laß,
Fraunhofer ICT Group

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"We need to build up an innovation ecosystem, which means we have to combine industry-based digital technologies in Germany more effectively."

Holger Graf, Fraunhofer IGD

Next, the team is planning to identify and create a map of Baden-Württemberg companies that are already working with metaverse technologies. "We intend to conduct an empirical study to find out what expectations and requirements these companies have and then process this data so that it can be shared with the wider public," reveals Prof. Hölzle. The project results will consist of scenarios for 2033: What role will the metaverse play in Baden-Württemberg by that point? What course of action should the government and companies take? How can participation by members of the public be facilitated? All of these results will be presented at the "Innovationsforum-Metaverse BW" (Baden-Württemberg metaverse innovation forum) event at the end of this year.

Are we at the threshold of the internet's next great development stage?

Outside of the industry sector, the world's attention is currently primarily focused on generative AI; however, it is most likely that in the future, the metaverse and strong AI (a form of artificial intelligence that can act independently and flexibly, with the ability to plan ahead like a human) will be used together in a complementary way. "For the metaverse to become established, we will need high-performance computers, advances in the area of self-learning systems, and scalable 3D data processing and internet bandwidth," says Mr. Graf of Fraunhofer IGD in Darmstadt. The mathematician is conducting research on industry applications of virtual and augmented reality. However, because of the enormous amounts of computing power required to produce a good metaverse simulation, there are probably many years to go yet before industrial metaverse solutions really work in an adequate, intuitive way. "What's more, the XR glasses market is in a state of permanent upheaval at the moment," adds Mr. Graf. "The current headset models are not practical for everyday working use." If major advances are to be made in terms of application in daily working situations, lighter display models that have a better field of view and function well with augmented reality applications will be needed. In fact, the ideal would be AR contact lenses that users apply directly to their eyes. But, as Mr. Graf. says, "that's still a long way off."

However, the experts at various Fraunhofer institutes and partner companies are already fascinated by the idea of what could happen when that possibility becomes a reality. "Experiencing situations in three dimensions and with all our senses will make it easier for us to grasp connections and expand our knowledge in the future," says Prof. Hölzle. For Dr. Michael Bau, head of the Institute for Performance Work Health (ILAG GbR), which collaborates closely with Fraunhofer FIT at the industrial park in Troisdorf, the key to successfully implementing this technology in companies is to make sure employees and managers are involved in the process. This is why he and his team are taking into account the effects on and benefits for the people involved in the evaluation step of the project. "Geographical distance, physical disabilities and linguistic barriers could be relegated to background issues in the near future," he predicts. "That would definitely be advantageous for all involved."

The potential is considerable, according to metaverse expert Dr. Laß. "The metaverse can quite definitely be described as a revolution, because in the future, it will change our collective modes of living, creating, learning, working, producing, selling and consuming at a fundamental level," he says. Prof. Vanessa Borkmann, a researcher at the Fraunhofer Institute for Industrial Engineering IAO also highlighted the metaverse's disruptive power: "In theory, anyone can take part — they just need the right technology and access permissions. This means the metaverse is expanding our scope for action in a way that has enormous potential for the world of work."

Now Frida Santos, our engineer from the future, is greeting her team as they all take a seat in the meeting room. Today, they plan to discuss how the technology for a solar cell prototype can be developed further. When Ms. Santos turns around, she can see a digital board where her colleague from San Diego is already presenting a list of the technical problems with the solar cell. The data is transferred over a 5G network, which is necessary for the enormous quantities of data involved; high-performance processors and memory storage are also required. Once the team has discussed solutions for the error messages, Ms. Santos goes on to the next metaverse space — her employer's production facility in Sydney. The young engineer goes up to one of the machines and adjusts a few settings. On location in Sydney, a robot carries out her actions immediately. It's as though Frida Santos had traveled halfway around the world within a couple of seconds.

Real objects have entered the metaverse

Yücel Uzun of Fraunhofer FIT has already started using real objects as digital twins for the metaverse. The technical manager and main developer for the mixed reality use case in the "5G Troisdorf IndustrieStadtpark" (Troisdorf 5G industrial park) project has programmed apps for displaying and using digital twins. His team is working with two industry partners, including Kuraray, a chemical company that manufactures products ▶

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such as industrial polymers and synthetic microfibers using industry machines from ZWi Technologies. However, as Kuraray operates in many different countries, it very often faces short-term technical problems, such as a machine breaking down in Japan or a need to train in new employee there. Right now, the only way of resolving these issues is for an expert to travel all the way over — that means booking a flight, canceling all other meetings for days and arranging for childcare. The cost is high, in terms of both money and working days.

However, Mr. Uzun's team has developed a solution — a system that can bring a specialist on location within seconds. With a HoloLens 2 and a VR headset, a German expert can use the metaverse to communicate with the factory worker in Japan as though they were in the same room. There is also a digital twin of the machine that needs maintenance work. "The two employees can enter the metaverse as avatars to talk and work on the virtual machine together," explains Mr. Uzun. "In the virtual space, it's also very easy for the German expert to send on instructions and important notes to help the factory worker."

One of the real objects Mr. Uzun is testing is a virtual 3D model of a granulator, a machine that collects excess film and granulates it to form dust. "That sounds simple, but it's not. We now know that in the metaverse, employees can get training on a machine or repair it directly when it's broken." The adjustments would then be carried out by a worker at the factory.

"We have to develop a mindset focused on ways of eliminating abuse."

The pioneers of the metaverse have high hopes that the internet of the future will be decentralized — i.e., that it will not be controlled by any state, company or individual. This would make it possible to connect different platforms and incorporate elements from one environment in the next. But this liberality also comes with many risks. "The primary points of criticism here are focused on the uncertainties regarding jurisdiction in the international sphere, the handling of user data and intellectual property, the danger of criminal activities, the high level of resource usage and the intensification of certain web 2.0 trends," recounts Dr. Oppermann, head of Mixed and Augmented Reality Solutions at Fraunhofer FIT. "If digital twins of factories or machines in the metaverse are used based on the same architecture as conventional internet business models, the uncertainty level will be too high for companies." He advises getting familiar with the technol-

"The metaverse is expanding our scope for action — and it has enormous potential for the world of work."

Prof. Vanessa Borkmann,
Fraunhofer IAO

ogy, so as to make the most of the advantages created by spacial interaction and minimize the problems. However, he adds that taking a collective approach is indispensable here. "A collective approach would enable German SMEs to benefit from excellent, versatile solutions for conducting improved remote maintenance on a digital twin of a machine, for example, without endangering their data," Dr. Oppermann points out. "In this early stage of the metaverse, we have to develop a mindset focused on ways of eliminating abuse and implementing an ethical system, to prevent the negative elements of web 2.0 from increasing exponentially," asserts Prof. Hölzle. Because the metaverse will only enrich our lives — rather than complicating them further — if it is built on a sound foundation of this kind.

Once these general conditions have been established, the metaverse's potential for retail, the real estate market, tourism, education and the public sector will be enormous. For example, scientists in the Fraunhofer Institute for Industrial Engineering IAO's research unit for Urban ▶

Where does the metaverse come from?

The term "metaverse" is a combination of the prefix "meta-" (meaning "beyond") and the word "universe." It first appeared in Neal Stephenson's science fiction novel "Snow Crash" in 1992. In the book, the main character switches continuously between his real life in Los Angeles and a virtual world, which appears as a wide street that runs all the way around a black planet. The avatars in this metaverse constantly strive to gain more knowledge, power and money. The novel describes a dystopian world, a frightening version of reality with a very undesirable social system. A similar virtual space appears in William Gibson's novel, "Neuromancer," albeit under a different name: cyberspace. This concept of a digital future also features in a whole host of films, including "Ready Player One," released in 2018.

Tech enthusiasts and companies have been developing digital worlds like the one featured in "Snow Crash" since the 90s. Gaming platforms like Roblox and Second Life gave many users got a foretaste of virtual reality, while video games like Fortnite allow users to enter a metaverse where they can attend concerts and film premiers. After some time, tech giants started to jump on the bandwagon. Microsoft is currently developing a virtual meeting space where avatars can work together, and aims to update Microsoft Teams so that virtual and augmented reality glasses can be used with the program by the end of the year. NVIDIA, the manufacturer of the world's fastest graphic processor, is also pitching in by developing the Omniverse, a platform that can be used to create metaverse applications. However, at the very latest, the term's entry into mainstream parlance can dated to the announcement that the Facebook group would be renamed Meta. The metaverse — which Mark Zuckerberg has described as "the next generation of the internet" — is set to generate 800 billion US dollars in revenue in 2030, according to the Bloomberg Intelligence financial service.

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Systems Engineering are working to transfer existing or possible urban environments into the virtual world, using the metaverse as a platform for quickly bringing city planning and development to the prototype stage. "These digital twins allow us to simulate future scenarios, so they become more tangible for investors and users," says Ronja Gaulinger, a research scientist in the Urban Systems Engineering research unit at Fraunhofer IAO. As well as simulating complete cities, the researchers can also create individual buildings in the virtual world, and use them to try out different layouts and look for problems. "With this system, investors can take a virtual tour inside a building before it is ever built," enthuses Ms. Gaulinger.

Meanwhile, researchers in Fraunhofer IAO's Future-Hotel innovation network are using the metaverse to explore what hotels might look in the future (see also page 56). However, the metaverse could also be a handy tool for vacationers, for example, by allowing them to visit hotels or other travel destinations in virtual reality so that they can book the perfect vacation in real life.

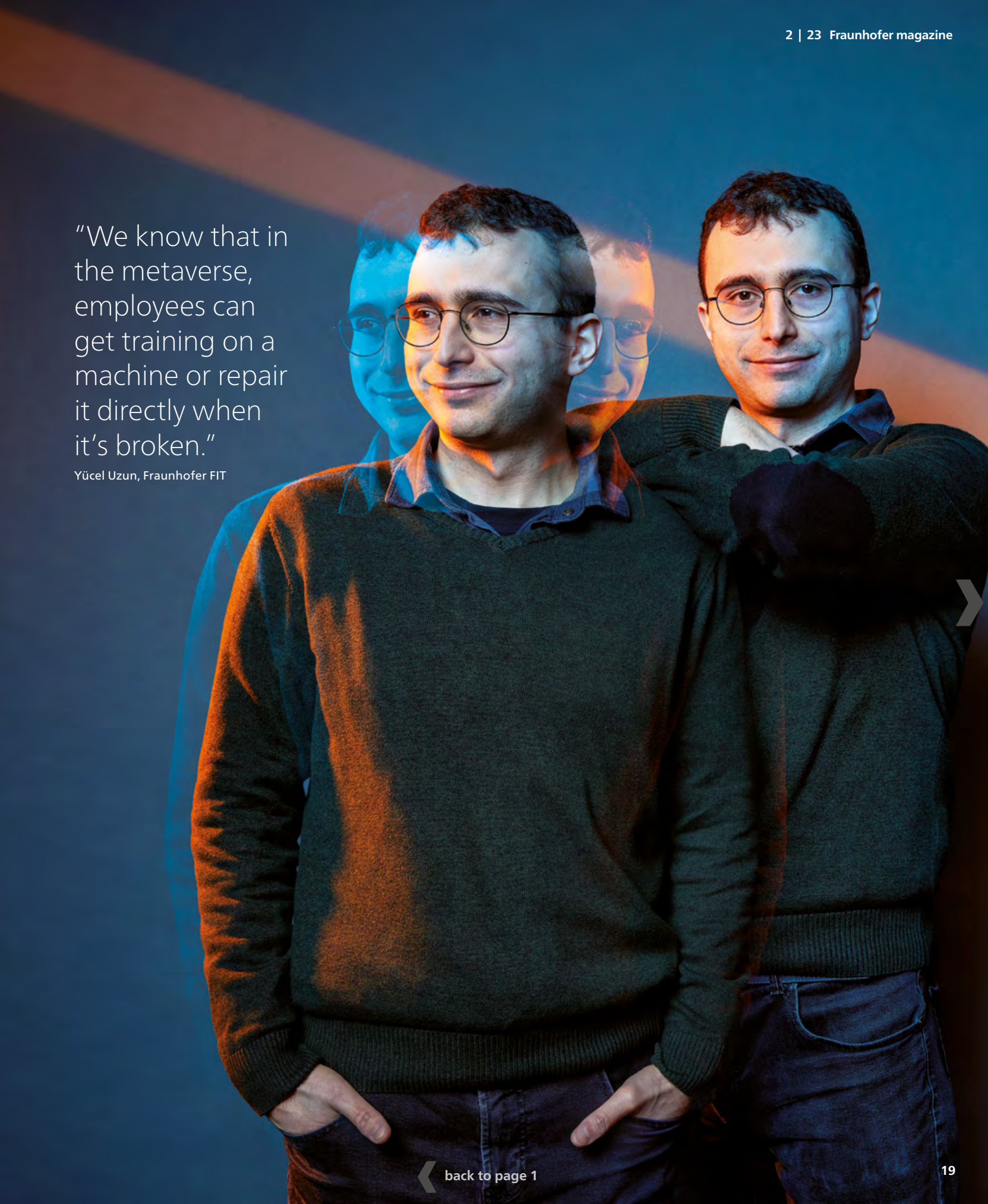
"The metaverse is a turning point for companies."

It is still hard to assess to what extent this technology will actually change our individual daily lives; however, it could be as revolutionary as the introduction of the smartphone. "Will we spend even less time in the great outdoors, with real people? Or will this technology give us the freedom to do just that?" asks Prof. Hölzle. "Maybe a counter-movement could develop here, with people making more effort to seek out the real, tangible world beyond the digital sphere, and strengthening their real-life contact with people outside the metaverse."

One thing is certain: The metaverse will bring radical change to the German industry sector. In particular, it offers enormous advantages for companies' innovation processes. Provided they have the right equipment, customers and suppliers from all over the world could participate in the ideation phase quickly and easily, meaning that product and service ideas can be even more accurately tailored to suit the needs of each situation. Processes like evaluating and selecting alternatives will be accelerated, because it will be possible to virtually simulate and test products such as cars or washing machines right from the planning phase. Companies could then use the results of these processes to improve products in a very simple way, as the new production data could be sent out to factories all over the world in a short space of time.

Estimates from a study by the industry consultancy firm McKinsey suggest that the metaverse could reach a value of up to 5 billion dollars by 2030. Some 95 percent of the managers surveyed in the study expect that the metaverse will have a positive effect on their sector within five to ten years, while 31 percent of them believe that it will fundamentally alter how work is done in their sector. "The metaverse is a turning point for companies when it comes to strategy," says metaverse expert Dr. Laß. He is in no doubt: the metaverse is just too big to ignore. ■

The making of a twin
Digital twins are set to generate more and more benefits for the industry sector. To create a visual representation of the "twin" theme for the images in this issue, photographer Maya Claussen and her assistant Jacek Wesolowski stood beside the Fraunhofer researchers, ensuring that their interactions with their avatars would look as natural as possible on camera.



"We know that in the metaverse, employees can get training on a machine or repair it directly when it's broken."

Yücel Uzun, Fraunhofer FIT

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Interview

“I’d like to see more optimism about the future!”

As CDU chair and opposition leader, Friedrich Merz argues for greater openness to technology. As an amateur pilot, he remains skeptical of the idea of flying a hydrogen-fueled plane.

Interview: Josef Oskar Seitz

Friedrich Merz, 67, chair of the union’s parliamentary group, outside his office in the Jakob-Kaiser-Haus building of the German federal parliament (Bundestag) in Berlin.

Mr. Merz, has Germany become a nation of grumblers?
We do lean toward pessimism rather than optimism, at any rate. To the Germans, the glass is usually half-empty. To the Americans, on the other hand, the glass is always at least half-full!

"Crisis has become the favorite word of our era." You know who came up with that quote? It was Norbert Blüm, and he said it in 1985. It seems that our eagerness to talk up a crisis is not just a contemporary trait.
And meanwhile, the proposed solutions have remained largely the same. If a problem arises somewhere, then the solution is to spend more money. If there is an administrative issue, the first reaction is to hire more staff. Constant increases in public administration staff, ever greater demands on the public purse — this cannot continue indefinitely.

Mr. Merz, during a 12-year hiatus from politics, you were chair of the supervisory board at BlackRock, the world's biggest asset management corporation. A question, therefore, for the man from industry: At what point does spending equate with sensible investment?
Public money is well-invested when it fulfills the social contract of the Basic Law of the Federal Republic of Germany (Grundgesetz, GG), when it safeguards the internal and external freedoms of the people and, what's more, when it flows into the national infrastructure. The benchmark for this should be an increase in national wealth. It's crucial that the younger generation feels the benefits.

You have remained married for 41 years, an almost indecent period by today's standards — and what's more, to the same woman. You have three children and six grandchildren. What will their future in Germany look like?
None of the six have come to any decision as individuals; they're still a little young for that. But this generation will be asking themselves a question that is more urgent than ever: what kind of future can our country offer? If the figures are correct, estimates say that even today some 180,000 German citizens, often well-educated young people, leave our country every year, and only about two-thirds ever return. There's a lot of talk about immigration. But maybe we should also be catering for those who want to emigrate because they see better opportunities for the future elsewhere.

Do you think outward migration from Germany is a real problem?

"Our country's innovative strength is, in some cases, breathtakingly good."
Friedrich Merz

If I'm correct, there hasn't been enough research into the phenomenon as yet, nor do we know enough about people's motives. And the balance of migration has been positive for many years: Germany's population is growing. At the end of 2021, we were taken completely by surprise when we saw that the population of German stood at 84.2 million people — not the 81 or 82 million that we had assumed. To this day, we don't know how many people from other European countries are living and working amongst us on a short- or long-term basis. If necessary, we could work this out by laboriously sifting through data from health insurance providers — but even then, the figures would not be sufficiently reliable. Our system of registration is still stuck in a more or less analog era. I would much prefer to work with more solidly based data. After all, our infrastructure needs to be more precisely tailored: daycare centers, schools, hospitals, homes.

So we are flying blind when it comes to infrastructural measures: What kind of Germany do you foresee for your grandchildren as they grow up?
The war in Ukraine has brought one thing to the fore, at any rate — we can no longer assume that they will spend their lives in a free, democratic and peaceful Europe. But that would be paramount.

A Christian country?
One whose cultural characteristics are based on Christian and Western traditions, in any case.

A country of immigration?
That's what we have been for a long time already, but hopefully we will become one that regulates immigration on a much more successful basis.

How can Germany source more skilled workers?
As well as boosting the potential number of skilled workers at domestic level, it is crucial that Germany can attract talent in from abroad. We are proposing a new federal immigration agency to handle immigration by skilled workers — the "Work and Stay" agency. This will be a one-stop ▶

Photo: Andreas Chudowski

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1989: Campaigning with a side parting

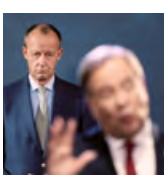
Until 1994 Friedrich Merz was a member of the European parliament. He had already joined the CDU back in high school.

2016: Party photo in Berlin

CDU deputy leader Julia Klöckner and Bavaria's minister for economic affairs Ilse Aigner are admirers of Merz. Behind them: Thomas Gottschalk, Carsten Maschmeyer, Dorothee Bär.

2021: Four decades a couple

Friedrich and Charlotte Merz met as law students. They have been married for 41 years.



2021: The man in the background

In the race for the CDU leadership, Merz is overtaken by Armin Laschet, later to become the candidate for chancellor.

shop where skilled workers can access the entire service: everything from job placement, checks on entry requirements and help with any necessary visas, right up to organizing legal residence status once they arrive in Germany. The federal immigration agency will take over all immigration procedures currently carried out by the German missions abroad and by the immigration authorities of each district and municipality, with the exception of asylum procedures. Right from the start, the work of this immigration agency will be carried out on an exclusively digital basis, and it will be equipped with the latest technologies. It will also act as a job placement agency for all workers from other European and non-European countries.

What kind of working life will your grandchildren experience?
Presumably, one that is very much more digital and mobile. And more varied. In contrast to their parents and grandparents, they won't be selecting a career, remaining in it and staying until retirement.

Do you worry about the future?
I believe our country is still dynamic and strong enough to solve a lot of issues very successfully. What I'd like to see from our country's political leaders is more optimism about the future. Too often, Germany hides its light under a bushel. That's something that strikes me every time I go abroad. Whenever I return from any foreign trip, my interactions there always send me home with the impression that our fellow nations' expectations of us are higher than what we actually deliver. And we believe the opposite: that we do not have to deliver as much those other countries out there really expect of us. We play down our image, in contrast to how we are actually viewed from outside.

As you see it, are we minimizing ourselves to the point of negligence?
Yes, to some extent.

What is your assessment of our country's innovative strength?
In some cases, breathtakingly good. We have established AI institutes in Germany; we have seen tremendous developments in the area of the latest technologies; and we are a country with the potential to make great strides in the fields of both hydrogen and regenerative technologies. We are a country with excellent biotechnology expertise — think of BioNTech, think of CureVac. To remain with this examples: As soon as both of those companies get big enough to really start producing, they need capital — so where do they turn? To the stock exchange in New York. That in itself is not an ideal situation. What I really find problematic, though, is another issue, and clearly, it is one that barely occurs to anyone in this country. It hardly even comes up as a topic for discussion. To look at the other end of the scale, a company like Linde delists from the German stock index because it has grown too big, yet this story is consigned to the back pages of the financial press.

What sort of contribution can or should research be making to a worthwhile future?
The planning process has to be streamlined: not just for projects like wind turbines, but also for the expansion of digital infrastructure. Ultimately we have to ask ourselves this question: In ten years' time, where do we want our strengths to lie? Pharma, biotechnology, mechanical engineering, environmental technologies, artificial intelligence and the combination of digitalization and decarbonization — potential for new value creation is everywhere all over the industrial hub of Germany. The social market economy and competition bring forth the greatest innovations. That is the only way to maintain our prosperity. However, apart from providing the necessary infrastructure, it is also necessary to make progress in the processes already initiated by the previous government, like online access to public services and data handling.

