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Fraunhofer: a success story through time

Rethinking masonry: Dr. Michael Prokein

Harnessing pollution for good

"Cutting-edge research is the driver of innovations"
Interview with Hendrik Wüst, minister-president and rising star in the CDU party

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Editorial

75 years of innovation

By Prof. Holger Hanselka

Prof. Holger Hanselka

The Fraunhofer-Gesellschaft proudly looks back on a 75-year history full of groundbreaking inventions and solutions to complex technological challenges. Since it was first founded, the organization has continued to grow and evolve, reaching many milestones along the way that reflect its innovative strength and commitment to excellence across all the different fronts of cutting-edge research. Rising from modest beginnings to international recognition as a research organization, Fraunhofer has always been defined by inventive spirit and entrepreneurial actions — just like our namesake, Joseph von Fraunhofer.

Countless examples from Fraunhofer's history have improved the lives of many people through innovation. Arguably one of the best known is the development of the mp3 audio format. Other impressive examples include the Industrial Data Space for secure exchanges of data in digitalized industrial environments and innovative technologies for strong and durable bionic components designed using lightweight materials. From the development of new materials and technologies to optimization of industrial processes, Fraunhofer applications revolutionize a wide array of industries. The task for the current generation is to build on this success story and pave the way for future answers to the key questions of our time.

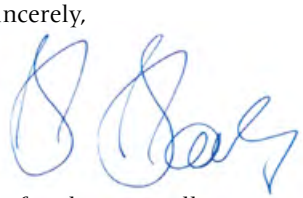
Ever since 1973, the Fraunhofer model, an optimal business model, has made it possible to develop applied research with close ties to the needs of industry. The Fraunhofer model is geared toward business and industry, with equal focus on three areas:

(1) industrial revenue, a factor that makes us unique in the German research landscape,
(2) public research funding obtained through competition, and
(3) institutional base funding, provided by the German federal and state governments, for strategic pre-competitive research.

Fraunhofer's mission is to support German and European industry with new technologies, serving industry and society as a supplier of innovation. At the same time, Fraunhofer focuses on key technologies and strengthens ethical value creation for a sustainable and successful future worth living in. Fraunhofer supports the development of new technologies from the initial idea through to market launch, thereby offering its partners solid and customized solutions to give them a crucial competitive edge.

The focus of the Fraunhofer model — which centers the needs of industry — is found nowhere else in the German innovation system. It is what makes the Fraunhofer-Gesellschaft an essential part of our society. That is why we focus unwaveringly on the needs of business and industry, providing valuable impetus for the evolution of key technologies that help to meet social challenges. This combination of research, industry, and society plays a crucial role in shaping the future, which also makes it highly important to the entire innovation system. The Fraunhofer-Gesellschaft will continue to play a central role in applied research in the years to come by forging ahead with development of innovative and targeted applications, strengthening partnerships, and developing sustainable solutions to global challenges. That's what I stand for as president. It's what our 32,000 people stand for. And it's what the Fraunhofer-Gesellschaft stands for.

Sincerely,



Prof. Holger Hanselka
President of the Fraunhofer-Gesellschaft

Photo: Fraunhofer/Stefan Obermeier

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Otto Lilienthal was an aviation pioneer. Now, Fraunhofer plans to make flying friendlier to the climate.

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Fraunhofer WKI plans to use debris to make new building materials — helping Ukraine in the process.

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Smart shopping at the click of a mouse

A study shows that greener online shopping is possible.

Green hydrogen is produced through electrolysis of water using renewable energy. Germany plans to build ten gigawatts of electrolysis capacity for this purpose by 2030. But that will only be enough to cover 50 percent of the country's demand for hydrogen at most. The rest would need to be imported.

50 %

Front and back cover photos: Maya Claussen (2), Daniel Hofer/laif, Boris Breuer; Content photos: Maya Claussen, Daniel Hofer/laif, Sven Döring, akg-images, Kay Nietfeld/both dpa, Lev Dolgachov/AdobeStock

Brief report

Non-stick frying without potential health hazards: The new PLASLON® coating does the job.

Replacing toxic "forever chemicals"

Researchers at the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM have developed a PFAS-free nonstick coating for items such as frying pans and packaging. Many per- and polyfluorinated alkyl substances, PFAS for short, have been proven to have harmful health effects. They are extremely stable and break down very slowly over time, which has earned them the name "forever chemicals."

The innovative PLASLON® coating features outstanding non-stick properties combined with great mechanical durability. The coating, produced using plasma technology, is designed as a gradient layer — an electrochemically created metal coating — to enable excellent adhesion to the product body while still featuring optimum non-stick properties.

Unlike other non-stick coatings, PLASLON®'s excellent adhesion and superior hardness make it also suitable for use on enamel, glass, stoneware, and porcelain. Products made from these materials are highly scratch-resistant, but have poor non-stick effects. ■

Smart textiles repel toxins

Researchers from the Fraunhofer Institute for Material and Beam Technology IWS and industry partners are working together to better protect firefighters from hazardous chemicals. They have developed a special suit that is effective in preventing contact with harmful polycyclic aromatic hydrocarbons (PAHs).

PAHs can be produced when mattresses, curtains, wood beams, plastics, and other organic materials burn. The innovative protective concept used for the suits involves high-tech materials and smart monitoring: Advanced nonwoven materials, the central element of the protective suits, prevent skin contact with these harmful substances. Ultraviolet (UV) sensors are also built right into the textile to detect when the protective layer is saturated with PAHs and needs to be replaced. The new protective clothing has already passed its first literal trials by fire, inside a fire training facility called a burn room. ■

PAHs can accumulate in the body, causing firefighters to be at increased risk of cancer.

More than 60 percent of all textiles are made from synthetic fibers.

Washing machine filter protects the environment

Microplastics pose a risk to the environment. The new fibrEX centrifugal filter keeps microscopic synthetic fibers from being released with the used water from washing machines. It was developed by researchers from the Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT. The versatile, maintenance-free filter separates the fibers that come off textiles during the washing process due to the water involved. Unlike a normal screen system, fibrEX relies on the difference in density between synthetic fibers and water, separating the two components during the spin cycle. This method allows it to capture at least 80 percent of the synthetic fibers present in the water. The new centrifugal filter can be installed in the washing machine itself or operated separately. Another benefit is that it hardly uses any additional energy.

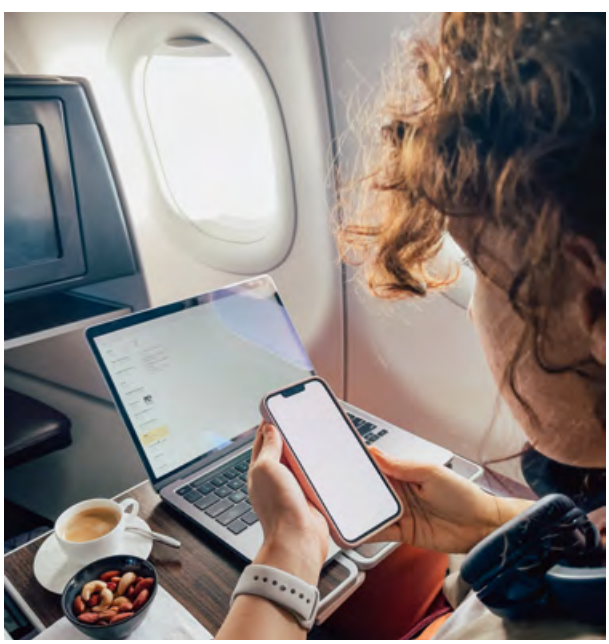
Synthetic microfibers from textiles make up anywhere from 20 to 35 percent of the microplastic found around the world. That makes them a significant source of microplastics. The fibrEX project is now entering the final phase, following extensive testing. Potential partners are currently being sought for the last steps up to the market launch. ■

Safety in the skies

How safe are lithium-ion batteries inside laptops, smartphones, or power banks during air travel? Researchers from the Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institut, EMI, and the Fraunhofer Institute for Building Physics IBP have teamed up with Airbus to find out.

If a portable electronic device (PED) gets caught in a seat or overheats while charging, the lithium-ion battery inside it can heat up and expand. In extreme cases, it can give off hot, toxic and flammable gases. According to the Federal Aviation Administration (FAA), these kinds of incidents on passenger flights have increased in recent years.

In the LOKI-PED project, the team of researchers are working to characterize the biggest risks posed by PEDs. The consequences of smoke and fire in the cockpit and cabin are being investigated at high-performance testing units such as the Flight Test Facility at Fraunhofer IBP and the TEVLIB battery testing center at Fraunhofer EMI. The TEVLIB center offers unique conditions for carrying out destructive tests, even on large battery systems. The experiments serve as a basis for numeric simulations and the subsequent risk assessment. The goal is to draft scientifically based recommendations — on topics such as ventilation concepts and certification of suitable safety equipment — for greater safety in air travel. ■



The FAA estimates that overheated batteries cause 35 to 50 incidents a year — and counting.

Drone detects buried victims

February 6, 2023: The ground shakes in southeastern Turkey and northern Syria. More than 125,000 people are injured, and nearly 60,000 bodies are recovered between then and April. Faster search and recovery and better targeted help mean higher chances of survival. In the future, drones equipped with a special microphone system will be able to detect acoustic signals from buried victims on a targeted basis from the air and guide rescuers to them faster. The new technology, named LUCY, was developed by researchers from the Fraunhofer Institute for Communication, Information Processing and Ergonomics FKIE. It significantly increases the chances of rapid rescue for people who need help but cannot be detected using cameras because they are buried underneath rubble or shrouded by smoke, fog, or darkness.

LUCY detects cries for help or knocking sounds so rescuers can focus their efforts.

To allow the drones to detect where noises such as cries for help, clapping, or knocking signals are coming from, the researchers attached a series of MEMS microphones known as a crow's nest array to the drone. The tiny, robust MEMS microphones are inexpensive. They are used in applications such as smartphones. The special feature of this system is that the microphones are attached to the underside of the drone in a special geometric configuration and can perceive sound from all directions. LUCY can also recognize frequencies inaudible to the human ear. The system blocks out distracting ambient noises such as from rescue equipment, wind or birds, as well as from the whirring rotors of the drone itself. ■

Protecting teens better from influencer marketing

In any given six-month period, more than half of teens spend up to 50 euros on products previously advertised by influencers on social media. That is one of the findings of a quantitative study of 1,000 teens in the FAIR research project conducted at the Fraunhofer Institute for Systems and Innovation Research ISI. The study set out to understand how influencers actually affect young people's consumption behavior and identify risk factors and protective factors.

Influencer marketing carries a higher risk of impulse buying, compulsive shopping, or social conflict, especially when it appears in "stories." To foster resilience among children and teens, the researchers have developed a handbook aimed at teachers and school counselors working with 14-to-18-year-olds. The book contains a wealth of tips for promoting reflective skills and media literacy among teens. ■

An influencer as role model: She shows viewers how to style their hair and makeup for maximum clout.

Editorial notes

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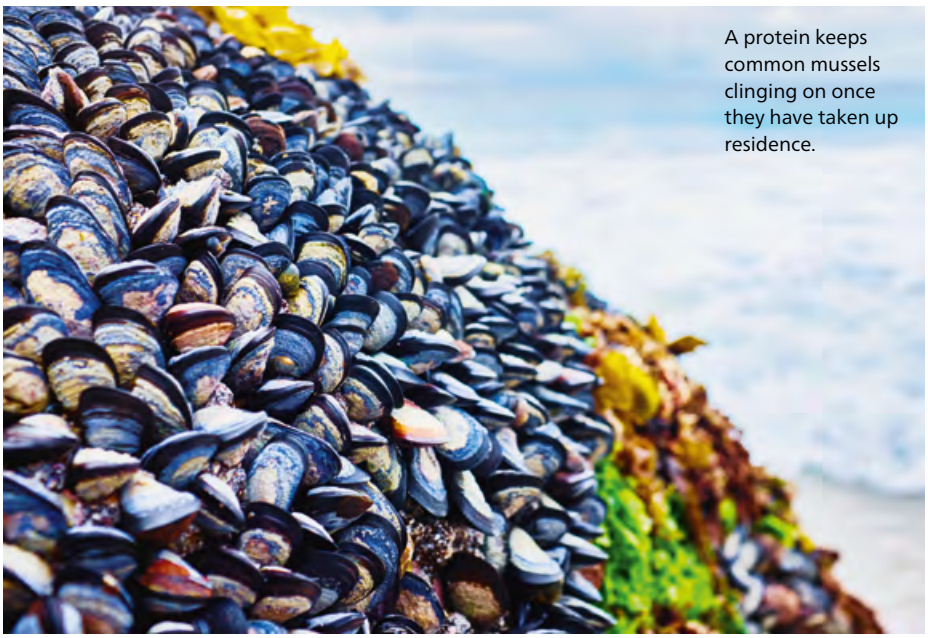


A protein keeps common mussels clinging on once they have taken up residence.

Clinging like mussels

An innovative biomimetic adhesive will keep titanium hip implants in place on the bone for longer. The researchers' innovative formulation was inspired by a true champion of stickiness: the common mussel.

Titanium hip implants lose their hold after a while inside the body, as the bone wears down. Researchers at the Fraunhofer Institute for Applied Polymer Research IAP have been working alongside the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB and the Fraunhofer USA Center for Manufacturing Innovation CMI to develop a tissue adhesive that can help avoid early replacement of prostheses in the future. The antimicrobial material can be 3D printed on the implants, where it bonds to the bone and adheres on its own.

The innovative formulation was inspired by the substance that common mussels use to cling to rocks and the hulls of ships. They are very difficult to remove once in place. This strong bond is due to a protein that contains dihydroxyphenylalanine (DOPA), an amino acid. "We have made use of this effective adhesion in our adhesive material by synthesizing polymers that contain dopamine, a chemical analog of DOPA," explains Dr. Wolfdietrich Meyer, a scientist at Fraunhofer IAP. "The dopamine-based adhesive can be mixed with a variety of additives, such as apatite particles (a substance that teeth are composed of), proteins and signal molecules. These promote the growth of bone cells and can be used to coat titanium implants, for example." The special coating allows the implant to appear more "natural" to the body, promoting the healing process and the integration of the implant.

The dopamine-based polymers are not just suitable for tissue adhesion: They can also be used for developing functionalized surfaces, antibacterial materials and intelligent coatings with special functions. ■

Title

The many uses of CO_2 in production: Prof. Ulf-Peter Apfel from Fraunhofer UMSICHT uses carbon dioxide from the cement industry to produce synthetic gases, for example.

Carbon dioxide: turning the problem around

Rehabilitating the prime suspect responsible for climate change: More and more technological innovations aim to harness CO_2 as a sustainable source of carbon.

By Beate Strobel, photography: Maya Claussen

One part carbon, two parts oxygen: Carbon dioxide is a fairly simple chemical compound. It also makes up just a tiny fraction of the air we breathe, currently 0.04 percent. But that's enough to cause big trouble for the entire world. The carbon dioxide in the atmosphere can absorb the heat emitted by the earth and reflect it back down to the planet's surface. Among the various greenhouse gases, carbon dioxide is the prime suspect responsible for climate change. And that's not even because it has an especially high greenhouse potential — nitrous oxide, hydrofluorocarbons, and methane rank much higher than CO_2 on that score — but because it is produced in the largest volumes and remains in the atmosphere for a relatively long time.

These days, reducing emissions of carbon dioxide is viewed as the single most effective way to combat climate change. But that alone won't be enough: The amount of unavoidable CO_2 emissions from Germany alone is estimated at some 60 million metric tons per year. And yet, the German federal government aims for negative emissions by 2050. How are we supposed to get there?

The trick will be to bind more carbon dioxide than is released. As for how to do that, three mechanisms have been proposed. Two of them focus on trapping the carbon emitted: carbon capture and storage (CCS) and carbon capture and usage (CCU). The third, carbon dioxide removal (CDR), takes a different approach. It calls for removing CO_2 from the atmosphere and permanently storing it in geological formations or oceanic carbon sinks, in biomass, or in durable products, thereby achieving true negative emissions. In terms of developing the technologies needed for this, time is pressing: Megatons of CO_2 will need to be separated to reach Germany's climate targets alone between now and 2030.

Capturing carbon dioxide directly from the air

The principle of direct air carbon capture and storage (DACCS) is geared toward filtering carbon dioxide out of the atmosphere. To achieve this, a fan moves the air past a sorbent material that soaks up the CO_2. "With the natural concentration of CO_2 in the air being so low, capturing this greenhouse gas is associated with very high energy use," says Dr. Barbara Breitschopf, a project manager at the Fraunhofer Institute for Systems and Innovation Research ISI, who explored the potential of DACCS with her team in a policy brief. So DACCS only makes sense in places where there is an adequate supply of renewable energy. "For energy efficiency reasons, though, we should prioritize capturing CO_2 at available point sources," Breitschopf explains. It is more efficient to capture the gas right where it is emitted than to allow it to escape into the atmosphere first and then spend a lot of energy and money filtering it back out.

One of these point sources for CO_2 can be the production of hydrogen from or through biomass. This is because H_2 is formed not only through ▶

CO_2

Germany's greenhouse gas emissions for 2023 worked out to the equivalent of some **673 million metric tons** of CO_2 — the lowest figure in 70 years. Germany is aiming for climate neutrality by 2045.

electrolysis, but also through conversion of organic residue and waste from fields such as food production and agriculture. In the H2Wood — Blackforest project, for example, researchers from the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB are working to use wood waste from Germany's Black Forest to generate hydrogen. If the biogenic carbon dioxide produced as a byproduct of these kinds of processes is captured and used or stored on a long-term basis, the hydrogen production is said to be CO_2-negative — a win-win from an environmental standpoint.

"The overarching term for all kinds of approaches like this is hydrogen bioenergy with carbon capture and storage, or HyBECCS," explains environmental scientist Sonja Ziehn. For her master's thesis, Ziehn participated in the RhoTech project at the Fraunhofer Institute for Manufacturing Engineering and Automation IPA in Stuttgart, studying how a purple bacterium named Rhodospirillum rubrum can be used to produce hydrogen out of fruit and dairy waste through a process known as "dark photosynthesis." In this method, the microorganisms use the sugar present in the residue as a source of energy instead of light. One big advantage of this "dark" production of hydrogen is that the process can be scaled up to almost any level using conventional stainless steel bioreactors. A follow-up project, RhoTech II, is now incorporating a bioreactor into the production workflow at a fruit juice company to set bacterial hydrogen production in motion using the residue generated there. "Fraunhofer's focus is on economic and ecological process optimization," Ziehn points out. "Under what conditions do we see mostly hydrogen, but also large amounts of CO_2 being produced?"

> "Under what conditions do we see mostly hydrogen but also large amounts of CO_2 being produced?"
>
> Sonja Ziehn, Fraunhofer IPA

Maximizing the production of carbon dioxide might sound like a paradox in light of climate change. But this biogenic CO_2 is easy to separate, plus it can be used as a raw material for chemicals and products that were previously based on fossil carbon dioxide, thus shrinking their carbon footprint. "Now that the financial incentives for biogas plants under the German Renewable Energy Sources Act are expiring, operators are looking for new business models," Ziehn explains. "Switching to hydrogen production using a HyBECCS plant is one option, especially since hydrogen is practically crying out to be used as an alternative to diesel for tractors and other agricultural machinery." HyBECCS technologies could make marketing "green" carbon dioxide an interesting source of supplemental income for the agriculture and food production sectors.

The researchers at the Fraunhofer Institute for Microengineering and Microsystems IMM offer another potential path forward for agricultural operations with biogas plants. So far, the biogas produced has been used mainly to produce electricity and heat, or it is processed and then fed into the natural gas network in the form of methane. With the current methods, the carbon dioxide released in the process simply escapes unused into the atmosphere. Although the CO_2 involved is biogenic rather than being from fossil sources, Dr. Gunther Kolb, a chemical engineer and the head of the energy division at Fraunhofer IMM, says that is still a waste: "It would make more sense to convert the CO_2 part of the biogas — which accounts for 40 percent of the total anyway — to methane and then feed all of the biogas into the natural gas network," he notes.

In the ICOCAD I project, the team of researchers developed reactors and catalysts that are able to use green hydrogen to methanize the carbon dioxide contained in the biogas — even with the existing methane being present. One of the challenges of doing this, Kolb explains, was building a pilot plant that also has good heat management: "Heat is generated inside the reactor, but it can be decoupled and used in a local district heating network, for example. This creates an overall process that is economically attractive for farmers, who are increasingly producing energy as well."

In the follow-up project, ICOCAD II, work is now under way to install a demonstration plant along ▶

Holding your breath? Biowaste might not smell very good, but to Sonja Ziehn, an environmental scientist at Fraunhofer IPA, it's a valuable base material for producing hydrogen and CO_2.

CO_2 as a basis for platform chemicals: Dr. Ulrike Junghans, Fraunhofer CBP, sees opportunities for the chemical industry and the transportation sector.

with a biogas feed-in unit to scale the process and optimize practical operation. Kolb says this technology offers huge environmental opportunities: "If all of the biogas from the 9,000 or so plants around Germany were fed into the natural gas network in full, it would be enough to cover about 13 percent of Germany's demand for natural gas — all from purely biogenic sources and with better quality than natural gas derived from fossil sources."

The Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT is using plants as "middlemen" in its work on storing carbon dioxide. After all, plants are known to absorb CO_2 from the air and split it via photosynthesis. The oxygen released in the process is emitted into the environment, but the carbon remains inside the plant itself, including in the roots. The CO_2 is released again when biomass is burned. The KARBO-SELF project at Fraunhofer UMSICHT aims to use a carbonization technology developed at the institute to burn biogenic residue while excluding oxygen, with the result that the carbon present in the plants remains bound and stable in the form of plant carbon, acting as a carbon sink.

Fraunhofer itself is planning to prepare this technology at its own locations and, at the same time, develop a method of certifying the plant carbon products as carbon sinks. There are also plans to study potential roles for plant carbon as additives in construction materials or in agriculture.

Platform chemicals to store CO_2

However, carbon dioxide can also be stored chemically. After all, carbon is an essential element of many everyday products. In the e-CO_2Met project, coordinated by multi-energy company TotalEnergies, researchers from the Fraunhofer Center for Chemical-Biotechnological Processes CBP are working to convert green hydrogen and carbon dioxide into methanol. For this purpose, plans call to use a pilot plant at Fraunhofer CBP that has been specifically adapted to this process. True, this will not involve long-term storage of CO_2 — but as Dr. Ulrike Junghans, a chemist and head of the regenerative resources department at Fraunhofer CBP, points out: "Methanol is an excellent platform chemical, and it serves as a starting material for a whole host of products in the chemical industry and for the transportation sector."

> "In the long run, industry will have no choice but to use non-fossil carbon sources."
>
> Dr. Ulrike Junghans, Fraunhofer CBP

Methanol produced via green methods is not yet competitive on price, but Junghans expects that to change soon, as processes grow more efficient and novel catalysts that are more efficient in handling CO_2 from industrial point sources are identified. "In the long run, industry will have no choice but to use non-fossil carbon sources," she says with conviction. "And that means carbon capture, whether from the air or at point sources, will be increasingly important going forward." Right now, there is plenty of CO_2 available, but that could change with advances in decarbonization across various industries. So will CO_2 be a sought-after commodity one day? Junghans: "I can certainly see it happening." Which, she points out, makes it even more important to implement this source of raw materials as part of a circular economy.