On the subject of innovative strength: As a keen pilot, when do you see yourself flying under hydrogen power?
Hard to say. Based on my own assessment, at least, I'll probably stick with synthetic fuels. Hydrogen is still very problematic in flight operations. Fueling has to take place at temperatures of well below zero and under conditions of extreme pressure.

Do you get the impression that research in Germany has a sufficiently broad focus?
I see a lack of willingness to examine every side of an issue, which is also a feature of our socio-political debate. We exclude many things too early on. And we phase things out before we know what we will be phasing in instead. We phased out nuclear energy — some 12 years

Friedrich Merz being interviewed in the office of the parliamentary group leader.

"Greater openness around technology is the right expression for it. But we have to imbue that concept with meaning. At some point, we must be prepared to take a leap into the unknown."

Friedrich Merz

ago — and yet we still don't know what we will replace it with. Now we are phasing out combustion engines. And we don't know what will take their place: Electromobility could be the answer. Or hydrogen. Or synthetic fuels. Or maybe the future of mobility lies in all of them working in together in parallel. This mindset, where we start at the level of highly ideological discussion, doesn't appeal to me. It is reckless of us to don blinkers. We end up excluding technological developments that we are not even aware of yet. The economist Friedrich August von Hayek called this the pretense of knowledge. A very good term for it. Would we still decide to phase out nuclear energy today? We can be fairly sure we wouldn't. Was it right for Germany to ignore the dual fluid reactor and allow its purchase by Canadian investors? Again, probably not.

Would you call this an impassioned plea for greater openness around technology, Mr. Merz?
Yes, that's the right expression. But we have to imbue that concept with meaning, and not fixate on individual cases. Politicians need to light the spark of self-confidence and openness for this country. The Germans have a highly developed sense of security. At some point, though, we must be prepared to take a leap into the unknown. This demands trust in our political leaders.

Who will be the next chancellor, Mr. Merz?
We already have one. And we are engaging with him.

You count among the usual suspects as a candidate to succeed him.
I'm honored.

More than half of the ten previous CDU leaders have gone on to become chancellor.
I could live with that.

But what is your party's position? In 2022, you yourself described the CDU as a "difficult political renovation project."
We now find ourselves in the second of three phases. Phase one was consolidation of our role in opposition. After the poor election result in 2021, we embraced this role successfully. But if we aspire not just to be the opposition of today, but the government of tomorrow, then we must abandon this mode of just being the opposition. We have to flick the switch and highlight what we want to do better. That is a task for the party and the Bundestag parliamentary group. Since last year's four state elections, I have therefore been focusing much more intensively on the party. We are right in the middle of a renewal process.

Phase two, as you call it.
Which will conclude in May of next year, in good time for the 2024 European election and the 2025 Bundestag election. ■

2021: On tour with his grandson

Together with the eldest of his six grandchildren, he took a bike tour from the source of the Ruhr in Winterberg as far as Arnsberg. As he put it, "The Sauerland region is just wonderful."

2022: Head of the party at last

On his third attempt, after trying in 2018 and 2020, Merz wins the absolute majority and officially becomes CDU chair on January 31.

2022: Night train to Kyiv

In May, Merz meets Mayor Vitali Klitschko. They saw (almost) eye-to-eye: 6"4 meets 6"6.

2022: Carefree trip to the island of Sylt

With his wife Charlotte, Merz flies his private plane to the July wedding of minister of finance Christian Lindner. "By now," he says, "my wife has lost any fear of flying with me."

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“This will save many lives”

A research team has discovered a new antibiotic with a unique mode of action that can even attack multidrug-resistant bacteria. This could open the door to better treatment for patients with lung diseases in particular.

By Mehmet Toprak

In 2019, almost five million people worldwide died of infections that could no longer be treated with antibiotics. And, according to the results of a study by an international team of scientists published in the medical journal The Lancet in 2022, this figure could rise to ten million by 2050 if the spread of multidrug-resistant bacteria continues. The increasing resistance of bacteria and pathogens to antibiotics, known as antimicrobial resistance (AMR), has become one of the greatest threats to public health. Experts warn of a lurking pandemic.

But now, there is a new beacon of hope in the fight against multidrug-resistant bacteria. A team of scientists has succeeded in identifying a natural substance that is capable of effectively attacking gram-negative pathogens: Known as darobactin, it could be used as an antibiotic against Pseudomonas aeruginosa, a widely feared type of gram-negative bacteria. It is among the most dangerous of the bacteria found in hospitals, where it is the primary cause of lung inflammation, as well as wound infections and heart disease. The World Health Organization (WHO) has placed Pseudomonas aeruginosa high on its list of top priority bacteria, i.e. bacteria for which new antibiotics urgently need to be developed.

Prof. Till Friedrich Schäberle is a leading member of the research team that successfully discovered the antibiotic substance darobactin. He leads the department for Natural Product Development at the Fraunhofer Institute for Molecular Biology and Applied Ecology IME in Giessen and holds a professorship at Justus Liebig University (JLU). As part of the current study, the researchers from Giessen collaborated with the department for pediatric infectious diseases at the University Hospital of Munich (LMU). Prof. Schäberle and his team were already involved in an international research collaboration in 2019 that led to the discovery of darobactin’s efficacy against gram-negative bacteria. Since then, they have continuously optimized this efficacy further through laboratory tests.

Attack until the bacterium dissolves

Darobactin is a small peptide, a compound of just seven amino acids, but the way its molecules link together make it very stable. However, what really makes darobactin special is its mechanism of action. Gram-negative bacteria have an additional protective shell consisting of a protein structure. Once these pathogens become resistant, conventional antibiotics are powerless against them. Prof. Schäberle explains the advantages of darobactins: “They attack a target structure that commercially available antibiotics do not use, which is located directly in the protective shell. There, they inhibit an essential protein, which renders the bacterium non-viable and causes it to dissolve.”

It’s a deceptively brief explanation, one that has taken many years to reach. “For 60 years, there have been no truly innovative antibiotics that work against gram-negative pathogens,” reflects Prof. Schäberle. “This makes darobactin a breakthrough.”

The new antibiotic candidate was discovered through conventional activity tests, where bacterial extracts obtained by fermentation are applied to pathogenic microorganisms. Next, the researchers test whether the growth of the pathogens has been inhibited. If the answer is yes, they begin to analyze the active substance and

its mode of action. This was the case with darobactin. The University Hospital of Munich sourced the multidrug-resistant bacteria required for the tests from patients.

The darobactin itself is isolated from the bacterial broth and purified in successive steps using chromatographic techniques. The researchers in Giessen have developed a biotechnological platform to produce the darobactins and further improve their efficacy by replacing or modifying the amino acids. The research team from Fraunhofer IME, the University of Giessen and the LMU in Munich have already passed some important milestones. In vitro testing has been completed and the in vivo phase is now beginning. In this phase, the scientists want to rule out the possibility of uncontrolled side effects and ensure that the substance will not have a toxic effect.

A long-awaited defense against multidrug-resistant bacteria

The Fraunhofer researcher Prof. Schäberle has no doubts about the drug's future potential: "For us, it is now a matter of finally bringing a new antibiotic to fruition, to help the fight against multidrug-resistant germs," he says. "This will save many lives." ■

Almost

5

million people worldwide

died because of multidrug-resistant bacteria in 2019.

Prof. Till Friedrich Schäberle with Pseudomonas aeruginosa, a gram-negative bacterium.

Photos: Rolf K. Wegst/Fraunhofer IME

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Electronics goes to print

Imagine if a package could raise the alarm itself if it fell to the ground — this is how good old paper could revolutionize the semiconductor market.

By Stefanie Smuda

The sensor layout is built up by printing the tracks and sensors in different inks — however, lining them up precisely is a challenge.

It was invented around 2,000 years ago. Today, there are more than 3,000 types available — from poster paper for billboards to paper towels and delicate cigarette paper that smolders rather than going out thanks to a special filling and coating. In the future? Paper, the epitome of the word "analog," is about to go smart. The Fraunhofer Institute for Silicate Research ISC is digitalizing paper — and it's making serious progress.

The ISC Researchers have developed smart paper for two areas of application. The first is a shock detection sensor that can be integrated into packaging — when a package falls to the ground, for example, it will send an alert via a cell phone app. The second application is a tamper-proof label that can protect manufacturers and consumers from fraud. This label can also be read using a cell phone. For around five years, Gerhard Domann, head of the Center Smart Materials and Adaptive Systems at Fraunhofer ISC, and his team have been investigating how to print electronics on paper without affecting its recyclability.

"We wanted to find out what functions we can carry out with materials that are both environmentally friendly and work well with additive processes," explains Mr. Domann. He is describing the goal of the SUPERSMART project, which was launched in 2018. Good old paper is still a very relevant material for several reasons: it's made from renewable raw materials and is stable, durable, recyclable and even biodegradable, provided it does not contain too many additives. It is also suitable for use in highly scalable production processes such as roll-to-roll printing.

"What we have now is a highly scalable technological process that we can use for roll-to-roll printing of labels and sensors, which means it can also be used in mass production," Mr. Domann is pleased to report. Sensors can now be produced by the meter, which could significantly reduce manufacturing costs. One key material in this process is piezoelectric printing ink. However, this must be handled in a very specific way: "First, the electric dipoles in piezoelectric materials need to be aligned, but it's just not feasible to manually pole thousands of sensors," explains Mr. Domann. For this reason, the project partner institutes developed an automated poling system that can help to efficiently activate thousands of printed piezo sensors. However, as it is not yet possible to produce the whole product via printing, conventional microelectronic components such as batteries and chips for communication devices must be applied to the paper substrates the old-fashioned way: automatic placement machines with pick-and-place technologies.

With the SUPERSMART project, the researchers have demonstrated that widespread use of this technology is drawing closer and closer. Paper-based sensors are suitable for a multitude of use cases. "The label and packaging industry in particular are experimenting with applying simple smart functions to substrates that are more environmentally friendly than the standard fiber-reinforced, non-recyclable plastics. We're seeing the technology readiness level increase here," says Mr. Domann. In addition to fraud protection and quality assurance, there are also other possible areas of application, such as in medicine and consumer electronics.

However, SUPERSMART has even more potential to offer — when used in combination with the internet of things, for example. This will require cost-efficient, environmentally friendly technologies to generate the (sensor) data and make it accessible. The prototypes from the SUPERSMART project meet these requirements. The international project team also impressed the jury at the Organic and Printed Electronics Association (OE-A) 2021 competition and took first place in the "Best Publicly Funded Project Demonstrator" category.

In an accompanying life cycle assessment (LCA), the team also looked into how resource-efficient it is to print electronics on paper, and where there is potential for improvement. When compared directly, paper is clearly superior to PET substrates: In almost all of the 18 categories examined as part of the LCA — including global warming, water consumption, nitrate pollution, ozone depletion in the stratosphere and ecotoxicity — it was found that using a paper substrate would have only 10 to 20 percent of the impact of PET.

Mr. Domann and his team want to harness these advantageous characteristics of paper substrates to an even greater extent. They are investigating the possibility of recycling materials with more complex structures. The researcher may have printed a simple electronic circuit on the paper substrate in the SUPERSMART project, but conventional circuit boards require multiple layers to increase the electronic components' integration density. In their follow-up project, CircEl-Paper, which is being funded by the EU, Fraunhofer ISC is once again working with European partners from industry and academia, with a view to increasing the complexity of circuits based on multilayer paper substrates and simultaneously ensuring that the functional materials can be efficiently recycled. ■

Photo: K. Selsam, Fraunhofer ISC

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A sting operation — fighting cancer with bee venom

Spring is here, and so are the bees. Researchers are on the hunt for a species with venom that can combat cancer cells.

By Kerstin Beckert

The days are getting longer, temperatures are rising and nature is coming back to life. Around this time, if you look closely, you will see a variety of animals starting to appear. Tim Lüddecke of the Fraunhofer Institute for Molecular Biology and Applied Ecology IME in Giessen, is taking a close look at small creatures. "These animals, in particular, have often developed very sophisticated methods of fending off predators, even ones that are many times larger than them." This includes the use of highly effective venoms — though these can be used for more than just defense.

Dr. Lüddecke, a biochemist with a PhD in biology, heads up the Animal Venomics working group at Fraunhofer IME. Venomous animals are his passion. However, rather than the harmful effects of the toxins, he's more interested in their potential benefits in medicine. The way he sees it, a loss of biodiversity also means a loss of bioresources, since every animal has its own cocktail of venom. If a species dies out before it is researched, "it's a missed opportunity to find a new active agent."

Tried-and-tested remedies

For Dr. Lüddecke, working with the venom of insects that bite and sting (bees, wasps and ants) was a natural choice. The animals use their venom to protect their young from parasites, hunt and ward off enemies — such as hungry bears that would otherwise destroy a beehive while searching for honey.

For hundreds of years, people have been using honey bee venom as a remedy: it combats bacteria, viruses and fungi, boosts blood circulation and lowers cholesterol. The venom cocktail constitutes an aqueous solution with solid content. This contains enzymes — small amounts of various proteins, odorous substances, sugar and histamines. "It generally consists of up to 50 percent melittin," explains Dr. Lüddecke, a toxinologist. This destroys the tissue around the puncture site by entering the cell membranes of red blood cells and creating holes in them until they disintegrate entirely. As part of a joint research project with the LOEWE Center for Translational Biodiversity Genomics (LOEWE TBG), which includes around 20 research groups in addition to Dr. Lüddecke and his team, scientists are looking for a melittin variant that can be better used in medicine. Eight species of bee made the shortlist — in addition to honey bees, the selection includes wild bees, too. In terms of developmental biology, wild bees are over 50 million years older. In addition, many of them are solitary — and lone bees do not have a beehive to defend. As such, the researchers presume that the more primordial melittin protein in the wild bees'

The venom from the carpenter bee has been shown to have a promising effect on cancer cells.

venom might be less toxic to human somatic cells, but more effective at destroying cancer cells.

Complex venom analysis

Ten to twenty specimens of each species were collected from the wild. Dr. Lüddecke and his colleagues needed a special permit to do this — and a net. After the insects were caught, they were initially "kept in special cages so they could acclimatise a little to begin with." Then the researchers surgically removed the stingers from the venom glands.

The first step was to carry out a biochemical analysis of the toxin from each bee species. There were only a few microliters of each venom cocktail available per animal — not nearly enough for the complex tests. To solve this issue, the individual components were chemically synthesized until the researchers eventually had ten milliliters of each venom to use for further tests.

The experiments on somatic cells and cancer cells were carried out by researchers at the Fraunhofer Institute for Translational Medicine and Pharmacology ITMP in Frankfurt. "A toxin can have a completely different effect on somatic cells than it does on cancer cells," explains Dr. Lüddecke. This means the researchers had to carefully examine how harmful the individual components are to the different cell types, and how they affect the cells' metabolisms.

Certain components stood out in the analysis results, such as the melittin of the violet carpenter bee (Xylocopa violacea). As temperatures have been warmer than average in the past two decades, owing to climate change, the violet carpenter bees' habitat has significantly expanded in Germany — they can now be found in the north as well as the south. Although it resembles a fat black bumblebee, this insect belongs to the Apidae family of bees. This buzzing insect gets its name from the slight purple shimmer on its wings and its preference for dead wood, in which it digs nesting tunnels.

A promising treatment for breast cancer

The venom from this carpenter bee has been shown to have a promising effect on cancer cells. Initial findings into its pharmacological potential were published in the scientific journal Toxins at the end of 2022. Further studies are planned in the next two years. "We want to expand our studies to include other bee species. We're particularly interested in finding out which components make up their venom," says Dr. Lüddecke. And of course, "which cancer cell-specific properties each type of melittin has." ■

"If a species dies out, it's a missed opportunity to find a new active agent."

Dr. Tim Lüddecke, Fraunhofer IME

Photo: Oliver Dum

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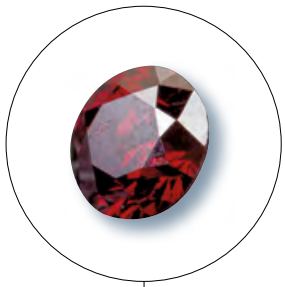
Most precious: diamonds increase freedom of movement



These glimmering red NV diamonds are created entirely in laboratories.

A glowing red jewel that increases freedom of movement for people with paralysis sounds like magic — but this is reality. Diamond-based sensors could enable more precise control of exoskeletons.

By Yvonne Weiß

Prof. Soekadar uses movable hand exoskeletons to train the machine in grasping movements. The devices weigh just under 400 grams per hand.

It's just a simple movement of the hand, nothing more. But for this patient whose hand was paralyzed in a stroke, reaching out to pick up a book means an awful lot. She opens it and turns to the first page. Her hand is encased in a kind of high-tech glove that she controls with nothing but her thoughts. Prof. Surjo R. Soekadar of the Charité — Universitätsmedizin Berlin hospital wants to make this special scenario an everyday reality. And he's working with project manager Dr. Jan Jeske of the Fraunhofer Institute for Applied Solid State Physics IAF and other partners in the flagship project NeuroQ to do it.

The interdisciplinary consortium wants to help people regain some of the freedom of movement that they have lost, due to a stroke or some form of palsy.

In addition to leading the Quantum Sensors group at Fraunhofer IAF, Dr. Jeske was also the initiator of NeuroQ. Now he and his team are developing highly sensitive diamond-based quantum sensors for the project. These sensors will be applied to the patient's scalp and read out the magnetic fields that occur with brain activity with high levels of accuracy. Then simply thinking about the movement would be enough to steer the neural hand exoskeleton with high levels of precision.

Together with his team, Prof. Soekadar, who is a professor of Clinical Neurotechnology and head of the Translation and Neurotechnology research group at the Charité hospital will go on to test the new sensors on patients.

The first attempts to translate brain signals into control signals via electroencephalography (EEG) were made back in the late 1950s. In 1999, the first EEG-based brain-computer interfaces with relevance for clinical use were presented. In clinical settings, it is now possible to take any brain signals that can be measured through the scalp via EEG and pass them on to an exoskeleton as control signals. However, conventional EEG systems can only read out the fields in a very inexact way, as the skull weakens and distorts the signals. While the hand exoskeleton can grasp and release objects, it is not yet possible to control more complex hand movements via a non-invasive system. That would require far more sensitive sensors.

Dr. Jeske has had the idea of developing a laser sensor based on NV diamonds since his days as a postdoctoral student. NV diamonds contain nitrogen vacancy (NV) centers, meaning that a few of their carbon atoms have been replaced by nitrogen atoms.

The diamonds, which are entirely lab-manufactured glow red because of their NV centers — and they could be about to revolutionize sensor technology. Their material makeup offers some considerable advantages. NV diamonds are biocompatible — i.e., they are non-toxic, non-irritant and non-radioactive, and they can be used at room and body temperature without issue. Dr. Jeske's idea of using NV diamonds that are illuminated by a laser system for high-precision measurements of magnetic fields is based on these characteristics.

His hope is that his laser system will enable quantum sensors to read out even the faintest magnetic fields generated by brain activity, so they can be converted into complex control signals. "From simulations, we know that quantum sensors are able to measure with a level of precision that was previously only possible through implants. That gives us a lot of motivation," emphasizes Prof. Soekadar. His decision to focus on non-invasive technologies was quite intentional, as this reduces the risks for patients.

However, the challenge here is that conventional magnetic field sensors have so far only been able to read out signals precisely when cryogenically cooled or in a shielded room. In everyday life, other magnetic fields produced by the earth and electronics, for example, distort the measurement results.

Now, Dr. Jeske's laser diamond could solve this problem. "NV diamonds offer enormous potential for the future, as they can measure with accuracy in spite of other, background magnetic fields," the scientist explains. Thanks to its special properties, the diamond sensor could function reliably in everyday life, he adds — that is, beyond shielded clinical spaces. "I am very excited by the prospect of being able to give people back some portion of their lost freedom of movement," he says. "If we can make a success of this passion project of mine, it would mean a lot to me."

A team from the University of Stuttgart are supporting the project to help achieve this goal. The university is a global leader in precision magnetic measurement using NV centers. A number of industry partners are also involved in NeuroQ, namely Twenty-One Semiconductors, Sacher Lasertechnik GmbH, Advanced Quantum GmbH, W+R Schirmungstechnik GmbH, neuroConn GmbH and NIRx Medizintechnik GmbH. They are dealing with the development of elements of the technology and the commercialisation in Germany. The project, which is funded by the German Federal Ministry of Education and Research (BMBF), started in December 2022 and will run for five years. ■

"I am very excited by the prospect of being able to give people back some portion of their lost freedom of movement."

Dr. Jan Jeske,
Fraunhofer IAF

Photos: Gordon Welters, Fraunhofer IAF (2)

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Wounds, dressed for success

A biodegradable fiber fleece made of silica gel is paving the way for new applications inside the body: The Renacer® membrane could help improve wound healing after surgery and enable drugs to take effect directly in the brain.

By Dr. Monika Offenberger

When treating extensive wounds and burn injuries, doctors face a catch-22: On one hand, the dressing material needs to be changed regularly; on the other hand, it's better not to disturb the wound's natural healing process. This dilemma is particularly pressing when it comes to chronic wounds with poor healing, for example on the feet of diabetes patients. "The materials currently available on the market must be removed every three days. This disturbs the wound and slows the healing process." So says Dr. Bastian Christ, a chemist at the Fraunhofer Institute for Silicate Research ISC in Würzburg. The solution? A fiber fleece made of absorbable silica gel developed at the ISC.

"First, our open-mesh fleece is cut to fit the geometry of the wound exactly; then, it is placed directly in the wound, ensuring that the fiber ends are in contact with healthy skin cells. From there, the connective tissue cells can migrate into the wound via the fiber structure and multiply," explains Dr. Christ. A clinical study found that almost all diabetic foot wounds that received this treatment healed completely within six to eight weeks. The material developed by Fraunhofer ISC retained its shape long enough for the cells to form a new tissue — only then did it biodegrade completely.

These properties distinguish the silica gel fleece from non-degradable wound dressings such as cellulose, as well as from biologically absorbable materials such as collagen, polylactic acid and polyglycolic acid. Fiber webs made of these materials are not dimensionally stable; rather, they contract over time and grow more dense. In the process, they lose contact with the healthy cells, which would not be able to grow into the increasingly narrow fiber mesh in any case. This means that these materials are less suitable for permanent insertion into wounds, unlike the materials developed by Fraunhofer, which retain a stable shape right to the end. Another advantage of the silica gel fibers is their ability to entirely decompose into nothing but orthosilicic acid.

"These are small, water-soluble molecules that are found everywhere in nature, including in our bodies' tissue fluid. Moreover, this bioactive substance can support the formation of skin, connective tissue, hair and nails in the body," explains Dr. Christina Ziemann of the Fraunhofer Institute for Toxicology and Experimental Medicine ITEM in Hannover. Contrary to its name, orthosilicic acid does not contribute to excess acidity — this is yet

Photo: Frank Baquet/plainpicture

Up to 100 nanometers thin: The dressing material can be adapted to the specific use case.

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another advantage that it holds over other biodegradable materials, which often dissolve into organic acids such as lactic acid or glycolic acid, leading to excess acidity in the tissues, and consequently to inflammation reactions in the immune system.

The fleece was tested in cell cultures for its biological compatibility in accordance with ISO standards. The result? It did not cause any damage to mammal cells. As such, the cell membranes and genetic material are unaffected and the growth and metabolic behavior of the cells remain

> "We could embed an antibiotic in the membrane and this would then be released into the wound."
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> Dr. Bastian Christ, Fraunhofer ISC

unchanged. This applies equally to the intact fleece and to its sole degradation product, orthosilicic acid. It also applies to Renacer®, a new silica gel fiber fleece that Fraunhofer patented in 2022 — and this new development offers yet another plus: "Our latest product has the same property profile as the previous fleece, which was approved as a Class III medical device back in 2010. And it can be spun into even finer fibers," explains Dr. Christ. "Our classic material has fiber diameters of around 50 micrometers, similar to a human hair. The new material allows us to achieve diameters between 1 micrometer and 100 nanometers. The thinner the individual fibers, the narrower the meshes in the fleece — and we can adjust this fairly precisely through the synthesis of our spinning fluid." This makes the Renacer® membrane suitable for a wide array of new applications, because, while body cells ▶

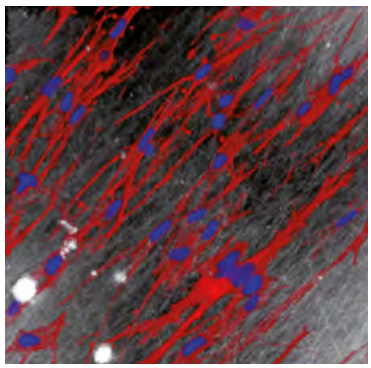
may or may not be able to pass through depending on the mesh size, the membrane always allows for the exchange of nutrients and other biomolecules.

"This could prove useful for regenerative medicine," explains Dr. Christ. "If we can ensure that the meshes are open enough, we can create a structure in the body that mimics collagen and will retain a stable shape for several weeks as it degrades. This will give connective tissue cells time to settle on it. So supporting the healing of wounds inside of the body, just as we do with external flesh wounds, is now a real prospect."

Human fibroblasts cultured in an incubator behaved as the chemist expected in practice. Within a few days, they grew into a fleece sample, penetrating it completely after two weeks. However, this is not always the aim. For example, doctors that have operated on an intestine or uterus will want to shield the wound from surrounding tissue to keep it from adhering to the peritoneum. In this case, they could use the tightest possible silica gel fleece to form a protective barrier and shield the wound from migrating connective tissue cells — this would later dissolve into orthosilicic acid.

The diameter of the fiber and the density of the mesh are not the only elements of the Renacer® membrane that can be adjusted. The novel fleece can also be loaded with therapeutic medications that are released over the course of decomposition. As Dr. Christ points out, this innovative drug delivery system opens up new options for treating wounds: "For example, we could embed an antibiotic in the membrane and this would then be released into the wound in order to prevent bacterial infections."

Another field of application involves aggressive brain tumors such as glioblastoma. Each year, approximately 3,000 people develop this condition in Germany alone — and even if they receive all of the available therapies, they only have an average of 15 to 20 months to live. First, as much of the tumor as is possible is surgically removed from the brain tissue. Then, the area is irradiated, treated with chemotherapeutic agents and, finally, exposed to alternating electric fields. "Nevertheless, we don't manage to kill all of the tumor cells. As such, new legions constantly develop, eventually killing the patient," explains Prof. Carsten Hagemann, head of the Experimental Neurosurgery section of the Department of Neurosurgery at the University Hospital of Würzburg.



"We want to modify our silica gel fibers with two drugs that are already approved for cancer therapy; these will then be released directly at the original site of the tumor."

Dr. Sofia Dembski, Fraunhofer ISC

Many highly effective cancer drugs are not suitable for treating glioblastomas, as they cannot cross the blood-brain barrier. Even the active agents that can overcome this barrier must be administered systemically — in other words, they do not target the tumor directly, but spread through the entire system via the blood stream. This often causes debilitating side effects in the rest of the patient's body.

"It would be better to deliver the drugs to the brain in a direct, local way, as this would increase their impact and minimize side effects," emphasizes Prof. Hagemann, a qualified biologist. This goal is what inspired researchers to use the Renacer® membrane for treating glioblastomas. "We want to modify our silica gel fibers with two drugs that are already approved for cancer treatment; these will then be released directly at the original site of the tumor," explains Dr. Sofia Dembski, who is head of the Biomaterials team at Fraunhofer ISC. Prof. Hagemann describes how this might work: "We envision a process whereby the surgical cavity is lined with the drug-loaded fleece after the tumor has been excised; this fleece would at least cover the walls of the cavity, or could even fill the cavity entirely. Of course, the advantage of this material is that it is flexible and can adapt to changes in the shape or volume of the surgical cavity. As the silica gel fibers decompose, they will constantly release the cytostatic drugs. If this occurs directly at the tumor's margin tissue, it could inhibit new tumor growth in that area with maximum efficacy."

The research teams at Fraunhofer ISC and the hospital want to explore whether their vision can be realized in the future, initially using two- and three-dimensional cell cultures. To this end, they will take the tumor tissue removed during surgery — with the patients' consent, of course — and place it in a culture, where it will come into contact with the drug-loaded Renacer® membrane. The German Federal Ministry of Education and Research (BMBF) is providing 1.6 million euros in funding for the pilot project. "Within three years, we hope to develop an effective method that will expand the current treatment options for glioblastomas," says Prof. Hagemann. "We hope that this will allow patients to live longer and enjoy a good quality of life." ■

Photo: Fraunhofer ISC

Knowledge relay

self-driving vehicles

everyday sight

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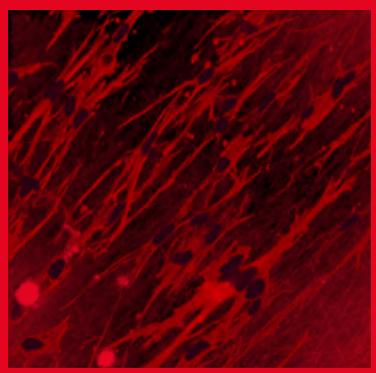

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Photo: Fraunhofer ISC

Knowledge relay

Professor Mario Trapp, when will ***self-driving vehicles*** become an ***everyday sight on German roads?***

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Knowledge relay, episode 8

Professor Mario Trapp, when will self-driving vehicles become an everyday sight on German roads?

Series:
Knowledge relay

The times we live in have raised **many questions — questions Fraunhofer researchers are working hard to answer.** A specialist **answers a question,** then poses a **question of their own** for the **next expert** to answer — it's a **"knowledge relay."** In this edition, **Prof. Mario Trapp,** director of the Fraunhofer Institute for Cognitive Systems IKS, answers a question posed by **Prof. Wilhelm Bauer,** director of the Fraunhofer Institute for Industrial Engineering IAO.

Driverless robotaxis are a must-have feature of any good science fiction story. They are virtually synonymous with the ideas of progress and the future. Any tech company that promises to take this vision from the realm of fiction into a tangible possibility can be sure that the public will take note. And these companies are not slow to take full advantage of the limelight. By providing us with glitzy demonstrations, they give the public the impression that traditional car manufacturers are stuck in the staid shadow of the past. But however much this elaborately staged narrative might suggest to us that this future is within touching distance, in reality, tech companies have what appears to be an insurmountable chasm to cross before they can make autonomous cars into everyday products — namely, vehicle safety and reliability.

On the other side of the chasm, you can find the classic car manufacturers. Moreover, the world's first automated vehicle was not unveiled by a tech company, but by a premium German manufacturer. This car drives itself automatically, at least in certain situations; it can take responsibility for the journey while the driver reads or works on emails. However, the human must take control again if the car

requests it. Obtaining safety approval for this system came with a price — namely, the car's use of intelligence had to be reduced to a minimum, meaning that it could only take effect under very limited conditions. What's more, this technology cannot be scaled to make the robotaxi dream a reality. So even with this product, we are still a long way from fully automated cars that are suitable for everyday use.

The situation is that we can either build intelligent vehicles or safe ones. But the ability to build vehicles that are both intelligent and safe will determine if and when we see driverless vehicles in everyday life. In our research at Fraunhofer IKS, we call this Safe Intelligence®.

Prof. Mario Trapp is director of the Fraunhofer Institute for Cognitive Systems IKS.

A question of safety

Artificial intelligence (AI) is essential to developing vehicles that can stand the infinite variety of our real world. From a safety perspective, however, AI is no shiny miracle cure — in fact, it mostly represents a massive problem. For as impressive as AI may be, we simply don't know why it works — or, more importantly from a safety perspective, when and why it doesn't work. Unfortunately, these breakdowns are no exception; rather, they occur too often to consider the system a reliably functioning technology. As such, the question of safety will be the ultimate deciding factor for the future of the autonomous vehicle. But sadly, the "answer" to this question is still totally open.

In any case, advocating for a loosening of safety measures in the name of progress would be a fatal move. Rationally speaking, robotaxis in German cities could only contribute to road safety to a limited extent compared to other measures; moreover, they would not support a transition toward sustainability in our transportation systems. What remains is purely a desire for convenience, dressed up in a sentimental narrative where a long-held vision of the future comes true. This does not justify risking human life.

Moreover, autonomous driving is by no means Germany's last resort for maintaining its position as a leading innovator. The technologies behind autonomous driving will soon make their way into our everyday lives: in logistics, on construction sites, in agriculture or in production. Although these applications may have to live in the long shadow of self-driving cars, we will find that autonomous systems are much more useful and easier to master in this type of scenario.

Whatever way the saga of autonomous driving develops in the future, autonomous systems will soon be a part of everyday life — although the reality may not align exactly with the predictions of science fiction. ■

The ability to build vehicles *that are both* intelligent and safe will determine *if and when* driverless vehicles *become part of everyday* life.

In the next issue:

When will *bioplastics* be able to completely *replace* plastics made from *petroleum?*

Photo: Kroll Photography

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Higher yields, lower losses

When it comes to food, we are used to safety and constant availability. But crises and empty shelves have shown we can't take that as a given. Fraunhofer researchers are working to achieve greater resilience.

By Dr. Janine van Ackeren, photos: Sven Döring

Title

Accounting for taste
Dr. Susann Vierbauch of Fraunhofer IVV is studying food value chains — even for the humble strawberry.

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As CURT rumbles across the field, it looks like a table that has escaped from the kitchen. This outdoor robot consists of two robust wheels — which allow it to cross even the roughest terrain — and a platform just over a meter in height. The platform bristles with high-tech equipment, including a camera that keeps CURT on track, allowing it to roll along the furrows to the left and right of the young potato plants without destroying the delicate green shoots. Or at least only destroying some specific green shoots: weeds. And it might handle pests someday, too.

In today's conventional agriculture, weeds are often removed using an herbicide called glyphosate. However, as this agent does not distinguish between different types of wild plants, it destroys them all, reducing biodiversity and intensifying the decline in insects. In the past 30 years, insect biomass has decreased by around 70 percent.

But now CURT is here. This agricultural robot was developed by Kevin Bregler, group manager at the Fraunhofer Institute for Manufacturing Engineering and Automation IPA as part of the Fraunhofer lighthouse project COGNAC, which involves seven Fraunhofer institutes. The CURT prototype is fully electric, and autonomously drives between rows of plants in potato fields. Fitted with laser scanners, a camera and a small GPS system, it finds its own way around the field and uses its manipulator to pull unwanted weeds out of the ground without damaging the little potato plants. "What's special about CURT is that it is selective about which weeds it removes. This means it can leave nettles along the edge of the field while pulling up other weeds," explains Mr. Bregler. The torn-up weeds are left lying in the field to become fertilizer. These developments are just the beginning: In the future, CURT will be put to work on permanent crops such as fruit, and there are already inquiries coming in from the coffee industry regarding use in coffee plantations.

"When plants are under stress, they release volatile gases."

Dr. Axel Wille, Fraunhofer EMFT

Always enough to eat: it all comes down to resilience

In recent years, the pressure put on food producers has risen enormously: they have to increase harvests, minimize losses and make deliveries safely even during crises, all while keeping sustainability in mind. For many members of generations X, Y and Z, the coronavirus pandemic will have been the first time they realized that even in Germany, food supplies cannot be taken for granted. The Russian war of aggression against Ukraine exacerbated this feeling. Climate change and shortages of skilled workers will affect security of supply in the long term. How can food production in Germany be made more resilient? To find answers to this pressing question, Fraunhofer has formed the Agriculture and Food Industry alliance. "In this alliance, 13 Fraunhofer institutes are pooling their expertise to offer a one-stop shop for industry customers," explains Prof. Mark Bücking, who heads up the alliance's central office.

For years, farmers in Altes Land, the largest contiguous fruit-growing area in northern Europe, have been battling both the effects of climate change and the consequences of human activities. Due to the river Elbe becoming deeper, the water table has sunk and the soil is becoming more salinated. In the SAMSON project, researchers at the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM are working together with the Hamburg University of Applied Sciences, the hochschule 21 university of applied sciences and the Hamburg University of Technology on automated systems to expand on the expertise of fruit farmers.

For example, the trees must not bear too much fruit, as this will lead to a poor harvest the following year. If the apple grower observes 30 percent too many blossoms, he usually cuts out 30 percent — even on trees where the number of blossoms would have been appropriate. This decreases the harvest, so the researchers are taking a different approach with their technology: "We collect data on each tree individually," says Benjamin Schulze, group manager at Fraunhofer IFAM. "Based on this a digital twin will be derived and exploited." As the farmer drives through the rows of apple trees and carries out other work, cameras and sensors automatically capture images in the visible and infrared spectral range, measure temperatures and collect accurate GPS data. Software solutions take this data and use intelligent algorithms to generate information on how best to handle the trees — an interactive user interface then allows the orchardist to see all the trees that consistently produce a smaller harvest, or plan specific cultivation measures for each tree. ▶

Individual objects: istockphoto (5), photocase (1)

Fresh and fast
In the FRESH project, Dr. Axel Wille of Fraunhofer EMFT is working on monitoring food products during transportation — all the way to the supermarket shelf.

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The data, which is interpreted using artificial intelligence, can also be used by robots to remove blossoms from each tree as required. "With our system, we want to safeguard harvests and make them more consistent and more predictable," says Mr. Schulze. In the future, a project farm will be set up where researchers will drive through the rows of apple trees once a month, using the newly developed sensor box to record data. This will allow them to build a small but highly innovative fruit farm. "From summer 2023, fruit farmers will be able to test our developments there. Ultimately, the aim of the project is knowledge transfer. Specifically, we want the technologies we develop to be brought into application," says Mr. Schulze. "We also want to ensure that fruit farming remains an attractive profession in Germany in the long term," he adds.

The AGRARSENSE project was recently launched in January 2023: Some 52 partners from 15 EU countries (including the Fraunhofer Institute for Electronic Microsystems and Solid State Technologies EMFT) are working to develop 49 new products for 7 areas of application, from agricultural robotics and optimized soil management and fertilization to water management — a topic that has become increasingly important over the years as temperatures rise.

Fraunhofer EMFT wants to find a way to measure the ever-increasing harvest losses caused by climate change, so that the help required can be managed with precision. "When plants are under stress, whether it's due to drought, pests or a lack of nutrients, they release volatile gases," explains Dr. Axel Wille, the technical and scientific coordinator for the overall project. "We want to detect these by giving robots a sort of electronic nose."

However, in order for these robots to detect these substances, their sensors must be able to get close enough to the gases. To solve this, Dr. Wille and his team are developing micropumps to suck in the gases. In the long term, this will not only be able to indicate whether a plant is under stress, but exactly where that stress is coming

"Resilience has to be feasible"

How to make our diet more secure — and more enjoyable. Prof. Andrea Büttner, Executive Director of Fraunhofer IVV, has been appointed as a scientific member of the German Research Foundation's Permanent Senate Commission on Food Safety.

Interview: Josef Oskar Seitz

Every ninth person on the planet is undernourished or going hungry. We have got used to swallowing this bitter pill, Prof. Büttner. Are there any new approaches being taken to solve this issue?
The problem actually goes much further than that. A much larger proportion of people are malnourished — it's a massive problem, even in rich, industrialized countries, where alongside mineral and vitamin deficiencies, overeating is also on the rise.

Is that not making the problem so big that it can't be solved?
What we have lost is our focus on what's most important. This is what we want to concentrate on in the Fraunhofer Agriculture and Food Industry Alliance. We're experiencing problems when it comes to resilience and sovereignty: in supplying energy, in healthcare — and food. We don't just need to look at this in purely technological terms, we also need to review our entire situation and consider possible future scenarios.

And what solution scenarios do you envisage?
Promoting regional production is a huge issue. We also need to develop entirely new crop cultivation methods. Vertical farming and indoor farming are technical advancements that will definitely help us move forward, but degrading soil and access to water are global problems that lie at the heart of every type of bioeconomic value creation. What we urgently need to change is how we handle resources. We are currently considering how residual and secondary material flows can be used, refined, traded and, above all, consumed on a large scale in this country, as well as worldwide.

"Residual material flows" sounds so technical. What do they involve exactly?
There's a lot to them. Fruit and vegetables need to conform to numerous standards and regulations these days. And anything that does not meet these

"The most important thing for us is knowledge transfer — we want to make intensive use of the technologies that already exist."

Dr. Susann Vierbauch, Fraunhofer IVV

from, i.e., pests, or a lack of water or nutrients. It's easy to see the benefits of this process: Water, fertilizer and pesticides will no longer need to be spread across large areas. Instead, they will be delivered to targeted plants as required.

Safeguarding production along the value chain

The Fraunhofer Center for Biogenic Value Creation and Smart Farming is also driving progress toward the agriculture of the future. Founded in 2022, this center is run by the combined efforts of the Fraunhofer Institutes for Integrated Circuits IIS, for Process Engineering and Packaging IVV, for Electronic Microsystems and Solid State Technologies EMFT, for Computer Graphics Research IGD and for Large Structures in Production Engineering IGP. Together, they are working to develop technologies that will ensure a resilient food supply. The German federal government and the state governments of Bavaria and Mecklenburg-Vorpommern provided 80 million euros in start-up funding for the center. "The most important thing for us is knowledge transfer — we want to make intensive use of the technologies that already exist, right along the entire value chain," explains Dr. Susann Vierbauch of Fraunhofer IVV. ▶

standards ends up on the trash heap. With our partners, we are developing technologies that will also allow smaller types of businesses, such as cooperative farms, to process these discarded foods into smoothies or crunchy products. As well as that, there's one concept that people still don't really seem to have grasped, despite the crises we've been through: stockpiling. Let's go back to your question about world hunger. In many regions of Africa, there would be no shortages if the people had access to the right machines and technologies to process, preserve and stockpile food at times when it is plentiful. We need to start there, immediately. And that's what we're doing, as a Fraunhofer Alliance, along with our strong partners such as the Weihenstephan-Triesdorf University of Applied Sciences and the Technical University of Munich. After all, Germany really isn't that far from Africa. We have cultivated a system here in which raw materials are usually taken from farmers for very little money to be processed and put to use in downstream industries. Rather than just growing and selling fruit and vegetables, farmers need the technology and mechanical solutions that will allow them to process these directly into products of their own, which will create more added value for them. This is how we will promote regional production, reduce losses during and after the harvest, and increase the amount of goods that those of us in the region can consume over the rest of the season.

Nice idea — but why would I, as a comfortable, satisfied consumer, want to change anything about a system that has only ever made me comfortable and satisfied?

Because you'll be able to enjoy the sensory joy of having greater variety. If we switch to a system where food is produced regionally and on offer in local supermarkets, you'll get a lot more diversity! We're already seeing many new products today and people are experiencing the joy of participating in this process and enjoying the new foods.

So you're promising the consumer greater variety and greater enjoyment. What incentive is there for industry to have the courage to make more changes?

Stable supply chains! And resilience for the future. I'm hoping that entrepreneurs will be able to think ahead and anticipate the legislative interventions that will one day regulate the whole food sector. Otherwise, the next crisis could rock the foundations of everything that they thought was secure in our complex global network.

Does that mean resilience is feasible?

Of course. And what's more, it has to be feasible. But to achieve it, we'll need to make extensive changes. However, there's one huge advantage to those changes: They have the potential to improve our whole quality of life. If we can create examples that prove this, those changes will continue to spread, like seeds. And grow. And flourish.

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Strawberries are a good example of what this involves: Due to a shortage of skilled workers, increasing labor costs and consumer demand for high-quality fruit, there is a growing need for automation right from the planting stage. Specialized robotics could be the answer. "The latest technological developments mean it's possible for a filling machine to put a specified amount of substrate in the planting containers. A robot then digs a hole in the substrate, uses pneumatically controlled fingers to grasp the strawberry plant by the root ball, places it in the hole and packs down the soil — without damaging the plant," says Kai Potthoff, a scientist at Fraunhofer IGP. This is quite a challenge — for optimal development, the plants must be equally spaced and not placed too deep or high in the substrate. The researchers are currently working to ensure that the robot keeps up with the speed of the filling machine.