Giving carbon dioxide a helping hand

The challenge with carbon dioxide is that the gas is "a really sluggish molecule," as Dr. Thomas Schiestel, head of the membranes department at Fraunhofer IGB in Stuttgart, puts it. The two oxygen atoms and one carbon atom are slow to release their double bonds so they can form other compounds. "It takes a lot of energy to utilize CO_2 effectively," Schiestel explains. And that very aspect is what makes using carbon dioxide expensive and not very sustainable, at least unless renewable energy is used. To address this, Schiestel is hunting for ways to make recycling CO_2 economically viable, either by transferring it into chemicals or products or by using it as an energy sink for volatile renewable energy. ▶

CO_2

The world's forests store **7.6 billion metric tons** of CO_2 in their biomass each year.

CO_2

Carbon boasts the greatest diversity of all the chemical elements, with **20 million** possible compounds.

With this in mind, the PiCK (Plasma-induced CO_2 Conversion) project is using excess electricity from renewables. Energy is used to split the stable carbon dioxide in a plasma — an ionized gas with highly reactive particles. To keep the products of this process, carbon monoxide and oxygen, from immediately re-bonding to form CO_2 in a reverse reaction, an innovative ceramic membrane is used to remove the oxygen particles from the system. "Since the membrane has to withstand the high temperatures in the plasma, which can be up to 1,000 degrees Celsius, along with the CO_2 concentration at the same time, we spun perovskites, a special kind of ceramic materials, together with polymers to form a thin-walled capillary," Schiestel says, explaining the membrane's special features. The NexPlas successor project plans to introduce hydrogen into the system as well to produce secondary reactions in the plasma — an additional challenge for the perovskite membrane.

The advantage of the plasma-membrane combination is its adaptability. It can be used wherever CO_2 arises: in combustion processes such as those that occur at power plants and in waste incineration, in the cement and glass industries, and at breweries, where carbon dioxide is a byproduct of alcoholic fermentation. "Industrial players have already signaled an interest in our plasma-membrane combination," Schiestel says.

Building on sustainable material innovations

Dr. Michael Prokein, group manager for functional materials at Fraunhofer UMSICHT, is taking a different approach to long-term storage of carbon dioxide. In the NuKoS project, which aims to use the carbon dioxide in slags, he and his team have developed a method that uses carbon dioxide to produce eco-friendly masonry blocks from steel industry residue. These items could come to entirely replace construction materials with a large carbon footprint.

"We're focusing on the part of steel slag that is too fine-grained to be reused for other purposes, which so far has meant it winds up in landfill, an expensive proposition," Prokein explains. The carbon dioxide, in turn, is taken from sources such as process gases in the steel and iron industry or cement production. In this way, NuKoS is addressing two environmental challenges at once: First, the steel and cement industry is a top emitter of CO_2, and second, Germany's iron and steel industries produce about 14 million metric tons of slag from steel production each year. "The fine part of the steelmaking slag is ground up and mixed with sand and water," Prokein says, describing the process. "The mixture is then pressed into the desired molded shape and then cured in a CO_2 atmosphere at 15 bars of pressure and 50 degrees Celsius." In the process, the carbon dioxide forms a lasting chemical bond with the stone, creating a carbon sink in the form of a brick. "The moderate production conditions hold high potential for energy savings in comparison to other curing methods," Prokein says. Another advantage is that for this process, the autoclaves currently used to make sand-lime brick can simply be retooled.

> "We grow a kind of microalgae that uses light to metabolize CO_2 and can produce fatty acids."
>
> Dr. Grzegorz Kubik, Fraunhofer IGB

The test results for the slag-based building materials are encouraging: "We can achieve compressive strength equivalent to that of concrete," Prokein confirms. Plus, production of one cubic meter of CO_2-cured stone results in an 80-kilogram carbon sink — while production of conventional sand-lime brick releases 250 kilograms of carbon dioxide per cubic meter. Or, as Prokein puts it: "Slag-based stone is amazing from a technological, economic, and environmental perspective!"

The construction industry has shown great interest, but bureaucracy presents a bit of a snag. "We're not sure yet whether it will be possible to use steel slag as a construction material for this use case," Prokein explains. Once questions like these are answered, industry could get down to work right ▶

Feeding CO_2 to microalgae is Dr. Grzegorz Kubik's biotechnological approach to producing textiles for sneakers at Fraunhofer IGB.

away. From a technological standpoint, the production process for the CO_2-negative building material is ready to transfer.

The microalgae make the sneaker

The textile industry is also looking for ways to shift from petroleum to bio-based materials — possibly using tiny organisms. AlgaeTex, a subproject of the BioTexFuture innovation space funded by the German Federal Ministry of Education and Research (BMBF), brings together teams of researchers from Fraunhofer IGB and CBP, the University of Bayreuth, and the Institute of Textile Technology (ITA) at RWTH Aachen University, along with sporting goods manufacturer Adidas, to work on solutions for storing carbon dioxide in functional textiles. How is this supposed to work? "We grow a specific kind of microalgae that uses light to metabolize CO_2 and, under certain conditions, can produce fatty acids," explains Dr. Grzegorz Kubik, head of the industrial biotechnology department at Fraunhofer IGB. These fatty acids, he says, can be chemically transformed into polymers, which Adidas then weaves into a kind of nylon fabric that can be used for things like the upper parts of sneakers — so the company is literally using shoes to shrink its environmental footprint.

Cultivating algae in the basement: The team at Fraunhofer IGB has developed a stackable photobioreactor that can be operated indoors as part of the AlgaeTex project. The advantage of this approach is that like with all reactors, it does not use any fertile agricultural land. It also eliminates dependence on locations with good sun availability. The disadvantage is that the microalgae need artificial light instead of sunshine to grow — up to 100 kilowatt-hours per kilogram of algae mass. "This means energy use is one of the key topics with this technology," Kubik explains. But the higher the proportion of renewables in the energy used, the greener and cheaper it becomes to cultivate microalgae in Germany. "Right now, the availability of renewable energy is where we need to thread the needle in terms of using microalgae to store CO_2." That is one of the reasons the team of researchers is currently working to optimize the amount of light needed, and with it the power consumption involved. Kubik says another area of focus is "reusing the algae, for example as fertilizer in agriculture or in livestock feed. We don't just want to increase the efficiency of algae production. We also aim to increase reuse and recycling."

> "CO_2 is a key raw material that we would do better to recycle as part of a circular economy instead of continuing to pull new carbon-rich resources out of the ground."
>
> **Dr. Arne Roth,** Fraunhofer IGB

These efforts to optimize the microbiological approach to CO_2 use could be worthwhile well beyond the textile industry. After all, algae are able to take light energy and carbon dioxide to form and store a whole range of other substances, such as starch: "So then we would no longer need to produce sugar from plant-based biomass, but could generate it from microalgae, freeing up agricultural land for other uses," Kubik explains. "Or we might use algae to sediment CO_2 in the form of lime and then either store it or use it in the construction industry." In the SmartBioH2 project at Fraunhofer IGB, purple bacteria produce hydrogen and products such as carotenoids from residue streams in a closed bioreactor. The carbon dioxide produced in the process is bound in biomass by microalgae — while releasing more hydrogen or products such as proteins.

A smart carbon cycle

From microorganisms to mega-scale: The Carbon2Chem® joint research project is also focusing on production of steel, cement, and lime as the ▶

CO_2

If there were no greenhouse gases in the atmosphere, the average temperature on the earth's surface would be **-18 degrees Celsius.**

Developing sustainable fuels based on CO_2: Dr. Arne Roth from Fraunhofer IGB is fine-tuning innovative process chains for that purpose.

CO_2

Carbon dioxide accounts for **89.4%** of Germany's greenhouse gas emissions.

(As of 2022)

biggest industrial source of CO_2 emissions. "We're looking for methods and technologies of optimizing the circular carbon economy so that carbon isn't released after it arises, but instead is locally reused and recycled sustainably," says Prof. Görge Deerberg, a chemical engineer and the director of transfer at Fraunhofer UMSICHT. He is one of the coordinators of the huge and sprawling project, which was launched in 2016. With funding from the German Federal Ministry of Education and Research (BMBF), the project spans the fields of basic and applied research, along with various industrial sectors. "This cross-industry network is key to the success of the Carbon2Chem® project," Deerberg says. His focus here is not solely on developing individual technologies, but also on integrating them into a cross-industry overall structure. Within that structure, the hope is that whole new forms of collaboration will take hold: "The opportunities and risks involved in CO_2 use need to be fairly distributed. That's a prerequisite for long-term success."

At the heart of Carbon2Chem® is the idea of substitution: The carbon required to produce many of the basic chemicals, plastics, and synthetic fuels used in industry will no longer come from fossil sources in the future, but rather from industrial process gases and waste incineration. The first phase of the project investigated topics such as gas purity. "In the steel industry, smelting gases are produced at blast furnaces and converters and also in coking plants, so the composition varies," Deerberg explains. For this reason, the team first developed technologies to analyze the gases and then purify them to the point that they can undergo further processing without disrupting catalytic processes. Another challenge lay in the fluctuating concentrations of components in the process gases: "The technologies used at chemical plants have tight tolerances. They aren't set up to deal with ranges," Deerberg explains. "We needed to map out a systematic approach that was adaptable for overall conditions that change not just from one minute to the next, but also over years as a result of the industrial transformation."

The second phase of the project, which is concerned with scaling the technology, launched in 2020. A pilot plant occupying 3,700 square meters was built right next to the plant grounds of thyssenkrupp Steel Europe AG in Duisburg, adding to the 500-square-meter lab on the Fraunhofer UMSICHT campus. The demonstration systems are hooked up to the wiring and plumbing for the steel mill. In 2018, the researchers succeeded in producing methanol from smelting gases for the first time. "It was only a small glass full," Deerberg says. "But it was definitely a very special moment for all of us." There are plans for a new plant to produce 12 metric tons a day.

The third and final phase of the project will deal with technology transfer to other high-emission, energy-intensive industrial installations like cement plants and waste incineration plants. "The goal of Carbon2Chem® is to support and advance the big industrial transformation," Deerberg says. After all, even amid vigorous ongoing efforts to reduce CO_2 emissions, there will always be sectors that inevitably produce carbon dioxide. To Deerberg, this means that even as innovative CCU technologies are developed, we should also work on carbon's image: "Right now, a lot of people are narrowly focused on strictly preventing carbon emissions. But we could flip that and think about continuing to use carbon, just not from fossil raw materials anymore."

Will CO_2 soon be a way to make money?

Dr. Jonathan Fabarius, senior scientist for microbial catalysis at Fraunhofer IGB, goes one step further at the biointelligence competence center: "Making money with CO_2?" is the title of a blog series. In one post, about turning the page on the fossil era, he discusses how carbon dioxide can be used to generate valuable and important chemical materials. Carbon dioxide as a rich source of funds? Fabarius's colleague Dr. Arne Roth, head of the sustainable catalytic processes department at Fraunhofer IGB, also stresses the importance of CO_2, calling it a "key raw material that we would do better to recycle as part of a circular economy instead of continuing to pull new carbon-rich resources out of the ground." However, creating the conditions for many of the proposed CO_2-based value chains to be commercially successful will require targeted and determined research and development to lay the technical groundwork.

In the EU's EcoFuel project, this idea is to be incorporated into the electrochemical production of synthetic fuels made from carbon dioxide and water. "Working with various European partners, we've devised an innovative process chain that starts with CO_2 from direct air capture," Roth explains. Then, as the next step, the gas is electrocatalytically converted to ethylene, a C2 gas, which is then converted in turn into liquid fuels. "Power-to-X" is the term used for this cascade approach. At the Center for Sustainable Fuels (ZENK), in Bavaria, researchers from Fraunhofer IGB and UMSICHT are working to identify new production methods for fuels based on CO_2, biomass, and renewable electricity and scale them to pilot plant levels.

Roth is convinced: "If we develop suitable process technologies and combine them in smart ways, we can use carbon dioxide to produce a wide range of chemical products." He is especially interested in combining CO_2 conversion with biotechnology: C1 chemicals like formic acid or methanol generated electrocatalytically from carbon dioxide can be used as fodder for microorganisms that produce higher-value chemicals out of them. Fabarius's team has already demonstrated these kinds of promising hybrid approaches: In the CELBICON project, for example, the researchers at Fraunhofer IGB managed to harness the synthesizing prowess of bacteria to convert CO_2 from the atmosphere into a terpenoid dye, a type of natural pigment also found in plants and algae. "Microorganisms are sensational chemists," Roth points out. "Even without high temperatures or pressures, they can metabolize carbon dioxide into products, some of which are even capable of long-term greenhouse gas storage. We should spend a lot more time looking to nature for examples."

That same idea also fascinates Ulf-Peter Apfel, a chemist who serves as the head of the electrosynthesis department at Fraunhofer UMSICHT and a professor at Ruhr University Bochum: "In nature, CO_2 isn't a problem chemical. As a C1 source, it's a hugely important base material. When it comes to using CO_2, we have a lot to learn from nature." That is why Apfel does not talk much about "decarbonizing" industry, preferring the idea of "defossilization" — reducing the amount of CO_2 derived from fossil raw materials. He is working on this in the CO_2-Syn project, which was launched in 2022, for example. The project focuses on the cement industry, which accounts for as much as eight percent of global carbon dioxide emissions. And that isn't likely to change anytime soon, since when calcium carbonate — one of the main ingredients used to make cement — is burned to produce calcium oxide, carbon dioxide is inevitably produced as well. "That is a huge point source we can use," Apfel says. Much like in the Carbon2Chem® project, the team here is also working on the use of CO_2 from waste gas streams — in this case, to produce synthetic gases (a mixture of carbon monoxide and hydrogen) that are then used as basic chemicals for olefins and higher alcohols.

The CO_2 generated during cement production is contaminated with dust and other potential pollutants, however. How can it be purified at reasonable cost? Or might there even be ways to avoid cleaning it altogether? "To do that, we need catalysts that are highly resistant to contamination," Apfel explains. Right now, he is focusing on sulfide-based catalysts. "They're really resilient. You can't contaminate them all that easily." The first tests of possible process routes have already been concluded, and now a pilot plant is to be commissioned. "We'll be able to convert 100 kilograms of CO_2 a day with the new plant," Apfel says. "It's the world's first plant on this scale."

> "In nature, CO_2 isn't a problem chemical. As a C1 source, it's a hugely important base material. When it comes to using CO_2, we have a lot to learn from nature."
>
> Ulf-Peter Apfel, Fraunhofer UMSICHT

Apfel is surprised German companies are often still skeptical about the idea of using CO_2. "It won't be long now before industrial processes are producing less and less carbon dioxide. There will be a lot of money in sustainable C1 point sources," he predicts. "But for that to occur, we need to invest in the right processes and systems now." Looking at the technological advances of the past five years, especially in the area of CCU, he offers another prediction: "I think we'll have really big plants everywhere by ten years from now." Germany cannot become carbon-neutral by 2050 solely by preventing emissions of the greenhouse gas, he notes. A much more diverse approach will be needed: "We have to stick with it and keep looking for new and promising routes to get there." ■

CO_2

Worldwide, CO_2 emissions rose by **1.1% in 2023, to 36.8 billion metric tons.**

On the upswing — at least at play
A child swings in front of heavily damaged apartment buildings in the small town of Borodianka, near Kyiv. Fraunhofer researchers are working to support a real recovery.

From the ashes

Concrete is the most commonly used construction material — and producing it emits as much carbon dioxide as the entire worldwide aviation sector. Rice is the world's most common food — and its husks have hardly ever been used. Fraunhofer experts have made a connection. The future of construction also holds out hope for rebuilding Ukraine.

By Franziska Sell ▶

Photo: Kay Nietfeld/dpa

"We build Ukraine"
That is the hopeful message posted on the fence around a construction site in Zaporizhzhia, the sixth largest city in Ukraine.

Sobering figures from the construction industry: It is responsible for 30 percent of the world's CO_2 emissions, 40 percent of all energy used, 50 percent of resource consumption, and 60 percent of all waste generated. And yet, the future of building could be completely different. It is no longer merely a vision that buildings made from concrete can conserve resources, minimize waste, and at the same time provide better insulation and longer life spans.

Prof. Libo Yan and his team from the Fraunhofer institute for Wood Research, Wilhelm-Klauditz-Institut, WKI, can prove it: In the ReMatBuilt research project, the experts are developing sustainable concrete construction materials and high-performance construction elements based on construction and demolition waste as well as plant-based production residue, together with partners from industry and science. The project is funded by the German Federal Ministry of Education and Research (BMBF) as part of the National Bioeconomy Strategy.

The project partners from Germany and China are focusing on real-world use — along with rapid implementation. "The idea of recycling construction materials and experimenting with alternative materials from nature is not new," says Yan, the project manager. "What makes our project unique is its holistic approach." With their sights firmly set on practical application, the researchers combine their knowledge of the methods and the properties of the different materials in order to understand their chemical, physical, and mechanical performance from the micro up to the macro level. This allows them to achieve a high level of technology readiness. They also design their products and all upstream process steps to meet both countries' specific regulations.

> "Rice husk ash is an excellent substitute for cement."
>
> Prof. Libo Yan, Fraunhofer WKI

Less waste, lower resource consumption

The experts use construction rubble — old concrete and masonry waste — and agricultural residue to produce recycled concrete. These components are reinforced with plant-based natural fibers such as flax, supplemented by forestry waste products such as wood chips from old wood.

Conventional concrete generally contains cement and usually gravel as an aggregate — a finite resource whose extraction damages the environment. In addition, it often has to be transported over long distances. Construction rubble and old wood, however, are found in large amounts all over the world, and there have been few efforts to recycle them effectively thus far. That makes both types of waste very attractive as substitutes from both an ecological and economic standpoint.

The situation is similar with cement. This binding agent among the construction materials is made from natural raw materials such as limestone, clay and quartz sand — and its production causes high carbon dioxide emissions that have been an increasing concern for the industry. Yan's team has succeeded in finding a potential substitute to reduce the amount of cement used in concrete construction: "Rice is the most common food in the world. Its husks have hardly ever been used. We have found out that the rice husk ash that is produced by a special combustion process is excellently suited as a cement substitute."

The test results speak for themselves: The recycled cement not only conserves finite ecological resources, but the components manufactured from it are lighter than their traditional equivalents and are impressive for their increased strength, durability, and heat and noise insulation. But there's more to it than that. As part of the project, the experts are also developing insulating materials made of plant-based waste products such as sawdust and rice and wheat straws as a resource-saving alternative to the currently dominant versions consisting of petroleum-based plastic, mineral and glass wool, or wood fibers. These sustainable insulation boards make it possible to connect the finished concrete components to form wall systems of insulated blocks. The experts have additionally designed systems that allow recycled concrete combined with laminated veneer and cross-laminated lumber to be used as floor slabs.

These hybrid construction elements combine the advantages of conventional concrete and plant-based construction materials. They are durable and have impressive mechanical, moisture, and

heat protection characteristics. In addition, they are easy to process and meet all fire protection specifications. In this way, the project partners' solutions are expanding the range of available options for cost-efficient building with increasingly strict sustainability requirements — for single-family homes and large building complexes alike.

From obstacles to milestones

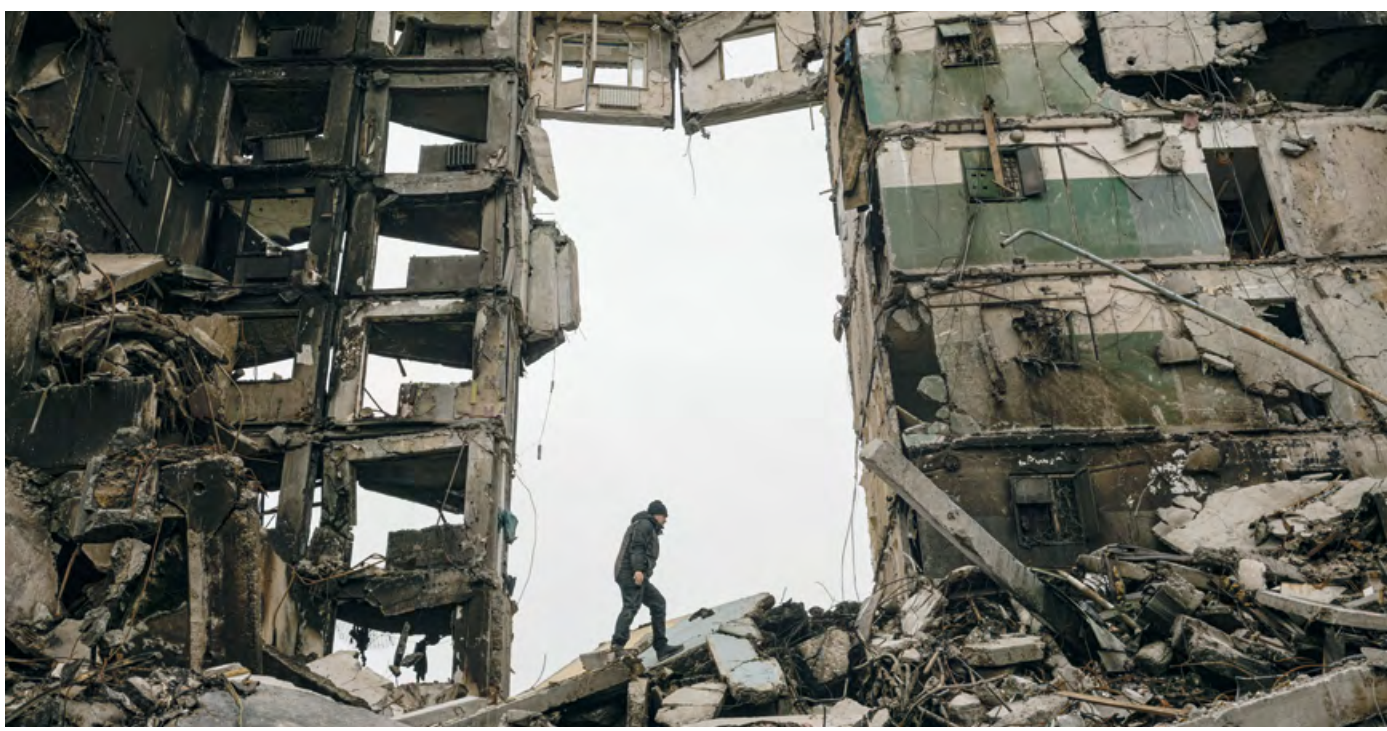
The research project's success was not a foregone conclusion. Ten days after the project officially kicked off, on March 1, 2020, the World Health Organization (WHO) declared the coronavirus a worldwide pandemic — which presented a massive challenge for Yan's international team. But that wasn't all. Following extreme rainfall, the German city of Braunschweig faced devastating flooding early that summer. The lab used for performing the experiments for the project was directly affected. The rising waters caused severe damage to the buildings, and the ReMatBuilt project group's research work there was heavily damaged. "We work with materials that are highly sensitive to moisture, from natural plant fibers to cement and wood. The water destroyed a large portion of our test samples, our experimental set-up — in short, all of the physical work we had done in Braunschweig," Yan explains.

Undaunted, the team forged ahead with the results they had already achieved and are now working on the extended project. Meanwhile, they are keeping their eye on the big picture: "Through our work, we're opening up interesting economic prospects for the insulation and construction industries and for agriculture and forestry. Beyond that, our partners in the recycling and mechanical engineering sectors are developing new methods for optimal production and further processing of plant waste," Yan says.