In order for the plants to produce as many strawberries as possible, they must then be fertilized, watered and protected. "We want to move away from using sensors that monitor all the plants in a greenhouse or field as a whole — instead, we want to measure the respective parameters on a local, individual basis," says Christian Wald, a scientist at Fraunhofer EMFT. The solution the team hopes to develop is a data platform that measures and evaluates all the relevant factors in a specific location over time, from nutrient levels, water supply and lighting through to air conditions.

Installing large numbers of sensors in polytunnels is only the first step. These sensors also need to be able to efficiently transfer their data to a collection point. This is where the mioty® wireless technology by Fraunhofer IIS comes in: Using X-ray technology, the researchers carry out quantitative analyses of root growth in the plants, which then allows them to determine the precise environmental conditions that the strawberries thrive in. In the long term, this data will make it possible to supply fertilizer and water as needed by each specific plant.

An important factor in efficient production is detecting plant diseases such as phytophthora, mildew and even damage by caterpillars as early as possible. The expertise of researchers at Fraunhofer IGD will be important here: They can evaluate spectral images to detect damage patterns early on, so that plant protection agents can be applied in a targeted way.

> "What's special about CURT is that it is selective about which weeds it removes."
>
> Kevin Bregler, Fraunhofer IPA

Waste not, want not: Reducing waste through digitalization

When the strawberries are ripe, they are harvested with a tactile gripper. This device detects the mechanical resistance of the strawberry, and thus knows how tightly the fruit can be held without sustaining damage. "The elastomer gripping technology has already been developed and Hohe Tanne GmbH is licensing it from Fraunhofer to bring it to market," says Dr. Vierbauch. The researchers want to optimize this approach even further. They are developing a foil sensor that not only measures the pressure on the strawberry, but will also detect ripeness and the presence of chemicals in the future. Food waste is a serious problem, with around 45 percent of fruits and vegetables currently ending up in the trash between harvest and consumption. But the team has a solution to this too: They use near-infrared sensors and optical measuring technologies to classify the strawberries and sort them during harvesting. They can then either go directly for sale or, in the case of the less visually appealing fruit, for further processing.

Edible coatings could also reduce food waste. "These are based on natural substances. When they are sprayed onto the strawberries, the barrier properties of the coatings mean that the fruit lasts longer," explains Dr. Vierbauch. As an avocado has different requirements to a strawberry when it comes to edible coatings, the researchers adjust the coatings according to the respiration rate of each fruit.

The team is also working on improving the shelf lives of foods through other means, including processing imperfect products, such as strawberries with visual defects, in healthy ways — i.e., without adding lots of sugar. "One possibility here is drying them using vacuum expansion. To do this, we dry the fruit beforehand and then put them in a vacuum for the final drying phase, which makes them pop open. This better preserves the vitamins, makes the color of the strawberries more intense and gives them a crunch — which you won't get with other fruit-drying methods," says Dr. Vierbauch. In addition, the dried fruit

Robots over rakes
Less herbicide, more harvest: With CURT, Kevin Bregler of Fraunhofer IPA has developed a robot that can differentiate between plants and weeds — and so can weed the fields autonomously.

has a long shelf life and takes up less weight and space during transportation.

And speaking of transportation — in the long term, gas sensors will be produced in the form of bits of film that can be used to monitor specific gases, temperatures and humidity in trucks, trains and so on. Not only are these film sensors cheap to manufacture, but they can also be stuck to the product like Post-it notes and read wirelessly. "We're currently working on developing the technology. It's not just that we need an inexpensive sensor that consumes hardly any energy — we also need a way to transmit the data," says Mr. Wald of Fraunhofer EMFT. "This data could be used to generate knowledge either in the cloud — meaning it's stored centrally — or on the edge in the sensor node." As a result, the strawberries would not only be produced and processed in an optimal way, but also be transported to the point of sale under the best possible conditions.

Following a resolution by the German federal parliament, the Federal Ministry for Food and Agriculture is funding the FRESH project, which is coordinated by Fraunhofer EMFT. In the project, researchers are developing a packaging sensor for monitoring the freshness of meat and fish. The researchers have been analyzing meat and fish in storage tests to check them for volatile substances that occur during spoilage, and can thus be used as indicators of the freshness level. As the concentrations of acetoin and 3-methlybutanal were the highest, the researchers developed specific sensor materials for detecting these two gases. The sensors can be integrated into packaging and will change color as soon as the product spoils. When combined with electronic analysis methods, this smart packaging will allow for continuous monitoring and digitalization of the food supply chain. In the future, it will also be possible to identify volatile gases using miniaturized systems that are currently being ▶

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More regional and more profitable
Apple juice straight from the apple? Even Dr. Björn Moller of Fraunhofer ISI hasn't managed that yet. But he wants to at least give fruit farmers the opportunity to increase value creation and lengthen shelf life when selling their products.

developed by THE Fraunhofer Institutes for Photonic Microsystems IPMS, for Molecular Biology and Applied Ecology IME and Fraunhofer IVV. "They are based on a mini gas chromatograph that analyzes volatile substances. The resulting device could be used as an indicator for product safety and to detect food fraud, such as counterfeit olive oil," says Prof. Mark Bücking, head of the Trace Analysis and Environmental Monitoring department at Fraunhofer IME. This device will be no more complex than a coffee machine, meaning that with a little training, laypeople such as the factory gate workers that oversee incoming goods will be able to use it.

Shortening supply chains — promoting regional production

If goods are being damaged during transportation, however, rather than trying to optimize this stage, the focus should be on reducing transit time. When food is produced on a more regional basis, the food supply becomes less vulnerable to crises than global supply chains, and the costs and environmental footprint are also lowered. However, distributing agricultural products regionally is not that simple. Let's take apple juice production as an example. Currently, German farmers have two options: they can press the apples themselves and sell the pure apple juice in their own farm stores within its short shelf life. Or they can sell the apples to a large producer that pours the juice into Tetra Pak cartons and distributes it to supermarkets nationwide. "There's nothing in between," explains Dr. Björn Moller, a futurist at the Fraunhofer Institute for Systems and Innovation Research ISI.

Researchers at Fraunhofer ISI and a number of European partners hope to fill this gap in the FOX (Food processing in a box) project. The planned outcome is that farmers will be able to process their apple juice in the box, using a gentle method that would maintain the same quality but give it a longer shelf life than freshly squeezed juice. The boxed juice could then be sold in local supermarkets. "One aspect of this project is about developing the technology — the project partners are working on that. And then it's also about developing the local food value chain," says project manager Dr. Moller. Put simply, the aim is to keep the value chain — from the farmer to the consumer — within one region, thus making it more sustainable without relying entirely on farm stores. "While food production only accounts for about 10 percent of the food value chain's environmental impact, in 10 of the 16 categories examined, including climate change and land use, logistics and trade accounted for 75 percent or more of the impact," Dr. Moller explains. This means it is crucial to keep the value chain regional. And not just for apple juice — the same applies for the energy-intensive process of drying berries and mushrooms, sorting pieces of fruit and wrapping them in environmentally friendly packaging and making use of residual materials from food production, such as using tomato skins in tomato soup.

> "While food production only accounts for about 10 percent of the food value chain's environmental impact, in 10 of the 16 categories examined, logistics and trade accounted for 75 percent or more of the impact."
>
> Dr. Björn Moller, Fraunhofer ISI

Breaking new ground: making production more intelligent

"As more and more soil becomes degraded, productivity levels are below what they used to be," says Prof. Stefan Schillberg, director of Fraunhofer IME. "Then there's also soil erosion and climate change. What's more, pesticides and fertilizers that are used in the fields often cannot be recovered." However, there is an alternative: vertical farming, where vegetables are grown indoors in rack systems. This method offers a number of advantages, for example, vegetable cultivation can take place year-round without using arable land, or being affected by climate conditions and the seasons. It also conserves raw materials. "Vertical farming only requires 5 percent as much water — ideally, the only water loss will occur through the products themselves, i.e., when a head of lettuce is harvested, for example. It also only needs 50 percent as much fertilizer. And you can completely avoid pesticides," explains Prof. Schillberg. However, indoor cultivation is significantly more expensive than the outdoor option.

Fraunhofer IME researchers are working to change this in the In4food project, part of the New Food Systems innovation space. This initiatives unites more than ▶

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50 partners from science, industry and society, including Fraunhofer IVV and IME and the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB. “One of the things we’re concentrating on is paracress: It produces the natural active ingredient spilanthol, which is used in sectors such as the cosmetics industry,” says Prof. Schillberg. Financial factors must be taken into account here, i.e., how expensive would it be to produce paracress using vertical farming? If we are to take advantage of the higher resilience of vertical farming and ensure a basic food supply in times of crisis, the costs will need to be comparable to conventional farming.

Veganz, a company from Berlin that processes pea protein to make meat substitute products, is exploring this possibility. In the past few months, the price of these legumes has shot up. If the company were able to produce peas itself using vertical farming, it could significantly improve its resilience. Not only would this shorten delivery routes, as the peas could be grown in a hall right by the production facilities, but was also give the company independence from global supply chains — and the price fluctuations that come with them. On top of that, the vertical farms would be resilient against summer droughts, heavy rain and winter snow.

> “By the end, we’ll have a very good idea of how many pea plants can be cultivated per square meter and how much that will cost.”
>
> Andreas Reimann,
> Fraunhofer IME

But is this alternative farming method financially viable? Together with Veganz, Fraunhofer IME is looking into whether this is the case, and in what circumstances. For their research, they will use a system called OrbiPlant®, developed by Fraunhofer IME. In this system, pea plants are grown on a conveyor belt that is 1.20 meters wide and 25 meters in length. This conveyor belt goes up and down at regular intervals, and the plants move along it, bit by bit. The roots hang down inside the humps, i.e., underneath the conveyor belt, where they are sprayed with a fine mist of nutrients and get oxygen from the air. This allows ▶

The scientist and the pea
At the research facility where Andreas Reimann of Fraunhofer IME works, the little pea is taking on an importance that belies its small size. This cultivation method has the potential to reduce the impact that climate factors, global supply chains and price fluctuations have on their products.

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the plants to grow particularly quickly. A process known as gravitropism also encourages rapid growth. Due to the winding conveyor belt, the plants have to constantly reorient themselves in the gravitational field, and this releases growth hormones. At the start of the undulating belt, there are only a few leaves, but by the end, the plants are bursting with life and covered in pea pods. Apart from the planting and harvesting, everything in the research facility is already completely automated.

"While lettuces and herbs grow quickly, peas take around two months to cultivate," says Andreas Reimann, a researcher at Fraunhofer IME's Aachen location. "What's more, pea plants can grow to be quite large outdoors — we need to control their growth using fertilizers, light and other factors in such a way that the plant is smaller and more compact but still produces plenty of peas per unit of volume." Tests are underway to find the best way to do this, and should be completed this year. "By the end, we'll have a very good idea of how many pea plants can be cultivated per square meter and how much that will cost," Mr. Reimann predicts.

"The first food products have already been manufactured — foods with proteins from microalgae. Granola made from wheatgrass. And crackers made from insect proteins."

Prof. Stefan Schillberg, Fraunhofer IME

More of a good thing: Quality ensures quantity

Ensuring a resilient value chain always comes down to quality. It is not just about getting food production lines up and running again as quickly as possible after a breakdown occurs; rather, it is also a case of ensuring the right level of quality and making sure the food is safe for consumption. If there is even the slightest doubt about the food meeting safety requirements, it cannot be distributed, which then leaves a gap in the supply chain.

This is why Fraunhofer IVV, Fraunhofer IME and the Fraunhofer Institute for Production Technology IPT have teamed up to detect weak points in the food supply chain and develop possible solutions in the ReSearchL innovation project (short for Resilient system architecture to safeguard food production). "We need comprehensive resilience management — clear communication structures and clear processes to handle disruptions," says Dr. Marc Mauermann, Deputy Director of the Processing Technology division at Fraunhofer IVV. On the basis of selected value chains, researchers are investigating current levels of resilience in food production in Germany. Oil mills, for example, have a low level of resilience, because in central Europe, oil mills almost exclusively produce vegetable oils from rapeseed and sunflower seeds. Efforts to diversify the raw ingredients have come to nothing, which means oil production is particularly vulnerable to disruptions such as crop failures.

In ReSearchL, the scientists are investigating which process chain strategies are most effective at ensuring these kinds of disruptions have as little impact as possible. To do this, the team plays out different disruption scenarios for oil mills and creates recommendations for action to ensure resilient production, in line with of the length of the outage. If the mill is only out of action for up to 24 hours, for example, the workers just need to halt the process of dehulling the oil seeds. The unhulled seeds can then be mixed back into the raw material. Although the press cake will then be of a lower quality, it will still meet acceptable levels.

On the other hand, longer-term supply problems require a different solution: a modular approach to building oil mills. This way, if there were issues with the supply of rapeseed and sunflower seeds, production could be switched over to another type of seed within a few days — instead of being stopped completely, as is the case today. In this use case, regional supply chains could also significantly increase production resilience by acting as a supplement to global chains.

Alternative proteins: A different way to eat better

Creating a resilient food supply also involves ensuring that people get the protein required for a healthy diet. However, as a source of animal protein, meat is far from sustainable. The search is on for more environmentally friendly protein sources that could support human nutritional needs within resilient production chains. And the quest might end with plants, algae, insects and fungi — according to the researchers in the Fraunhofer

lighthouse project Future Proteins, which involves the Fraunhofer Institute for Optronics, System Technologies and Image Exploitation IOSB, for Machine Tools and Forming Technology IWU and Fraunhofer IME, IVV, IGB and UMSICHT. "To do this, we're using four indoor systems, which have already allowed the institutes to gain expertise and quickly increase technology readiness levels in the areas of vertical farming for plants, insect farming, bioreactors for fungi and photobioreactors for algae," explains Prof. Schillberg of Fraunhofer IME.

The light source? Collected sunlight!

When it comes to vertical farming, efficient lighting is top of the agenda — it is essentially the main cost driver associated with this approach. Sunlight collectors are used to trap light and direct it toward the plants via optical fibers and mirrored light tubes while leaving the heat outside. For protein production, the researchers are cultivating various crop types, including a special kind of potato that they have removed the slightly toxic solanine from using mutations. This allows the proteins that are destroyed during cooking to be isolated from the raw, now non-toxic potatoes. Light is also the be-all and end-all when it comes to cultivating microalgae in photobioreactors. When grown in optimal conditions, microalgae have a protein content of up to 50 percent. Although they're not suitable for vegetarians and vegans, mealworms are a valuable source of raw materials, and have now been approved as a foodstuff. New detection systems will prevent pathogens from disrupting mealworm breeding by detecting harmful pathogens in the worms at an early stage; in the future, biochips could enable parallel screening.

The fourth cornerstone: fungi

The final cornerstone of the project is the cultivation of fungi. However, instead of the fruiting body that has been part of humans' diets for thousands of years, researchers are focusing on the much larger portion of the fungus that grows underground. Which fungi are suitable for this purpose? To answer this question, the team is researching different varieties in terms of their growth rate and protein content. In order for the production of their new fungal protein to be as sustainable and competitive as possible, the researchers have created circular processes. They take the waste heat from one system to maintain the temperature of another, turn insect feces and dead insects into fertilizer and utilize waste product streams such as potato peels as the base of growth media. They also looking into protein processing, while keeping in mind the aesthetic appeal, texture and protein content of new products. "We have already manufactured the first food products," Prof. Schillberg is pleased to report. "Foods with proteins from microalgae. Granola made from wheatgrass. And crackers made from insect proteins." ■

Cutting-edge photography
Photographer Sven Döring traveled across Germany with specially produced posters. Specifically placed cuts allowed the Fraunhofer researchers to combine the virtual and real worlds for these photos.

Photos: Josef Oskar Seitz

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A brief history of artificial intelligence

1956
At the University of Dartmouth (USA), leading information theorists gather for a workshop. The goal: to develop intelligent machines. The term "artificial intelligence" is used for the first time.

1957
AI researchers Allen Newell and Herbert A. Simon program the General Problem Solver (GPS), modeling it on human problem-solving behavior. The GPS can solve simple puzzles.

1972
AI research leads to what are known as expert systems. The most famous of these is MYCIN, which supports the diagnosis of blood infections. Comparative studies show that MYCIN can perform similarly to medical experts. The broader public is becoming more aware of AI.

1986
In 1986, the British computer scientist and psychologist Geoffrey Hinton is the first person to train a neural network using the backpropagation method. This approach allows necessary adjustments to be calculated in response to errors, and achieves some impressive feats.

1997
IBM's Deep Blue computer defeats the world chess champion Garri Kasparov. This spectacular event shines a spotlight on AI research worldwide. Deep Blue does not owe its victory to cognitive intelligence, but to pure computing power — it calculates all possible moves.

2011
Watson, an artificial intelligence program from IBM, beats two champions of the popular American game show Jeopardy. The secret to its success? Watson develops strategies to help make sense of tasks posed in natural language, which are often interspersed with wordplay.

2016
Google's AlphaGo beats Lee Sedol, the world's leading Go player, in four out of five games — given the complexity of this East Asian board game, it causes quite a stir.

2020
The company OpenAI publishes their language model GPT-3. Amply supported by financial investments and developer resources, and equipped with enormous computing power, the model uses massive amounts of data to achieve a level of performance the likes of which had never been seen before.

AI art created by Midjourney, a sort of ChatGPT for images. We fed the AI with particular terms: trustworthiness, European values and culture, AI foundation models, technological sovereignty, data protection and diversity.

AI — and what about Europe?

Bigger, more powerful, more versatile: American tech giants are finding themselves in fierce competition for dominance in the world of artificial intelligence, as China is also investing billions. Europe needs to forge its own path — and it's not too late.

By Dr. Sonja Endres

ChatGPT took everyone by surprise — even the AI experts. This super-powered chatbot can complete tasks that it was never trained for, and can even explain jokes. No one knows exactly how it does it. It was only trained to give responses by finding the word that was most likely to follow the preceding word. ChatGPT has developed new characteristics all by itself. Experts call this "emergence" — it is a feature particular to the new, large AI models that, compared to their already powerful predecessors, are based on up to 100 times more training data. In 1997, Deep Blue defeated then-chess grandmaster Garry Kasparov; in 2011, Watson beat two champions of the popular U.S. game show Jeopardy; in 2016, AlphaGo defeated the world's best Go player — these feats all garnered a great deal of attention worldwide, but they are nothing compared to the next generation of artificial intelligence.

A new era began in the summer of 2020 with the release of the GPT-3 language model, which ChatGPT is also based upon, by U.S. company OpenAI. While initially only a select few people had access to GPT-3, in recent months it has become publicly available online for free in a more advanced form: ChatGPT. Dr. Gerhard Paaß, mathematician and senior scientist at the Fraunhofer Institute for Intelligent Analysis and Information Systems IAIS, explains why the powerful bot keeps delivering new surprises: "These large AI models — the most famous of which at the moment is certainly GPT — can do more than just understand language, summarize texts and translate. They are trained on huge amounts of general data and can be easily adapted to a wide variety of tasks." Experts refer to this phenomenon as homogenization. Task-specific training is no longer necessary; the models respond to instructions and provide the basis for a wide range of applications, which is why they are also called foundation models.

ChatGPT can program like a professional developer, collate specific information from medical texts and pass law exams. Foundation models are also multimodal, which means they can process various media, including speech, images and videos, in addition to text. In order to quickly drive development, Microsoft has invested additional billions of dollars in OpenAI; as a result, the company has since followed up with an even larger model, GPT-4. The technical details have not yet been published, but a variety of test results have suggested that it can reproduce facts even more reliably than GPT-3. Meta and Google are also working hard to create their own models. Some 73 percent of the major AI models are currently being developed in the U.S., and 15 percent in China — but as it stands, less than 2 percent in Europe, including models such as Luminous by the German startup Aleph Alpha.

The huge impact of language on AI

This will soon change, according to the authors of the LEAM feasibility study, which was presented to the public in January. Conducted by Fraunhofer IAIS together with other research institutions, trade associations and companies, the study describes the conditions that must be put in place if Germany is to maintain a competitive position when in comes to developing foundational and language models for AI. The study was funded by the German Federal Ministry for Economic Affairs and Energy. "Training AI with European languages is a matter of immense importance," says Dr. Paaß, who took part in the study. Language has a huge impact on AI, as language represents culture, with all its unique characteristics, norms and values. "Only 3 percent of the training data for GPT-3 was in German. This means, for example, that detailed facts about German history, geography and technology, as well as our norms surrounding data ▶

Photo: KI Midjourney, Courtesy of the Carnegie Mellon University Archives, action press, ddpimages
Source: Geschichte der KI: Dittmann, Frank und Seising, Rudolf, Können Maschinen denken?, in: Natur & Technik 3/2020, pp. 8–13.

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protection, are severely underrepresented in the model and therefore hardly come into consideration. GPT-3's knowledge, and consequently the answers it provides, are much better in English than in German," he explains.

The experts involved in the LEAM study agree that large AI models will have a considerable impact on industry and society. To them, the language models that are currently popular are only the first step. They predict that, in the coming years, even more powerful models trained on a much wider, diverse range of data will revolutionize the market. In order to remain technologically independent and economically competitive, Europe absolutely must develop its own model. To do so, the LEAM initiative is relying on an open-source model that gives industry the opportunity to experiment. But is there any chance that Europe can catch up with the American tech giants' considerable leads?

Developing a foundation model costs billions: The authors of the LEAM study estimate that a 380 million euro supercomputer infrastructure is needed for detailed experiments with the models, though no such infrastructure exists yet in Germany. Conducting a training run of a large model also requires about as much energy as 30 single-person households would consume in a year. Numerous highly specialized developers familiar with this type of AI would also be required. Sven Giesselbach, team leader for Natural Language Understanding at Fraunhofer IAIS, believes that it is better not to get into a competition to create the largest model, but rather to approach from a different angle. Above all, he says, they could score points for quality: "At Fraunhofer IAIS, we have developed criteria and techniques for designing trustworthy, safe AI that could also be adapted for a large European model." To be trustworthy, an AI must meet basic requirements in six areas, known as "dimensions": fairness, reliability, autonomy and control, transparency, safety and data protection. The AI assessment catalog by Fraunhofer IAIS gives information on how these can be implemented and controlled. This catalog of structured, concrete guidelines for developers is constantly being updated thanks to Dr. Maximilian Poretschkin, head of AI Validation and Certification, and his team.

> "A European model would enable us to clearly differentiate ourselves from the American models and gain a competitive advantage with high-quality AI that guarantees security for its users."
>
> Dr. Gerhard Paaß, Fraunhofer IAIS

Even the first dimension, fairness, is difficult to implement: A trustworthy AI must not discriminate against anyone on the basis of their race, gender, background or religious affiliation. But training datasets contain (often hidden) social biases — these are then picked up by the AI. "If a particular minority is underrepresented in a data set, this can result in discrimination — if the AI is trained with less sample data for a particular minority, it won't work as well for that minority," explains Dr. Poretschkin. This means developers must take great care when selecting data. Sometimes data must be selectively removed or added to ensure adequate representation for a certain minority. As such, it may be necessary to carefully introduce a bias against reality into a data set in order to improve the overall model.

The trustworthiness of AI also depends on its reliability — this can be ensured through systematic testing. But this is also challenging: Unlike traditional software, AI cannot be broken down into individual modules for review. "You always have to test the overall functionality, which is challenging from a technical point of view," Dr. Poretschkin points out. This also applies to another essential factor of trustworthy AI: autonomy and control. There must be options for intervention or a permanent monitoring system for the application that can ensure human beings always remain in charge of the process.

Transparency also fosters trust. With this in mind, researchers are seeking to reveal the decision-making processes within AI. Despite all the complexity, there are ways of finding an explanation. According to Dr. Poretschkin, "It is hard to imagine, but a neural network's process for generating output text is by no means random."

Overlapping methods of validating AI

The dimension of security primarily focuses on the risks from malfunctions, manipulations, external attacks and accidents. In order to minimize these risks, the recommendations outlined in the Fraunhofer IAIS guide include protective measures to defend against malware, as well as extensive tests that intentionally trigger an outage of the

AI application. Data protection is a particularly important factor in the trustworthiness of AI systems — after all, linking extensive training data sets makes it easy to draw conclusions about sensitive or personal data. Dr. Poretschkin believes the most important countermeasure here is to identify risks up front, become aware of the risks and comply with data protection standards. Ultimately, all measures and methods for safeguarding AI overlap with each other; ideally, they should all be taken into consideration during the development phase. This also applies to the new foundation models — though the fact that they are several times larger is a challenge.

GPT-3 consists of around 175 billion parameters, i.e., decimal numbers that represent the special properties of the model. Large-scale AI models usually have around 20 billion parameters, as these models are able to accurately respond to queries. The sheer variety of possible applications for these models means that conducting a risk analysis is a complex, difficult process. Nevertheless, meeting the requirements stated in the AI assessment catalog is crucial for the use of AI. After all, what company would use an AI that is impossible to control or does not function reliably? As powerful as ChatGPT is, the chatbot quickly reaches its limits. It won't admit when it doesn't know something — instead, it will "hallucinate" the answer, as the experts say. In other words, it will formulate an answer that seems convincing at a glance, but is in fact completely made up. Even if the user recognizes the error and points it out to the bot, the bot will stick to its original statement. Its stubbornness is astounding, says Mr. Giesselbach with a smile. Among developers, tricking AI models and uncovering their limitations has developed into a kind of sport. For example, Bing Chat, which is also based on GPT, will often provide absurd responses or will seem to be offended if the user points out its errors and asks it to apologize. This shows that human control is indispensable for everything generated by AI. Mr. Giesselbach says: "As a developer, I would never let ChatGPT write my code without me looking over it afterward."

The trustworthiness of AI is not yet at a level where it could be used in safety-related applications. That is why the LEAM initiative intends to systematically record risks from the start as it begins developing a European model. This will allow the risks to be quantified, and taking the account various dimensions of trustworthiness into account help with risk reduction. "A European model would enable us to clearly differentiate ourselves from the American models and gain a competitive advantage with high-quality AI that guarantees security for its users," asserts Dr. Paaß. As a first step in its efforts to support German industry, Fraunhofer IAIS is working with the Fraunhofer Institute for Integrated Circuits IIS and other partners in the OpenGPT-X project. The goal of the project, which funded by the German Federal Ministry for Economic Affairs and Energy, is to develop European alternatives for AI language models by the end of 2024. As part of OpenGPT-X, researchers are developing specific use cases for large AI language models in areas such as mobility, media and insurance.

> "At the moment, we're seeing a real rush of talent to our institute. More and more developers are invested in building models that incorporate European values and are fair, reliable and resource-friendly."
>
> Sven Giesselbach, Fraunhofer IAIS

How can Germany remain competitive?

In particular, realizing the vision of creating a model that can perform as well as GPT-4 — and will eventually be even better — will require the development of a competitive AI computing infrastructure and the construction and long-term operation of a high-performance center, with the help of a team of experts. "There's no shortage of talent," says Dr. Paaß — though many are emigrating to the U.S. Mr. Giesselbach interjects: "At the moment, we're seeing a real rush of talent to our institute. More and more developers are interested in building models that incorporate European values and are fair, reliable and resource-friendly."

The business sector is taking notice, too. 80 percent of companies contacted have shown great interest in investing in the technology's development. Many have significant reservations about sharing their data with American tech giants in order to use their AI services. Mr. Giesselbach offers them some hope: "In Germany, we have the possibility of developing a secure alternative that complies with data protection regulations. It's not too late. But we have to take an intelligent approach from a different angle — and above all, act fast." ■

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A colleague for difficult times

The coronavirus pandemic has left its mark in the form of a skilled worker shortage, especially in the catering and hotel industries. Fraunhofer IGCV and Fraunhofer IAO are investigating how robots can help with this and what the hotel of the future might look like.

By Yvonne Weiß

Felix slowly approaches from the other end of the corridor, accompanied by a quiet whirring and stuttering sound. He has already cleaned three floors of Das Hürner, a 97-room hotel in Ansbach, Bavaria, in less than an hour. "We couldn't imagine the team without Felix anymore," says Ljiljana Sladojevic, an employee at Hotel Hürner. "We won't be giving him away." Every day for nearly seven months, the robot has been cleaning carpets across the five floors of the hotel. His human colleagues are glad of the help: it means less time pressure, a lighter work load and less stress.

The first step toward automation was taken by managing director of the hotel Jens Blank, together with Shuang Lu and Klaus Fink from the Fraunhofer Institute for Casting, Composite and Processing Technology IGCV via the Mittelstand-Digital center in Augsburg. The project was a result of the pandemic and the resulting shortage of skilled workers — something that has also affected Mr. Blank. "At the time, I thought to myself, I have to do something about this now," remembers the hotelier.

Together with Ms. Lu, a research scientist for process control and robotics at Fraunhofer IGCV, Mr. Fink, a research scientist in the department of Flexible Production Automation department, and the company Kenter GmbH, Mr. Blank initiated a needs analysis for the hotel and began testing the first robots.

"We are looking for service staff" the chalkboard says. Staff shortages continue in the hotel and catering industries.

Photo: Ernst Weingartner/Chromorange/mauritius images

This allowed the team to identify where there might be a need for other robots that Fraunhofer IGCV could develop in the future.

Ms. Lu and Mr. Fink emphasize that the robotic systems they are working on "will not replace humans, but rather support them." For his part, Mr. Blank, the managing director, does not want to replace any employees — quite the opposite in fact. "I would like to retain my employees and make our sector a more attractive career option again." Mr. Blank is not only interesting in reducing the physical burden on his staff, but in ensuring more pleasant working hours. For instance, his employees will no longer have to clean the meeting rooms late at night — this task will now be done by Felix.

Prof. Vanessa Borkmann of the Fraunhofer Institute for Industrial Engineering IAO is also working to make the hotel of the future a reality. Prof. Borkmann, leader of the Smart Urban Environments team and the FutureHotel joint research project, has been working on solutions for the hospitality and catering industry since 2008. Working together with the industry, she researches how traditional job profiles are developing as a result of technological trends; in the process, she identifies opportunities for digitalizing the hospitality and catering industry. She confirms what Mr. Blank has learned from practice: "We have to use technology to make these occupations more attractive. In this skilled worker shortage, that would add a lot of value."

The pandemic had a particularly hefty impact on the catering industry, and its effects can still be felt today. According to the Federal Statistical Office of Germany, the number of staff working in bars and pubs in 2022 was 21 percent less than in 2019. In cafés, restaurants and diners, there was a decrease of 9.5 percent in this time frame. In 2022, the number of new apprenticeships for chefs was one-fifth lower than it was in 2019. As such, technological support is set to become ever more important. Together with her team, Prof. Borkmann is exploring the potential that could come from combining the abilities of humans and machines. "Our mission is to provide practical innovations and research for the industry."

Hotels as we know them will undergo fundamental changes in the future, says Prof. Borkmann. For instance, she expects that the conventional reception desk, where an employee manually checks in guests at all hours of the day, will be a thing of the past. Instead, digitalized processes will provide guests with flexible access to their hotel rooms at any time through an access code on their smartphone; this way, business travelers in particular will save valuable time and will be able to check themselves out even in the early hours of the morning. This also creates more flexibility for employees, allowing them to plan their working hours more freely — a decisive advantage in the ongoing skilled worker shortage.

However, Prof. Borkmann's vision goes even further. "The hotel of the future will be a place that brings people together, giving them a temporary home," she predicts. "But that doesn't have to be limited to overnight accommodation — it could also have a virtual dimension."

In other words, hotels could develop into a kind of hub that offers bundled services, such as brunches, co-working spaces, home meal delivery, and child and pet care, in addition to overnight accommodation. These services would be available both to guests and people from the local neighborhood. According to Prof. Borkmann, the hotel of the future will link the real world with the virtual realm: Encounters will not only take place physically, but will extend into the metaverse.

There was a **21%** **staff shortage** in bars and restaurants in 2022 as compared to 2019.

So how do things stand for Mr. Blank? Together with Fraunhofer IGCV, the managing director is already planning research projects in the field of social robotics — i.e., robots that communicate directly with humans. For example, if a guest beckons a robot, it could approach their table and ask if their plate should be cleared. Moreover, Mr. Blank can easily imagine using robots to help in the kitchen — after all, he is also finding it increasingly difficult to recruit staff for the restaurant industry.

Above all, however, the hotelier wants to get closer to realizing his dream robot, with the help of Ms. Lu and Mr. Fink: Using a variety of attachments, this flexible robot will not only be able to put chairs up on tables and push service carts carrying food, but also autonomously transport luggage carts. That is to say: it won't be too long before Felix gets an intelligent friend. ■

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Dresden shapes up: this model of the city's famous church, the Frauenkirche, is one of many 3D printing endeavors by Fraunhofer IWS.

A new dimension for production

Keeping the production industry secure is a serious challenge in times of fragile global supply chains, but new technical innovations are turning additive manufacturing into a promising solution for many industry sectors. With 3D printing, even custom products can be manufactured quickly, cheaply and locally.

By Beate Strobel

The idea dates back to the year 1984, when an American by the name of Charles M. Hull filed a patent for 3D printing, or "stereolithography" as he called it. The original purpose of the technology was to speed up the development and manufacturing of prototypes. Since then, numerous different additive manufacturing processes have been developed — 3D printing is just one among the many — but for a long time, they were almost exclusively used for rapidly manufacturing 3D versions of product ideas to conduct initial performance testing.

Now, almost 40 years later, the technology has outgrown the prototype niche. A study by the consultancy company McKinsey attributed a current value of 13.4 billion euros to the global additive manufacturing market and predicted that the sector would see 22 percent annual growth. According to a survey conducted by the 3D printing specialist Sculpteo across 86 countries, 49 percent of the companies that responded are already using 3D printing for high-volume production, and 18 percent have even applied it at mass production scale.

"Today, the industry sector has not only recognized the staggering potential of additive manufacturing, but has even started exploiting it to some extent," says Prof. Christoph Leyens, director of the Fraunhofer Institute for Material and Beam Technology IWS. Since 2013, the Dresden-based institute has coordinated the AGENT-3D association — a strategic alliance consisting of more than 120 partners from industry and science (including eight Fraunhofer institutes), all working together to further develop generative processes and pave the way for their application in industrial production. As the association has achieved its goals and fulfilled its purpose, the partners are now working on a new strategic focus to drive the next phase of development: establishing additive manufacturing in the industry sector.

> "Additive manufacturing may not eliminate existing barriers, but it does expand them considerably."
>
> Prof. Christoph Leyens, director of Fraunhofer IWS

The Additive Manufacturing Center Dresden AMCD, which is operated by Fraunhofer IWS and TU Dresden, is one of the largest facilities of its kind in Europe. The AMCD's pilot plant houses for all major manufacturing processes, from plastic and metal to ceramics. This diversity is very much in evidence at the center, where a display case containing printed components just a few centimeters in size can be found beside a wheel printed from titanium; measuring 1.5 meters in diameter. The optical table, to give its proper name, is one of the main components of a space telescope and will shortly be sent to the European Space Agency (ESA) for the final manufacturing steps, as Dr. Elena Lopez, head of department for Additive Manufacturing at Fraunhofer IWS explains. "If all goes well, then we will send a version twice that size into space in 2028," she adds.

These days, many experts are talking about a new industrial revolution triggered by 3D printing, but Prof. Leyens prefers to call it a paradigm shift in the production sector. He points to a spiked piece of metal on his desk and explains that this aerospike nozzle, a rocket engine part for a microlauncher, was additively manufactured at Fraunhofer IWS. "The design principle for this nozzle has existed since the 60s," he explains. "But until now, we haven't had a technology capable of manufacturing it."

What makes this nozzle special is that it consists of just two components — and a lot of hollow space. It would be impossible to mill a shape like that out of a metal block by conventional means. However, with laser powder bed fusion, an additive manufacturing procedure, metal powder can be built up in successive layers and fused with lasers at specific points. In this way, the component slowly builds up from the bottom, with the excess powder being removed from the hollow spaces at the end. This saves material and reduces weight — a vital factor in space travel. A rocket engine with an aerospike nozzle would use up to 30 percent less fuel than a conventional launch vehicle. Aviation companies are also hoping to reduce vehicle weight through 3D printing. For example, the aviation company Airbus is already using more than 2,500 components that were additively manufactured. ▶

Photo: Fraunhofer IWS

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According to Prof. Leyens, the revolutionary aspect of additive manufacturing stems from the fact that the material and the component are produced together. By contrast, in conventional production methods, the material has to be produced first and milled thereafter to form the component. As 3D printing is also opening up new possibilities in construction and design — such as delicate lattice structures, for example — design engineers will have to adopt new modes of thinking. As Prof. Leyens puts it, "Additive manufacturing may not eliminate existing barriers, but it does expand them considerably."

The recent pandemic boosted the technology's visibility, as it facilitated the quick, on-site production of the face masks and ventilators that were so urgently needed in the early days of the corona crisis. The logistics fragility caused by the pandemic and the war in Ukraine could also prove to be a catalyst for 3D printing: A demand-driven, on-site manufacturing of required parts would not only sidestep the problem of supply chains, but also reduce dependencies on Asian suppliers, as well as the need for transportation and storage and the resulting climate damages. Fraunhofer researchers are playing their part in driving technological advancements that will help the industry sector make this new shift toward 3D printing — and quite possibly turn additive manufacturing into a game changer.

Critical success factors: saving time and reaching goals more quickly

One obvious way of reducing production time is to increase production speed. If the manufacturing rate goes up, the cost per item will go down, thus making the technology switch a financially attractive option. The Fraunhofer Institute for Machine Tools and Forming Technology IWU has an answer to this need to up the tempo: a high-speed 3D printer for high-performance plastics. This screw extrusion additive manufacturing (SEAM) technology is a combination of a 3D printer and a plastic injection unit, with a movable table that slides back and forth under the plastic injection nozzle at breakneck speed. "With this system, we can produce a strand of material about 1 meter long every second," says Christopher Schlegel, Research and Development project manager at Fraunhofer IWU. He reports that the SEAM process reduces production time by up to 70 percent when compared to conventional systems.

Meanwhile, the Fraunhofer Institute for Manufacturing Engineering and Automation IPA is investigating another time-saving approach. R&D Additive Manufacturing group leader Patrick Springer and his team are working with the machine manufacturing company Arbug and the sensor production firm Balluf to print sensors with customized designs, in a research project focused on integrating electronic functions into additively manufactured components. The first device developed in this project is a proximity sensor that can be installed on assembly lines, for example, where it will detect objects lying on the conveyor belt. Up until now, these sensors have been housed in metal cylinders that contain their electronic innards — a circuit board, a magnetic coil and a connector. "Now, however, we have succeeded in printing a flat plastic case that incorporates all these elements," reports Mr. Springer. The main challenge faced by the Stuttgart-based team was accurately printing the conductive paths that would form the contacts for the electrical components alongside the mate-

The AMDC's pilot plant is home to devices for all the established additive manufacturing variants.

Photo: Christoph Wilsnack/Fraunhofer IWS

rial for the casing. Having tried a silver paste to begin with, the researchers are currently investigating the possibility of using flexible, conductive plastics (thermoplastic elastomeres) instead.

The Fraunhofer Research Institution for Additive Manufacturing Technologies IAPT is also helping drive advancements in this field, for example, by conducting a case study on the production costs for the door hinges of a sports car. The component was developed specifically for additive manufacturing using a design-to-cost approach, and optimized for a variety of parameters, including material expenses, weight and support structures. The researchers found that, in a sports car manufactured on a small-scale basis, 3D printing could reduce the production costs for articulated arms by up to 50 percent when compared to conventional milling processes.

A research collaboration with the Australian RMIT Centre for Additive Manufacturing and Fraunhofer IWS gave the IAPT a chance to fine-tune quality as well as costs. The three partners are working together in project UltraGrain to make 3D-printed components more stable and thus more long-lasting. The team aims to use ultrasound to prevent column-like structures from forming in the material during additive manufacturing, as these can have a negative impact on mechanical performance in certain situations. Ultrasound can be used to force the material to form tiny, round micrograins, which makes the parts of the component that have to bear particularly high levels of loads more stable. "UltraGrain will help to bring additive manufacturing into wider industrial application," asserts Fraunhofer IWS director Prof. Leyens.

Critical success factors: ensuring sustainability with future technologies

While 3D printing is an energy-intensive production process, the technology can still contribute to sustainability in a number of ways. For example, it uses less material and usually generates less waste than subtractive processes.

Additive manufacturing also makes it possible to carry out production on a more regional basis, another point in its favor in terms of sustainability. "Generative manufacturing is less intensive in terms of personnel," notes Prof. Leyens. "This makes personnel costs less of a pressing issue, which reduces the attractiveness of far-flung, low-wage countries." This would in turn save on the expenses and pollution incurred through transportation — and it could also create jobs for skilled workers in Europe.

> "The global additive manufacturing market is worth 13.4 billion euros — and counting."
>
> Dr. Arne Schirp, Fraunhofer WKI

The materials 3D printers can process range from metal to plastics and ceramics. There are various ways of making these materials more sustainable, for example, in the case of fiber-reinforced composites, a greater proportion of renewable ▶

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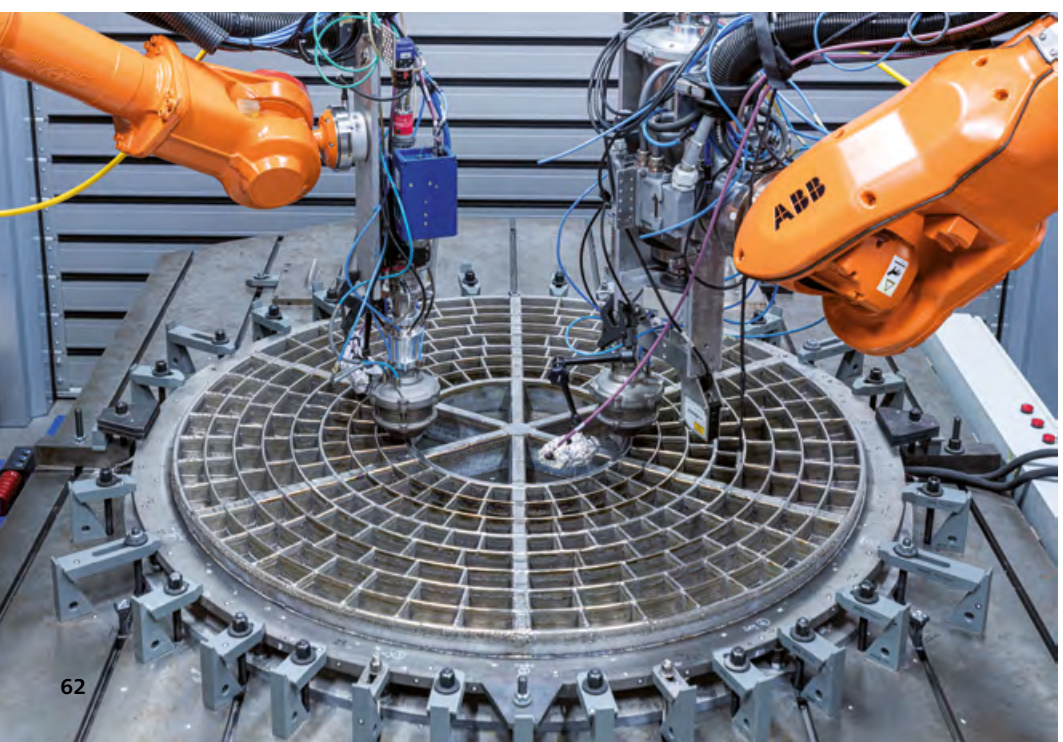
materials could be used. However, plastics that are reinforced with flax or hemp fibers have yet to match their fiber-glass and carbon-fiber equivalents in terms of sturdiness. Dr. Arne Schirp, one of the experts in the Technology for Wood and Natural Fiber-Based Materials department at the Fraunhofer Institute for Wood Research, Wilhelm-Klauditz-Institut, WKI, is researching biobased plastic filaments — the plastic threads that are fused during 3D printing to form a component — that can be incorporated into more conventional materials. In one of his experiments, for example, Dr. Schirp coated plant-based fibers with biopolymers to form filaments around 3 millimeters thick. A large 3D printer could use these filaments to produce components for the construction industry, such as individually manufactured partition walls for open-plan offices or girders for ceiling construction. "With 3D printers, we could design these structures in such a way that the areas that are under particular stress are stronger and the other areas are weaker," explains Dr. Schirp. That would save material. What's more, in the future, these lightweight girders made from renewable materials could partially replace the world's most important construction material: cement, a major culprit when it comes to harmful carbon emissions.