Hope for Ukraine

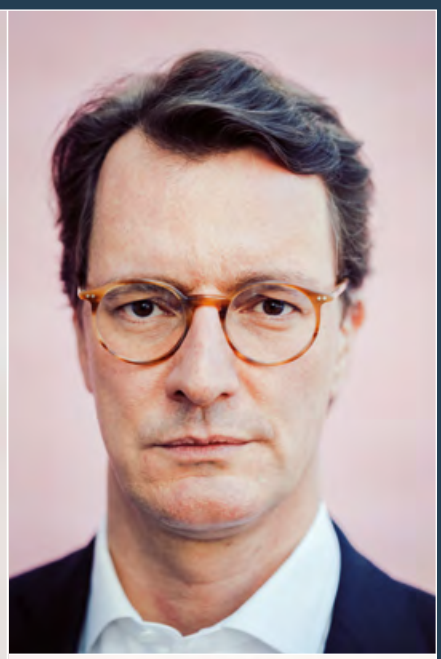
Yan sees one idea as especially important: "Our work can make a significant contribution to rebuilding Ukraine," he points out. "It's terrible, but huge amounts of rubble are generated there day after day. The country is also rich in natural resources and one of the world's largest exporters of agricultural raw materials, such as grains — wheat, corn and rice." Against this background, the team is currently hard at work on putting their results into application. Their goal is to provide crucial support to the people of Ukraine in rebuilding quickly, economically, and sustainably. ■

Rubble as raw material
Fast, economical, and sustainable rebuilding is the goal — Fraunhofer researchers are helping to accomplish that.



Photos: Andriy Andriyenko / ZUMA Press, Vadim Ghirda, AP / both dpa

Interview



“Cutting-edge research is the driver”

Rising star Hendrik Wüst took over the governance of Germany’s most populous state from predecessor Armin Laschet in October 2021.

Hendrik Wüst, minister-president of the state of North Rhine-Westphalia, is viewed as a potential candidate for chancellor. In this interview, the 48-year-old calls for reliable prospects for science, research, and industry.

Interview: Josef Oskar Seitz

Let's talk about the future. What qualities does the next German chancellor need to have to lead Germany out of the multiple crises it is currently facing?
A rational mind, determination, and strong leadership. They also have to keep their promises. There are too many examples in which the sitting chancellor has been slow to act or hasn't shown the necessary political will — take the pact aimed at accelerating planning and approval procedures, for example, or the power plant strategy. The biggest political challenge facing us right now, migration, is also being approached much too timidly. Current studies show all our officeholders that many people in Germany have lost trust in the state and its ability to get things done. I'm sure the ongoing squabbling within the German federal government hasn't helped.

Let's turn to the present, then. Is it worth asking whether you would be interested in running for chancellor as a CDU candidate in 2025?
People can always ask.

I see. It's tough. Let's talk specifics. Here's a question for you as a lawyer: Can you put together an argument for Germany as an industrial hub in three sentences?
Germany is distinguished by a highly innovative economy, top-notch research landscapes, and a strong industrial base. With its central location in Europe, it offers companies incomparable access to the markets in the EU, reinforced by a robust legal system that protects and fosters investment and innovation, and a well-educated populace. To continue to play to these strengths in the future, we need a fast-acting growth program that includes tax reform, cutting red tape, action to counteract the shortage of skilled workers, and lower energy costs.

Are growth and climate action contradictory?
We need to show that we can both protect the climate and unleash economic growth. That forms the basis for well-paying jobs, prosperity, and a stable society. That's the only way we will be able to protect our climate effectively in the long term. Otherwise, we won't have the buy-in we need for climate action — not just here in Germany, but worldwide. We can't convince other countries that climate action is needed unless we also show that we can stay strong, economically and industrially. What we need for that is a political framework that drives innovation in climate action and attracts investment in clean technologies.

"Providing targeted support for research and development is crucial."

Hendrik Wüst

Those two aspects overlap in your state. You have big chemical, steel, and coal industries. And you're in a coalition government with the Green party. How are you navigating that?
North Rhine-Westphalia has set out to be the first climate-neutral industrial state in Europe — and we're making good progress. In Duisburg, for example, there are plans to produce green steel with hydrogen instead of coke in the future. At the state government level, we supported this investment with the biggest single grant in our state's history to show how growth and climate action can be reconciled with an eye to the future and long value chains can be kept right here in-state.

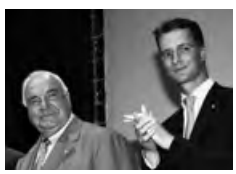
Where does the research sector fit in?
It has a very important role to play. Cutting-edge research is the driver of the innovation we need to overcome key challenges — whether that's the energy transition, the digital transformation, or, in medicine, the fight against widespread diseases like cancer and dementia.

What can be done to bolster the research sector?
We're making sure there are dependable overall conditions and investing in our higher education and research institutions so research can proceed freely, and we remain attractive as a location of cutting-edge research. And we're especially cultivating interdisciplinary networks, like EIN Quantum NRW and KI.NRW [Editor's note: central organizations focusing on quantum technologies and artificial intelligence, respectively]. ▶

Photos: Daniel Hofer/laif (3)

When Hendrik was still just "Henne"

"Handball was always my sport," Hendrik Wüst recalls. He played with TV Rhede as his sports club right up until the end of his teenage years. His nickname was "Henne."



Theft among party leaders

At 1.91 m in height (over 6'3"), Wüst towered over Helmut Kohl, the former German chancellor. Kohl once stole Wüst's meat right off his plate: "He was hungry, but I was full!"

A career low

Wüst resigned as CDU secretary-general in 2010. He had offered sponsors one-on-one meetings with then minister-president Jürgen Rüttgers for a price of 20,000 euros ("rent a Rüttgers").

A moving response

In a special session held on October 27, 2021, the North Rhine-Westphalia state parliament elected Hendrik Wüst to serve as the new minister-president.

Hydrogen is viewed as the energy source of the future, especially for the steel industry. Fraunhofer and Salzgitter AG are already working on a project to make this a reality. What do policymakers need to do to advance the decarbonization of heavy industry?
Hydrogen will play a key role in putting heavy industry on a sustainable and climate-friendly path. There are three key measures that should be taken there. First, providing targeted support for research and development is crucial. The project you mention is a good example of that. In North Rhine-Westphalia, we've created a platform called IN4climate.NRW that is unique in Germany. It brings industry, the science and research sectors, and the policy level together to craft innovative strategies for climate neutrality in industry. Second, we need to create a clear legal and regulatory framework that makes it easier to use hydrogen technologies. Third, it's important to create economic incentives that make the transition to decarbonization attractive for business. That means things like tax incentives, but also accelerating planning and approval procedures for new and climate-friendly investments.

The German federal government cut the funding available for battery research by 75 percent. What do these reductions mean for battery research in Germany?
Research and development involving high-performance battery storage is key to the success of the energy and transportation transformation. We need to strengthen this area for the long term. It requires ongoing, dependable funding. The federal government is facing calls to restore the research funding that had originally been planned as part of the climate and transformation fund. Both the science and industrial sectors need a reliable vision of the way forward.

What can be done to scale up alternative battery technologies faster?
Partnerships between research and industry are key here, too, when it comes to accelerating technology transfer and bringing innovations to market fast. The Fraunhofer Research Fab Battery Cells FFB in Münster is a good example. The FFB PreFab, which is due to open shortly, is to set up a sample line for small-scale production of complete battery cells as an important intermediate step toward the industrial scale. The FFB Fab will then make it possible to harness plant technologies on an industrial scale to produce complete battery cells. The projects illustrate how targeted investments in research, development, and the creation of prototype facilities can bridge the gap between research and mass production.

Your state is viewed as one of the centers of AI research in Germany. How can Europe hold its own as it competes with others, like the U.S. and China?
Within the North Rhine-Westphalia state government, we have a clear goal of bringing cutting-edge research, innovative spirit, and entrepreneurship together with our push for AI made in NRW. One key there is forging even better connections among our existing quality players. The KI.NRW expertise platform will help with that. It is being headed by the Fraunhofer Institute for Intelligent Analysis and Information Systems IAIS, located in Sankt Augustin, near Bonn, which is one of Europe's leading research institutes in the fields of artificial intelligence and machine learning.

You've pointed to what you call an "oppressive lack of speed" at the federal level that is causing people to doubt whether the state is capable of action. Where do you get things done fast in NRW?
We've passed a number of packages specifically aimed at unleashing activity and cutting through bureaucracy. But we keep running into legal hurdles at the federal and European levels. That's why I'm extra happy we managed to negotiate a substantial pact between the German federal and state governments aimed at accelerating planning, approvals, and implementation. Now it needs to be put into action, and quickly. Of course, we're taking action wherever we can as a single state. We're the nationwide leader in approving wind turbines, for example. We ramped up hiring at the district government level to expand the electricity grid. And in terms of the digital transformation, our Wirtschafts-Service-Portal.NRW business platform is considered a role model for the whole country. One specific example where we really got things done fast was the FFB PreFab in Münster. Construction was done in just nine months. The property was turned over to Fraunhofer at the end of last year and is going into operation at the end of March. And the second section of construction is also making great strides. But it's clear that we still have our work cut out for us, including in North

"Are real solutions the best way to defang populism?" — "Yes."

Hendrik Wüst

Rhine-Westphalia — and we're pushing ahead with it.

What areas of focus in research activity would you fight for in a German federal government led by the CDU?
From North Rhine-Westphalia to the federal level, innovation is one of the pillars of an economy and society that is viable for the future. Research policy should be geared toward that, regardless of the political level.

You've called the AfD party your main political opposition. Aren't real solutions for people's anxieties about the future the best way to defang populism?
Yes. Truly robust solutions to problems can only be found in the democratic center. But they also have to be tackled. In recent weeks, we've also seen huge public opposition to the AfD, to right-wing extremism, and huge public support for cohesion across our society and for democracy. That shows that the AfD doesn't speak for a silent majority, as it has always claimed. We need to face down the AfD on the issues and take clear positions. Above all, that means showing people what consequences and impact AfD policies would have in terms of their daily lives — for workers, for example, or the social safety net. When you dig a little deeper, you can see that the AfD poses a risk to our prosperity and democracy. We can see that just from their calls for Germany to leave the European Union.

You became a parent late in life, if you'll excuse the term, at 45. Has having a child changed your view of the future?
Being a parent does change your personal view of the world, of course. There are new roles and responsibilities involved, which I enjoy. Each and every day, my daughter Philippa is a living reminder of what our decisions mean for the future. And that includes asking what we can do today to make the possibilities even better for those who will live in the world of tomorrow. Life expectancy for today's babies and toddlers is longer than the German republic has been in existence today. That's humbling, for one thing. But it's also a call to action. We need to take advantage of every opportunity to lay the foundations for all of today's children to be able to lead a good life in every possible way.

Are you confident when you think about the country where Philippa will grow up?
As far as North Rhine-Westphalia is concerned, we have excellent chances of solving the big challenges facing us today. As for me personally, I'm doing my best, taking it one day at a time. ■

Not a hair out of place
Dieter Schlebes from the town of Rhede has been cutting the head of state's hair for more than 30 years now: "He wants to make sure he looks good."

Work-life balance
May 14, 2022 — Election Day: Wüst and his wife, Katharina, head to the polls with daughter Philippa.

Frunning for fancellor?
Shown here with actress Annette Frier in 2023, Wüst stumbles while reading aloud. The children's book *Der Fönig* is challenge — every K is replaced with an F. Maybe he should run for chancellor instead?

A backhanded compliment
In March 2024, Wüst praises CDU party chair Friedrich Merz, saying he is "a marvelous opposition leader." The race for the chancellorship is on.

Photos: Hendrik Wüst@Instagram (2), Hendrik Wüst@Facebook, Clemens Bilan, Rolf Vennenbernd/dpa (2), Christoph Hardt/imago-images, Lars Heidrich/Funke Photo Services/imago images

CHILE

Green hydrogen from Chile

Scientists from Germany and Chile are studying how solar energy can be used to make hydrogen derivatives on a large scale in technical, economic, and ecological terms. To that end, the team from the Fraunhofer Institute for Energy Economics and Energy System Technology IEE is working with Fraunhofer Chile Research and other partners to investigate the entire process chain. The focus of the "Power-to-MEDME-FuE" project is developing efficient, low-cost methods of producing two CO_2-neutral synthetic fuels, methanol and dimethyl ether (DME). Both can be used as fuel alternatives in heavy goods transport, and they also have ideal export properties. Various industrial electrolysis technologies are to be evaluated, catalysts developed, and seawater desalination analyzed as a source of heat. Plans call for the construction of a pilot production site in the north of Chile to produce either green methanol or renewable DME in the megawatt range, depending on the market situation.

The new H_2 production unit is also to be used to train specialists in how to operate it.

Fraunhofer worldwide

Locations of the Fraunhofer-Gesellschaft

Gentler therapy boosts the chances of survival.

EUROPE

Hope for preemies

An international team of researchers headed by Klinikum Nürnberg is developing an artificial placenta to help treat serious lung and kidney problems in premature infants. It is designed as a substitute for risky invasive treatments involving ventilators and dialysis machines. The new technology, known as "ArtPlac," connects to the blood vessels in the infant's navel through a specially developed umbilical cord. Much like a natural placenta inside the mother's body, it performs vitally important organ functions, supplying the baby with nutrients and oxygen and regulating the blood circulation, thereby supporting lung and kidney activity. The Fraunhofer Institute for Biomedical Engineering IBMT is developing microfluidic components for gas and electrolyte exchange for the device and incorporating sensors to monitor key blood flow and dialysis parameters. The external placenta's sole source of energy is the newborn's heartbeat, which transfers the energy through the vessels of the umbilical cord. Unlike with existing forms of treatment, the infant does not need to be sedated, but can breathe and interact instead, which is very helpful in ensuring the treatment's success.

There is no need to clear rain forest to grow macauba palms.

BRAZIL

Sustainable palm oil

To advance efforts toward sustainable production of vegetable oil, protein, and fiber, the Fraunhofer Institute for Process Engineering and Packaging IVV is working with its Brazilian branch lab in Campinas on ways to use the whole fruit of the macauba palm tree. This tropical plant does not require much water, so it supplies large amounts of oil even in dry regions. An innovative fractionation technology developed by Fraunhofer IVV in cooperation with Brazilian partners has now made it possible to separate the raw materials present in the macauba fruit into high-quality oils, fibers, and proteins, thereby tapping into the previously unused potential offered by the residue left over after pressing and oil extraction. The utilization concept unlocks a variety of different applications in fields such as the food and cosmetics industries and in production of biodegradable packaging. The palm tree also significantly enhances soil fertility, which means the space between the palms is more productive in growing grass for livestock grazing or even crops such as soy or coffee beans. The partners in Fraunhofer spin-off Macauba Ingredients GmbH are currently looking for partners to build a production facility in Brazil.

ESTONIA

Biomass as a substitute for coal and natural gas

Torrefied beechwood (right) has greater fuel value than untreated wood of the same kind (left).

The Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB and New Standard Oil, an Estonian start-up, are working to make plant-based biomass usable as a climate-friendly alternative to fossil fuels. To achieve this, the Fraunhofer researchers have devised an energy-efficient method of using biological residue such as wood and hay for material and energy. The biomass is first dried in an atmosphere consisting of superheated water vapor without oxygen and then torrefied, meaning it is broken down thermochemically. The volatile organic compounds (VOCs) are reclaimed as condensate during the process, so the valuable "green chemicals" from the biomass are retained for further processing. The torrefied biomass, a kind of bio-coal, can be shaped into pellets or ground into dust and used as a substitute for coal or natural gas as a way to operate power plants on a climate-neutral basis. The unit can process up to 150 kilograms of bio-residue per hour. The method has now been implemented commercially for the first time in a large technical pilot plant.

FRANCE

Climate research with diamonds

One important piece of the puzzle when researching global warming is how much heat the earth radiates into space. Researchers from the Fraunhofer Institute for Applied Optics and Precision Engineering IOF and the Institute of Applied Physics at the University of Jena have now developed an innovative diamond structure for a satellite spectrometer of the European Space Agency (ESA), which is based in Paris, to enable precise measurements of this heat radiation in the extreme far infrared range for the first time. The diamond surface is about the size of a credit card. It acts as a beam splitter for the spectrometer, which is to be used for precise analysis of the earth's radiation levels starting in 2027. The challenge was to make one surface of the diamond antireflective on a broad spectrum without adversely affecting the infrared range. Inspired by the cone-shaped surface structure of moth eyes, the scientists developed a special method that relies on reactive ions, in which microscopic pyramids are etched into the diamond's surface. Diamonds are chemically resistant, and as one of the hardest materials in the world, they are difficult to structure. On top of that, the far infrared range requires pyramids with extremely precise forms.

How much heat radiates from the earth into space? A new satellite spectrometer aims to find out.

The dream of good flight

The first challenge was lifting off. Once we conquered the skies, we flew all over. Now the goal is to make aviation more ecofriendly — hybrid electric could be the solution of the future.

By Dr. Janine van Ackeren

Modeled on birds: Aviation pioneer Otto Lilienthal (1848–1896) tested his flying apparatus on Berlin's Fliegeberg (literally "Flight Mountain").

Ecofriendly aviation? When it comes to passenger aircraft, Airbus is betting on hydrogen. The group plans to launch the world's first hydrogen-powered commercial airliner in 2035. On their own, electric batteries have only been able to keep smaller aircraft aloft for short trips so far. Hybrid electric drives are the next big hope. Combining an electric drive and a gas turbine goes something like this: A traditional engine like the ones typically found under the wings today is in the body of the aircraft. It powers a generator that produces electricity, which is then stored in a battery — and used to drive the rotors under the wings via electric motors.

Sounds like a roundabout solution? It actually isn't. The approach might seem complicated, but there are good reasons to do it this way. One key advantage is fuel economy. Right now, the pilot typically pushes the engine well beyond the "design point," the point where it was designed for optimum performance, during take-off. Six metric tons — 6,000 liters — of jet fuel have already been used up before the wheels on an A380 leave the ground. An aircraft doesn't reach its optimum fuel economy until it is in the air. "Having a battery as a power buffer in between means you don't have to use the engine's full energy every time you take off. Instead, you can run the engine at the design point the whole time," explains Dr.-Ing. Christoph Hubig, who works in the sustainable aviation business unit development at the Fraunhofer Institute for Machine Tools and Forming Technology IWU. "It's like if you were to drive about a steady 80 miles per hour on the freeway, which also uses much less gas than stop-and-go traffic on city streets."

A premiere for Rolls-Royce

But first, the engine that can do all this needs to be developed, certified, and brought to market. Under the leadership of Rolls-Royce Germany, Fraunhofer IWU, the Fraunhofer Institute for Material and Beam Technology IWS, the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, the Fraunhofer Institute for Applied Polymer Research IAP, Brandenburg University of Technology Cottbus-Senftenberg (BTU), and the Center for Hybrid Electric Systems Cottbus (chesco) are working with other partners to make this a reality. For Rolls-Royce, which has thus far been known in the aviation sector primarily for its gas turbines, these are the first attempts to electrify aircraft engines. At the same time, the project also aims to help achieve structural transformation in Germany's Lusatia region, as the state-level funding is earmarked specifically for efforts toward structural transformation by phasing out coal. The underlying idea is to transfer knowledge to Lusatia to create highly qualified jobs there. The IWS, IFAM, and IWU have founded a new establishment in Cottbus as part of these efforts, with shared offices on the BTU campus right near chesco as the nucleus.

Achieving ecofriendly lift-off: rendering of a hybrid electric aircraft

> "All these drives share a few things. They're quiet, operate at low temperatures, and have zero emissions."
>
> Dr. Christoph Hubig, Fraunhofer IWU

Electric drive meets turbine

Hybrid electric aviation is flexible. "How, exactly, the engines are designed depends on what they are supposed to do," Hubig explains. "The researchers are developing a modular system of electrified drives that can be combined together in various ways. All these drives do share a few things. They're quiet, operate at low temperatures, and have zero emissions." A single battery supplies enough energy for urban flights, while ranges of 80 to 100 kilometers or more require the addition of conventional drives such as a centrifugal compressor gas turbine powered with jet fuel or other fuels. "Depending on the requirements, we can configure the drive and energy source freely," Hubig says.

One major plus to these kinds of drives is their low noise. "An electric motor generates very high torque. That means you can design the rotor blades to be larger, so they don't turn as fast — which means they make less noise," explains Dr. Uwe Frieß, head of the department responsible for car body construction, assembly and disassembly at Fraunhofer IWU in Chemnitz. "Since the engine is encapsulated in the body, it also creates a smaller noise footprint."

One other important aspect is that conventional aircraft always have two engines. That means each one has to be smaller, which makes it less efficient. If only one engine is needed, it can be designed to be larger, ▶

Photos: akg-images/dpa, Rolls-Royce Germany

translating to greater throughput and more favorable thermodynamics. The costs of maintaining the second engine are also eliminated. Overall, the researchers estimate that the savings compared to a conventional turboprop engine with a range of 500 kilometers will add up to at least 20 to 30 percent. Figures like these are important to airlines' bottom line.

Rapid prototyping

Right now, the task is to get the prototypes built — fast. "While Rolls-Royce is redeveloping the drive system, the team at Fraunhofer is working on the production methods," Frieß says. The components needed for the drive systems are highly optimized for flow — ultra-complex geometries with thin walls made of materials such as titanium or nickel-based alloys that are difficult or impossible to work with using traditional methods. Plus, since the job involves prototypes, each component tends to be needed in single-digit batches, not by the hundreds or even thousands. This is a far cry from mass production, in other words. And that means the challenges are daunting:

The IWS and IFAM, along with BTU, are utilizing additive manufacturing by printing their components. One possible method involves melting a metal powder locally with a laser beam in a sinter bed so the granules fuse into a solid piece. The powder simply crumbles away in the places left untouched by the laser beam. In this method, components are built up out of the bed of metal powder, one layer at a time. Fraunhofer IWU is working with forming methods instead, creating a combustion chamber out of high-performance sheet metal. "Deep drawing processes are used for mass production in the automotive sector, for example. Making the tools for presses that large takes months," Frieß explains. This is not a feasible way of producing individual prototypes, a process that requires quickly making small unit quantities of new geometries. As a result, the researchers are focusing on versatile tools that can be assembled in different ways, or even tools made from wood, which only takes a few hours to mill to the right size and configuration. The team is also rethinking the deep drawing process itself: Instead of shaping the entire component in one go, the sheet metal is only pressed onto the mold locally, using means such as water pressure.

A gas turbine generates electrical energy that is fed into intermediate battery storage. The hybrid electric aircraft gets its power from there.

Fraunhofer IWU is researching the electronic components. For example, an innovative machine is being built to produce coils. In these components, wire is wrapped many times around a solid material. The finished coil generates a magnetic field when electricity flows through the wire. "We can change the diameter of the wire as we wrap it, along with the shape of the wire and the winding radius, which allows us to really dial in the magnetic field generated by the coil — this is completely uncharted territory," Frieß explains. This results in greater engine efficiency, so a smaller engine supplies the same amount of power.

> "While Rolls-Royce is redeveloping the drive system, the team at Fraunhofer is working on the production methods."
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> Dr. Uwe Frieß, Fraunhofer IWU

Speed is of the essence

All of this means that a range of skills and expertise is needed to meet a host of different specialized requirements. One factor that can help reach the required pace of development is digitalization. Fraunhofer IAP is working to digitalize the manufacturing processes for components with rotational symmetry and production machines alike. These systems were previously adjusted based on experience and a trial-and-error approach, but processes are now being optimized digitally. This yields a considerably better result on the very first try. Fraunhofer researchers are keeping the products in mind — or, more precisely, the digital twin of the components across the entire life cycle. All this information is being consolidated on a single platform with the goal of achieving high levels of certainty about the processes and machines right at the outset.

The components, produced with Fraunhofer expertise, are to be assembled into prototypes by chesco and then put through extensive testing. That makes chesco a kind of intermediary between Fraunhofer and Rolls-Royce. Once the first drives are certified, Rolls-Royce will work on production, and hybrid electric flying will really be getting off the ground. ■

Photo: Rolls-Royce Germany

Knowledge relay

stance

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Photo: Rolls-Royce Germany

Knowledge relay

Prof. Lauster, how do we ***collectively*** arrive at a neutral ***stance*** on the ***best solutions*** ***with an eye to*** current and potential ***crises***?

Knowledge relay, episode 11

Prof. Lauster, how do we collectively arrive at a neutral stance on the best solutions with an eye to current and potential crises?

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. Michael Lauster,** head of the Fraunhofer Institute for Technological Trend Analysis INT, answers a question from **Prof. Andrea Büttner,** head of the Fraunhofer Institute for Process Engineering and Packaging IVV.

Science is a human activity that creates knowledge, and as Plato tells us, knowledge is justified true belief. That means there are three conditions that must be met if we want to create knowledge: We have to find true propositions we can justify and believe in. "Truth" is a complex philosophical notion with multiple facets. Roughly speaking, there are three different concepts of truth: truth by correspondence, truth by coherence, and truth by consensus.

1. As scientists, we are heavily influenced by the first of these concepts: Our mental constructs are true if they have a corresponding element in the ontological background — that is, reality. We justify them by posing questions to reality through experimentation. The right question is always: How can I bring down my mental construct? Can I elicit responses from reality that argue against my hypotheses? The more often we fail at bringing down these mental constructs, the more we believe in them.

Prof. Michael Lauster has been in charge of the Fraunhofer Institute for Technological Trend Analysis INT in Euskirchen, near Bonn, since September 2012.

2. A less reality-based concept is that of truth by coherence: A proposition is true if it fits into an existing system of propositions without any contradiction. This is a view familiar from the humanities, and especially from mathematics. We justify these propositions through appropriate methods of argumentation and presentation of evidence, and we believe in them as long as all evidence to the contrary fails. In this concept, there is no need for correlates in physical reality, but they can often be found by analogy and are not detrimental when they are found.

3. The most problematic concept of truth, which is the farthest removed from science and, in my view, should always be fought, is that of truth by consensus: If a sufficiently large number of people believe in a certain proposition, then it becomes true. These propositions are often justified by ignoring or denying facts or through conspiracy theories and pseudoscientific arguments. A connection to physical reality tends to be detrimental to this form of truth, and it is often also prevented through violence. All of the world's religions, sects, ideologies, and dogmatic systems are based on this conception of truth.

This is why finding optimal solutions and assessing them objectively and independently between different people is a task that requires the scientific method. Karl Popper's critical rationalism is the best means we have so far of distinguishing truthful statements from beliefs and dogma. We need to work together to uphold our scientific standards and raise the next generation in the same spirit.

But science does not serve only to create knowledge. It also shows us that what we think we know is just a tiny island in an ocean of ignorance. It teaches us humility by showing us that every answer to a question opens up a universe of new questions. And it teaches us that our knowledge is only provisional and can be modified by new discoveries at any time or even carried on ad absurdum. ■

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Photo: Fraunhofer INT

In the next issue:

Fresh starts **and sweeping change: How will *AI* change our world?**

Referenzfabrik.H2

Turbocharging hydrogen

Climate change is proceeding faster than expected, the energy transition more slowly than had been hoped. Referenzfabrik.H2 aims to accelerate the production of hydrogen systems and open up new business fields for industries such as the automotive sector, in a push Fraunhofer is calling "Fit4H2."

By Beate Strobel, photography: Sven Döring

How do we take the hydrogen sector to the next level? That's a key question for Dr. Ulrike Beyer, head of Referenzfabrik.H2 at Fraunhofer IWU.

Keeping things rolling: Stefan Lohberger, a technician at Fraunhofer IWU in Chemnitz, is involved in the development of a hydrogen motorcycle.

What can be done to accelerate production of fuel cell stacks? Dr. Andreas Willert, Fraunhofer ENAS, is working at the pilot plant at Fraunhofer IWU to figure that out.

How do we share knowledge with external parties? Mary Esther Ascheri is responsible for H_2 cooperation projects in Namibia and South Africa at Fraunhofer IWU.

Six tiny bolts, six matching nuts, and a whole bunch of transparent, black, and colored rectangles: Even a dollhouse-sized demo version of an electrolyzer stack isn't exactly child's play to put together. Twenty heads are bent over the miniature parts here at the training room at the Fraunhofer Institute for Machine Tools and Forming Technology IWU in Chemnitz, as 20 people try to stack the parts in an order that makes sense and then hold them in place. With mixed results: "Could there be an extra membrane left over at the end?"

No, of course not. But it's not a big deal, either. After all, the two-day Fit4H2 workshop at Fraunhofer IWU is all about learning. The goal is to get people better up to speed on hydrogen technology. The participants have come from companies across Germany, Austria, and the Czech Republic. Most are hoping to glean inspiration and insight for new fields of business to explore, for example because the looming discontinuation of combustion technologies will necessitate broadening their product portfolio — or even require the whole company to pivot. Others are already working in the hydrogen sector and are now looking for ways to optimize processes. Home to five vehicle and engine plants and 780 component and machinery suppliers and service providers in the mobility industry, the state of Saxony is known for its focus on the automotive industry. Some 95,000 jobs are clustered in this sector here, more than 80 percent of them with suppliers.

"We want to gain insight into the technology and the requirements and challenges involved," Ulrike Michel-Schneider noted during the round of introductions. She is participating in Fit4H2 with Dušan Poliaček, whose company 1to1design, based in Prague, is part of a German-Czech research consortium that is currently working with Fraunhofer IWU to develop a hydrogen-powered motorcycle. 1to1 design's role in the Hydrocycle project is to design a sleek, lightweight body that still has enough space to accommodate an entire fuel cell system. With that mission in mind, Michel-Schneider and Poliaček want to know not only how a fuel cell is structured, but also how much it can be shrunk down without impairing its power. Poliaček, a designer, is fascinated by the idea of an H_2 motorcycle: "There are already purely electric motorcycles, so there isn't much room for innovation there." He also thinks hydrogen will allow for more enjoyable rides over longer distances. "Hydrogen can become an important alternative, including for small vehicles."

The "cheese" of the renewable energy sector

The hydrogen sector as a technology of the future is a key subject for Dr. Ulrike Beyer, head of Referenzefabrik.H2 at Fraunhofer IWU. If Germany, Europe as a whole, and other countries around the world are to be able to fulfill their decarbonization commitments, a massive increase in the production of renewable energy will be needed. "But renewable energy is like fresh milk: It has to be used right away or turned into a product with a longer shelf life — like cheese," Beyer explains. "Hydrogen has the potential to be the 'cheese' of the renewable energy sector, helping to support the energy transition."

For that to happen, however, there will need to be an extreme scale-up in the production volume of "green" hydrogen — that is, hydrogen produced through electrolysis using renewable energy or biomass. "But H_2 technologies aren't yet designed for industrial mass production, and they're still too expensive," Beyer notes right at the start of the workshop. To change that and put the gas on an even footing with fossil fuel energy, including in terms of price, Fraunhofer IWU teamed up with the Fraunhofer Institute for Production Technology IPT to create Referenzfabrik.H2 in 2022 and brought in the research content of the Fraunhofer Institute for Electronic Nano Systems ENAS in Chemnitz as well.

In her role as head of Referenzfabrik.H2, Beyer is especially concerned about the fact that both electrolyzers and fuel cells — the two key systems for generating hydrogen and reconverting it to electricity — are still being produced in much too meager unit volumes in Germany these days. "With renewables gaining ever more market share, demand for these technologies will skyrocket between now and 2050," she says. Industry needs hydrogen for various reasons, such as a substitute for natural gas and as a storage medium for the renewable energy needed to decarbonize production methods. In the mobility sector, demand for H_2 is expected to jump in the heavy goods transportation segment first, starting in 2030, and then in aviation and shipping as well from 2040 onward. A recent meta-study by the Fraunhofer Institute for Systems and Innovation Research ISE predicts that hydrogen will account for four to eleven percent of total final energy demand around the world by 2050. The German federal government's revised hydrogen strategy postulates that some 50 to 70 percent of the H_2 demand

expected for 2030 will have to be met through imports. That is, unless domestic production can pick up the pace.

Predictions like these are a clear "signal to get into this market," Beyer tells the participants, who are diligently taking notes. After all, she notes, there will soon be "a huge shortfall of production technologies," by which she means the electrolyzers and fuel cells needed to meet future demand. Beyer points to the many start-ups springing up in the H_2 technology segment as another sign of this market's future viability: "We're in the early days of production development." The Fraunhofer hydrogen network believes annual value creation for German manufacturers of electrolyzers and fuel cells could come to 10 billion euros in 2030 and 32 billion in 2050.

To tie in with that theme, the message printed on the packs of candy each of the Fit4H2 participants found waiting at their spot is a simple one: "Fueling your value creation." "To 20 by 27" is Referenzfabrik. H2's motto: The goal is to lower production costs for hydrogen systems to 20 percent of present-day costs by 2027, making hydrogen technology from Germany competitive. "This could be a way for us to recapture some of the value creation we lost with battery power," Beyer says.

"To 20 by 27" is an ambitious goal, but in light of global competition, an aspirational vision is what counts. For example, the U.S. Department of Energy has launched what it calls its "Hydrogen Shot" program for the United States, aiming to reduce ▶

"To 20 in 27" is the motto of Referenzfabrik.H2

How can production of bipolar plates (BPPs) be made more efficient? Sebastian Melzer pursues this topic at the pilot plant at Fraunhofer IWU.

the costs of clean hydrogen by 80 percent, to one U.S. dollar per kilogram, within the next decade. If others are to keep up, the research and industrial sectors will need to work closely together. Referenzfabrik.H2 has already brought in 25 companies as integral partners in the value chain community and is pressing ahead with further growth. One of the partners is the Schaeffler Group, an international automotive supplier that has already set its sights on a range of hydrogen technology applications. Another is Spreckelmeyer GmbH, a medium-sized artisan business from Lengerich, a town in North Rhine-Westphalia, whose core business is mechanical engineering, automation, and robotics. "We also need this down-to-earth, can-do spirit when it comes to advancing the topic of hydrogen," Beyer points out.

Hy-Ventus to provide industrial tailwind

Referenzfabrik.H2 is pushing to bring hydrogen technologies made in Germany to market from two directions. The first of them involves a flagship project funded by the German Federal Ministry of Education and Research (BMBF) called H2Giga, in which it has joined forces with Fraunhofer IWU, IPT, IPA and ENAS and with the Fraunhofer Institute for Microstructure of Materials and Systems IMWS in the FRHY project to develop flexible solutions for mass production of electrolyzers. These devices are used to split water into hydrogen and oxygen by applying energy. However, mass production of electrolyzers is not yet competitive with the available technologies.

Hence Referenzfabrik.H2's efforts to provide a tailwind: Hy-Ventus, an innovative electrolyzer stack suitable for high-rate industrial production. Right away on the first day of training, Sebastian Melzer from Fraunhofer IWU takes the group through the individual parts of the stack, including bipolar plates (BPPs) made from half-plates that are mechanically embossed and rolled at high speed and then welded together with an electron beam, all using a method developed in-house. The proton-exchange membranes, embedded in a stable film framework, are sandwiched between the BPPs by porous transport layers (PTLs) or gas diffusion layers (GDLs). Gold-plated contacts at either end of the stack are used for the energy supply. That sounds simple — but when tasked with putting together their own miniature stacks, some of the participants realize the concept hasn't quite clicked yet: "Where do the gold things go, again?"

Hy-Ventus is currently being designed on a large scale from the manufacturing perspective and is slated to go into industrial production in 2025. It's about time, too: As Melzer notes, 190 million of these stacks will be needed in order to produce 70 million metric tons of hydrogen globally by 2030. Put together, the BPPs required for this would stretch across 16,000 football fields, and laid end to end, the welds (about one meter per BPP) would reach from the earth to the moon five times over.

How can MEAs be made in large volumes and at low cost?

Dr. Andreas Willert, Fraunhofer ENAS, has high hopes for inkjet printing.

The second area of emphasis in Referenzfabrik.H2's research activities is fuel cells, which it is pursuing with funding from the German Federal Ministry for Digital and Transport (BMDV) as part of the H2GO National Plan of Action for Fuel Cell Production, a joint project of 19 Fraunhofer institutes coordinated by Fraunhofer IWU. The researchers in Chemnitz are working on a range of topics, including how best to produce the membrane electrode assembly (MEA), the centerpiece of any fuel cell stack, in large quantities, making it cost-effective. There are high hopes for inkjet printing for this, explains Dr. Andreas Willert, deputy head of the Printed Functionalities department at Fraunhofer ENAS, who presents the machinery concepts specially developed for this at the pilot plant. One of the challenges here is fine-tuning the viscosity and composition of the coating material in such a way that the print head does not clog and the membrane is coated evenly — and so rapidly that it doesn't have time to swell or bulge.

The Fraunhofer researchers are also working on error tolerances in the case of electrolysis and fuel cell membranes and bipolar plate production. "Activation, by which we mean breaking in a stack, currently accounts for about five percent of the total production costs," explains Sören Scheffler from Fraunhofer IWU. "We're handling that for industry, thanks to our H_2 testing lab." Another objective is to detect the parameters for efficient production conditions. Right now, industry is pursuing a zero-tolerance approach, because even a single faulty MEA massively shortens the lifespan of the entire stack. And that means a lot of waste, which could be reduced if the relevant error tolerances of the stack components were known. There is also still a lack of data for digital simulation of the aging process. Scheffler says the researchers are flying blind in this regard: "Right now, a stack has to be operated for 1,000 hours to be able to say for sure that it can be operated for 1,000 hours."

A modular technology kit for industry

Referenzfabrik.H2 is tapping into collective intelligence, bringing the science, research, and industrial sectors together with the aim of forming a value chain community that together can ramp up the use of hydrogen technologies in Germany and across Europe. They aim

to create a kind of technology kit by putting together building blocks for the production of electrolyzers and fuel cells and offering them for knowledge transfer purposes. A "technology mall" provides key stack components on a modular basis. And technology services provided by Fraunhofer researchers will help partner companies incorporate existing expertise and infrastructures into hydrogen system production.

There are even already plans for the H_2 specialists of tomorrow: Referenzfabrik. H2 is the German sponsor of the H_2 Grand Prix, which was launched by Horizon Educational, a Czech company. The series invites elementary and secondary school students to work in teams to develop lightning-fast miniature hydrogen-powered vehicles and compete against each other, first nationally and then in international competitions. Last year's contest was limited to Saxony, but as Katrin Zieger, who is responsible for strategic communication at Referenzfabrik.H2, notes, "Our stated goal is to roll out the Grand Prix program all across Germany." After all, it's never too early to get the specialists of tomorrow on board with the idea of "Fit4H2." ■

Business, industry, and the science and research sectors join forces to ramp up the use of **hydrogen technologies**.

Fraunhofer Hydrogen Network:
For more information on hydrogen technologies, visit www.wasserstoff.fraunhofer.de

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Green hydrogen for clean steel

Steel production emits millions of metric tons of carbon dioxide year after year. Using hydrogen in the process chain could make the dream of climate-neutral steel production a reality.

By Mehmet Toprak

Smelting iron ore in a blast furnace at temperatures as high as 2,000 degrees Celsius and using coke to reduce it into raw iron generates huge amounts of CO_2. According to the Competence Centre on Climate Change Mitigation in Energy-Intensive Industries (KEI), the German steel industry alone emits some 55 million metric tons of carbon dioxide every year. That's about 28 percent of all CO_2 emissions generated by the entire German industrial sector. To address this issue, the steel industry has been looking for practical technologies to decarbonize production for years.

And indeed, there are much cleaner methods available, as researchers from the Fraunhofer Institute for Ceramic Technologies and Systems IKTS, the Fraunhofer Institute for Systems and Innovation Research ISI, and the Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT have shown in a joint project with Salzgitter AG. They are using hydrogen instead of coke. Just like coke, hydrogen deprives the iron ore of oxygen through direct reduction. What remains is the valuable raw pig iron. This process also generates much less carbon dioxide. "If the electricity used to produce the hydrogen through electrolysis comes from renewable sources, the climate-damaging carbon emissions from raw steel production can be reduced by as much as 97 percent," explains Dr.-Ing. Matthias Jahn, head of the energy and process engineering department at Fraunhofer IKTS in Dresden.

Pilot system at the plant

In electrolysis, water is split into hydrogen and oxygen by applying an electrical current. The team of researchers at Fraunhofer IKTS have now taken this method to a new level, utilizing high-temperature electrolysis based on solid oxide electrolysis cells (SOECs). Unlike other methods of electrolysis, this technology uses water vapor, which can be generated using the waste heat from the steel industry's own high-temperature processes. This makes it possible to increase efficiency as compared to other methods. In simplified terms, more hydrogen can be generated using the same amount of electricity.

Clean steel requires a lot of water

The researchers at Fraunhofer IKTS have developed their own electrolysis cells and stacks and are now working to scale the technology to achieve greater output and production capacity. To that end, the technology is now being put to the test under real-world operating conditions. Salzgitter AG has installed a pilot and demonstration system 30 meters tall at its plant. The team from Fraunhofer IKTS plans to connect the high-temperature electrolysis to this unit so they can study it in connection with direct reduction of iron ore using natural gas and hydrogen. Another area of focus in their research is enhancing the efficiency of water use. Huge volumes of water will be needed for electrolysis in future steel production, so the researchers are studying how the water generated during iron ore reduction using hydrogen can be processed and used in electrolysis.

In the BeWiSer project, which is receiving funding from the German Federal Ministry of Education and Research (BMBF), the researchers and their partners are now working to improve the entire process chain with an eye to resource and energy efficiency — from high-temperature electrolysis, membrane methods, and gas separation to water treatment, process simulation, and modeling all the equipment using a digital twin. Dr. Alexander Redenius, head of resource efficiency and technology development at the Salzgitter Mannesmann research arm, says: "The direct-reduction demonstration plant enables us to optimize the reduction process and how it interacts with the other process steps. Through this work, we are creating the basis for clean, sustainable steel production." The company aims to convert a third of its steel production to the climate-friendly process with hydrogen as early as 2026. ■

Photo: Julian Stratenschulte/dpa

Hydrogen makes climate-friendly steel smelting possible.

A voice from the business world

Dr. Roland Busch, 59, president and chief executive officer of Siemens AG

Harnessing AI for good

AI will unlock greater productivity, enabling more innovation and sustainability. It is the big opportunity of our time. To harness it, Germany needs a wise immigration policy — and a culture of openness.

Viewpoint: Dr. Roland Busch, president and chief executive officer of Siemens AG

I introduced Danny at this year's Siemens general meeting. Although Danny is artificial, it acts extremely intelligent. I can talk to the AI like I would to a person, and it can answer me the same way. Danny is still in training, but the AI will soon have in-depth knowledge of industrial technologies. And when it comes to programming robots, Danny has skills equivalent to those of our top experts. It is living proof — or perhaps I should say human-created proof — of how generative AI will change the world.

AI unlocks greater work productivity and accelerates innovation, and it can also support us with sustainability. It helps address the shortage of skilled workers. And it is a huge factor we can harness for sustainable economic growth and competitiveness by revolutionizing entire industries and reinvigorating national economies. It is the big opportunity of our time. And Germany can be the nucleus for generative AI in industry — industrial AI. How will we do that? Three answers.

First: Germany is home to many world-class ecosystems, such as automotive, chemicals, pharma, manufacturing, and universally relevant, machine building — all with strong ties to the scientific community. Successful ecosystems require one thing above all: creative, engaged people. And that also includes people who come to Germany and want to contribute their skills, so we need a wise immigration policy, paired with a culture of inclusion and openness. In Friedrich-Alexander-Universität Erlangen-Nürnberg and the Fraunhofer Institute for Cognitive Systems IKS, we have a strong ecosystem for accelerating the digital transformation of train systems. Together, we are using AI to develop driverless trains (see pp. 56/57). We use AI for companies such as Heineken and Northvolt, conserving energy during the beer brewing process and optimizing production at battery gigafactories.

And where some people see competitors, we see partners. We work with NVIDIA to create photorealistic visualizations for the industrial metaverse. Together with Amazon Web Services, we make it easier to incorporate AI into apps. And we've joined forces with Microsoft to develop the Siemens Industrial Copilot, which makes human-machine interactions faster and more intuitive than ever before. This industrial copilot is what we named Danny. Schaeffler is the first customer to use it in the real world.

"AI will unlock greater work productivity and accelerate innovation."

Dr. Roland Busch

- has been the CEO of Siemens AG since 2021. The company has about 320,000 employees across 190 countries and posted sales of 77.8 billion euros in 2023.
- has worked in many areas over his three decades at Siemens, from automotive technology to the internet of things. He joined the managing board in 2011 and became the deputy CEO and labor director in 2019.
- joined Siemens in 1994 in the role of project head within the corporate research and development department. He has said he joined the company out of a belief "that technology can solve the world's biggest challenges."
- was born in Erlangen in 1964. He studied physics at Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU) and the University of Grenoble before completing his doctorate at FAU in 1993.

Second: At Siemens, we have years of expertise in using AI for our customers. And since the release of ChatGPT, we've touched off a wave of ideas and projects in our research and development department — including Danny. Our entire experience tells us that humans will not be replaced by AI. Humans will be replaced by other humans who use AI. That's why continuing education is so important. We already have about 1,500 proven AI experts at Siemens today. And 40,000 of our colleagues attended AI training in 2023.

Third: The EU's planned AI regulation definitely has good intentions, but it might impede AI-based business models. There are similar risks with the EU data regulation and taxonomy regulation. None of these regulations are wrong in principle, but taken as a whole, and especially in the fine print, they may jeopardize innovation at a time when innovation is more important than ever. They are slowing things down at a time when speed is crucial to our competitiveness.

But I am a firm believer in our country's innovative strength. That's one of the reasons Siemens is investing a billion euros in Germany's future, in spite of slow growth and an increasing trend toward investing in other countries.

We are using the funds to create a high-tech campus in Erlangen as a blueprint for the industrial metaverse. We're combining the real and digital worlds to create an immersive space — a virtual world almost indistinguishable from the real one. AI engineers and their human colleagues can work together in real time there to solve the biggest challenges of our time.

I see AI as a factor we can harness for growth. It also offers us chances to do good. If we promote open ecosystems and a positive basic attitude and find a reasonable approach to regulation, we can harness AI to make great strides. ■

Photo: Enno Kapitza

Born to kill: The illustration shows how a T cell attacks a cancer cell.

Taking the fight to cancer

Individualized therapies have good success rates — but, at 250,000 euros per treatment, a steep price as well. Fraunhofer institutes are working to make these therapies affordable. The methods used are also suitable for mRNA vaccines.

By Dr. Janine van Ackeren

A scattershot approach used to be the standard way to treat cancer. These days, there are individualized treatments that can fight back. But these treatments, which cost upward of 250,000 euros, are currently only approved for patients who have not responded to chemotherapy or radiation — right now, for certain forms of leukemia and lymphoma. Essentially, the process works like this: Blood samples are taken from the cancer patient and used to isolate immune cells. Those cells are then genetically engineered and reintroduced to the body, where they are then able to attack the cancer cells. The success rate is high, with one in two patients — who have had no success with conventional treatments — responding favorably to these forms of treatment.