In project BioFusion 4.0, Linus Aulich, a biotechnologist at the Fraunhofer Institute for Production Systems and Design Technology IPK is working to find additives that will make the biopolymer polyhydroxybutyrate (PHB) fit for 3D printing. It's a challenging mission, but he does have a valuable little helper: the bacterium Ralstonia eutropha, which can produce PHB when grown on fat. "We get our fat from various sources, including slaughterhouse waste and old frying oil," he reports.

PHB is no one-trick pony: not only can it be grown using waste products, but it is also fully biodegradable and can be broken down within a year, depending of factors such as temperature or humidity. In addition, because it is easy to compost, the material could be a good option for eco-friendly disposable products such as packaging, disposable tableware and agricultural mulch film. According to Mr. Aulich, the combination of PHB material with 3D printing processes could also be a solution for medical engineering products, such as orthoses, which need to be adjusted for individual patients, but then have to be disposed of reasonably quickly. "What's more, PHB is non-toxic and can be absorbed by the body without issue, which means that we could also consider using it for additively manufactured drug delivery capsules."

The USA was quick to identify the potential of additive processes for industrial batch production and establish a leading position for itself. China and Japan are also long-established competitors in the field. And as far as Prof. Leyens is concerned, Germany is very much playing in the top leagues when compared to other countries, particularly as regards machine technology and applications. The director of Fraunhofer IWS has dubbed Germany a "fast follower" within the international scene: "When it comes to machine technology and applications, we are at the very least keeping pace with the top players." He adds that the city of Dresden in particular is driving innovation here, thanks to groups such as AGENT-3D, the highly effective regional research alliance DRESDEN-concept and the German-Polish collaborative initiative ATeM (see next page). Now, however, the industry has an obligation to implement these technological achievements in production processes and products. "This is where the evolutionary part of the revolution comes in," says Prof. Leyens. "Research results must be implemented in industry so that we do not lose our momentum." And so that Germany can make it as a major player, even in the top leagues. ■



"Research results must be implemented in industry, so that we do not lose our momentum."

Prof. Christoph Leyens

Printed from titanium: An optical table for a space telescope is one of the many components that has been additively manufactured in Dresden.

Photos: Christoph Wilsnack/Fraunhofer IWS, Amac Garbe/Fraunhofer IWS

A 3D-printed lab-on-a-chip system.

"We will be able to print exactly what the patient needs, right where it is needed."

Anne-Katrin Leopold, head of the ATeM central office

Critical success factors: custom-made, mass-produced medicine

Establishing additive manufacturing as a standard process in medical engineering is the goal that drives the German-Polish high-performance center Additive Technology for Medicine and Health ATeM (operated by the Fraunhofer-Gesellschaft in Dresden). "Our job is a little like what moving walkways do for passengers at airports. We want to accelerate knowledge transfer from research into industry and everyday life in hospitals," explains Anne-Katrin Leopold, an engineer and head of the ATeM central office.

The coronavirus pandemic gave Next3D — a working group run by two ATeM participants, the Fraunhofer Institute for Machine Tools and Forming Technology IWU and the University of Leipzig Medical Center — an opportunity to show what 3D printing is capable of. Within a single week, the researchers developed a 3D-printed emergency ventilator, the Next3d Airlog 2020, which could be used when high-tech ventilators were in short supply.

However, additive manufacturing techniques are good for more than just producing back-up options in a crisis. They are also fanning the flames of another trend: the growing demand for customization. Some sports shoe manufacturers have already begun using 3D printing to produce inserts that exactly match individual consumers' feet and gait, and optical businesses are printing spectacle frames that suit the buyer's face shape — it is batch size one and mass production all at once.

Individual solutions are vitally important in the medtech industry, as it is a field where the "one size fits all" approach rarely works properly. Additive manufacturing has long been used to make patient-specific dental crowns, hearing aids and implants. Now, thanks to the high-precision software Cuttlefish, the expert team led by Prof. Philipp Urban at the Fraunhofer Institute for Computer Graphics Research IGD is manufacturing detailed artificial eyes out of plastic with a 3D printer. This accelerates the manufacturing process for false eyes considerably. And if the prosthetic should get lost or broken, a replacement can be printed in no time.

For patients with suspected brain tumors, the next step is a biopsy. To keep the risks involved as low as possible, Next3D joined forces with Fraunhofer IWU's Medical Engineering department and the Fraunhofer Plastics Technology Center Oberlausitz to develop the Leipzig DBS-Unit, a stereotaxy platform where all the cranial equipment, including the biopsy needle, is specially manufactured to suit the patient. This makes the risk of damaging brain tissue on the way from the skullcap to the potential tumor much lower. Next3D has brought its expertise to bear in vascular surgery as well, by creating 3D-printed, patient-specific models of the blood vessels. This allows surgeons to prepare stents (implants that hold the heart's blood vessels open) of exactly the right size before conducting operations, which can reduce operation times from a matter of hours to just 90 minutes.

However, 3D printing is not only changing treatment itself, but also the path to finding the right treatment. Additively manufactured lab-on-a-chip systems — another research focus at Fraunhofer IWS — have already made patient-specific drug testing and laboratory diagnostics a reality. In these systems, human cells are integrated into a circuit so as to create organ models. "These days, it's even possible to connect these organ systems with each other, so that the effects of medications can be observed in a more holistic way," explains Ms. Leopold. This means that there will be less and less need for animal experimentation in drug testing. These credit-card-sized labs also allow scientists to test how drugs will affect a specific patient.

The idea of additively manufacturing entire organs for transplantation out of patient cells is still something of pipe dream, however. "There's definitely a long way left to go before that concept reaches industry application," Ms. Leopold confirms. She believes that the vision of using 3D printing to optimize and accelerate certain processes in clinics could be realized much more quickly. For example, during an operation on a patient with cranial trauma, it would be possible to scan their skulls and print and sterilize the part of the bone that requires reconstruction, so that it can be implanted immediately. The day when every hospital — and every hospital pharmacy — will have a 3D printing lab for manufacturing patient-specific products is not so far off, predicts Ms. Leopold. "In these labs, we will be able to print exactly what the patient needs, right where it is needed."

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More than a facade

The potential of vertical surfaces: Facades protect buildings from the weather and are pleasing to the eye — but they can also offer a lot more. As temperatures rise across the globe, the outer walls of buildings have their work cut out for them.

By Beate Strobel

Combining nature with stone and glass: the Kö-Bogen in Düsseldorf, designed by famous architect Daniel Libeskind. Photo: Ralf Ibing/ picture alliance

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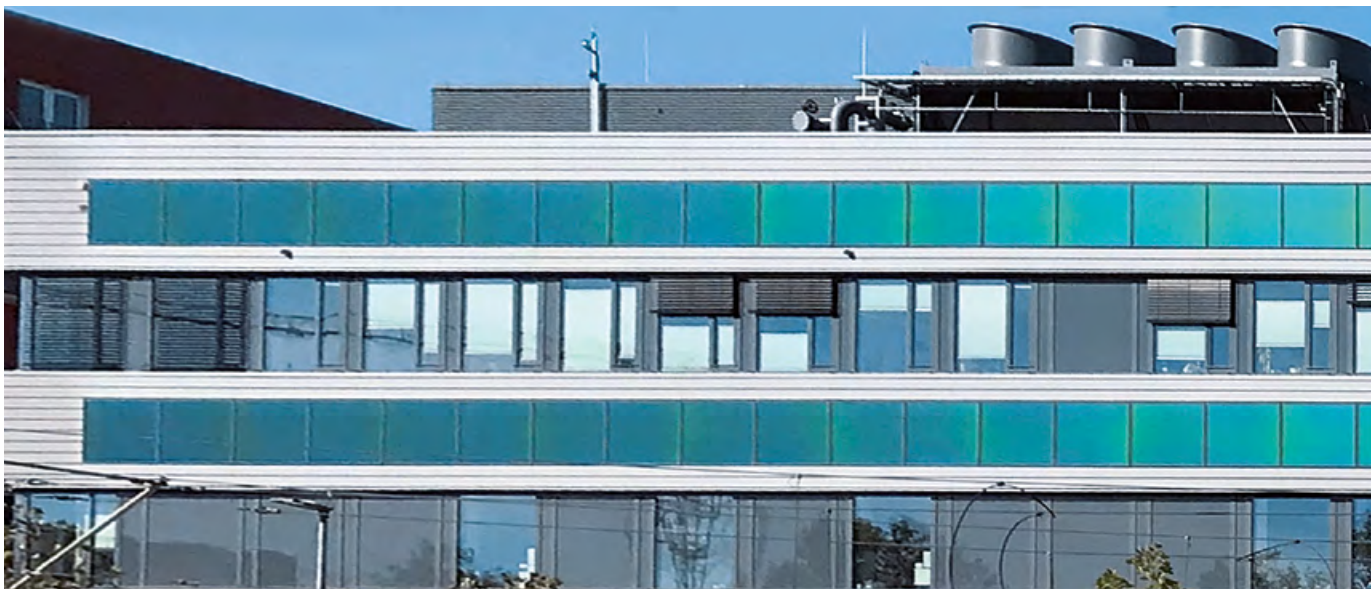

Green in both senses of the word: Solar panel modules at Fraunhofer ISE produce solar energy — and thanks to their MorphoColor® coating, they look good doing it.

A three-storey house in Holzkirchen, Bavaria sits within earshot of the A8 autobahn; at first glance, it could be mistaken for an office building. But take a closer look and you'll notice that the facade has some unusual features: floor-to-ceiling windows, external roller blinds, a sunshade attached from the inside. On the third floor, there is a black photovoltaic module attached between two windows on the external facade. Why the inconsistency?

There is method to the apparent madness of this exterior design. This mini high-rise is no ordinary building — it's an experimental facility for energy and indoor climate studies (Versuchseinrichtung für energetische und raumklimatische Untersuchungen, VERU). It is run by the Fraunhofer Institute for Building Physics IBP in the Upper Bavarian municipality of Valley, and its ability to transform its facade is one of the key features of its design. Between an underlying structure of reinforced concrete, there are individual segments that can be quickly and easily swapped out for new facade solutions. This allows the function and efficiency of these solutions to be tested for the purposes of research or on behalf of industry.

Facades that make a difference, both inside and out

Herbert Sinnesbichler, the group manager for Evaluation and Demonstration at Fraunhofer IBP, is master of the test house. Mr. Sinnesbichler is a technical physicist who joined Fraunhofer IBP as a graduate student; he has been conducting tests on solar shading and cladding systems at VERU for nearly 20 years alongside an interdisciplinary team. To him, a facade is more than just a creative cover for a building. "A facade is the point of contact between a building and the outside world; as such, it has a significant effect on the property's energy demand and can create a comfortable climate within the rooms." In Mr. Sinnesblicher's expert opinion, anyone who reduces a

> "A facade is the point of contact between a building and the outside world; as such, it has a significant effect on the property's energy demand and can create a comfortable climate within the rooms."
>
> Herbert Sinnesbichler, Fraunhofer IBP

Photo: Benedikt Bläsi/Fraunhofer ISE

building facade to its purely aesthetic function is underestimating its potential in terms of physical construction possibilities and energy use.

Future facades will have a laundry list of tasks: keeping out the wind and weather, letting in light, maintaining the best possible indoor temperature throughout all four seasons and, ideally, generating additional energy (see: building-integrated photovoltaics, BIPV) — and looking good while doing it.

Fraunhofer UMSICHT has added yet another item to this list. For more than eight years, UMSICHT researchers have been working on vertical greening systems that allow building facades to become active parts of urban environments. "Together with partner companies, we have developed special construction elements for building green walls that are not attached to the ground," explains Holger Wack, deputy head of the Product Development department at Fraunhofer UMSICHT. Vertical greening processes involving grasses, flowers, herbs and even crops can improve air quality, decrease CO_2 levels, reduce noise and bind fine particulates. They also counteract some effects of climate change, including heavy rain, heat, drought and biodiversity loss.

Inspired by butterflies

For several months, the Center for Highly Efficient Solar Cells at the Fraunhofer Institute for Solar Energy Systems ISE has been fitted with BIPV facade modules that can become green — literally. On top of supplying the institute with around eleven megawatt hours of solar power per year, this pilot project will also give the building green accent walls. This is made possible by the MorphoColor® coating developed by Fraunhofer ISE, which adds color to the solar panels while maintaining at least 90 percent of the modules' efficiency. In developing this design, the researchers looked to nature. Blue morpho butterflies do not simply have blue pigments in their wings to give them their distinctive hue — instead, the impression of luminous color is created by a multitude of wafer-thin scales layered on top of each other like bricks. These refract incident light in such a way that only the blue light waves are reflected back. Similarly, the coating on the MorphoColor® panels reflects only a certain color of the light spectrum, while the rest of the sunlight can pass through the layer unimpeded and be used for energy.

By combining aesthetics with functionality, these panels have the potential to win over customers that remain hesitant about the idea of BIPV modules. It would be relatively easy to integrate these PV modules into the many surfaces on building facades that are already extensively glazed. Fraunhofer ISE estimates the technical potential of BIPV modules in facades in Germany (including both residential and non-residential buildings) to be around 440 gigawatts at peak — just slightly less than the potential of BIPV modules on roofs (560 GWp). The addition of ▶

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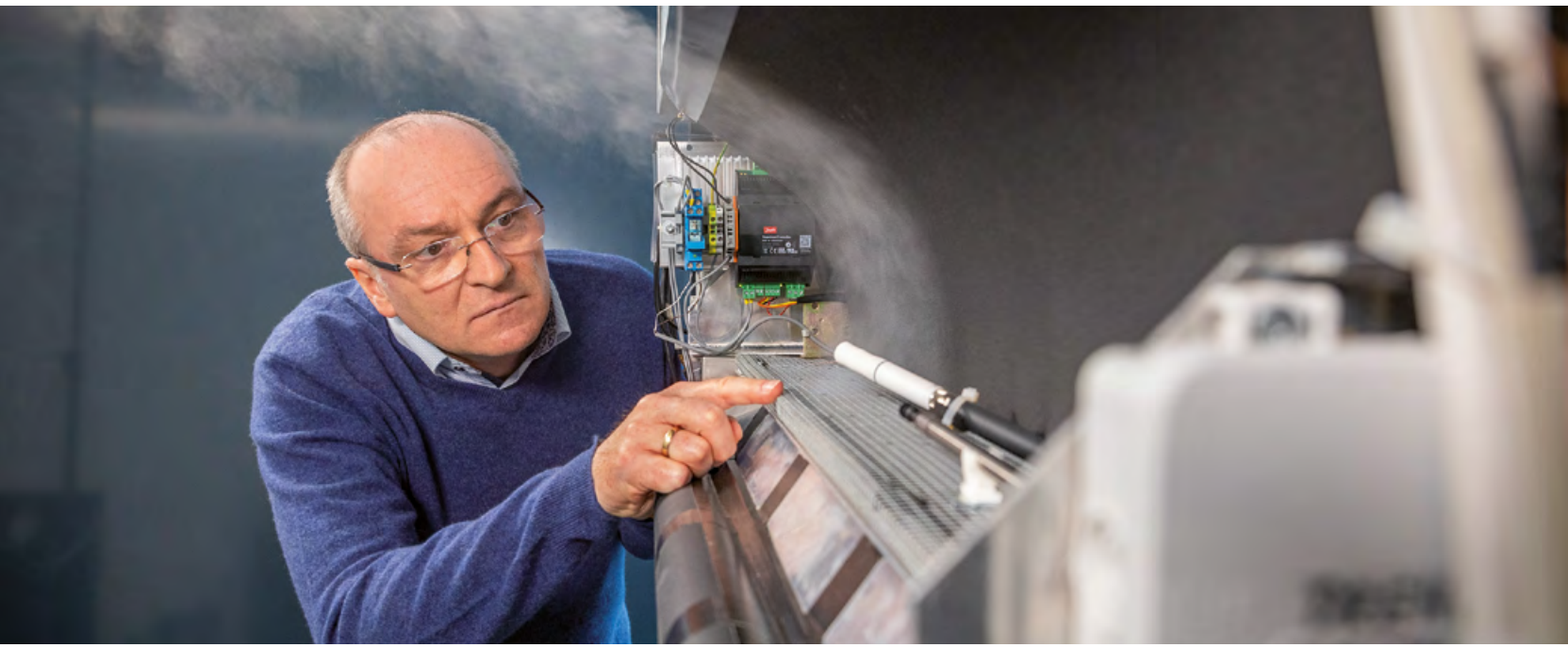

Is there a draft? While testing the RE modular facade, Herbert Sinnesbichler of Fraunhofer IBP uses a fog machine to visualize airflows.

colors could help increase this potential. However, despite providing solar energy, glass facades come with a considerable problem: Along with light, they let in heat, which can be especially problematic in summer. The PV module currently in place on the southern face of Fraunhofer IBP's VERU facility could help here. Part of a facade module for air conditioning in buildings, it was developed by Fraunhofer IBP and the Fraunhofer Institute for Energy Economics and Energy System Technology IEE in collaboration with industry partners. The photovoltaic element generates enough renewable energy to ventilate the office space on the other side of the wall; in addition, it has a miniature heat pump that allows for heating and cooling. As such, it represents an all-inclusive solution: All of the heating, cooling and ventilation technology needed for the office space indoors is integrated into the facade module. Apart from these, the office just needs a power connection for the times when the solar energy is not enough to fully power the components. Since all of the important components are already in the module, the researchers believe that renovating buildings, particularly existing stock, to make them more energy-efficient will be a quick and inexpensive process.

But does the renewable energy (RE) modular facade work as intended? Michael Eberl, a scientist at Fraunhofer IBP, has equipped the facade of the VERU test room with a prototype and fitted out the room itself with all kinds of measurement technology that will examine the functionality of the system, record energy flows and measure comfort parameters such as air temperature, humidity and air velocity. Two black metal tubes in the center of the room are used in combination with humidifiers to represent the heat and humidity inputs of the office workers that will one day work on the other side of the wall from a RE modular facade such as this. This functional mock-up is used to test and optimize the module itself and the interactions between the various components in the room. Although he doesn't want to make any predictions regarding test results, Mr. Eberl is quite satisfied so far.

These experimental setups generally run for at least nine months, in order to include as many seasonal changes as best as possible. Mr. Sinnesbichler says the VERU site in Valley is ideal for this because of its extreme weather conditions: Be it sun, wind, rain, frost or snow, the foothills of the Alps see plenty of every type of weather over the course of a year. Now, in early Spring, snow and fog are still enveloping the VERU in a wintry shroud of white and gray; it is bitterly cold in front of the experimental building and in the stairwell. However, the prototype test room itself is warm and toasty — another good sign.

"In order to know the sensation of a room that is equipped with a certain facade solution, or what it's like to sit and work there, you just have to sit there and feel it."

Herbert Sinnesbichler,
Fraunhofer IBP

Taking a seat: Michael Eberl adjusts the sensors on DressMAN. This measuring manikin is used to record the overall thermal comfort of the room.

For large-scale building projects, around 15 to 25 percent of construction costs go toward creating the facade. In view of the sheer scale of the costs, it is a good idea to invest in pre-testing new designs and concepts using functional mock-ups. This can help detect possible weak points at an early stage and avoid expensive efforts to rework the finished structure. "Relying solely on the drawing board and digital simulations means accepting a high level of risk," says Mr. Sinnesbichler, an engineering graduate. Simulation tools are often used during the studies conducted at VERU. However, the models used for this purpose are usually checked and validated on the basis of real measured values collected beforehand.

A glimpse behind the facade

VERU turns the concept of flexibility into a house: The measuring cells are so variable that it is possible to simulate different structures, including individual offices, open-plan offices and conference rooms, without any problems. Moreover, the second floor hosts two identical test rooms — known as energetic twin rooms — that can allow for comparative measurements. Now and again, people are invited to take part in the tests so that researchers can look beyond the objective measurement data and record subjective impressions of the indoor climate. This usually takes a lot of time and effort, however: "If we want the data to be representative, we must invite a really high number of people to the test," explains Mr. Sinnesbichler.

That is why the team at Fraunhofer IBP prefers to use DressMAN — a life-size climate measuring manikin that is equipped with numerous sensors, from its blue sneaker-clad feet to its synthetic forehead. Mr. Eberl carefully bends the dummy's limbs until it sits at a desk like a human being. All the measurement data that the DressMAN (or woman, as there is of course also a female version) provides to researchers is fed into an algorithm that can be used to calculate the overall thermal comfort of the room. For companies, the comfort of DressMAN — and as a result, of their office workers — is a high priority. Compared to employees that enjoy a good work climate — literally — employees that spend their working day sweating, freezing or complaining about drafts are less productive and more prone to making mistakes.

In order to know how it feels to be inside a room that is equipped with a certain facade solution, to understand what it's like to sit and work there, "you just have to sit there and feel it," says Mr. Sinnesbichler. If he was able to, DressMAN would probably agree. ■

For large-scale building projects, around **15 to 25 percent** of construction costs go toward creating the facade.

Photos: Axel Griesch/Fraunhofer IBP (2)

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A voice from the business world

Klemens Haselsteiner, 42, has been CEO of STRABAG SE since the beginning of this year; the company took in more than 16 billion euros in revenue in 2021.

We need a revolution in construction. Now!

The construction industry accounts for about 38 percent of global CO_2 emissions. As such, the entire industry is responsible for ensuring that value chains become more sustainable. That means it's not only time for us to rethink construction, but to actually "redo" it.