"A dramatically lower price would help make these treatments available to patients at early stages of cancer, too," says Dr. Ulrich Blache, a group manager at the Fraunhofer Institute for Cell Therapy and Immunology IZI. "It's also important to increase availability. It simply has to be possible to produce enough of these therapies to be able to help a large number of patients," he continues. High price and low availability have both dogged the new methods so far. Little amounts of the cells have to be cultured in a cleanroom setting for weeks for each individual patient. The treatment is useless to others, as their immune systems would reject the foreign cells.

Little amounts of **individual cells** have to be cultured in a cleanroom setting for weeks for each patient.

Fraunhofer researchers are tackling both challenges as part of Fraunhofer's RNAuto flagship project. Coordinated by Fraunhofer IZI, the project also involves the following Fraunhofer institutes: The Fraunhofer Institute for Toxicology and Experimental Medicine ITEM, the Fraunhofer Institute for Experimental Software Engineering IESE, the Fraunhofer Institute for Production Technology IPT, the Fraunhofer Institute for Manufacturing Engineering and Automation IPA, the Fraunhofer Institute for Microengineering and Microsystems IMM, and the Fraunhofer Institute for Microelectronic Circuits and Systems IMS. "The vision is to drive costs down to a five-digit amount — and maybe even to a tenth of what they are now," Blache says. For comparison, the costs of even conventional cancer therapy add up to five- or six-digit figures over the months and years involved. In the long run, the new treatment could thus not only be more successful, but also less costly.

"One key aspect here will be the automation of the manufacturing process and the complete digitalization of quality control," adds Rolf Hendrik van Lengen, Program Manager Digital Healthcare at Fraunhofer IESE.

Cancer therapy: mRNA instead of viral vectors

With this vision firmly in their sights, the researchers are turning the production process in a whole new direction. In the previous method, a certain kind of immune cells known as T cells are taken from a sample of the patient's blood, then cultured and genetically modified. This modification causes the immune cells to be equipped with a receptor. "You can think of the receptor like a key that specifically fits certain molecules on the surface of the cancer cells — the lock. Putting the key in the lock starts the process of destroying the cancer cell," Blache explains. Pharmaceutical manufacturers use viral vectors to insert the molecular weapon into the cells of the sample through the protective cell membrane.

The Fraunhofer team is taking a different tack, instead using messenger RNA (mRNA) — short, single-strand messenger molecules. "The mRNA carries the blueprint for producing the receptors for that specific type of cancer inside the T cells. That means it has to be different for breast cancer than for leukemia or lymphoma," Blache explains. There are various advantages to using mRNA instead of viral vectors to "arm" the cells. For one thing, mRNA is less costly as a starting material than viral vectors — although this is not ex- ▶

"The vision is to drive costs down to a five-digit amount — and maybe even to a tenth of what they are now."

Dr. Ulrich Blache, Fraunhofer IZI

Illustration: Tim Vernon/Science Photo Library; photo: Fraunhofer IZI

"Encapsulating the mRNA is a key factor."

Rolf Hendrik van Lengen, Fraunhofer IESE

pected to produce the big price reduction researchers are hoping to see. Much more importantly, it is also safer for patients. This is because the viral vectors currently in use permanently integrate themselves into the genome of the cells taken from the patient. This causes the CAR T cells to be therapeutically active for years, but the long-term ramifications of this lasting genetic modification remain unknown. That is not the case with mRNA. It does not become a part of the human genome, and instead is broken down within the body in just a few days. "This means unforeseen long-term consequences are very unlikely with mRNA," Blache says.

From individual to multi-patient

Using mRNA instead of viral vectors is an important step, but it is not enough on its own to overcome the major challenges involved. After all, this method would still entail weeks of painstaking work done by hand to produce a single treatment for an individual patient. With this in mind, the researchers aim to design the effective therapy to be suitable for all patients — an "allogeneic" treatment. This would make it possible not only to sharply reduce the price, but also to increase availability. Ultimately, the treatment could be produced in volumes hundreds of times larger, with largely automated manufacturing processes. Patients would also no longer need to wait for weeks to receive treatment, since stocks of allogeneic therapies can be produced in advance.

The researchers aim to design the effective therapy to be suitable for **all patients** — an **"allogeneic" treatment.**

The challenge is daunting. "We can't use T cells for allogeneic treatments, since foreign T cells would be rejected by the patient's immune system. That's not the case with natural killer cells, or NK cells, which can be administered to different patients across the immunological barrier," Blache explains. Initial study results on this topic have been promising. As far as the final effects are concerned, Blache does not yet have detailed predictions to offer: "We're really on the very front lines of research with this." But one thing is already clear: The multi-patient approach will work well for certain indications. In the future, the new allogeneic therapies could be used to treat various forms of cancer, but that is not all. Notably, they could also be used for autoimmune diseases. Blache firmly believes in this approach: "There is a jump between this form of treatment and treating conditions other than cancer. The whole field is expanding, which increases the pressure on new developments."

The researchers working on the RNAuto project are targeting not only cancer therapies, but also mRNA vaccines like the ones first approved and used worldwide for COVID-19. "We can use the same techniques to produce vaccines that we do for mRNA therapies," says Dr. Jasmin Fertey, group manager for vaccine technologies at Fraunhofer IZI. The mode of action is to inject the mRNA — genetic blueprints, so to speak — into the body. The mRNA itself is already the active ingredient. The cells of the body read the blueprint and produce specific proteins also present in the virus. The immune system is then "trained" for the specific pathogen, protecting the body by producing antibodies to match. If and when the virus does invade, it is quickly detected and targeted for destruction. Like in the cancer treatments, the mRNA itself breaks down within days; all that remains is the antibodies and immune memory.

Fighting West Nile virus

As a real-world example, the researchers point to a vaccine candidate for West Nile virus, which is increasingly spreading toward northern Europe as a result of climate change. There is no approved vaccine so far. But the researchers at Fraunhofer IZI have patented a clinical candidate. The team is using this mRNA vaccine as an example to develop the necessary production technologies and equipment — which will then also translate to production of cancer therapies.

Production of appropriate volumes of mRNA active ingredients is handled via a pilot plant at

Fraunhofer ITEM, where the researchers work in tandem with colleagues from Fraunhofer IZI on good manufacturing practice (GMP). "One of our primary goals is to scale production of mRNA to the volumes needed for a safe and reliable pharmaceutical process," Blache explains.

The project's targets also include encapsulation the mRNA. If the mRNA vaccine were injected directly into the body, it would break down immediately. "Encapsulating the mRNA is a key factor," van Lengen points out. This task is handled by a screening unit operated by Fraunhofer IESE, IPT, and IMM. Tiny globules of fatty acids known as lipids are used as the encapsulation material. They carry the genetic cargo inside them to the destination. However, a COVID vaccine requires a different lipid composition than a vaccine for West Nile virus, and the same is true of cancer therapies. How successful the encapsulation is depends not only on the length and structure of the mRNA itself, but also on the size, viscosity, and charge of the lipid and on machine settings such as pressure, flow rates, and temperature.

Scaling up to industrial levels

What the optimum encapsulation for a certain kind of mRNA is like and what encapsulation parameters are needed will be determined in the future by a screening unit — for volumes up to industrial levels. "Not only does it automatically pack the mRNA into the lipid globules, but it also handles quality control and stores all the information in the digital twin," van Lengen explains. The encapsulation process itself is a self-assembly. Biochemical reactions cause the mRNA to encapsulate itself inside the globules largely automatically. To get the process going, two liquids — one containing mRNA, the other lipids — are mixed together using two pumps and a micro-mixer. Even though the process is self-organized, it is anything but simple. The design and construction of the micro-mixer already raise many questions: How can the tiny lipid structures be designed to be as smooth as possible, so the globules do not tear back open? How can the micro-mixer be cleaned?

Quality control without losses

One of the unit's special features lies in quality control. During production of the COVID-19 vaccine, it was always necessary to take a sample and then analyze it in a lab setting, which is problematic with small production batches. But now, the product can be analyzed during production using methods such as dynamic light scattering, all without destroying it. The idea is that it will be possible to use various filtering methods to immediately remove any globules that are too small or too large, along with those that do not contain enough mRNA. Documentation is also automatic, thanks to digital process control. "Based on real-time measurements with sensors such as those from Fraunhofer IMM, we use the control software COPE developed at Fraunhofer IPT and the Eclipse BaSyx open-source software solution developed at Fraunhofer IESE to supply data to a digital twin," van Lengen says. "So, we always know which manufacturing parameters were in place at what time and can optimize the process by comparing the quality and parameters. By doing this, we're translating Industry 4.0 to pharmaceutical manufacturing — Pharma 4.0, if you like — which is completely uncharted territory." Once the unit is complete, the mRNA for West Nile virus will be packed automatically and then tested for efficacy at Fraunhofer IZI. The timeline calls for Fraunhofer to extend access to the unit to industry partners in late 2025. ■

Automation in the production process and digitalization in quality control hold promise for scaling the new treatments up to industrial levels.

Photos: Fraunhofer IESE, iStock.com/gorodenkoff; peterschreiber.media; Deagreez; luismmolina; edited by Fraunhofer IESE

Streamlining public transit

Fast, reliable, simple, convenient — that's how public transit should be, to get people out of their cars and onto buses and trains. The reality is often very different. How artificial intelligence can help.

By Dr. Sonja Endres

Nuremberg's U-Bahn line 3 has been speeding along underground without a driver for nearly 16 years now — safe, reliable, and with an on-time rate of 98 percent. Automatic controls permit twice as fast a cycle rate, optimized operation lowers energy and maintenance costs, it's easy to add further trains flexibly at peak times, and short staffing is never an issue. In short, this is a successful model that allowed local transit operator Verkehrs-Aktiengesellschaft Nürnberg to switch a second U-Bahn line to driverless operation just two years after it was first launched.

There are about a hundred fully automated train systems running underground around the world, but operators have thus far been an essential part of aboveground railway systems — the openly accessible tracks are difficult to secure. "Fallen trees, stopped trains, people on the tracks — anything is possible," says Dr. Gereon Weiß, head of the Automation Systems department at the Fraunhofer Institute for Cognitive Systems IKS in Munich. That means a train isn't really comparable to a subway, where carriages move exclusively along their tracks within closed tunnel systems. Weiß is working with 15 partners from the industrial and research sectors, associations, government agencies, and testing and standardization organizations as part of the safe.trAIn project, which aims to develop a driverless regional train. The goal is to use artificial intelligence (AI) to allow the autonomous train to recognize hazards reliably in the future, making commuters' dreams of greater reliability, more connections, and shorter wait times come true.

To that end, Weiß and his team are working to make AI more reliable in camera-based environmental sensing applications. There are many different obstacles that the system needs to dependably recognize and distinguish. With this in mind, the project team's first step is to determine the overall conditions under which the AI works and was tested. This is known as the operational design domain. Then they will train the AI on both real-world data from tests performed by project partner Siemens Mobility and synthetic — computer-generated, in other words — images. This lets the researchers make certain they have included a wide enough range of different examples for matters like detecting people: women, men, children, half hidden, from the front, from the side, in fog, rain, or snow, at night, during the day, in front of noise barriers or leafy trees, against a field, and so on. Weiß explains: "We use one half of the data to train the AI and the other to test it." To verify that the AI really works dependably, he and his team are working on further testing methods. The project's goal is to create a virtual test field. "Once the field is in place, for example, it will be possible to use it to simulate a section of railway with different

No operators at all: the U2 and U3 lines in Nuremberg. They travel on a 100-second cycle — twice as fast as with manual controls.

Photo: Ralf Schedlbauer/City of Nuremberg

challenges. And then we can check whether the system recognizes everything correctly," Weiss says.

Trains have great potential

Does that mean resilience in the face of strikes? Even amid all these advances, there will be no replacing train operators for now. They are responsible for running the train, but also perform other tasks, such as checking the overhead lines for problems and identifying and eliminating issues affecting the train itself. Aside from that, the infrastructure needed for autonomous trains is not yet in place. One fundamental requirement for fully automated train operation is that the rail lines will need to be equipped with the European Train Control System (ETCS). This system uses sensors to monitor factors such as train speed and position, checks to ensure that the tracks are clear, and automatically clears trains to proceed. According to Deutsche Bahn AG, about 500 kilometers of railway was equipped with the ECTS as of 2023, including the rapid line between Munich and Berlin. That works out to 1.6 percent of the overall network. But Weiß is confident that the system's expansion will pick up steam quickly at this point: "If you want to cut carbon emissions, you simply have to shift more traffic to trains." He also notes that it would be easy to make the switch first on sections of the network that are already equipped with the ETCS and feature good conditions. "There's much greater potential for trains, which have to move along pre-established routes, than there is for autonomous vehicles in urban settings. It's just that trains haven't attracted as much attention yet, unfortunately."

Nicole Wagner-Hanl also aims to harness AI to make public transit a more appealing option. Wagner-Hanl has a background in business administration with a focus on business informatics. She currently works as a project manager specializing in passenger mobility and digital transformation at the Fraunhofer Institute for Material Flow and Logistics IML, in the Prien am Chiemsee office. In the KI4autoBUS pilot project, which concluded in December 2023, she and her team managed to control autonomous DB Regio shuttle bus traffic in Bad Birnbach, a market municipality in Germany's Lower Bavaria region, with significantly greater efficiency. The vehicles have been operating in municipality on a trial basis for eight years now, providing both regularly scheduled service and on-demand trips requested by phone or app. Wagner-Hanl and her team feed the booking information into a self-learning AI. "This has let us predict travelers' needs, optimize the routes, shorten wait times, and improve ridership." After a while, the AI even knew where service would be needed — so the shuttle was waiting at the stop even before the request came in.

Wagner-Hanl firmly believes on-demand transport is a great opportunity to better connect remote locations and communities to public transport again. Instead of running large regularly scheduled buses through the area twice a day with almost no riders, shuttles or shared taxis can be used for these trips on demand. "The district of Rottal-Inn is one of the districts with the most scattered settlements in Germany. Running traditional bus service here is really expensive. On-demand transportation systems are a low-cost, efficient alternative," she explains. And vehicle size isn't the only thing that could be adjusted flexibly. So could the vehicle features themselves. Do passengers need a smart wheelchair ramp that extends automatically, or audio information for the visually impaired? That and more could be requested and taken into account ahead of time. "And then, looking down the road, if we had autonomous shuttles that travel without drivers, unlike today, the personnel costs would also be lower." As for Bad Birnbach residents and tourists, they love riding with AI. "Some of them even come to town just to see the autonomous shuttles," Wagner-Hanl says. ■

Biting back against bacteria

European snakes are seldom deadly. But their venom is a complex cocktail with valuable potential for fighting disease. Biochemist Dr. Tim Lüddecke analyzes the venom of the Milos viper, native to Greece — and finds promising properties.

By Mandy Bartel

The Milos viper (Macrovipera lebetinus schweizeri), also known as the Cyclades blunt-nosed viper, averages 70 centimeters in length. It is one of Europe's most venomous snakes. It mainly eats migratory birds, which it hunts right up to where they sleep, on the branches of bushes and trees.

Whenever others shudder, Dr. Tim Lüddecke knows he has good reason to take a closer look — especially where creepy, crawly creatures are involved. Lüddecke, a scientist at the Giessen office of the Fraunhofer Institute for Molecular Biology and Applied Ecology IME, studies the biochemical composition of animal toxins and their possible uses. He has been able to isolate new biomolecules that may help in treating multidrug-resistant organisms or be useful as crop protectants from the toxins secreted by spiders, ants, and bees.

But the subject of his latest research project is more of a mystery. It lives only on a scant few islands in the Cyclades archipelago of Greece, especially the island of Milos. The Milos viper, as it is known, is one of Europe's few venomous snakes. With venom significantly less toxic than that of their tropical cousins, they have also been the subject of much less research. Estimates put the number of fatalities due to snakebite at over 100,000 a year worldwide, but very few of those occur in Europe. Complications are not uncommon, however.

Lüddecke and his team sourced their Milos viper toxin from a snake farm. "What really makes these animals special is that they have adapted to a very narrow ecosystem, so their range of prey is really focused on birds," explains Lüddecke, who is also the head of the Animal Venomics junior research group at Fraunhofer IME. "We now know that changes in prey frequently correlate with changes in toxin composition. So we were interested in whether this kind of effect can be observed in the Milos viper." Since the snake is a close relative of Macrovipera lebetinus, the blunt-nosed or Levant viper — arguably Europe's most dangerous venomous snake — the team also studied whether its venom can do similar damage.

Poisons cooked up by nature

Snake venom consists of about a hundred components — a highly complex mixture of enzymes, proteins, and toxins that work in various ways to paralyze or kill prey and facilitate digestion. Most of these components are present in tiny amounts. The main ones fall within four to five families of toxins. Each snake species has a unique toxic effect. The researchers at Fraunhofer IME used state-of-the-art mass spectrometry to identify the composition of the Milos viper's venom for the first time. "There are two challenges here. The first is that we have to be really careful due the toxic nature of these substances, and the second is that dissolved snake venom breaks down quickly," Lüddecke says, providing a window on his work. "So we store venom as a solid and then dissolve it in water at the desired concentration for analysis purposes. But the experiments have to be scheduled close together, since the results could be distorted otherwise."

Each snake species has a unique toxic effect.

Active ingredients to fight infection

In studies performed as part of a research project at the LOEWE Centre for Translational Biodiversity Genomics, the Fraunhofer team showed that the Milos viper's venom cocktail is almost identical to that of various blunt-nosed viper subspecies. That is also why its potency is comparable. In addition to identifying the components, the research group focused on characterizing them in functional terms: "We have identified several toxins that belong to protein classes known for having an antibacterial effect. So we may be able to use them to develop new lead molecules as candidates for drugs to fight infectious diseases," Lüddecke explains. Initial activity studies on the toxin confirm that it is highly effective against a number of medically relevant types of bacteria. The researchers' next objective is to isolate these components and further develop them. But even beyond that, the many poisons cooked up by nature offer a wealth of untapped potential — and right in our own backyard, no less: As their next step, Lüddecke and his team have set their sights on largely unresearched species that live in Germany, such as the common European adder (Vipera berus) and the European asp (Vipera aspis). ■

"We have identified several toxins that belong to protein classes known for having an antibacterial effect."

Dr. Tim Lüddecke, Fraunhofer IME

Photos: Lennart Schmid, Fraunhofer IME-BR

The threat of climate change

Heavy rain, storms, and drought are taking their toll on even centuries-old structures. How do we preserve our cultural heritage?

By Dr. Sonja Endres

Hailstones the size of billiard balls pounded down on the Fraunhofer Center for Conservation and Energy Performance of Historic Buildings, in the historical Benediktbeuern former monastery in Upper Bavaria, on August 26, 2023. Not a single roof or window was spared, and gaping holes were left in the exterior facades. The storm had a devastating impact on nearby towns as well. Insurer Versicherungskammer Bayern has called it the third largest loss event in its history. "I've never seen anything like it," says Prof. Ralf Kilian, head of cultural heritage research at the Fraunhofer Institute for Building Physics IBP. He is clear on the takeaway: "We have to protect our cultural heritage better against extreme weather events like this in the future." To accomplish that, he and his team are working on individual risk assessments for historical buildings and monuments. Among other things, they are measuring the hygrothermal properties of the old materials, which relate to the movement of heat and moisture, along with moisture permeabilities, the indoor air exchange rate, contamination with harmful materials, and microbial growth. This allows the researchers to identify vulnerabilities, develop a plan for long-term preservation, and initiate targeted preventive measures.

Kilian has spent the past 14 years working in and around the "Alte Schäfflerei," the building formerly used for making barrels and other wooden vessels, in the area of the monastery formerly reserved for work in the trades. He and his team are studying how historical structures and materials can be preserved and protected — especially against the impacts of climate change. The building, which dates back to 1760, is used not only as office space and an experimental workshop, but also a living lab for renovation work, where new methods, technologies and materials can be tried out directly. The "transparent building site" also serves as a locus of research and learning activities. Continuing education takes place here, so tradespeople working in historical preservation can learn about the research results and see the innovative techniques for themselves.

AI-generated, but still realistic: Giant hailstones are falling from the sky more frequently.

A structure under the roof would probably have helped avert the worst of the hail damage to the Alte Schäfflerei, Kilian believes. The original roof structure was preserved when the historical building was last renovated, from 2010 to 2016. "We'll fix that now, during the repairs," he says. "If the roof tiles should break again, we have a second layer of roofing underneath, so the water can simply run off instead of flowing into the ceiling of the top floor."

Half-timbered houses at special risk

Increased winter precipitation is one of the biggest threats to historical buildings in Germany. In Bavaria alone, simulations performed by the EURO-CORDEX initiative, which is receiving funding from the World Climate Research Programme, predict an average increase of about 15 percent in precipitation during the six wettest months of the year between now and 2098. Half-timbered houses are at special risk of damage, as the way they are built is especially susceptible. The medieval town of Quedlinburg, on the edge of the Harz mountains, is one of Germany's best-preserved half-timbered towns. It was officially designated a UNESCO World Heritage site in 1994. There are 1,300 half-timbered buildings in Quedlinburg alone, out of some two million throughout Germany.

"We have to protect our cultural heritage better against extreme weather events in the future."

Prof. Ralf Kilian, Fraunhofer IBP

As part of the KERES project, which is receiving funding from the German Federal Ministry of Education and Research (BMBF), Kilian studied the buildings, which feature a typical "skeleton" made of timber, and developed preventive preservation measures aimed partly at providing better protection against extreme weather. "The wood is constantly in motion. It expands, it contracts. This makes it very easy for cracks to form, especially at the joints between the wood and the infill, the material filling in the space between the beams. And then water penetrates, especially in heavy rain," he explains. Together with his team, Kilian is working on an innovative facade protection system with a plaster base made from Typha, a genus of bulrush or reed that is right at home in wet environments. "We plan to produce plates out of Typha and use them to cover the joints. This will let us separate the wall from the plaster, creating a flexible ▶

Photos: sergiolucci/123rf, Fraunhofer IBP

system that can absorb moisture," Kilian explains. The innovative, renewable construction material is also suitable for interior insulation. Growing Typha through "paludiculture" in restored peatland areas also reduces CO2 emissions. Undamaged peatlands are a key climate factor, as the peat layer stores huge volumes of carbon. This means Typha has a positive impact in two ways at once: as a way to help protect the climate and as a means of guarding against moisture.

If water enters the building's walls despite this, for example due to flooding, another innovative technology from Fraunhofer IBP can help: FastDry. The team of researchers has installed the FastDry system in the open-air museum in Bad Windsheim, in Germany's region of Franconia, where numerous half-timbered buildings were underwater as a result of the disastrous flooding there in 2021. FastDry needs only 20 percent of the energy that conventional devices require, is much quieter during the drying process, and takes only half the time. "Speed is crucial," Kilian says. The faster the drying process is, the less significant the later damage and costs of repairs.

The FastDry modules are attached directly to the affected walls. The panels incorporate a woven heating fabric much like an electric blanket. Behind it is a layer of moisture-permeable insulation that traps the heat energy inside the wall. This saves electricity and keeps from heating the space unnecessarily. The system has a working temperature of around 55 degrees Celsius, which does not harm even sensitive building materials. The moisture escapes into the space through the panel, where it can simply dissipate into the air.

Droughts: another threat to cultural heritage

Although moisture is the biggest threat to historical buildings and monuments, increasingly dry summers are also a big issue. Dry conditions can cause soil subsidence, or sinking, underneath building foundations. As the foundation settles, cracks can form in the walls, jeopardizing their stability. In the ancient city of Petra, in present-day Jordan, drought has spawned an increasing number of sandstorms. The sand blasts against the facades, which are more than 2,000 years old, eating away at the stone and destroying the unique rock-hewn World Heritage site. Kilian is hard at work on protecting cultural heritage there as well, together with a Jordanian research team and colleagues from Oxford University. The researchers are using computer simulations to understand how the climate of the ancient Nabataean city has changed over time and identify ways to preserve it. One line of inquiry involves bringing more green plants to Petra, just as is being done in modern cities to fight the effects of climate change. Kilian explains: "Plants can protect the facades from storms and help to store rainwater over longer periods. Evaporation cooling lowers the high ambient temperature." He and his team will be holding summer study sessions in Petra, inviting students from all over the world to learn about various risk analysis methods and working with them on a climate adaptation strategy so this and other ancient sites are also preserved for future generations. ■

The hailstorm caused severe damage at the Benediktbeuern monastery site. The Alte Schäfflerei structure alone sustained half a million euros' worth of damage.

Photos: Birk/SDB (3)

Fraunhofer at 75 — cause for celebration...

... because technology is the future! Fraunhofer has been combining cutting-edge research with real-world applications for 75 years and is an international leader in this field. Happy birthday and congratulations on this success! The Free State of Bavaria has been a driving force and close partner right from the start. Fraunhofer and Bavaria form a great alliance, one that we plan to continue to strengthen in the future. As part of its High-Tech Agenda, Bavaria is currently investing over 5.5 billion euros in science and research throughout the federal state. In addition to room for 13,000 more students at universities and 1,000 professorships for the brightest minds, we are actively promoting the transfer of knowledge from research to real-world applications. "Live long and prosper!"

Dr. Markus Söder, Minister-President of the Free State of Bavaria

... because the Fraunhofer-Gesellschaft has been harnessing tremendous innovative strength and creative ideas to blaze new trails in science and research for 75 years now. Saarland especially needs this inventiveness and outstanding research findings, paired with the courage to forge new paths, if we are to advance the transformation process. I extend my best wishes to the Fraunhofer-Gesellschaft on its many years of successful work in applied research, which has brought important advances for the whole of humanity and for our local companies.

Anke Rehlinger, Minister-President of Saarland

FRAUNHOFER
75 YEARS OF INNOVATION

... because the Fraunhofer-Gesellschaft, more than any other institution, stands for Europe's leading position in applied research. Our unique European research landscape, combined with the internal market and wealth of innovative medium-sized businesses, is the essential driver of growth and forward-looking jobs in Europe. Many thanks for all you do — and keep up the good work!

Ursula von der Leyen, President of the European Commission

... because the cutting-edge applied research of the Fraunhofer-Gesellschaft has been a driver of growth in the German economy for 75 years. Innovative strength and openness to new technologies are the only way forward as we tackle the challenges we face these days. The Fraunhofer-Gesellschaft is setting a shining example. It is an important factor in making our country attractive as a place to do business.

Christian Lindner, German Federal Minister of Finance

... because Fraunhofer stands for new beginnings, innovative strength, and excellence in research. And because the Fraunhofer institutes and all their hardworking employees are important sources of fresh impetus, in Saxony and beyond. The research organization was also an instrumental part of Saxony's successful development after the German reunification.

Michael Kretschmer, Minister-President of the Free State of Saxony

Fraunhofer research highlights

They make smartphones more powerful while using about 30 percent less energy: microchips produced using lithography.

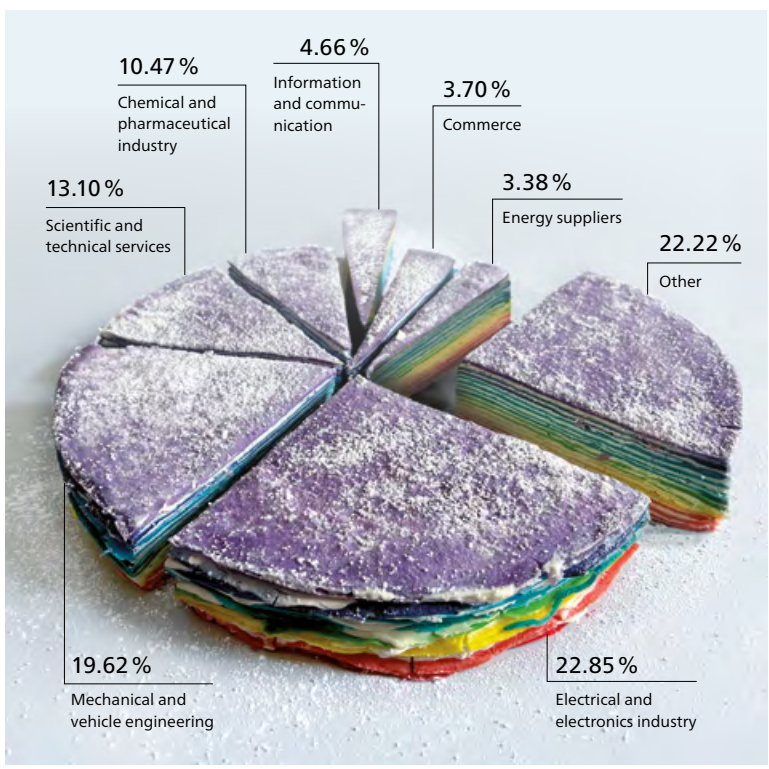
2019 A quantum leap in chip production

EUV lithography makes it possible to shrink microchips while improving performance and lowering both energy use and production costs — all of which are required for advances in artificial intelligence, autonomous driving, and 5G. The first smartphones with microchips manufactured using EUV lithography have been on the market since 2019. This technology was developed at the Fraunhofer Institute for Applied Optics and Precision Engineering IOF in Jena in cooperation with Zeiss and Trumpf, two private-sector companies.

Fraunhofer researcher Dr. Sergiy Yulin had been working on complex layer systems for EUV optics with the aim of harnessing extremely short-wavelength EUV light for microchip production for 30 years. The breakthrough came with the use of the world's strongest pulsed industrial laser, from Trumpf AG, and a highly precise collector mirror and projection optics from Zeiss. The new method makes it possible to transfer tiny three-dimensional structures just seven nanometers in size onto wafers. For comparison, a single strand of human hair averages 70,000 nanometers in diameter. The German president presented the German Future Prize in recognition of this innovative technology in 2020, marking Fraunhofer's ninth such award. ■

» Cutting-edge research and technology for 75 years:That's something to be proud of. Best wishes on your anniversary! My own career has been influenced in many ways by the time I spent as a doctoral candidate and postdoc at Fraunhofer IFU. The ability to work scientifically laid the foundations for my career and remains a crucial part of my professional practice to this day."

Dr. Edeltraud Leibrock, Partner & Managing Director, Connected Innovations; formerly: Fraunhofer IFU



Fraunhofer industrial revenue for 2023: The biggest piece of our homemade rainbow birthday cake represents the electrical and electronics industry, followed closely by mechanical and vehicle engineering.

Tests at the S3 safety laboratory show that the vaccines made using electron beams have protective effects comparable to those of conventional vaccines.

2021 Protection against diseases

Faster, ecofriendlier vaccine production with greater efficiency and lower costs is possible with a new technology developed by the Fraunhofer Institute for Cell Therapy and Immunology IZI, the Fraunhofer Institute for Organic Electronics, Electron Beam and Plasma Technology FEP, and the Fraunhofer Institute for Manufacturing Engineering and Automation IPA. The new technology makes it possible to inactivate pathogens within milliseconds using electron beams.

Toxic chemicals such as formaldehyde are often used to inactivate viruses in killed vaccines. However, there are considerable disadvantages. The toxic substances destroy part of the external structure of the virus, but they harm the environment, even when disposed of correctly. They also require the vaccine to be extensively purified before use. On top of that, the inactivation process can take weeks or even months, depending on the virus.

The research team was honored with the Fraunhofer Prize for Human- and Environment-Centered Technology for their innovative method in 2021. This prize, which comes with 50,000 euros in prize money, is given out every two years by the Fraunhofer-Gesellschaft, the Fraunhofer Future Foundation, former board members, institute directors, and other supporters. It is awarded for achievements in research and development that improve people's quality of life or help make our world more sustainable. ■

Photos: Sittiphong/istockphoto, personal, Vierthaler und Braun, Fraunhofer IZI

FRAUNHOFER
75 YEARS OF INNOVATION

2024

Today, the Fraunhofer-Gesellschaft is the world's leading applied research organization. It operates 76 institutes and research units and has 32,000 employees, primarily with backgrounds in physical and life sciences or engineering, all working on solutions for the challenges currently facing society as a whole — from climate change to health and artificial intelligence.

2023

Prof. Holger Hanselka became the 11th president of the Fraunhofer-Gesellschaft on May 25, 2023. Hanselka, a mechanical engineer, was familiar with Fraunhofer, having served as the director of the Fraunhofer Institute for Structural Durability and System Reliability LBF in Darmstadt from 2001 to 2013. He joined with the stated intention of modernizing and consolidating structures and processes within the organization and renewing its focus on market-driven contract research.

2020

Fraunhofer launched its "Fraunhofer vs. Corona" initiative to support industry and society in fighting the pandemic. The program bolstered research on innovative diagnostics and on vaccine and drug development, supplied IT capacity, and provided rapid and straightforward assistance with producing components for personal protective equipment.

2019

The National Research Center for Applied Cybersecurity ATHENE began working as a research unit of the Fraunhofer-Gesellschaft, with the Technical University of Darmstadt and Darmstadt University of Applied Sciences as the other partners. ATHENE is the largest research center for applied cybersecurity research in Europe, and a key part of Germany's cybersecurity strategy.

2017

The Fraunhofer Group for Innovation Research joined the seven existing cross-institute groups in 2017. It was the first group to have a socioeconomic focus. The five member institutes were tasked with identifying changes in industries, markets, and technologies early on and increasing their involvement in policy consulting.

2015

The Fraunhofer-Gesellschaft founded its first-ever regional high-performance centers, where Fraunhofer institutes work closely with industry and other partners on a local basis, covering projects on related topics. The goal was to pool strengths and tap into local potential. The first center opened in Freiburg with plans to expand into a location for cutting-edge research on sustainability. Pilot projects were financed by the state of Baden-Württemberg, private enterprises, and the Fraunhofer-Gesellschaft. High-performance centers were established in Erlangen and Dresden shortly afterward. Today, more than 20 centers bring suitable partners together.

2007

To remain competitive on worldwide markets, technological innovation was urgently needed. The German federal government introduced a research union between industry and academia. The new committee was made up of leading scientists and entrepreneurs and co-chaired by Fraunhofer president Prof. Hans-Jörg Bullinger and the president of donor organization Stifterverband für die deutsche Wissenschaft. The members formulated research tasks and recommended specific action plans to policymakers. At the new union's urging, nine new innovation alliances were formed, with a business volume of 3.8 million euros. The Fraunhofer-Gesellschaft ramped up its presence in Berlin through the Fraunhofer Forum, a meeting and conference center inside the SpreePalais building, where the organization also moved into its own offices in the German capital.

Fraunhofer research highlights

Protein-rich lupines belong to the legume family, just like peas, garbanzo beans, and peanuts.

2014 Sustainable nutrition

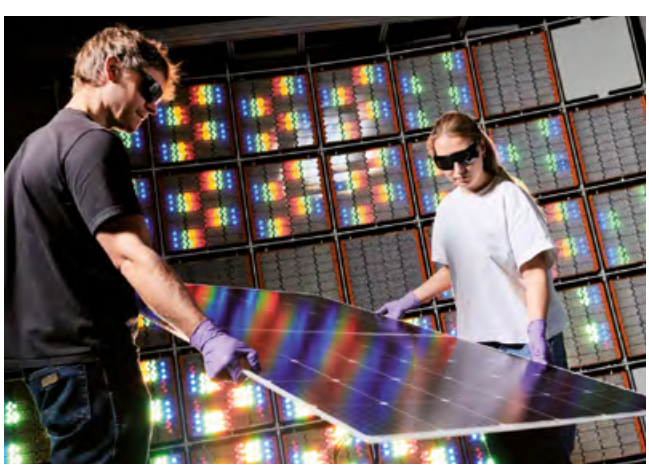
The world's population is growing and arable land is getting scarce — how can we ensure food security in the future? Researchers from the Fraunhofer Institute for Process Engineering and Packaging IVV believe protein-rich lupines could be the answer. They have isolated a protein from the wildflowers that is now used as a basis for various new developments in the food market. It won the German Future Prize in 2014. The team succeeded in neutralizing the bitter, grassy and "beany" taste of the protein-rich seeds of the narrow-leaved lupine, thereby making it possible to use them for food. The protein is highly versatile and can be used in many different production methods — for example, as a milk substitute in ice cream, in yogurt, or in soft drinks. Lupines are undemanding. There is no need to clear-cut rain forests to grow them as with soy, and they thrive in Germany. Consuming a plant-based diet is one way to greatly increase the efficiency of cropland use. By comparison, about five times as much land is needed to produce the same amount of protein from pork as from grain or legumes. ■

2009 Solar cell world record

In the wake of the 1973 and 1979 oil crises, the Fraunhofer-Gesellschaft forged ahead with research on renewable energy. In 1981, the Fraunhofer Institute for Solar Energy Systems ISE was founded in Freiburg and went on to make great strides in improving the efficiency of solar cells.

While solar cells made of crystalline silicon have dominated the market from the beginning on, the specialists in Freiburg began experimenting early with alternative elements such as gallium, indium, arsenic, and phosphorus, using them to create promising innovative semiconductor compounds for high efficiency multi-junction, or tandem, solar cells. Stacking different solar cells vertically on top of each other, each optimal for a different wavelength range, allows for a more efficient conversion of broadband sunlight into electricity. The researchers spent more than ten years tinkering with these so-called III-V solar cells before achieving a world record of 41.1 percent for a triple-junction solar cell in early 2009 under concentrated sunlight. Today Fraunhofer yet again holds the record for world's most efficient solar cell: a III-V four-junction solar cell boasting an efficiency of 47.6 percent — about ten times more than the first solar cell invented back in 1953. ■

Pictured here is an LED-based solar simulator at Fraunhofer ISE, which allows for precise spectral adjustments, and a new generation perovskite-silicon tandem module under test in the foreground.



» Fraunhofer scientists often move into business or industry or to other innovation organizations. Even after I moved from Fraunhofer FOKUS to Initiative D21, I've still stayed in close touch with 'my' institute, including as a strategic advisor on the advisory board. People can also keep in contact with the institutes, think outside the box, learn from each other, and grow together through Fraunhofer-Alumni e.V. It's a bridge between the past and future that promotes the sharing of experience and ideas."

Lena-Sophie Müller, managing director of Initiative D21 and member of the Digital Council of the German Federal Ministry of Defence; formerly: Fraunhofer FOKUS

» The Fraunhofer-Gesellschaft has been a part of my entire professional life so far. This is where I got my first management experience, and even later on, I still had close contact through various forms of collaboration and board activities. I'm really grateful to my companions from the 'Fraunhofer world,' old and new, for all these opportunities. My wish for the Fraunhofer-Gesellschaft going forward would be for it to remain scientifically independent and closely connected with its industrial partners — and in that way, to stay a successful trailblazer for the whole of the German economy."

Dr. Michael Mertin, former chairman of the executive board of Jenoptik AG; formerly: Fraunhofer ILT

Photos: Maksims Grigorjevs/istockphoto, Fraunhofer ISE, Jeibmann Photographik, Tobias Koch

2005

Increased internal networking and the pooling of competencies were a success: The Fraunhofer-Gesellschaft saw industrial revenue rise by 36 percent year over year in 2005. The Pact for Research and Innovation, a research support initiative of the German federal and state governments, guaranteed Fraunhofer a three percent annual increase in base funding, allowing the organization to plan for the future.

2002

The group structure of the Fraunhofer-Gesellschaft was expanded. That year, there were more than 50 institutes working together across seven groups: Production, Life Sciences, Light & Surfaces, Materials and Components, ICT, Microelectronics, and Defense and Security (VVS). A change in the statutes gave the group chairs a bigger say in operations, so the executive board was required to involve them in decision making.

1997

Following the 1984 establishment of the Fraunhofer Group for Microelectronics, additional Fraunhofer institutes began ramping up their efforts to join forces in 1997, forming thematically focused groups and developing shared marketing concepts and research strategies. Headquarters established internal funding programs to support cross-institute cooperation

1994

The Fraunhofer-Gesellschaft established its first-ever legally independent foreign affiliate in 1994: Fraunhofer USA. It acted as an umbrella organization for branches known as resource centers, which cooperated closely with individual Fraunhofer institutes in Germany. Two years later, the organization founded representative offices in Malaysia and Singapore as well as in the city of Beijing in a bid to forge ties with the world's key economic areas. In the years to come, Fraunhofer would continue to drive internationalization by founding further foreign affiliates and representative offices.

1993

While the institutes' industrial revenues rose significantly, government funding slowed as a result of the costs of reunification and rigorous austerity measures. The institutes joined forces, adopting the "Leitbild 2000" guiding principle, which set out a shared strategy calling for closer connectivity and clearer areas of focus, among other things.

1990

Germany's reunification presents opportunities to expand. Moving swiftly and resolutely, the Fraunhofer-Gesellschaft is quicker than other research institutions to seize the day, setting up more than 21 new institutes and research units in the federal states that have newly joined the Federal Republic. They began their work in 1991 — initially in makeshift settings in many cases.

1983

A computer scientist by profession, new Fraunhofer president Prof. Max Syrbe was quick to recognize the potential of computerization. He had all Fraunhofer workstations brought up to the very latest standard in information technology. To boost efficiency, he also launched a continuing education initiative for managers with the goal of saving on costs through professional project management going forward. These measures were a success: Contract research grew by 107 percent between 1984 and 1989, and industrial revenue even more, by 136 percent.

1978

The Fraunhofer-Gesellschaft honed a standardized image and built a professional media presence to raise its profile with the public at large. All institutes were given the uniform title "Fraunhofer Institute for..."

FRAUNHOFER
75 YEARS OF INNOVATION

Fraunhofer research highlights

1995 LED breakthrough

LEDs were initially used mainly for device displays, owing to their low light output. That all changed in 1993, when Shuji Nakamura, a researcher working in Japan, developed the first high-brightness blue LED, followed a short time later by a white one. He went on to win the Nobel Prize in 2014 for his research. Scientists at the Fraunhofer Institute for Applied Solid State Physics IAF made a breakthrough based on this innovation in 1995, producing white light cheaply and quickly with just one light-emitting diode chip. The principle generated great enthusiasm in industry all around the world. It was put into action, and steady gains were made in the energy efficiency of LEDs — including by researchers at the Fraunhofer Institute for Applied Optics and Precision Engineering IOF in Jena. Together with OSRAM, they received the German Future Prize presented by the German president for their high-performance LED modules in 2007. ■

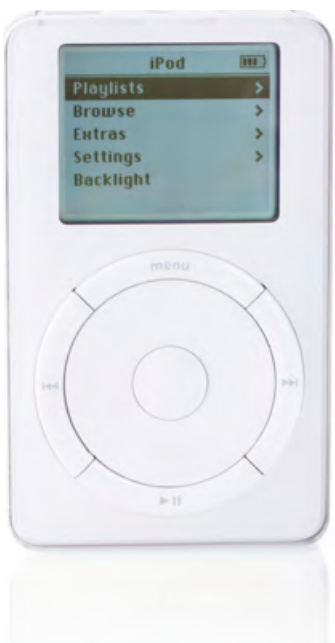
Brighter — faster — stronger: LEDs made by Fraunhofer. The German postal service even came out with a special commemorative stamp to honor it in 1999.

» My experiences at the Fraunhofer-Gesellschaft played a crucial role in shaping my professional career: the ability to gain experience with various cutting-edge digital topics early on, to come into contact with outstanding researchers, and to drive the digital transformation for the good of society. All of that significantly expanded my understanding and abilities in this area and allowed me to form a broad network. The worldwide name recognition and excellent reputation of the Fraunhofer-Gesellschaft, which we at Fujitsu work together with in various places, underscore the important position this research institution has held for me."

Isabel Netzband, Head of Public Policy & Governmental Affairs Central Europe, Fujitsu; formerly: Fraunhofer ICT Group

Find out more about Fraunhofer-Alumni

The first iPod was unveiled on October 23, 2001. It weighed just 185 grams and could hold about 1,000 songs.



1995 A revolution in music

A new file format revolutionized the music industry in the late 1990s: mp3. It was developed at the Fraunhofer Institute for Integrated Circuits IIS. The method used reduces the size of music files by 90 percent — without any perceptible loss of audio quality. The trick is that audio codecs analyze the signals and focus on the audible segments which they sophistically save to reduce the data volume. Initially dubbed "MPEG-1 Audio Layer III" — quite a mouthful — the revolutionary method was assigned its own file extension, .mp3, in 1995. mp3 technology was born, taking the Internet by storm. It marked the first time that audio files could be sent quickly and without any hassle. Music sharing services like Napster sprang up, and mp3 players like the Apple iPod suddenly allowed people to carry thousands of songs with them instead of just the few tracks found on a CD. This radically reshaped the buying and consumption of music. The Fraunhofer-Gesellschaft used the revenues from mp3 licensing in the three-digit million range to establish the Fraunhofer Future Foundation in November 2007. Since then, the foundation has provided significant funding in support of new patents. ■

» My doctorate with Fraunhofer was the educational opportunity I had been looking for to flesh out the theory I learned in college, to look at relevance through the 'industry lens' and work to create new things. In my start-up, I've changed sides now, so I'm the customer (which makes me always right). I see Fraunhofer as a state-of-the-art research department with an instrumental role in meeting my objectives. Now, at Fraunhofer's 75th anniversary, here's to a fruitful collaboration, and thank you for everything!"

Dr. Miro Taphanel, founder and managing director of Gixel; formerly: Fraunhofer IOSB

» My time at Fraunhofer ISE gave me a thorough grounding and all the tools I needed for my professional path. Thanks to the outstanding technical equipment, incredibly capable colleagues, and especially the extremely high motivation at the institute, I was able to build a treasure trove of experience, which I regularly draw on to my benefit even now, years later."

Dr. Stefan Reber, managing director of TPRC GmbH, founder and former managing director of NexWafe GmbH; formerly: Fraunhofer ISE

» At my institute, I experienced a unique sense of intellectual freedom and got support for my idea. It was a success with customers, but that's not all. We also won a transfer award. I'm still in close touch with Fraunhofer today as I work on the next stage of the Peerox self-learning assistance system. Fraunhofer is the perfect ecosystem for anyone looking to start their own business to develop new technologies with a lot of contact with industry and gain an understanding of markets."

Andre Schult, founder and CEO of Peerox GmbH; formerly: Fraunhofer IVV Dresden

Photos: Fraunhofer IOF, Fujitsu, benoitb/istockphoto, Gixel, personal, Timm Ziegenthaler

1972

The "Fraunhofer model" was created to govern the institutes' future financing, promising an increase in state funding as the revenue earned from contract research increased. This brand-new, performance-based form of base funding acted as a huge catalyst, ultimately bringing growth levels that had previously been thought impossible. At the same time, the Fraunhofer-Gesellschaft adopted new statutes, which installed a full-time, three-person executive board with clearly defined areas of responsibility, greater authority, and a significantly more prominent leadership role for the president.

1959

Ten years after its inception, the Fraunhofer-Gesellschaft already had nine institutes of its own, 135 employees and a budget of 3.6 million German marks. Fraunhofer continued to expand, offering secure funding and a scientific home for numerous research groups. In 1964, the politically influential German Science and Humanities Council (Wissenschaftsrat, WR) recommended that Fraunhofer receive institutional support.