Klemens Haselsteiner, CEO of STRABAG SE, shares his thoughts

What we build will last, often for years or decades. Some things will be here forever. This means we have to deliver, not only when it comes to infrastructure, but for housing too. After all, there is an urgent need for affordable, energy-efficient housing, especially in cities. Germany alone requires 400,000 new apartments per year. On one hand, we need to achieve this target; on the other, we must bring the energy transition to fruition — this means we have no choice but to renovate existing buildings at an increased rate. As it stands, only 500,000 apartments per year are modernized to make them more energy efficient. Given Germany's overall stock of 42.5 million homes, this figure amounts to slightly above 1 percent. This is simply not enough.

Thinking about the future means confronting the present in no uncertain terms: We will only achieve our climate and housing construction targets if we make our planning and building process more sustainable (i.e., they conserve more resources and become more environmentally friendly) faster than we ever have before. And to do that, we need to think and act differently. No ifs, ands or buts. Just doing!

The "how" is key

As the leading group for construction technology in Europe, we are well aware that carrying on with "business as usual" is not viable. That is why we have set ourselves the ambitious goal of achieving carbon neutrality along our entire value chain by 2040 and working with our partners to develop eco-friendly, sustainable solutions for construction. For us, this means three things:

First: being bold and fostering an innovative corporate culture. To this end, we hold an Innovation Day and Stakeholder Dialogue events, which we use to connect future topics and developments within the group and promote exchange between colleagues, customers and customers. Moreover, our corporate start-up program adAstra also offers the opportunity to bring innovative ideas to life and use them to found start-ups. We are currently working on the future of construction as part of over 250 innovation projects and 400 sustainability projects.

"Thinking about the future means confronting the present in no uncertain terms. No ifs, ands or buts. Just doing!"

Klemens Haselsteiner

- joined STRABAG in 2011; since January 2023, he has been responsible for the overall business activities of the Austrian construction technology group as its CEO.
- helped with the company's digital transformation in his role as Chief Digital Officer; he also played a key role in drawing up STRABAG's sustainability strategy, which the company will use to accomplish its aim of becoming climate-neutral by 2040.
- is driving more than 250 innovation and 400 sustainability projects in the company with his team and 74,000 colleagues.
- studied business administration in Chicago and was appointed to the group's executive board in 2020. He is married and has three children.

Second: searching for partners. After all, revolutionizing construction is not a task that we can achieve alone. It requires expertise and external know-how. We work closely with research institutions and think tanks. We have tested photovoltaic facade elements with the Fraunhofer Institute for Solar Energy Systems ISE in Freiburg. These elements, once integrated into building facades, produce green energy and supplement the building's energy generation process. And with the University of Stuttgart, we are researching software-based life-cycle assessment processes for building systems. With the help of artificial intelligence, IoT-based communication and cloud-based building control technology, we are aiming to improve resource efficiency in the long term across the entire life cycle of a building.

Third: recognizing that digitalization can allow us to consistently automate processes. The construction sector is still lagging behind other industries in terms of the digital transformation. However, new technologies offer a host of opportunities to make construction planning more sustainable. One example is artificial Intelligence. Automated processes such as generative design can help us plan buildings and construction sites more quickly and efficiently and use fewer resources in the process. Planning and production are more closely linked and stakeholders receive better access to data. This makes it possible to precisely calculate the optimization potentials for material requirements and emissions, even in the early stages of a project.

Quicker and more daring

I believe that climate protection can drive innovation and competitiveness in our sector. For this to continue, we need a reliable political framework. That means speeding things up. Planning and approval processes must be completed more quickly. It means more circular processes: There must be a focus on closing material cycles. And it means being more daring: The spirit of innovation needs to be fostered, not hindered. From our company's examples and from our collaboration with partners, it's clear to see that if you are open to approaching things differently and trust your own innovative strength while simultaneously working as part of a partnership, then it is possible to achieve a revolution in construction. ■

Photo: STRABAG

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These sensors can be spread over the aircraft like a second skin, collecting important data during the flight.

The Airbus comes to its senses

Flying is fast, fun — and detrimental to the climate. Fraunhofer IZM is working on increasing its energy efficiency, making air travel more environmentally friendly.

Illustration: AdobeStock/Who is Danny

Energy efficiency has to take to the skies. But how? Researchers at the Fraunhofer Institute for Reliability and Microintegration IZM are working hard to find the answer. One possibility would be to develop lighter, more durable materials and optimize aerodynamics.

In order to make improvements in these areas, researchers need exact data on the level of wear, air resistance and stress that an aircraft experiences during flight. The scientists have been commissioned by Airbus to develop a type of sensor skin that can be stretched over the wings. These robust sensors would reliably measure temperature, air pressure, oscillation and vibration and would be integrated into the plastic cladding of the aircraft. They must not only withstand extreme winds, turbulence and pressure differences, but also be impervious to chemicals such as de-icing agents and kerosene. Moreover, it is imperative to avoid damaging the sensitive components and the plastic coating made from thermoplastic polyurethane (TPU) during assembly.

To begin with, the researchers characterized the plastics in order to determine the values for important parameters like thermal expansion and elasticity. These findings were incorporated into further simulations that predicted both the specific weak points and the service life of the TPU under mechanical and thermomechanical stresses. Using this data, it was then possible to establish the ideal process parameters (e.g., temperature, pressure settings) for foil lamination and soldering of the devices and components.

Pliable and flexible

The researchers were able to create the circuit pattern for the elastic sensor module via the standard lithography and etching processes used in circuit board manufacturing. Following the assembly and soldering of the components, the team led by Dr. Stefan Wagner and João Alves Marques demonstrated two processes for protecting the components from external influences. The first involves the polyurethane-based casting compound glob top, which, once hardened, acts as a seal for microelectronic components; the second involves integrating thin chips right inside of the substrate through flip-chip assembly. A clear advantage of these technologies and materials is that as a circuit carrier with integrated sensor modules, the TPU offers a high level of flexibility. This pliable substrate can cling to the wings, while simultaneously protecting its in-built electronics. ■

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Little pumps, big potential: Thanks to Agnes Bußmann, micropumps could soon be improving the lives of many patients and bringing about new medical innovations.

First prize: Dr. Agnes Bußmann

Pump it up: harnessing the potential of micropumps for medicine

At 5 millimeters by 5, they are smaller than a fingernail. But in the medical world, they can punch above their weight: Micropumps could be used to administer cancer or pain medication over long periods, or insulin for diabetes. They could also simplify bioprinting and organ-on-a-chip applications. So why aren't they in use already?

By Mandy Bartel

Dr. Agnes Bußmann is a mechanical engineer. But for some time now, she has also been turning her focus to medical engineering. During her doctoral studies at the Fraunhofer Institute for Electronic Microsystems and Solid State Technologies EMFT in Munich, she was able to combine both interests by researching piezoelectric micropumps. "The medical potential of these micropumps is obvious. They are small, energy-efficient, precise, and can be adapted flexibly; they can be implanted or easily applied to the skin, which would mean better quality of life for patients," summarizes the young scientist. So far, so good, but: "Despite this, the micropump has yet to become established in the medical engineering market."

Dr. Bußmann investigated the reasons for this, and following comprehensive research, she came up with two significant

Hugo Geiger Prize

Prize for talented young scientists

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

obstacles to market introduction: For one thing, the pumps have so far been tested using water or other substitute liquids in most cases, which highlights pump performance, but masks the effects on the liquids being transported. So there is a clear lack of studies that use the pumps with pharmaceuticals or biological liquids in order to determine their suitability for use with medical products. Laborious approval procedures, as well as cost- and time-intensive development processes, often present another hurdle. To circumvent these, manufacturers usually just make minor adjustments to their existing products, instead of attempting real innovations — but this means they only achieve limited improvements.

"This has created a gap between research and practice, which I aimed to close in the course of my work," says the scientist. To do this, she has combined knowledge from the areas of materials and engineering science, electrical engineering, physics, chemistry and medicine. During her doctorate, she explicitly investigated the interactions between the pumps and the media, and further developed existing steel and silicon-based micropumps so that liquids containing cells or proteins neither get damaged by the pumping process, nor clog the pumps themselves. As a result, the scientist was able to confirm the theoretical potential of the micropumps in practice.

> "Finding new or improved treatments for serious disease is the main motivation for my research."
>
> Dr. Agnes Bußmann

She went on to find a solution for companies seeking to develop these little medical devices in a more cost-effective way. Together with her colleague Dr. Claudia Durasiewicz, she designed a technology platform for making flexible combinations of multiple microfluidic components and testing them in various medical applications. "The fundamental idea was to spread the initial costs of technical development and approval across multiple products and reduce the individual levels of expense. This means the micropumps can be brought to market more quickly and efficiently," says the researcher.

Now, in her role as group manager at Fraunhofer, Dr. Bußmann is driving the transfer process. "The Fraunhofer model, with its close ties to industry and a focus on interdisciplinary, applied research, was of great benefit to my work," she says. Soon, her team and its industry partners in the Moore4Medical project will transfer the new manufacturing processes into a production environment. This clears the way for getting medical micropumps into practical use, which could make life easier for many people in the future. As well as simplifying dosing for medication, the pumps are also suitable for use in hydraulic implants like artificial urethral sphincters. They could also optimize bioanalytic organ-on-a-chip systems, which are becoming increasingly important as a potential substitute for animal experimentation. While liquids for the cell cultures of these artificial organs are still being transported manually, integrated micropumps could enable automation of this process in the future.

As a result of her scientific contribution to future healthcare and her entrepreneurial thinking, Dr. Bußmann took first place in the Hugo Geiger Prize awarded by the state of Bavaria and the Fraunhofer-Gesellschaft. ■

Photo: Fraunhofer EMFT/Bernd Müller

Scan here for the podcast:

Read on for second and third prize ▶

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Second prize: Dr. Chiara Lindner

Measure better with quantum light

The composition of gases, chemicals and synthetic materials can be analyzed using a Fourier-transform infrared spectrometer. For the first time, this established procedure has now been combined with measurement principles based on quantum sensor technology — which opens up entirely new areas of application.

The optics laboratory is where she is in her element: To Dr. Chiara Lindner, this is where the abstract quantum world becomes tangible. The quantum physicist wasn't too enamored with this field at first: "At university, I often found it too theoretical, too awkward," she recalls. Until she came to work at the Fraunhofer Institute for Physical Measurement Techniques IPM in Freiburg, she never imagined that she would ultimately do her doctorate in this very discipline: Here she conducts research into how quantum effects can be used to significantly improve established measurement techniques.

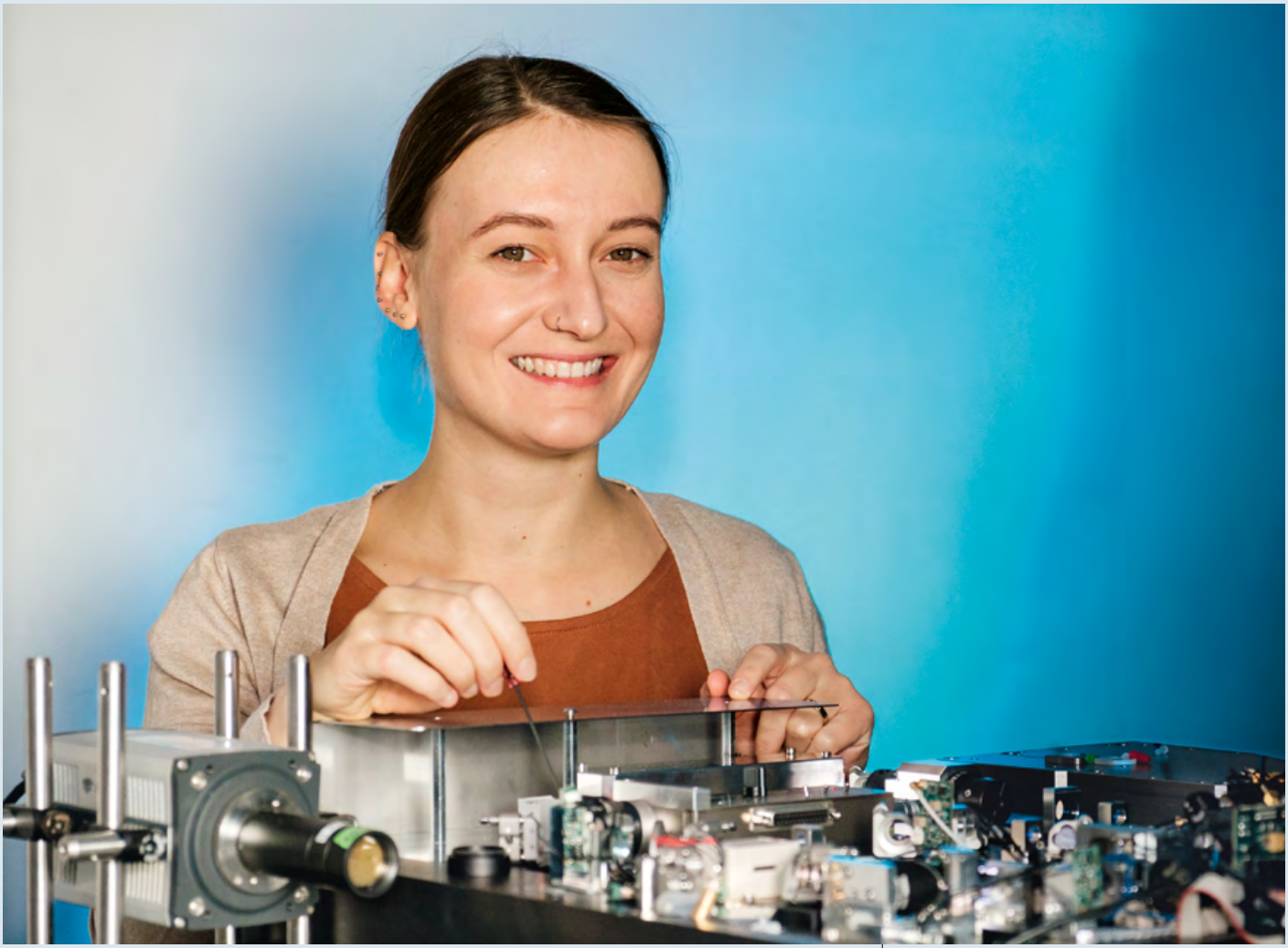
For decades now, the Fourier-transform spectrometer has been an integral part of any analytical laboratory. It uses characteristic transmission spectra to detect various molecules. This allows analysts to draw conclusions about material composition for in applications such as environmental analysis, pharmaceutics and material testing. The problem is that until now, this has required infrared detectors, which are slow and expensive. In her dissertation, Dr. Lindner found a way to improve these measurements, in terms of quality, cost and speed.

A quantum trick makes the invisible visible

To bypass infrared detectors and their limitations, the scientist relies on a quantum trick. She uses quantum-mechanically entangled pairs of infrared and visible light particles to measure the spectral information in the sample. One photon acts as a sort of visual aid for the other somehow. While the infrared light particle is the only one that "sees" the sample, its visible partner photon is registered by a highly sensitive silicon detector. Since the entangled quanta are closely connected, the fate of the infrared photons influences the behavior of the visible ones. This means that when the sample absorbs infrared light particles, there will be a change in the characteristic form of the signal from the visible photons. It is therefore possible to measure the properties of the sample under infrared light, even without detecting any infrared photons! This could allow traditional infrared detectors to be replaced with silicon detectors that are faster, cheaper and quieter.

> "Within four years, we have come from absolutely basic research all the way to the cusp of practical application."
>
> Dr. Chiara Lindner

Very early in her doctoral studies, the physicist had her eureka moment when for the first time, she got to see with the naked eye how the entangled photon pairs are generated. If a green laser beam is used to illuminate a special crystal, the entangled photons become visible on screen in the form of a faintly glowing red circle. Within a few months, Dr. Lindner managed to demonstrate the initial transmission spectra. She went on to achieve a global first by using "undetected photons" to map the fine spectral structure of rotational lines in a gaseous sample. This new procedure is of particular interest in biological sampling, where samples are often very light-sensitive and can behave differently when illuminated. The reason is



Inspired by the possibilities of quantum physics: Chiara Lindner has developed the first quantum Fourier-transform spectrometer.

Photo: Fraunhofer IPM

that the quantum trick reduces the required level of light intensity by a factor of approximately one million when compared to classical measurement methods. The scientist wants to build on this potential: "In the future, our plan is to combine our spectrometers with imaging techniques, making hyperspectral imaging a possibility."

With her dissertation, Dr. Lindner achieved second place in the Hugo Geiger Prize awarded by the Bavarian Ministry of Economic Affairs, Regional Development and Energy (StMWi). At the end of 2022, she also received the Quantum Futur Award from the German Federal Ministry of Education and Research (BMBF). So in retrospect, she is glad to have chosen quantum optics as her topic: "Ultimately, I got to experience the diversity and excitement of quantum technologies as a field of research. When you apply these concepts in a practical setting or laboratory experiments, the abstract suddenly becomes quite tangible." ■

Scan here for the podcast:

If a green laser beam is used to illuminate a special crystal, the entangled photons become visible on screen in the form of a faintly glowing red circle.

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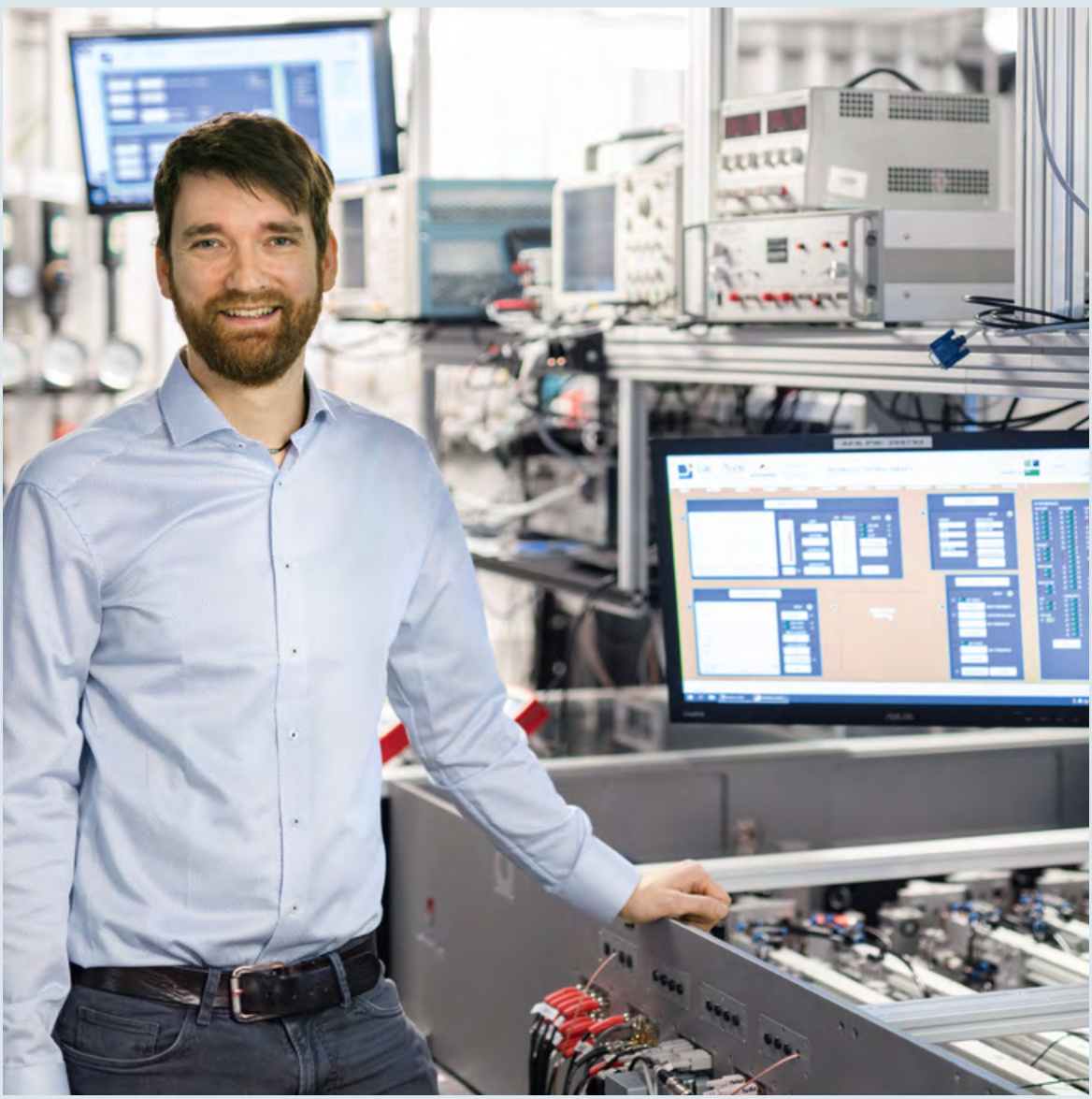
Third prize: Dr. Robert Klas

The large-scale research facility that fits on an optical table

Extreme ultraviolet light radiation brings many benefits, but generating it is a very complex matter. However, thanks to Dr. Robert Klas' work in one area of short-wave research, it is just possible that large, expensive research facilities will no longer be needed for this in the future.



Dr. Klas can do with an optical table what it usually takes a huge building to achieve. During his doctoral studies, he developed the most powerful source to date for laser-like extreme ultraviolet light (EUV) on a laboratory scale.

The road from idea to innovation was a rocky one for Dr. Robert Klas. Many experiments failed, designs had to be reworked, setups adapted, and new optics tested — all of which took six years. "During my doctorate, I took a chance by looking into a completely new area that no one else had entered before. So there was no previous knowledge base to fall back on," recalls the physicist. However, the chance paid off: "We went through the calculations so many times beforehand that it just had to work!"

Dr. Klas' research area is not just extremely challenging, but above all extremely ultraviolet: EUV radiation is a very short-wave spectral range of light that borders on the X-ray range. Its short wavelengths measure only 10 to 50 nanometers — and for scale, 1 nanometer is equal to a millionth of a millimeter. This light is therefore suited to generating correspondingly small structures, or simply making them visible. The semiconductor industry already uses EUV light to apply more than ten billion transistors to a chip the size of a fingernail. But its potential is even greater again. In the future, EUV light could be used in microscopy too, to make visible very small structures that cannot be seen under natural light.