1951

In its early years, the Fraunhofer-Gesellschaft's mission was predominantly to raise funds and pass them along to individual researchers. Wilhelm Roelen, an industrialist from the German state of North Rhine-Westphalia, was elected to serve as the next president in 1951. Former Weimar chancellor Hans Luther took over as senate chair. That same year, Fraunhofer received funds under the Marshall Plan established by the United States, also known as the European Recovery Program (ERP). This was a success for the general management, who served on a voluntary basis, and a testimonial to Fraunhofer's increasing recognition in the political sphere.

FRAUNHOFER
75 YEARS OF INNOVATION

1976

The Fraunhofer program to promote contract research for small and medium-sized enterprises was initiated, forging ties between Fraunhofer and a key new customer segment. The institutes were able to approach SMEs with attractive offers, with the state covering between 40 and 60 percent of the project costs. Within the space of six months, these contracts gave rise to a host of innovative products and processes.

1968

The years of the *Wirtschaftswunder* — the German postwar "economic miracle" — were over. To spur fresh economic growth, policymakers increasingly turned their sights on the development of innovative technologies, ushering in the era of applied research. The German federal research ministry awarded its first grant to the Fraunhofer-Gesellschaft, in the amount of two million marks, and then created a special committee aimed at promoting the expansion of the Fraunhofer-Gesellschaft in 1968. The committee devised a new structure and drafted new statutes.

1954

Newly elected president Hermann von Siemens, grandson of inventor and Siemens founder Werner von Siemens, realized that Fraunhofer would need to build research capacity of its own if it was to stand up to competitors. At the same time, the organization widened its scope of activity from Bavaria to the whole of West Germany. On June 1, 1954, the Fraunhofer-Gesellschaft founded its first institute, the Institute for Applied Microscopy, Photography and Cinematography IMPK, in Mannheim. It had a staff of seven. A few months later, it also began working with four institutes run by the German federal defense ministry. In return, it received regular payments that allowed for the creation of further civilian institutes.

1949

Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. was founded in Munich on March 26, 1949. The initiators aimed to spur economic development and advance the industrialization of Bavaria, a heavily agricultural region at the time. The patron and first senate chair was Hugo Geiger, a state secretary at the Bavarian economics ministry, and the first president was nuclear physicist and Munich university rector Prof. Walther Gerlach.

Fraunhofer

2024

Science Year Freedom

What does freedom mean in a high-tech society? How do AI and similar advanced technologies affect our freedom? How trustworthy are these technologies and the decisions they make? Fraunhofer is exploring these questions in Science Year 2024.

Fraunhofer calendar of events

- April 22–26 Hannover Messe
- May 14–September 27 MS Wissenschaft tour
- May 16–17 Bonner Wissenschaftsnacht (Bonn Science Night)
- June 22: Lange Nacht der Wissenschaft (Long Night of the Sciences), Berlin
- June 27–30 Festival der Zukunft (Festival of the Future), Munich
- November 1–10 Berlin Science Week

Every drop counts

Paint makes everyday items pop. But a lot of material is lost during the spraying process. That costs money, wastes resources, and is not sustainable. Fraunhofer IPA is on the case, looking for ways to eliminate "overspray."

By Manuel Montefalcone

Every drop of paint is unique. No two are alike. Even with all this variety, researchers from the Fraunhofer Institute for Manufacturing Engineering and Automation IPA have managed to study the properties of paint involved in drop formation and work out specifications for different paints and nozzles. Their work was prompted by "overspray," a factor that "has been on the minds of the entire industry for years now," as project manager Thomas Hess explains. Overspray is the excess paint that is sprayed during the painting process and does not end up on the workpiece. It results in unnecessary paint consumption, costly and time-consuming cleaning of the paint booth, and complex machinery and engineering. "It's not sustainable or resource-friendly," Hess says. "And it's far from cost-effective, too."

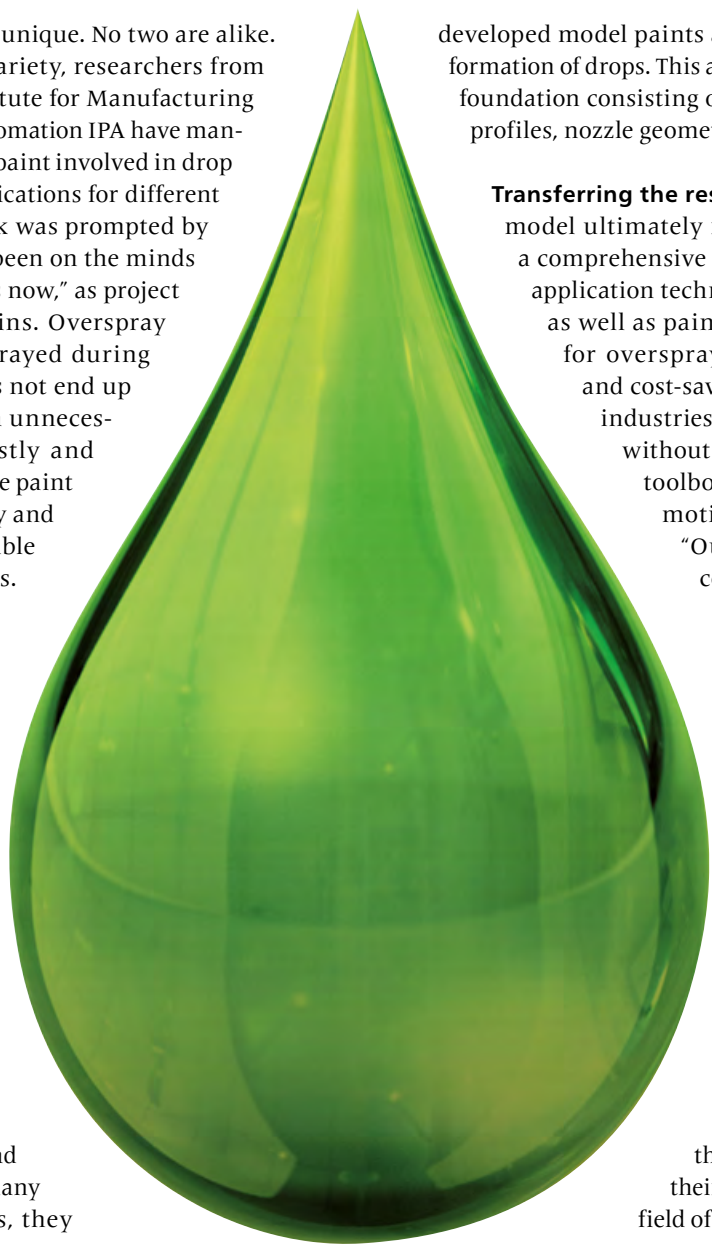


Photo: istockphoto

To prevent overspray and increase the efficiency of the painting process, the paint could be applied in individual targeted drops from the nozzle. Hess and Franz Balluff from Fraunhofer IPA pursued this idea by studying the physics and chemistry behind the coating substances. As part of the DigitalPainting project, the researchers worked on the application of the paints, their composition, and how they form coatings. After many experiments and simulations, they developed model paints and studied how they affect the formation of drops. This allowed them to devise a scientific foundation consisting of characteristics, paint property profiles, nozzle geometries, and process parameters.

Transferring the research findings to a simulation model ultimately resulted in the development of a comprehensive toolbox. The new toolbox offers application technology and paint manufacturers as well as painting companies a new solution for overspray-free, highly individualized, and cost-saving painting. "All of the various industries where painting should be done without overspray can benefit from our toolbox, from wood finishers to automotive manufacturers," Hess says. "Our method allows for selective coating and even two-tone paint jobs without costly, time-consuming, and labor-intensive masking." There has been interest from across the industry. Small and medium-sized enterprises are especially keen to eliminate overspray and improve efficiency while cutting costs.

Hess and Balluff's solution also impressed the judges for the Otto von Guericke Prize, awarded by the German Federation of Industrial Research Associations (AiF): The team of researchers received the award in 2023 in recognition of their outstanding achievements in the field of industrial collective research. ■

A greener way to browse

Online shopping is booming. It's simple, convenient — and has a significant environmental impact. Fraunhofer researchers have found ways to lower the carbon emissions associated with e-commerce.

By Yvonne Weiß

On average, it takes just 48 hours from click to doorbell. And there the order is, right on the customer's doorstep. Quick. Easy. Convenient. But the 2.1 billion or so packages that customers in Germany receive each year do leave a trail behind them on their journey from warehouse to living room — not just online, but also in terms of environmental footprint.

Working on behalf of Bundesverband E-Commerce und Versandhandel, the German association of the e-commerce and mail order industries, researchers from the Fraunhofer Institute for Systems and Innovation Research ISI have published their "Study of the Ecological Sustainability of Online Commerce in Germany." This marks the first-ever analysis of the entire ordering process and its effects on the climate, from searching for the product, to ordering, further processing, packaging and shipping all the way through to a potential return step. Their calculations show that the environmental impact of online purchases varies greatly, depending on individual circumstances — but there are also ways to change it.

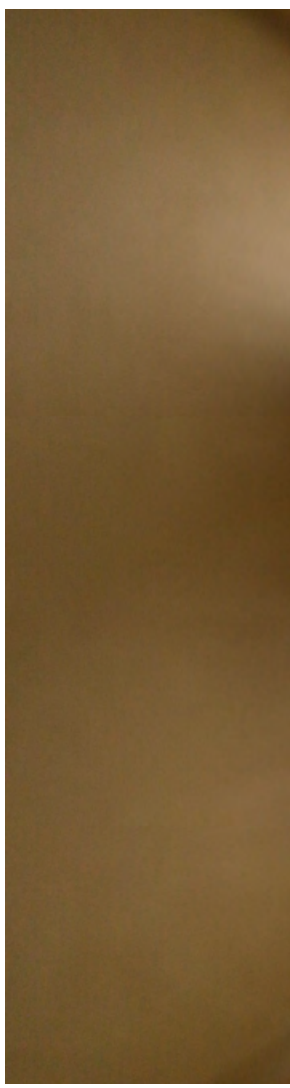
Around
2.1 billion
packages make the journey from warehouse to living room, leaving a trail not just online, but also in terms of environmental footprint.

From the moment an order is placed in the shop through packaging and transportation, including possible returns, an average online purchase generates the equivalent in greenhouse gas emissions of driving nine kilometers in a car with a combustion engine. At some 2.1 billion packages a year, that adds up to about 18.9 billion kilometers — 126 times the distance from the earth to the sun.

In the worst case, a single order can generate the equivalent of 4,426 grams of CO_2. This adds up to nearly 27 kilometers traveled by an average car. The good news is: "In the best case, only about one-tenth of these emissions are generated," notes Prof. Matthias Gotsch, a project manager and head of the study at Fraunhofer ISI.

The actual environmental impact caused by an order depends on a number of factors: How long does the customer take to search for and order the merchandise, and using what kind of device. How full are the vehicles used to transport the order. Are packages grouped together for delivery, an especially important factor in rural areas.

The last few miles a package travels on its journey are crucial in determining its carbon

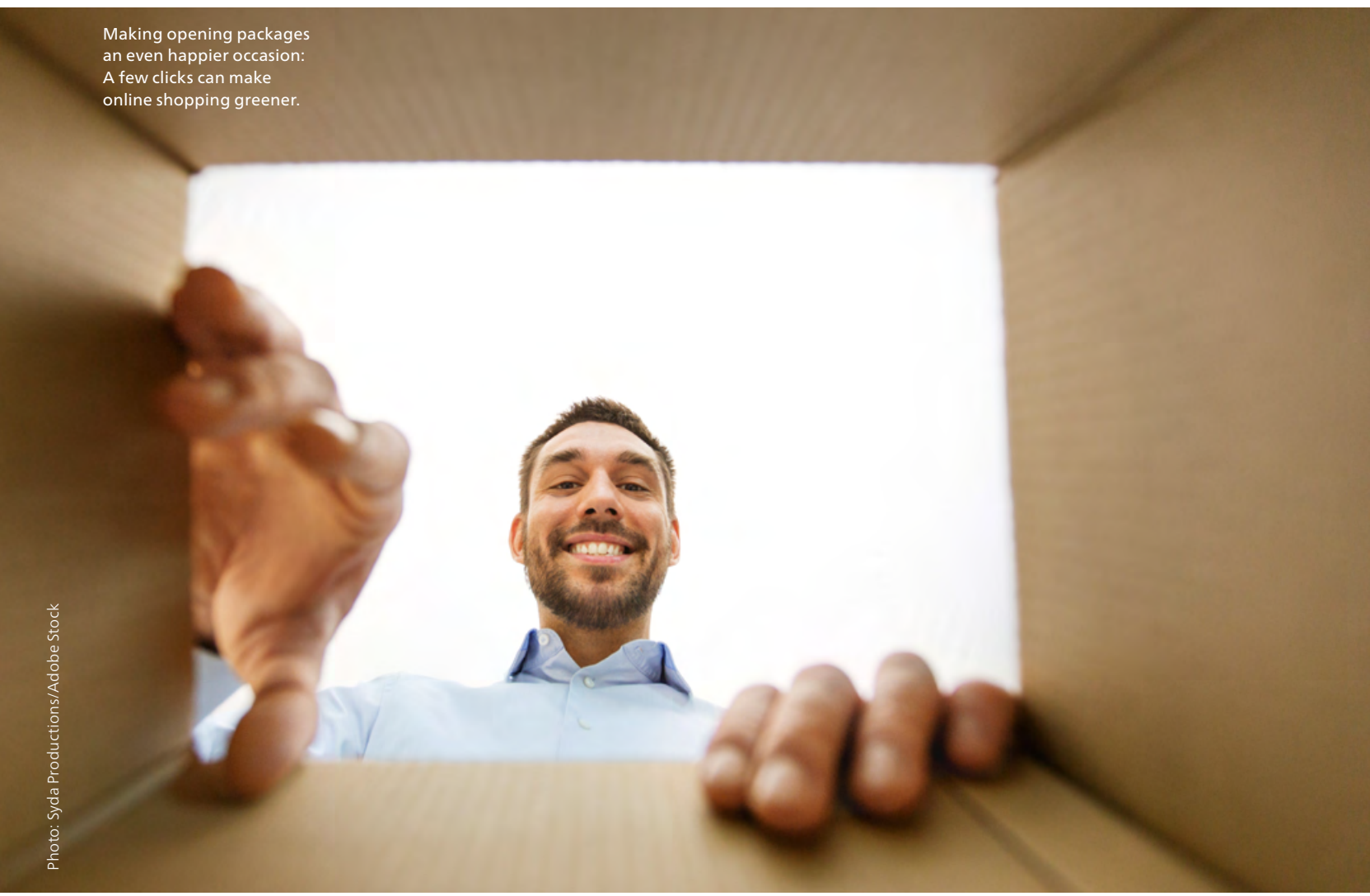


footprint. "If the package is delivered by an electric vehicle, that cuts emissions per order by a quarter," explains Clemens Brauer, a research scientist at Fraunhofer ISI. "That's a huge factor we can use to make online shopping greener."

Packaging is another key to greater sustainability, Gotsch believes. Many items could be shipped directly in their outer product packaging, for example. This would decrease packaging volumes by nearly one-quarter. Reusable pouches are also a possibility, he notes. Calculations show that they could reduce greenhouse gas emissions from packaging by as much as 98 percent. This would require that the sturdy shipping pouches be reused enough times and be recyclable at the end of their useful lives. Consumers would also have to be willing to return them.

The study also shows that delivering items to an access point or locker within walking distance instead of right to the customer's front door can cut the carbon emissions from the delivery process in half. Buying used items through "re-commerce" platforms has additional environmental benefits. Consumers should also avoid returning items wherever possible, as returns are responsible for 13 percent of the greenhouse gas emissions associated with e-commerce transportation. All this means customers can decide for themselves with just a few clicks how green they want their orders to be. ■

Delivering items to an access point or locker instead of the customer's front door cuts carbon emissions from the delivery process in half.



Making opening packages an even happier occasion: A few clicks can make online shopping greener.

Photo: Syda Productions/Adobe Stock

Save as: DNA

Storing data in DNA? Yes, it's possible! A Fraunhofer consortium aims to use biologized technology to create powerful data storage media that hardly need any space at all.

By Stefanie Smuda

Traditional storage solutions are increasingly reaching their limits: Between now and 2027, the worldwide volume of data is projected to grow to an unimaginable 284 zettabytes. One zettabyte is equal to one sextillion bytes — a 1 followed by 21 zeros. What isn't growing at the same pace is the available storage space. And yet, ever-larger volumes of data still need to be archived for the long term. With this in mind, three Fraunhofer institutes have joined forces in the interdisciplinary BIOSYNTH project to research an alternative way of storing data that is supposed to provide a wealth of volume while taking up little space. Their goal is to do this by "biologizing" technology: The scientists plan to use deoxyribonucleic acid (DNA) as the basis for a storage medium.

"This technology of the future has not been researched much in Europe so far," says Dr. Uwe Vogel, head of the business unit Microdisplays and Sensors at the Fraunhofer Institute for Photonic Microsystems IPMS and the project's coordinator. That is about to change.

The Fraunhofer Institute for Photonic Microsystems IPMS, the Fraunhofer Institute for Cell Therapy and Immunology IZI-BB, and the Fraunhofer Institute for Toxicology and Experimental Medicine ITEM are working together to develop a modular, high-throughput-capable microchip platform for future mass data storage, made from synthetic DNA. The project was launched in June 2022. The consortium's first step was basic research — albeit with bright prospects: Synthetic DNA has the potential to become a sustainable, durable, space-saving storage medium that conserves resources. Considerable improvements in DNA synthesis will be needed to develop biological mass data storage with

DNA instead of diskettes: Fraunhofer researchers are working on the data storage media of the future.

The worldwide volume of data is projected to grow to

284

zettabyte

between now and 2027.

high storage density and durability, however. So far, there is no high-throughput technology for this.

Storing data in DNA

But how can DNA be used as a storage medium? Our DNA has four bases: adenine (A), thymine (T), cytosine (C), and guanine (G). Differences in how they are arranged are what defines our DNA as a "blueprint." The binary code used for processing digital information has a similar function. To use DNA as mass storage, this means that the first step is to turn digital information into DNA sequences. This is done by translating a binary code of zeros and ones into a sequence of the nucleotides A, C, G, and T. This produces an artificial strand of DNA. The goal of BIOSYNTH is to generate error-free sequences of up to 250 nucleotides.

This process — the coding — takes place digitally, as does the decoding. Mechanical processes are also needed to synthesize and sequence the DNA. The microchip platform that the Fraunhofer consortium is developing enables thermal synthesis, among other things. To that end, thousands of tiny heating elements are built into the chip to support the synthesis of microbiological molecules such as DNA, RNA, and peptides. Organic light-emitting diodes (OLEDs) and photodiodes monitor the process. Going forward, the researchers can also envision OLEDs activating the microbiological synthesis process, Vogel explains. In this way, molecules can be composed artificially according to a preestablished blueprint and then used to store data. The scientists have already developed their first technology demonstrators.

A lot of room, no errors

They have three primary goals in the project. First, the researchers aim to dramatically increase storage density. They also plan to considerably speed up the rate at which data are written, meaning transferring bits and bytes to DNA. The third goal is to achieve zero errors. Since writing and reading the data will necessarily involve isolated errors, there need to be ways to detect and correct these mistakes. The consortium has already identified approaches they can use for all three points. Storage density can be increased by way of synthetic microbiology. "Nine terabytes (TB) of coded DNA bits can be stored in a single cubic millimeter. A single DNA base fits inside a cubic nanometer," Vogel says. The synthesis equipment, which currently takes up a lot of room, is to be replaced by portable, low-cost systems that do not use a lot of energy. This makes commercial, biologically based data storage possible. This method also promises practically infinite shelf life, as research findings on the DNA present in the bones of Neanderthals suggest.

Modern microelectronics can be used to dramatically increase write speed by performing simultaneous writing operations. The Fraunhofer experts are also working on on-chip monitoring. This feature will detect errors early on during the write process and cause the data to be corrected right away.

This kind of microchip platform will benefit many users, including those that have to archive large volumes of data, like the German Federal Archives and health insurance funds. "This technology has vast potential, including in the chip industry or, for example, in synthesizing molecules for drug development," Vogel says. ■

Photo: istockphoto/Rawpixel Ltd.

Even a single hair is disruptive when researching tiny microstructures: Dr. Maximilian Lederer has made a crucial contribution to furthering the understanding of ferroelectric hafnium oxide and making it usable for a wide range of applications.

First place: Dr. Maximilian Lederer

Investigating a material with superpowers

Going forward, a new property of a material that has been known for some time will enable faster, ecofriendlier, more secure forms of storage that conserve energy, along with neural networks for artificial intelligence (AI). Dr. Maximilian Lederer's dissertation was a crucial contribution to furthering the understanding of hafnium oxide and improving its processing — two key aspects that have now won him first place among the Hugo Geiger Prizes.

By Mandy Bartel

In materials science, it isn't every day that something known is rediscovered all over again. Or, to put it more precisely: a new property that can lead to completely new applications. But that is exactly what happened in Dresden in 2011. The material behind this story is called hafnium oxide (HfO_2). The crystalline white substance is a functional ceramic well known in the semiconductor industry. It has long been used to produce transistors, thanks to its electrical insulation properties. And then its new superpower came to light: ferroelectricity.

Ferroelectric materials can shift their atoms up or down like a light switch, so they undergo spontaneous electric polarization. The direction of the polarization can be shifted by an external electric field. This meant that HfO_2 layers were suddenly of interest for a whole range of potential new applications, such as FeRAM (ferroelectric random-access memory) chips, which can store data even without a supply of electricity, making them suitable for applications in space exploration, autonomous driving, or quantum computing. They can also be used for sensors or neuromorphic devices like those used in AI systems. Hafnium oxide has significant advantages over other ferroelectrics that had previously been used in these

Hugo Geiger Prize

Prize for talented young scientists

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

fields: It contains no lead, so it is substantially eco-friendlier than alternatives containing lead. In technological terms, it allows for much thinner layers in the memory chips, down from 500 to 10 nm, so components and devices can be designed to be significantly smaller.

Furthering understanding of ferroelectricity

When Lederer first heard about this new discovery as a student in a lecture at Friedrich-Alexander-Universität Erlangen-Nürnberg some years later, he was electrified himself. The effect was already known, but the structure and behavior of hafnium oxide were poorly understood at that time, so the material could not yet be used reliably in new applications. Lederer wanted to change that. He went on to write his dissertation at Dresden University of Technology, teaming up with the Fraunhofer Institute for Photonic Microsystems IPMS to investigate the material's nanostructural properties in detail. For his research, Lederer combined knowledge from the fields of solid-state physics, materials science, computer science, and electrical engineering. He made several important discoveries in the process, employing a new method of analysis that let him delve deeper into the microstructure and microprocesses of HfO_2 than anyone before him and visualize these aspects. In this way, he was able to trace the material's crystallization behavior in detail for the first time ever — and thus further develop and optimize it with an eye to factors such as grain growth.

Alongside ferroelectricity, Lederer also demonstrated the material's ferroelasticity, a related property. "People used to think the only way to switch the polarization of the atoms was by applying an electric charge," Lederer explains. "I was able to show that this is also possible through mechanical stress, such as pressing or pulling." That is hugely important with regard to the processing of HfO_2: Production steps need to be adjusted in such a way that mechanical influences do not cause any changes in the thin layers, thus reducing their reliability.

Ultimately, Lederer also identified a solution to an additional problem: The process of getting the material from the amorphous phase to the crystalline one, when it is ferroelectric, had previously been limited during production to thermal methods that required high temperatures. Lederer devised a new method called electric field-induced crystallization as a better approach: "With electric field-induced crystallization, all you have to do to cause ferroelectricity is apply alternating voltage. This persists even when the voltage is no longer applied in that case. And that way, you get even better and more robust properties than with the thermal method," Lederer says. The method has another advantage: The circuits with HfO_2 storage are also more secure as a result of the electric field-induced crystallization, as the hardware allows the data to be encrypted in three dimensions and at the same time prevents reading of the data from outside.

Lederer's work caused a splash not only in the scientific world, where it has been cited over 800 times to date, but also in industry. Right now, multiple producers, such as Sony and X-FAB, are working to incorporate memory chips with ferroelectric hafnium oxide into their products to make them faster, smaller and more energy efficient. Dresden-based chip manufacturer GlobalFoundries is among them and is currently working with Fraunhofer IPMS to test ferroelectric memory devices in a research and development line. The maximum reliability of the components is a key success factor for everyone. And Lederer was instrumental in that regard. In the role of lead scientist at Fraunhofer, he is continuing to explore the many possible applications of hafnium oxide. ■

Read on for second and third prize ▶

Photo: Sebastian Lassak/Fraunhofer IPMS

Second place: Dr. Sascha Dick

The full home cinema experience

How can movies be streamed more efficiently — and also accessibly? How can realistic audio scenes in virtual reality applications be reproduced in real time? And how do we even hear in three-dimensional space? Dr. Sascha Dick answered all these questions in his dissertation, which received the second-place Hugo Geiger Prize.

A cozy evening at home, a thrilling blockbuster, a bowl of popcorn. And now, let the adventure begin! The listening experience is an important part of it. People want the sound to be realistic and immersive, as if they were right in the middle of the action. But wait, what did the main character just say? It can sometimes be hard to pick out the dialogue when the sound is very rich and varied. "To solve this problem, you have to understand what human spatial hearing is like in detail," says Dr. Sascha Dick. He has spent more than 16 years working at the Fraunhofer Institute for Integrated Circuits IIS in Erlangen, the same institute where mp3 was invented in the late 1990s. The principle of audio compression made it possible to significantly reduce the size of music files without diminishing sound quality. The difference: "What our ears do and don't perceive is easy to calculate in stereo," Dick explains. "It's much more complicated when you get into 3D audio, since theatrical releases might bring together as many as 128 sources of sound."

As with mp3, the key here is how to simplify matters intelligently without any perceptible decrease in quality, thereby bringing 3D sound efficiently into home living rooms. In his dissertation, Dick developed a method that combines the sources of sound into a few audio objects, thereby reducing them. To find out which sources of sound the human sense of hearing perceives in 3D and how, his first step was to perform extensive listening tests. Inside the sound lab, his test subjects heard beeping, rumbling, whooshing, and other sounds from different directions. They were then tasked with describing their perceptions. When analyzing the data, Dick made a discovery: "The accuracy of localization of spatially distributed sources of sound can also be determined and predicted analytically through high-definition physical measurement of sound at the ears. This significantly reduces the time and effort involved, and the measurements are also more accurate."

Creating perfect 3D sound for home theater systems: Dr. Sascha Dick of Fraunhofer IIS.

A map for spatial hearing

Based on these findings, Dick developed psycho-acoustic models that describe and portray the

"One important finding was how dependent on direction our ability to localize sounds is."

Dr. Sascha Dick

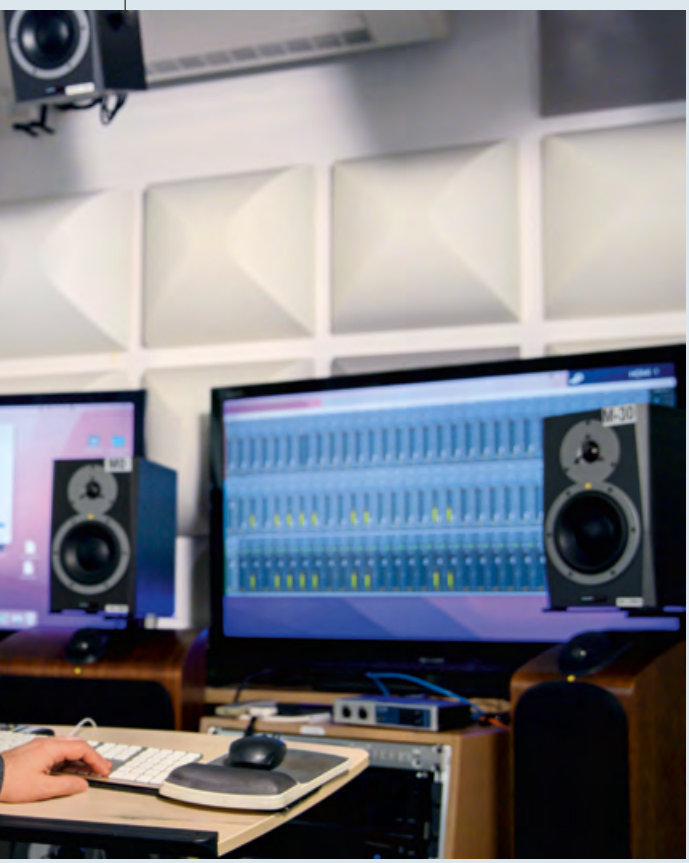


Photo: Paul Pulkert /Fraunhofer IIS

perceived distribution of volume in an audio scene, localization accuracy, and masking effects in 3D audio scenes. He calibrated these models to the results of his listening experiments: "One important finding, for example, was how dependent on direction our ability to localize sounds is," Dick says. "Because we hear with greater accuracy in the horizontal plane than up and down, the perceived distance between right and left is greater than between top and bottom. I incorporate that into a perceptual coordinate system that makes it possible to factor in the accuracy of localizing sound sources more effectively, for more efficiency in processing audio information.

On the basis of these psycho-acoustic models, Dick developed algorithms to simplify and encode the 3D audio scenes based on perceptions. Operating on the idea that sounds that cannot be distinguished sharply also don't need to be transmitted separately, this means sound sources that are indistinguishable to the human ear can be combined. This makes it possible to reduce the complexity of 3D audio by a factor of ten. Instead of transmitting soundtracks with 60 sound sources, just six consolidated audio objects are enough to deliver a realistic sound experience — without any loss of quality. This drastically reduces not only the amount of computing resources required for audio coding, but also the transmission rates needed for streaming. Dick's findings and algorithms are also being incorporated into the new MPEG-H audio standard, which Fraunhofer is playing a key role in advancing. It is the great-grandchild of mp3, so to speak.

Improved speech intelligibility

In practice, this method is interesting not only for home theater experiences, but also for mobile VR/AR or gaming applications, since it unlocks high-quality 3D audio scenes in real time. And it offers another crucial advantage: The fuller and more diverse the audio scenes in a film are, the more difficult it can be to understand the speakers. This method allows people with hearing impairments to personalize the audio scenes for their use.

"Combining the sound sources intelligently into spatial audio objects lets me keep the dialogue sound sources separate from the sources of other sounds," Dick says. "And that means it's possible to improve the intelligibility of speech when there is background noise or music by raising the level of the dialogue or dialing down the rest. So, even when a speaker is moving around in space, you can hear them accurately in any position." In the future, there could even be a button for clear speech in 3D audio content — so there would truly be no obstacle to the full theatrical sound experience right in people's own living rooms. Except for maybe the crunching of popcorn. ■

Theatrical releases bring together as many as

128

different sources of sound.

Third place: Dr. Susann Allelein

Communicating at the cellular level

Cells communicate through tiny packets of information. For a long time, they were thought to be how cells got rid of waste, but now researchers know they have vast potential for detecting cancer and other health problems with a single drop of blood or urine. In her dissertation, Dr. Susann Allelein found ways to isolate and characterize the messages transmitted by cells. She has received the third-place Hugo Geiger Prize for her work.

Each year, 500,000 people in Germany are diagnosed with cancer. One in two people will suffer from the disease at some point in their lives. A cancer diagnosis is the start of a race against time. When tumors are caught early enough, chances of recovery are often good. That is why researchers have long been working to optimize not only treatments, but early detection above all. But current detection methods such as invasive tissue biopsies are often time-consuming and imprecise, plus they require the tumor to have reached a certain size. Biopsies also carry a risk of infection and cannot be repeated as often as researchers might like. Studies of liquid specimens such as blood or urine are a much faster, less risky way to identify tumor markers.

> "The vesicles are like mirrors of the cells.
>
> Dr. Susann Allelein

These bodily fluids contain millions of particles called extracellular vesicles, which had gone largely unresearched until now. "You can think of the vesicles like little packets that every cell sends out through the body's fluids for communication purposes. Each one has a sender and an address and contains basic information," explains Dr. Susann Allelein from the Fraunhofer Institute for Cell Therapy and Immunology IZI in Leipzig. "They're like mirrors of the cells. Cancer cells also form and secrete vesicles, which are received by organ-specific target cells, for example, to form pre-metastatic niches. We can use that." Allelein received the third-place Hugo Geiger Prize for 2023 for her dissertation on the isolation and characterization of prostate cancer-specific extracellular vesicles from liquid biopsy samples.

From cellular waste to beacon of hope

Extracellular vesicles were long viewed as cellular waste products. It was not until relatively recently that there was a sharp increase in scientific interest in these structures. They turn out to have great potential in two ways. First, they contain proteins, RNA, and lipids, all of which convey disease-specific information about the exact composition of cells, such as tumor cells, which can be used for diagnostic purposes. Second, they could also be used as a way to transport therapeutic active substances. The crux of the matter is that all cells, including healthy cells, form and send out various kinds of extracellular vesicles. So sifting through the many different cellular communication packets to find those transmitted by any tumor cells that may be present is like searching for the proverbial needle in a haystack. On top of that, the particles are just a few nanometers to micrometers in size, making them as tiny as viruses, so they are difficult to isolate using conventional methods of cellular research. To make them accessible for medical diagnosis and treatment, this meant it was necessary to find a way to isolate them and pick the relevant vesicles out from the rest.

The objective of Allelein's dissertation was to find out whether extracellular vesicles can be used for early detection of prostate cancer specifically. She focused on prostate tumors because there has been a wealth of research on the specific proteins involved. "These cancer cells — and thus, also the vesicles they emit — carry the prostate-specific membrane antigen

If cancer is detected early, treatment prospects improve. Dr. Susann Allelein's research has laid key foundations for this.

Photo: Michaela Grunert/Fraunhofer IZI

(PSMA) on their surface, for example. To analyze this surface protein on the vesicles directly from bodily fluids, we developed an antibody microarray for clinical diagnosis. Now, for the first time, this array can be used to study as many as 33 surface proteins from a sample and a large number of patient samples simultaneously," Allelein explains. She also devised a specific enrichment method by which what are known as capture molecules can be used to magnetically isolate the vesicles with PSMA from the mass of irrelevant vesicles in urine or blood samples.

Things sometimes take an unexpected turn

And then there was a surprising key moment while Allelein was writing her dissertation: "The results were promising, but PSMA ultimately turned out not to be a suitable marker. Vesicles do reflect the cells, but there are exceptions. And one of those exceptions was PSMA," she explains. But Allelein was undaunted. After all, her work is foundational for the emerging but promising field of extracellular vesicle research.

She now plans to study further markers and apply her methods to other diseases, such as Alzheimer's. "Another advantage to extracellular vesicles is that they can pass through the blood–brain barrier. And that means they can be used to find and analyze neuronal information in the blood," Allelein says, looking down the road. "They can also be used therapeutically. Right now, we're starting to research whether the vesicles of CAR T cells have potential for supportive cancer treatment." ■

Photo & Fraunhofer

WowWow project helps furry friends

Dedicated dog owners make sure to do more than just pet their dogs a lot; they also take care of their coats. After all, man's best friend can be delicate when it comes to skin issues: dogs have a tendency toward dermatological conditions. Atopic dermatitis, a form of neurodermatitis, affects ten to 15 percent of dogs, for example, leaving their skin dry and itchy. Constant scratching causes inflammation and can even result in infection.

Emollient shampoos and lotions can help, but animal testing of cosmetics has been banned in the EU since 2013. To ensure that veterinary care products and treatments can still be tested for efficacy and tolerability, molecular biologist Dr. Anke Burger-Kentischer and her team at the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB in Stuttgart have now developed a full-thickness dog skin equivalent that is nearly identical to real canine skin.

In the WowWowSkin project, the original skin used as the starting tissue for the skin equivalent came from veterinary practices, where it is frequently necessary to remove canine skin for medically necessary procedures. "We had to conduct a whole host of tests to find the right combination of enzymes and nutrient media," Burger-Kentischer recalls. But their patience paid off. In addition to therapeutic processes, the skin equivalent can also be used to test grooming shampoos and soaps. "When we apply a substance to it, we can quickly see whether the medication has an effect, whether it has no effect at all, or whether it actually makes the disease worse — or whether a care product is bothersome to the skin or even damages it."

The first manufacturers have already come forward to register their interest in the full-thickness skin equivalent. The Fraunhofer team plans to develop in-vitro full-thickness canine skin equivalents for various breeds, along with skin equivalents for horses and cats: "WowWow" for all!

Just as the eyes are the window to a dog's soul, its coat reflects its state of health. That makes it even more important to use only substances that are proven effective for skin and coat care.

Photo: Elke Vogelsang

Less stress for plants

Species extinction and climate change call for an ecological transformation of agriculture as we know it. Five Fraunhofer institutes have teamed up to use new sensor technologies in the search for efficient, sustainable — and most of all, fast — solutions.

By Dr. Monika Offenberger

The recent protests by farmers across Germany are still fresh in the public's minds. They have a laundry list of requirements to meet: protecting the soil, water, and climate; setting aside more habitat for wild bees and other pollinators; reducing chemical use — and at the same time providing high-quality food for a growing population. And they are supposed to do it all amid global warming, which brings not only extreme heat and drought, but often also torrential rains and unseasonable freezing weather. Where to start? "We urgently need more-robust plants that can cope with environmental and climate conditions in their specific location," says Dr. Stefan Gerth, a physicist from the Fraunhofer Institute for Integrated Circuits IIS in Fürth. In the Biogenic Value Creation and Smart Farming (BWSF) initiative, Fraunhofer IIS has joined forces with the Fraunhofer Institute for Computer Graphics Research IGD, the Fraunhofer Institute for Large Structures in Production Engineering IGP, the Fraunhofer Institute for Process Engineering and Packaging IVV, and the Fraunhofer Institute for Electronic Microsystems and Solid State Technologies EMFT to identify solutions for the agriculture of the future.

At the Fraunhofer Development Center for X-ray Technology EZRT at Fraunhofer IIS, Gerth harnesses the invisible rays to bring the hidden properties of crops to light: "We can now use X-ray methods to watch selected plants grow underground for the first time without destroying them. We're interested in how quickly and at what angle individual seedlings form roots when under drought stress. That's what decides whether they are better at absorbing water close to the surface or tend to reach deeper-seated stores of water instead," he explains. Root architecture is a key factor in cultivating new, climate-resistant plant varieties, along with others such as seed germination capacity, the photosynthetic properties of the leaves, and the number and size of bulbs, grains, and fruits. Together with many other hereditary traits, these features make up a plant's "phenotype," the sum of its observable characteristics. Describing these characteristics is known as phenotyping.

"For millennia, phenotyping of crops was limited to what happens above the ground. And assessing breeding stock for desired characteristics is still done mainly by experts who go out into the field and assign scores by appearance. Our goal is to capture phenotype information in much greater detail — and above all, objectively — from the seed to the mature plant," Gerth says. To achieve that, his team has developed a computed tomography (CT) system to survey plants completely automatically, both above the ground and under it. The system then uses special algorithms to generate data relevant to cultivation of new varieties. In addition to X-rays, 3D laser tomography and other imaging methods are used, Gerth explains. "Depending on the question, we also measure near-infrared light or use mul-

> "We urgently need more-robust plants that can cope with environmental and climate conditions in their specific location."
>
> Dr. Stefan Gerth, Fraunhofer IIS

tispectral imaging to identify certain plant behaviors."

Fraunhofer IIS has already supplied fully automated phenotyping systems that incorporate CT technology to major seed producers and research institutions in Europe, Australia, the U.S., and China. A new unit that is available for rent is to begin operating in Triesdorf, in Germany's Franconia region, by the end of this year, Gerth explains. "We want to make this costly infrastructure available to local start-ups and SMEs in addition to major players, with the aim of advancing biogenic value creation in Germany. Users will be able to assess the quality of seed or seedlings or analyze growth in plant structures like wheat roots and potato tubers." And time is pressing. After all, getting from the initial breeding idea to the final new variety can take ten to 15 years. "We need to get much faster," Gerth says, "and learn even more from nature. Even with all our experience of breeding and cultivation, there's still too much we don't know about how certain plants actually work, especially in situations of stress."

"We know that plants emit certain gases in response to stress or pest infestation. We aim to use new sensor technologies to visualize these gas molecules, which occur in very low concentrations," says Christian Wald from Fraunhofer EMFT in Munich. His team is also using "on-plant sensors" to watch as plants breathe, via organic polymers printed as 2D or 3D structures directly onto the leaf, where they react to the slightest change in moisture. This makes it possible to record the exchange of gases through the "pores" by which plants breathe over time, extrapolating from there to the plants' vitality. Prof. Joachim Wegener is pursuing a different approach at the Fraunhofer EMFT branch lab in Regensburg: He is using insect cells cultured in nutrient solutions to detect harmful substances in samples taken from the environment. Healthy cells behave differently on surfaces than those exposed to various toxins — and sensors can be used to detect the differences.

Soils communicate wirelessly

The BWSF researchers plan to use another smart tool to measure and analyze physical environmental conditions with greater accuracy and in greater detail than before — both in the Fraunhofer IIS phenotyping infrastructure and out in the field. "We're working on a new groundwater extraction device that combines sensor elements with a suction probe, a piezoelectric micromembrane pump, and an antenna for wireless data transmission," Wald explains. The instrument is designed to measure key soil-related data such as moisture, pH, and levels of ammonium, nitrate, and dissolved oxygen reliably and in real time, directly in the soil, and transmit this information wirelessly to a central measurement station. In the future, these independent probes may take the place of the time-consuming and costly process of extracting groundwater samples and analyzing them in the lab. For this research project, Fraunhofer ▶

> "We know that plants emit certain gases in response to stress or pest infestation."
>
> Christian Wald, Fraunhofer EMFT

Quality control for seed and seedlings: Fraunhofer IIS has developed a technology for this.

Photo: Kate Leigh/istockphoto

EMFT has partnered with six other research institutions and universities; the project is receiving funding from the European Joint Programme EJP Soil under the name FAMOSOS (FArm MOnitoring via Real-time SOil Sensing). The partners plan to test their measuring system in various crop and grassland systems using both conventional and organic agricultural methods. The vision is that the data collected will be used to optimize sowing and harvesting in the future.

Researchers at Fraunhofer IGD in Rostock are also using the gas sensors developed by Fraunhofer EMFT for new applications in agriculture. Combined with camera technology in the RGB, multispectral, or hyperspectral range and with drones and robotics, the sensors are to supply farmers with valuable data even beyond their fields: from former bogs. Although these lands make up only about five percent of Germany's area, they have a tremendous influence on the global climate. Untouched wet bogs bind 1.3 billion metric tons of carbon in Germany alone, while drained, cultivated bogs release huge amounts of greenhouse gases such as CO_2 and nitrous oxide. This is why the German federal government has pledged, as part of the climate agreement, to restore a whopping 1.8 million hectares of bogland by 2050. Fraunhofer IGD plans to provide scientific support for this process.

Untouched wet bogs bind **1.3 billion metric tons** of carbon in Germany alone.

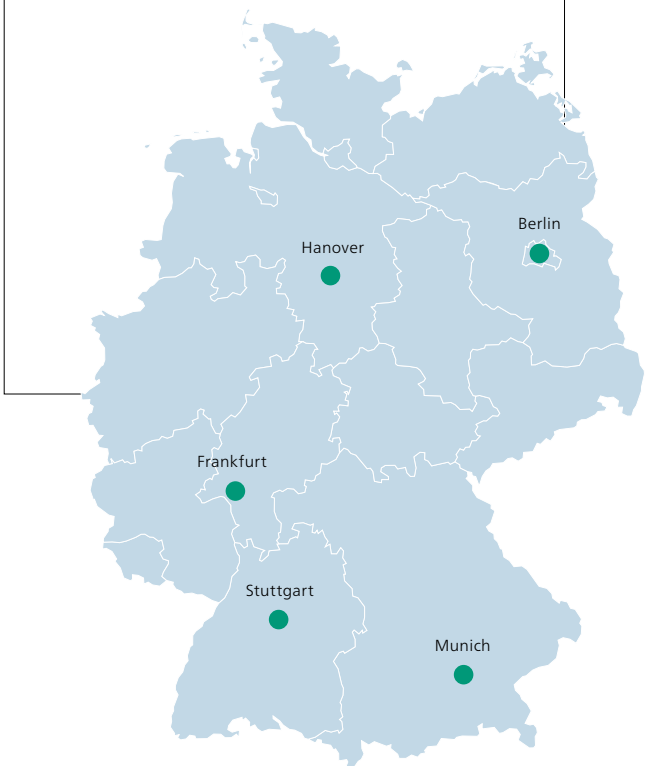
"We're working closely with the University of Greifswald to quantify the roles bogs play in the wider ecosystem," says Dr. Philipp Wree, head of the Smart Farming department at Fraunhofer IGD. "We're combining various layers of information in the process. We use cameras mounted on drones to identify the vegetation in high resolution, right down to individual plant species. We measure the amount of carbon in the soil with gas sensors. We also determine water levels. Then we can use the interaction between these parameters to show that formerly drained bogs resume their valuable functions within the ecosystem after they are restored. Biodiversity and carbon sequestration increase, and emissions of greenhouse gases go down." As Wree notes, these connections were already known in principle, but could not be quantified before now. "That's exactly what we're trying to do. After all, with every piece of wetland that is restored, the owner loses pasture or cropland, which also means a loss of income. At the same time, it's a valuable way to support the necessary transformation of our society. So, this kind of repurposing to benefit the environment is only interesting to farmers if it pencils out. Our goal is to use our smart tools to document this revaluing of ecosystems and capture it in numbers." ■

High-tech aid to selection in the search for climate-resistant plants

Field robot DeBiFix examines entire wheat fields to show how the kernels are developing inside the ears.

Photos: Fraunhofer IIS, Paul Pulkert

Fraunhofer on the road



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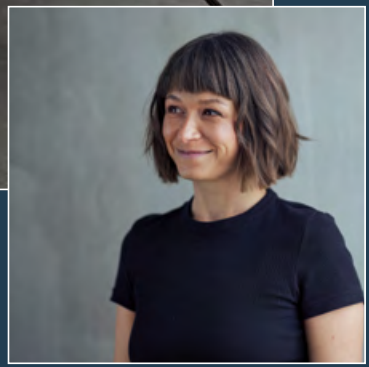
Feeling claustrophobic?
Photographer Maya Claussen had one key concern when producing this issue's cover story: What if one of the researchers had a panic attack? After all, they would have to stick their heads through a small hole in the background material, then have tape wrapped around their necks — and then: lights! Claussen didn't have to worry for long: "Everyone was super nice!"



Maya Claussen

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