Ultra-fast laser dynamics

At present, applied research using EUV light presents quite a challenge, because up to now, it has only been possible at large-scale research facilities, which are costly and difficult to construct and operate. These synchrotrons have long waiting lists, and if you manage to get a slot, everything had better go to plan, as there can often be a long wait for the next opportunity. During his doctoral studies, Dr. Klas collaborated with the Fraunhofer Institute for Applied Optics and Precision Engineering IOF in Jena to find a more efficient avenue for this research. "The compact experimental setup for our laser-like EUV source costs a fraction of an equivalent large-scale research facility, fits on a standard optical table and is much simpler to operate," he reveals.

> "The findings of my doctoral thesis could drive developments in many important areas — in the energy and storage efficiency of chips, in biology and in medicine."
>
> Dr. Robert Klas

To generate the EUV light, the physicist uses powerful, state-of-the-art ultra-short pulse lasers, after doubling and compressing the pulse frequency. He uses these extremely short light pulses of 10 femtoseconds — where 1 femtosecond is equal to one billionth of a millisecond — to accelerate electrons. These then produce EUV light by recombining with their parent ion. The main challenge here is to superimpose the released radiation consistently, i.e., to control it in such a way that its wave crests accumulate in the extreme ultraviolet spectrum. After many attempts, Dr. Klas has succeeded in developing the most powerful laser-like EUV source to date on a laboratory scale — it is one hundred times more powerful than what was previously available.

Broadening the visible spectrum

More power means quicker measurements. This makes it possible to conduct real-time measurements that previously took an hour or more. This is an exciting development for microscopy in particular. "You can't think of EUV microscopes in the same terms as a classical microscope," says Dr. Klas. "We use the stray light from a sample, which lets us draw conclusions about its appearance; then, we can use digital optics to create a precise color image of the sample from that stray light." The method could be used for imaging bacteria or viruses. "At some point, we also hope to use this method to image DNA, which has a diameter of about 2 nanometers," reveals Dr. Klas.

In the meantime, the use of EUV lithography in chip production represents another field of application that is ripe for rapid implementation. Transferring the tiny three-dimensional structures onto a wafer requires masks, which are reflected as duplicates. Dr. Klas' source allows these masks to be checked for defects even before the lithography process begins — and at the same wavelength that is later used to etch the chip. The short wavelengths could also be used during material machining to bore holes a few nanometers deep, for example.

For Dr. Klas, his perseverance has paid off: Due to his outstanding doctorate, the scientist achieved third place in the Hugo Geiger Prize awarded by the state of Bavaria and the Fraunhofer-Gesellschaft. His research findings are already on course for practical exploitation through the Fraunhofer spin-off Active Fiber Systems GmbH in Jena, a member of the TRUMPF Group. ■

Scan here for the podcast:

Photo: Fraunhofer IOF

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Photo & Fraunhofer

Ocean energy

When waves crash spectacularly against a quay or endanger a heavy tanker, their power becomes palpable. Theoretically, ocean waves could produce enough energy to meet global electricity demand — according to the estimates of the World Economic Forum. But how can we harness this force of nature?

For over a decade, researchers have been exploring the possibility of wave power plants; in Israel and Spain, for example, the first, small port facilities are already in operation. However, on the open sea, where there is ample space and the swell is strong, wave power plants have so far not progressed past the prototype stage: they are too expensive and require too much maintenance. Moreover, given their costs, the energy volumes they produce are too low.

Now, however, the world of research and industry is making another attempt: The project WEDUSEA (Wave Energy Demonstration at Utility Scale to Enable Arrays) will demonstrate the potential of a grid-connected wave power station with an electrical capacity of 1 megawatt in the Atlantic Ocean above the northern coast of Scotland. WEDUSEA is a consortium project involving 14 industrial and scientific partners from the UK, Ireland, France, Spain and Germany, including the Fraunhofer Institute for Energy Economics and Energy System Technology IEE. "In WEDUSEA, our main tasks are to do with designing the electric drive train and, later, optimizing the plant control system," explains Fabian Thalemann, a project manager at Fraunhofer IEE.

The project is being managed by OceanEnergy, the Irish company that developed the OE35, the world's most powerful floating wave power station. Simply put, the system, which is anchored in the sea, consists of a hollow structure with openings below and above the waterline. Incoming waves push the air in the hollow spaces out through the hatches above the surface; as the waves recede, they draw in new air. No matter which direction it flows in, the moving air propels the turbine to generate electricity, which can then be transported to land via cable or used to power off-shore systems.

WEDUSEA, which is scheduled to run until 2026, will use the OE35 to take wave energy technology to the next level in terms of efficiency, reliability, scalability and sustainability. So that we can finally harness the power of the waves on a large scale.

Photo: Thomas Reich, bilderreich.de

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Green electricity from the tank

When it comes to expanding the share of renewable energies in our power supply, energy storage systems are key. Redox flow batteries offer large storage capacities at a low cost. However, their market share so far has been negligible. That could soon change.

By Michael Krapp

This January, the world's largest redox flow battery began operation in the port city of Dalian in Northeast China. This battery has a capacity of 100 megawatts and can store 400 megawatt hours of energy from a large wind farm. With an average annual power consumption of 4,000 kilowatt hours, the battery could supply 100 households with electricity for a year. However, the technology is mostly used to stabilize the power grid for periods of hours. Germany and Europe also urgently require new battery systems — not only due to the current energy crisis, but in the long term for the energy transition.

Redox flow batteries come with a variety of different advantages. For instance, they are recyclable, easily scalable and long-lasting; they have an efficiency rating of over 75 percent and, since the electrolytes are stored in two separate tanks, their rate of self-discharge is extremely low. Thanks to their aqueous electrolyte liquids, they are also non-flammable. "Stationary energy storage systems with lithium-ion technology are a fire hazard in the truest sense of the word," says Mr. Noack, a chemical engineer from the Fraunhofer Institute for Chemical Technology ICT in Pfinztal, near Karlsruhe.

Despite their many advantages, the market share of flow batteries has so far been negligible due to the high costs associated with chemical battery systems.

Mr. Noack, a chemical engineer, believes the levelized costs of storage (LCOS) are a key factor influencing companies' decisions to invest in flow batteries. LCOS refers to the average cost of electricity discharged, taking into account all expenses incurred for the installation and operation of the energy storage system during its lifetime. When it comes to the LCOS for large stationary energy storage systems, flow batteries now have an advantage over their competitors, lithium-ion batteries. With proper maintenance, liquid electrolyte-based battery systems have a service life of up to 20 years; they can also be scaled up to the gigawatt-hour range and are very safe to operate. In contrast, lithium-ion battery storage systems are limited to about 3,000 charging cycles and can only offer capacities in the megawatt-hour range. Moreover, procuring raw materials for the batteries can be problematic.

Photo: Fraunhofer ICT

The redox flow battery at Fraunhofer ICT includes an extensive network of piping. The battery has a capacity of 20 megawatt hours.

Up until now, vanadium appeared to be the ideal raw material for flow batteries. However, manufacturers of vanadium redox flow batteries are struggling with price fluctuations on the world market. Furthermore, around 75 percent of the global vanadium supply comes from China, South Africa and Russia. The European Commission therefore classifies vanadium as a critical raw material. In order to avoid forming new dependencies as we develop future battery systems, it is crucial that we select inexpensive, readily available and wholly ethical raw materials.

"Researching flow batteries now involves a global race to find new electromaterials," reports Noack. Europe is aiming to take the lead. Through SONAR, a project coordinated by Mr. Noack, researchers intend to help achieve this goal. The project uses simulation to search for innovative electroactive materials suitable for organic flow batteries, as well as working on the batteries' design and operation. The European Commission is providing the research project with 2.4 million euros in funding.

"In order to stay competitive, we have to reduce the costs of new battery systems up to the point that they enter the market and shorten the development time," says Dr. Jan Hamaekers. He heads up the Virtual Material Design department at the Fraunhofer Institute for Algorithms and Scientific Computing SCAI in Sankt Augustin, near Bonn. Within the SONAR project, he is responsible for putting research results into industrial practice. In order to determine which materials are suitable alternatives to vanadium, modeling must be carried out at various levels. "We combine different simulation methods on different physical scales, from the quantum mechanical level to visible, macroscopic behavior," explains Dr. Hamaekers.

The simulation runs are executed on the project partners' high-performance computers, and generate an enormous amount of result data that is constantly growing. In order to analyze this data, the researchers employ machine learning methods that were also developed at the institute.

"The results of the automated search also include substances that don't even exist yet," reports Dr. Astrid Maaß, a colleague of Dr. Hamaeker. While these substances may theoretically be ideal for use as electrolytes in a flow battery, Mr. Noack and his team at Fraunhofer ICT are researching whether they are actually suitable in practice by testing them in the laboratory.

"Our project will run until the end of 2023. Until then, we can offer the industry various services for screening new active materials," says Dr. Hamaekers. This will also include simulation tools that can be used to record processes in the battery cells and determine aspects of cost and benefits in specific systems as early as the planning phase. "This represents an important advantage for European companies, as it can considerably shorten the time between developing new flow batteries and bringing ready-to-use electricity storage systems onto the market," he asserts. To this end, the academic project partners — which, in addition to Fraunhofer ICT and Fraunhofer SCAI, include the Technical University of Denmark, the Laboratoire de Réactivité et Chimie des Solides (LRCS) at the Université de Picardie Jules Verne in Amiens, the Zurich University of Applied Sciences, the Karlsruhe Institute of Technology and the University of New South Wales in Sydney — are working in collaboration with renowned industrial partners. "Companies' experiences are particularly valuable to our research work," emphasizes Dr. Hamaekers, an expert in computer-aided materials design.

In early February, Mr. Noack, the project coordinator, presented the initial research findings at a conference on materials research in Rotorua, New Zealand. The audience showed great interest. The pace is picking up in the race to create the best flow battery system. Can Europe keep up? Mr. Noack is optimistic, but believes we need to step up our game: "In China and the U.S., considerably more public funding is being invested in research for new battery storage systems." ■

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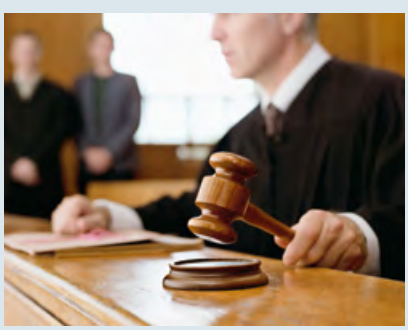
AUSTRIA

Convicted by an avatar

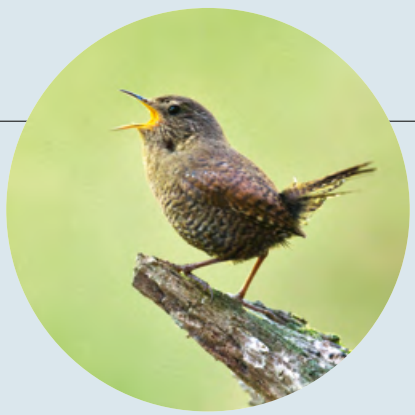
In large countries such as Australia and Canada, where online appointments help people avoid making long journeys, conducting court hearings via video conferencing has long been a norm. Soon, these online hearings will also become part of everyday life in Europe. Researchers at Fraunhofer Austria are working on a new software program that could prove to be a trailblazer. The core element of their new development is the program's ability to transmit users' eye movements and facial expressions to proxy avatars in a virtual courtroom. The data is collected using a webcam, meaning that technical VR equipment such as glasses and headsets are not required. As soon as the system detects the direction of the user's gaze on the screen, it makes the avatar's head move in the same way, thereby simulating eye contact. It also transmits facial expressions and mouth movements. Currently, researchers are programming the synchronization of tracking data. In the recognition software, each avatar will be depicted in their specific role in the court — these roles are being developed in close collaboration with international lawyers. Researchers have already successfully tested a prototype of the virtual courtroom, which can be adapted to country-specific requirements.



Soon, judges will be bringing down the gavel in a virtual courtroom.

Fraunhofer worldwide

Locations of the Fraunhofer-Gesellschaft



The monitoring system can reliably recognize a bird species by its song.

EUROPE

Biodiversity in the field

As part of the EU project BioMonitor4CAP, partner organizations from ten European countries and Peru are working to preserve biodiversity on agricultural land. Using a new approach to biodiversity monitoring that combines conventional indicator systems with acoustic, optical and molecular methods, the researchers intend to show changes in species diversity over a longer period of time — a technological first — and develop measures for sustainable agricultural management. In this project, the Fraunhofer Institute for Digital Media Technology IDMT is responsible for the acoustic monitoring of birds, bats and crickets. For their field studies, researchers are using intelligent high-frequency sensor systems. These can even detect animal sounds in the ultrasonic range, such as the sounds emitted by bats and insects. The sound signals are automatically evaluated with the help of artificial intelligence and used to reliably identify the different animal species. The meta-information forwarded by the sensor nodes allows the researchers to create comprehensive spatial, temporal and statistical models of the data.

FRANCE

A better way of recycling vehicle batteries

The higher number of electric cars on our roads means a higher number of used batteries: By 2030, the volume of used batteries in Europe will increase eightfold to over 400 kilotons per year, according to calculations by the Fraunhofer Institute for Systems and Innovation Research ISI. As part of the RecyLIB joint research project, colleagues from the Fraunhofer Institute for Silicate Research ISC are working with partners from Belgium, France and Germany to investigate how to successfully produce sustainable vehicle batteries using a recycling method that preserves the functions of components. By means of electrohydraulic shockwaves, the battery components are gently split apart at the join between different materials using a water-based separation and sorting process; they are not broken down into their original, individual raw materials, as is the case with the current established recycling processes. This allows the active functional material to be recovered and reprocessed to form the same material composition again. The goal is to return the recycled electrode material directly to the manufacturing process without compromising cell performance. The use of toxic solvents will be avoided in order to ensure a sustainable, circular battery ecosystem.

How well do recycled materials perform compared to primary raw materials? This is also being investigated as part of the project.

BRAZIL

Getting rid of plastic waste

Every year in Brazil, more than 2.4 million tons of plastic ends up in landfills or as litter in the environment. In order to significantly increase the rate of recycling for plastics and create socio-economic structures for a decentralized collection and recycling system, the Fraunhofer Institute for Chemical Technology ICT is collaborating with German and Brazilian partners to develop an integrated, resource-conserving value chain for complex PET packaging, such as opaque and multilayer packaging. The focus of the overall revolBRAS concept is to recycle this previously non-recyclable PET waste. In collaboration with local companies, an innovative chemical recycling process known as revolPET® is being further developed for the Brazilian market; this process isolates impurities from mixed and multilayer packaging and releases their monomeric components. This allows PET plastic to be recovered without the use of fossil raw materials. The second research focus is to study waste streams with the aim of developing structured, financially viable take-back systems.

A new chemical recycling process will make it possible to recover materials instead of burning them.

PORTUGAL

Ensuring the future viability of viticulture

The Fraunhofer Portugal Center for Smart Agriculture and Water Management AWAM is collaborating with the Fraunhofer Institute for Machine Tools and Forming Technology IWU, the Fraunhofer Institute for Ceramic Technologies and Systems IKTS and the University of Lisbon to research the resource-efficient use of water, energy and residual materials for a zero-waste value chain in viticulture. The project focuses on sustainable energy management. The project partners are conducting experiments into producing biogas containing methane. Their method involves fermenting organic residues such as grape pomace and crop residues. The scientists' tasks also include analyzing the high volumes of wastewater generated during the various stages of winemaking and evaluating possible technological processes for purifying this water. Researchers predict that creating more flexible production processes will unlock additional potential for saving water. At a later stage they will also investigate the production of hydrogen from organic waste in collaboration with other Fraunhofer institutes.

Climate change is putting increasing pressure on Portuguese winegrowers, with water shortages being the most pressing concern.

Photos: Chris Ryan, rockptarmigan, zentilia, shaunl, Pollyana Ventura/all photos from istockphoto

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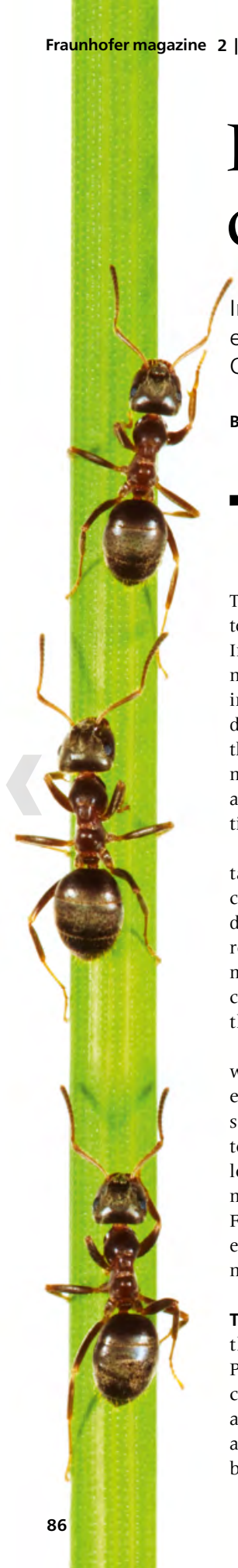
How industry can learn from ants

In the future, production will need to follow nature's example and adopt a fully interconnected system structure. One bio-inspired software is laying the foundations for this.

By Andrea Kaufmann



Trees communicate with each other and ants maintain close relationships with particular plants species: Ecological systems are a network of interdependencies and interactions. The scientists at the Fraunhofer Institute for Production Systems and Design Technology IPK are following nature's lead. In the BioFusion 4.0 project, they are working on developments that include a platform concept for the manufacturing industry. This platform allows tasks to be dynamically distributed between humans and machines and is based on the principle of self-organization and self-optimization. This means that machines for manufacturing would be joined in an intelligent network to ensure independent communication and flexible coordination between them.

"What makes resilient systems different is that they take a self-organized approach to adapt to changes and challenges in their environment," explains Theresa Riedelsheimer of Fraunhofer IPK, who is the project manager responsible for BioFusion 4.0. "In contrast to conventional manufacturing processes that are optimized using central controls, here we are decentralizing control to focus on the individual steps."

Fraunhofer IPK is achieving this by developing software that is capable of individually monitoring all of the elements involved in the manufacturing process. This software digitally maps each element's specific characteristics, properties, condition and behavior — from the long-serving logistics robot to the high-tech milling machine. According to IT expert Christopher Mühlich of Fraunhofer IPK, "These autonomous units follow the example of natural biodiversity to send and receive information, allowing them to control production."

These digital representations, called digital twins, form the foundation of the decentrally organized platform. Products and machines will gain the ability to act and communicate autonomously by becoming "virtual agents" in their own right, which can be customized according to the specific role, capabilities and responsibilities of their physical representatives.

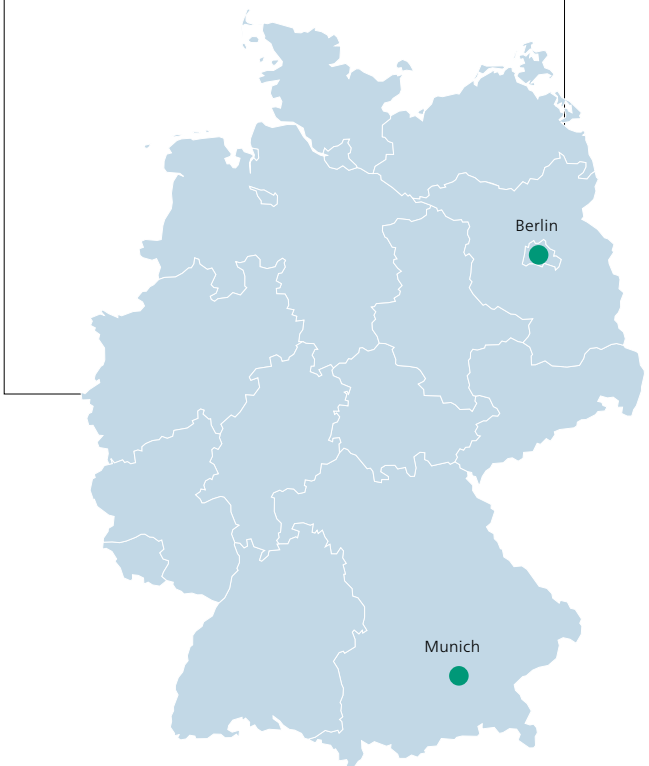
An agent is a software system that is located in a specific environment and has the ability to autonomously take action in this environment to achieve its individual objectives. Just like organisms in natural ecosystems, which each carry out a certain function and are connected to other organisms, these virtual agent systems use networks to communicate, negotiate tasks and make decisions. This means the machines themselves know whether they have free capacity or should pass on a task to another machine. The ultimate goal is for products to actively control their production process, and for equipment to determine its next workflow stages independently.

The agent system is based on the cognitive model of natural beings — namely, to perceive, conclude and decide. Ants follow this information processing chain as they search for food by following pheromones — they perceive the scent, classify the information and, based on this, decide whether to follow the scent trail or go a different way. A networked, self-regulating digital system functions in exactly the same way — just like in a natural ecosystem, it is influenced by the conditions in the surrounding environment and dynamically adapts to stay balanced. For example, the system itself recognizes whether all the agents are working effectively, to prevent overload and underload. Feedback loops are key here, as they allow the system to learn from errors.

Another advantage of the decentralized platform solution is that each employee has their own access to the network of agents; not only that, but their view into the current status of the processes ensures that they are able to make changes as necessary. Similarly to an ecosystem, these mechanisms allow the system to react to unexpected events and continuously improve, ensuring greater resilience. The platform is being tested on assembly lines, including ones that produce modules for battery-powered electric vehicles. Tests are already underway with industrial partners to demonstrate how the platform will work in practice. ■

Photo: Andrey Armyagov/AdobeStock

Fraunhofer on the road



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CURT can do what glyphosate can't

Like the weedkiller, the outdoor robot battles weeds in the fields — but it does so selectively, without damaging other plants. "This means it can leave nettles along the edge of the field while pulling up other weeds," explains CURT's developer, Kevin Bregler of Fraunhofer IPA. Fitted with laser scanners, a camera and a GPS system, the fully electric outdoor robot drives around and pulls unwanted weeds out of the ground.

Fraunhofer